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Review Article

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Role of microbes in degradation of synthetic plastics and manufacture of bioplastics

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ABSTRACT

Most micro-organisms are used as a source of bioplastic manufacture and also used for degradation of plastics. Although manufacture of bioplastics is considered costly than synthetic plastic, it has many advantages over them. A large number of micro-organisms are being used for degradation of plastics as well as manufacture of bioplastics. Some biopolymers have also gained public acceptance and are now being manufactured. For degradation of plastics micro-organisms should be studied extensively so that solid waste can be degraded. Thus, microbes play important role in degradation as well as manufacture of plastics.

Keywords: Micro-organism, biodegradation, enzymes, plastic, bioplastic.

INTRODUCTION

Plastics can be defined as overall range of synthetic or semi-synthetic materials that can be molded into objects of different shapes. These are the polymers composed of carbon, silicon, oxygen, hydrogen, nitrogen, and chloride. Basic materials of plastics are extracted from coal, natural gas, and oil. Most common forms of plastics are polyethylene, poly-propylene, polystyrene etc. Plastics are seen as environmental threat because they are difficult to degrade [1]

Microorganisms degrade natural polymers and synthetic polymers by the process called as biodegradation. Polymers like polyethylene are used as substrate for microorganisms' growth when they are being degraded. Degradation of polymers can be indicated by cracking, erosion, discoloration, and phase separation [1].

A new type of plastic called as bioplastic is now being manufactured. Bioplastics are biodegradable in nature meaning that these are either manufactured from fossils or from biomass Biodegradation is the ability of different microorganisms to use synthetic polymers as carbon source. Polymers being used for the production of bioplastics include polyhydroxybutyrate. Some microorganisms use this polymer as a source for carbon and energy. Microorganisms also secrete enzyme polyhydroxyalkanoates depolymerases which helps in plastic degradation [1].
Plastics can be biodegraded by reducing the polymer chain length by oxidation which may be accessed by microbes. The change can be detected by increase in microbial growth after being exposed to biotic environment but most

importantly by CO2 production. In this review, we will try to focus on microbes studied to degrade plastics and advantages of using bioplastics over plastics.

Factors involved in biodegradation of plastics

Chemical and physical properties of plastics play important role in their biodegradation. Side chain possessing polymers are difficult to degrade when compared to polymers with no side chains. It should also be kept in mind that polymers with high molecular weight are difficult to degrade. Other factors involved in the biodegradation of polymers are their morphology, melting temperature, and degree of crystallinity. If the polymer is amorphous, then it will be degraded easily as compared to crystalline polymer. Polymers with high melting temperatures are difficult to biodegrade.

Thus if biodegradation of plastics is to be done at industrial level, all these factors should be kept in mind [2].

Degradation of plastics by microbes

Several studies have been conducted in order to assess the ability of microbes in degrading plastics.

As early as in 1998, Oda *et al*., reported that bacterium *Alcaligenes faecalis* produces polycaprolactone depolymerase. He also isolated several polycaprolactone (PCL) degrading bacteria from soil. PCL is a biodegradable polymer, which can undergo degradation by aerobic and anaerobic microorganisms [3].

Furthermore, PCL was also reported to be degraded by fungi *Penicillium* and A*spergillus*. Strain ST-01 of *Aspergillus*, isolated from soil is reported to degrade PCL at incubation of 50°C for 6 days. In the case of Penicillium, strain 26-1 was studied and the results showed that PCL was degraded in 12 days by this strain. Fast enzymatic degradation of PCL by *Penicillium funiculosum* and *Aspergillus flavus* is also reported in amorphous region. Enzymes degrading PCL are lipase and esterases [2].

Plasticized polyvinyl chloride (pPVC) is vulnerable to microbial attack due to the presence of organic acid esters like dioctyl adipate (DOA) and dioctyl phthalate (DOP). Ester based plasticizers can be degraded by fungi and bacteria. If pPVC loses plasticizers because of microbial degradation, it leads to its failure [4].

Owing to this, Webb and his colleagues in 2000 studied colonization of fungus and biodegradation of pPVC under in-situ and ex-situ conditions. Their study reported that *Aureobasidium pullulans* established itself on pPVC between 25 and 40 weeks of exposure. Furthermore, after 80 weeks of exposure yeast and yeast like fungi, *Rhodotorula aurantiaca* and *Kluyveromyces spp*. was found to be established on pPVC [4].

Further studies conducted on A. pullulans demonstrated that A. pullulans can grow on undamaged pPVC as source of carbon. It degrades DOA and produces extracellular esterase. Many yeast isolated were not able to degrade DOA. Thus, this study demonstrated that fungus *A. pullulans* is important in degrading pPVC [4].

Polyester polyurethane (PUR) is degraded by both fungus and bacteria. In 2000, it was reported by Russell *et al*. that endophytic fungi can degrade synthetic polymer polyester polyurethane (PUR). It was reported that *Pestalotiopsis microspora* were growing on PUR and using it as sole source of carbon in aerobic as well as anaerobic conditions. Further characterization demonstrated that PUR was being degraded by serine hydrolase. Endophytes are microorganisms living in inner plant tissues and play important role in decomposition of plant after death of host tissue. Theses endophytic fungi are also able to degrade complex lignocellulose polymers suggesting that these organisms should be screened for their ability to degrade plastic which is also a complex polymer [5].

In another study conducted by Kathiresan in 2003, it was demonstrated that microbes from mangrove soil (bacteria as well as fungi) are able to degrade plastics but at a slower rate. These microbes comprised of gram negative and gram positive bacteria and eight species of fungi. Dominant species included *Streptococcus*, *Staphylococcus*, *Micrococcus* (Gram-positive), *Moraxella*, and *Pseudomonas* (Gram-negative) and two species of fungi (*Aspergillus glaucus* and *A. niger*). Thus, the work revealed that many plastic degrading microbes can be isolated from mangrove soil [6].

Moreover, mangrove soil from Niger delta was also studied for plastic degrading microbe population. Two *Aspergillus* species were isolated which were studied for degradation of Low-density polyethylene (LDPE) and high-density polyethylene (HDPE) films. The results obtained showed that the carbon source for the two *Aspergillus* species (*Aspergillus japonicus* and *Aspergillus terreus*) was polyethylene films. Thus, the results proved that fungi isolated form mangrove soil of Niger delta can be used for biodegradation of PE films. LDPE is the most common solid waste and accounts for 60% of total plastic production [7].

The garbage sites in India are filled with plastics which are still not biodegraded out of which polythene is the most common source of solid waste, more studies should done to isolate microbes which are able to biodegrade polythene and other polymers. Studies should be designed to isolate microbes on their ability to degrade plastics. Some common plastic degrading microorganisms are listed in Table 1.

Table 1: Plastic degrading microorganisms

Microorganism	Enzyme produced	Polymer degraded	Reference
Alcaligenes faecalis	Polycaprolactone depolymerase	Polycaprolactone (PCL)	Oda *et al*., 1998
Aureobasidium pullulans	Extracellular esterase	Dioctyl adipate (DOA)	Webb *et al*., 2000
Rhizopus delemar	Lipase	Polylactic acid	Masaki *et al*., 2005
Pestalotiopsis microspora	Serine	Polyurethane	Russell *et al*., 2011
Comomonas acidivorans	Estrase	Polydiethylene adipate	Russell *et al*., 2011

Bioplastics: an alternative to plastics

Plastics derived from renewable sources like oils, corn starch, vegetable fat etc. are referred to as bioplastics. They can also be made up using microorganisms, agricultural byproducts, starch, biopolymers etc.

Types of bioplastics

There are different types of bioplastics being tried to be manufactured at large scale. Some of these are mentioned below.

Starch-based bioplastics: These are the most widely used bioplastics and these can also be manufactured at home [8]. Starch can absorb humidity which makes it suitable candidate for drug capsule production. Starch can also be processed thermo-plastically as sorbitol and glycerine can also be added to starch. Starch based bioplastics are sometimes mixed with biodegradable polyesters to produce polycaprolactone. These blends are biodegradable [9].

Polylactic acid (PLA): Corn and dextrose is used to produce polylactic acid which is transparent in nature. It carries same characteristics as petrochemical-based plastics and can also be produced using production method followed for conventional plastics. PLA is generally used in production of films, fibers, cups, and bottles [10].

Poly-3-hydroxybutyrate (PHB): Certain bacteria producing glucose and corn starch can is used for production of poly-3-hydroxybutyrate. It carries same characteristics as that of plastic polypropylene. South American sugar industry uses PHB in packing purpose. PHB can also be processed into transparent film and has melting point higher than 130°C and is biodegradable in nature [11].

Polyhydroxyalkanoates (PHA): These are linear polymers produced by bacterial fermentation of sugars and lipids. Bacteria produce it to store carbon and energy. At industrial level, the polymer is extracted from bacteria and is used in sugar fermentation. PHA is more ductile but less elastic, PHA is also biodegradable. PHA also has its application in the medical industry [12]

Polyamide 11 (PA 11): It is derived from natural oils and is under trade name Rilsan B, manufactured by Arkema. PA 11 is not biodegradable and its properties are similar to PA 12. PA 11 finds its application in automatic fuel lines, pneumatic airbrake tubing, flexible oil and gas pipes. Polyamide 410 (PLA 410) is derived from castor oil under trade name EcoPaXX and is manufactured by DSM. PA 410 has high melting point of approximately 250°C, has low moisture absorption, and is highly resistant to some chemical substances [13]

Genetically modified bioplastics: There is still no bioplastic produced which can be called as genetically modified. GM bioplastics would require use of GM crops. In future, some of second generation bioplastics manufacture methods might employ plant factory model which will use GM crops of GM bacteria to optimize efficiency.

Polyhydroxyurethanes: Polyhydroxyurethanes can be produced by reaction between polyamines and cyclic carbonates. These are usually isocyanate free and biodegradable. The cross-linked polyhydroxyurethanes can also be recycled and reprocessed by dynamic transcarbamoylation reactions.

Environmental Impact: The environmental impact of bioplastics is usually debated, as there are many alternative metrics for "greenness" (e.g., water use, energy use, deforestation, biodegradation, etc.) and tradeoffs usually exist [14] the talk is additionally difficult by the actual fact that several differing types of bioplastics exist, every with totally different environmental strengths and weaknesses, therefore not all bioplastics will be treated as equal. The production and use of bioplastics is typically regarded as a a lot of property activity when put next with plastic production from crude oil (petroplastic), because it needs less fuel for its production and additionally introduces fewer, net-new greenhouse emissions if it biodegrades.

The use of bioplastics may end in less unsafe waste than oil-derived plastics, which stay solid for many years.

Petroleum is usually still used as a supply of materials and energy within the production of bioplastic. crude oil is needed to power farm machinery, to irrigate crops, to produce fertilizers and pesticides, to move crops and crop products to process plants, to method raw materials, and ultimately to provide the bioplastic. However, it is possible to provide bioplastic exploitation renewable energy Jar made from PLA-blend bio-flex, a bioplastic sources and avoid the utilization of crude oil.

Italian bioplastic manufacturer Novamont [15] states in its own environmental audit that manufacturing one kg of its starch-based product uses five hundred g of crude oil and consumes virtually eightieth of the energy needed to provide a traditional polythene compound. Environmental information from Nature Works, the sole business manufacturer of PLA (polylactic acid) bioplastic, says that creating its plastic material delivers a fuel saving of between twenty five and sixty eight per cent compared with polythene, partially due to its getting of renewable energy certificates for its manufacturing plant.

A detailed study examining the method of producing a number of common packaging things from ancient plastics and polylactic acid distributed by Franklin Associates and printed by the Greek deity Institute shows that exploitation bioplastic incorporates a lower environmental impact for some product, and the next environmental impact for others [16]. This study, however, doesn't think about the end-of-life environmental impact of those products, including possible alkane emissions from landfills attributable to biodegradable plastics.

While production of most bioplastics leads to reduced carbon dioxide emissions compared to ancient alternatives, there is concern that the creation of a world bioeconomy needed to provide bioplastic in giant quantities might contribute to AN accelerated rate of deforestation and eating away, and will adversely have an effect on water provides. Careful management of a world bioeconomy would be needed.

Other studies showed that bioplastics end in a forty second reduction in carbon footprint [17].

On October twenty one, 2010, a bunch of scientists reportable that corn-based plastic hierarchic higher in environmental defects than the most product it replaces, like HDPE, LDPE and PP. within the study, the assembly of corn-based plastics created a lot of natural action, carcinogens, ecotoxicity, eutrophication, gas depletion, metabolic process effects and smogginess than the synthetic-based plastics they replaced [18] but the study additionally ended that biopolymers trumped the opposite plastics for biodegradability, low toxicity, and use of renewable resources. The Yankee Carbon written record has additionally free reports of laughing gas caused from corn growing that is 310 times more impregnable than CO2. Pesticides also are employed in growing corn-based plastic.

Biodegradability of bioplastics: The word employed in the bioplastics sector is some- Packaging air pillow manufactured from PLA-blend bio-flex times dishonest. Most within the business use the term bioplastic to mean a plastic created from a biological source. All (bio- and petroleum-based) plastics are technically perishable, which means they'll be degraded by microbes underneath appropriate conditions. However, many degrade thus slowly that they're thought-about non-biodegradable. Some petrochemical-based plastics are thought-about perishable, and will be used as an additive to enhance the performance of business bioplastics [19]. Non-biodegradable bioplastics square measure referred to as sturdy. The biodegradability of bioplastics depends on temperature, compound stability, and obtainable oxygen content. The normal EN13432, published by the global organization for

Standardization, defines however quickly and to what extent a plastic should be degraded underneath the tightly controlled and aggressive conditions (at or higher than a hundred and forty °F) of an industrial composting unit for it to be thought-about perishable. This normal is recognized in several countries, together with all of Europe, Japan, and therefore the America. However, it applies solely to industrial composting units and doesn't come into being a typical for home composting. Most bioplastics (e.g. PH) biodegrade quickly in industrial composting units. These materials don't biodegrade quickly in normal compost piles or within the soil/water. Starch-based bioplastics square measure an exception, and can biodegrade in traditional composting conditions [20]. The term “biodegradable plastic” has additionally been used by producers of specially changed petrochemical-based plastics that seem to biodegrade [21] perishable plastic bag makers that have twisted their product’s biodegradability could currently face legal proceeding in the America state of CA for the dishonest use of the terms perishable or compostable [22] ancient plastics such as polythene square measure degraded by ultra-violet (UV) lightweight and element. To forestall this, method makers add helpful chemicals. However, with the addition of a degradation instigator to the plastic, it is possible to realize a controlled UV/oxidation disintegration process. This kind of plastic could also be remarked as degradable plastic or oxy-degradable plastic or photodegradable plastic as a result of the method isn't initiated by microbic action. Whereas some degradable plastics manufacturers argue that degraded plastic residue can be attacked by microbes, these degradable materials do not meet the necessities of the EN13432 business composting normal. The bioplastics business has widely criticized oxo-biodegradable plastics, which the industry association says don't meet its needs. Oxo-biodegradable plastics – called “oxos”- square measure standard petroleum-based merchandise with some additives that initiate degradation. The ASTM normal for oxo-biodegradables is called the quality Guide for Exposing and Testing Plastics that Degrade within the atmosphere by a Combination of oxidization and Biodegradation (ASTM 6954) [23] each nut 13432 and ASTM 6400 square measure specifically designed for PLA.

Advantages of using bioplastics: Plastics made from polymers obtained from biological sources like potato sugar cane are called as bioplastics. According to European Bioplastics, a plastic is termed as bioplastic only when it is biodegradable, bio-based, or both. There are many advantages of using bioplastics.

Less CO2 emission occurs as only 0.8 metric tons of CO2 is required to make bioplastic which is 3.2 metric tons less than plastics. Bioplastics are cheap to manufacture and do not generate toxic material. While oil based plastics need fossil fuels manufacture of bioplastics does not require fossil fuels thus reducing carbon footprint. Most importantly, using bioplastics will reduce waste material which is difficult to biodegrade and causes environmental damage [24].

Significance:

Microbial population is now being extensively studied for biodegradation of plastics. Microbial biodegradation uses enzymes to degrade the plastics. Some microbes also use these polymers as their sole carbon source thus degrading the polymer. The biodegradable pathways of these microbes should be studied to gain insight in the degradation mechanism. If plastics can be degraded by microbes, it will reduce solid waste which causes environmental issues.

Since microbes are catabolically versatile, we should advantage and identify microbes which can degrade plastics. Genome based studies can be done and degradation pathways should be studied to develop strategies using microbes to degraded plastics.

Furthermore, bioplastics should be advertised so that people can use them. These plastics are biodegradable and made form oil, corn starch fats etc. Bioplastics does not cause environmental pollution and are readily degraded. Thus these should be used instead of plastic which causes environmental problems and are difficult to degrade.

Future perspective: Plastics were first manufactured in the 20th century at large scale. These plastics, although cheap, are toxic in nature and non-biodegradable. An alternative to these plastics is bioplastics which are biodegradable and are produced using renewable biological sources. These renewable sources can be plant, seaweed, and microbial sources. According to recent studies, bioplastics from sea weeds are still under research and make a good future prospective for bioplastic manufacture. Researchers are also trying to find alternative raw material for the production of bioplastics. Results show that marine red algae can be used as a raw material [25]. Even though production of bioplastics is costly, their application is of interest owing to the drawbacks of conventional plastics [25]. Thus, the future trend is to maximize the for production of bioplastics by enhancing the properties of bioplastics producing microorganisms, plants, and algae [25].

CONCLUSION

In recent years, public has shown interest and concern over environmental issues. Most of the solid waste in India comprises of plastics which causes pollution. The studies related to biodegradation of plastics are being done by microorganisms. As microorganisms are able to degrade organic and inorganic material, interest has increased to study microbes for their ability to degrade plastics. Thus the area of research for biodegradation of plastics by microbes should further be explored to gain new insight in the mechanism of action of microbial degradation of plastics.

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