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Review article

MICROBIAL DEGRADATION OF WASTE: A REVIEW

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Abstract

Background: *Garbage or waste material are the substances discarded by human beings due to a perceived lack of utility or usefulness. An increase in the level of these waste materials may lead to increased levels of pollution, global warming or even cause major health issues as they may contain toxic, non-biodegradable substances as well. Thus, there arises a need for proper methods of disposal of waste.* ***Objective:*** *The objective of this review is to study the possibilities for degradation of non-biodegradable garbage, basically plastics and similar materials with the help of microorganisms and to find out ways to suitably manage these materials in view of their relation to global warming and other such issues.* ***Methods:*** *Extensive literature survey was carried out through various databases like Google Scholar, PubMed etc. and the information were collected and analyzed, and accordingly possibilities for waste management were studied with special reference to non-biodegradable waste like plastics.* ***Results and Discussion:*** *From the literature survey that was carried out, it has been found that researchers are trying to find out alternative packaging material and to search for microorganisms which can degrade the plastic and other such type of materials. Thus we can say that alternative packaging material could be helpful in the management of garbage. At the same time, search for microorganisms which can degrade plastic materials can also be carried out simultaneously.* ***Conclusion:*** *It is therefore better to degrade the existing polymeric materials with the help of suitable microorganisms. Also, the future packaging materials should be made up of biodegradable material.*

Keywords: Waste; Plastic; Microorganisms; Plastic-eating bacteria; Enzymatic action; Bioplastic; Challenges; Degradation.

Introduction

Microorganisms, as their name suggests, are very small organisms that are found around us and inside our body and usually require a microscope to observe them. These microorganisms are being categorized into a wide range of category which includes bacteria, viruses, fungi, archaea, protozoa and algae. Some bacteria and fungi are well known for the process of degradation [1]. Microbial degradation here alludes to the microbial change of natural compounds, regularly those of that contrarily sway human well-being, to less harmful or increasingly helpful structures, in the earth or the research center. Information on the qualities, catalysts and pathways engaged with this procedure acquires helpful items, engineer remediation of dirtied situation and anticipate the destiny of synthetics in the planet. A common example

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is the bio degradation process which involves the catalyzed reduction in complexity of chemical compounds. This mini review center the previous ten years of research in this field [2].

Life existed on the planet for around 3.6 billion years. During this period, the microorganisms have been capable of catabolising almost every source of carbon. According to estimation, there are 5×10^{30} prokaryotes on Earth [3]. All the free living prokaryotes typically consist of 1000- 10000 genes [4] makes this enzymatic diversity approximately 10^{34}. The range of microbial biodegradative metabolism is broad and expandable almost infinity. To more systematically organize and display the information reported in the scientific literature, the University of Minnesota bio-catalysis/biodegradation Database (UN-BBD) [5, 6] began in February, 1995.

What is garbage?

i. As given by the Basel Convention," by the guidelines provided through the provision of national laws, the substances which are intended or required to be disposed off is termed as garbage or waste."

ii. The European Union defines waste/garbage as an object that needs to be discarded, intends to be discarded or requires to be discarded.

iii. Waste Management Licensing Regulations 1994 characterize waste as: any substance or object that the maker or the individual in possession of it, disposes of or intends or is required to dispose of however with the special case of anything excluded from the scope of the waste mandate.

iv. As indicated by the United Nations Statistics Division, the waste is created during the extraction of impure materials, the handling of untreated garbage in processing the final products, during the consumption or utilization or breakdown of products and other human activities.

Garbage formation in India

As per a report from the Press Information Bureau, India has been generating 62 million tons of waste (both recyclable and non-recyclable) annually [7]. According to a report by the India Today, India has been generating more than 1.5 lakh metric tons of solid waste every day which leads to severe pollution levels. Out of the total collected waste, only 20 % is being processed completely and the remaining 80 % is being dumped into landfills and dumping grounds. In 2007, a study of the metro cities in India revealed an estimated municipal solid waste composition to be 41 % organic or biodegradable waste, 40 % inert, 6 % paper, 4 % plastic 4 % textiles, 2 % glass, 2 % metals and 1 % leather. But according to the India landing Commission in 2014, the municipal waste study included 51 % of biodegradable waste, 32 % of inert or non- organic waste and 17 % of recyclable waste [8]. An alliance held between the United Nations University and (ITU) International Telecommunication Union) estimated that in 2016, 1.975 million tons of e waste that accounts for around 1.5 kg, are generated by our country. [9]. According to a report by the Associated Chambers of Commerce and Industry, the rapid growth in the economy and the changing consumer attitude, the e waste generation is likely to increase to 5.2 million tons per year [10, 11]. Also, the Swachh Bharat Abhiyan or Clean India Mission which is a country worldwide campaign from 2014 to 2019 to eliminate open defecation and improve the waste management in urban and rural areas. Its objective also includes the eradication of manual scavenging, bringing about a change in the behavior of the citizens regarding sanitation practices, dumping habits, etc. and generating awareness among the people.

Garbage formation worldwide

As per a report published by the World Bank, the global waste production will increase by 70 % if the current situation prevails. Nearly about 2.01 billion metric tons of municipal solid waste are generated annually worldwide. Also the World Bank estimates that the overall waste production will increase to 3.40 billion metric tons by 2050 [12]. Surprisingly, a large portion of the household waste is found in smaller geographical countries like Kuwait and the Caribbean Islands nations. Kuwait generates 5.72 kg of waste per capita per day of municipal solid waste. Its accumulation of trash owes its own country lack of proper landfills for disposing all the waste [13]. Some of the largest dumpsites in the world are Agbogbloshie e-waste dump, Accra Ghana which receives around 192,000 tons of e-waste annually. The Bantar Gebangdumo in Bekasi, Indonesia with 230000 tons of household waste added every year. Jam Chakra dumpsite, Pakistan with 202 hectares and 5000 people and affects the life of 5 million people [14].

Global waste trade: The developed countries of the world often sell their toxic and hazardous wastes to poorer developing countries. This practice is known as global waste trade. Here the rich countries usually exporting their problems to the poor countries, mainly Asia and Africa.

Toxic colonialism: It is the practice of using underdeveloped states as a cheap way for the rich countries to get rid of toxic waste. Here, the richer countries are exporting waste that is actually beneficial and have resources. But the countries importing these waste, most often do not understand the ways to handle it and hence no proper protection is thus taken [15].

Sources of garbage

a. *Municipal waste*: It is commonly known as trash or garbage includes all the solid waste or everyday items that we use and then throw away for example product packaging, furniture, grass clippings, clothing, bottles, food scraps, newspapers, electrical appliances, paints, household waste, footwear and batteries. This comes from our homes, shops, schools, hospitals, and businesses. Municipal waste may contain a variety of pathogens, which is often found in disposable diapers. It has been found that as many as 10 % of the fecal solid disposable diapers entering landfills contain enteroviruses. Another main/primary source of the pathogens is sewage bio-solids, where co-disposal is practiced. Pathogens may also be present in the domestic pet waste (e.g., cat or dog litter) and food wastes. Municipal solid wastes from households have been found to average 7.7 × 108 coliform bacteria and 4.7 × 108 fecal coliform bacteria per gram. Salmonella has also been detected in domestic solid waste. In unlined landfills, such pathogens or bacteria may be present in the leach ate beneath landfills [16].

b. *Medical/Clinical waste*: These are the waste generated from the hospitals and nursing homes example, waste generated during medical research, immunization, testing, diagnosis, treatments, etc., culture dishes, gloves, bandages, glassware, needles, scalpels, swabs and tissues. It contains infectious materials. This is also called as biomedical waste (BMW). In general, there are four major types of medical waste:

i. General waste: consists of typical household and office waste.

ii. Infectious waste: waste that can cause infection in humans like human tissues, blood or any body fluids.

iii. Hazardous waste: the waste that is not infectious, but are dangerous like discarded surgical equipments, chemicals etc. They have some potential threads in the environment and to mankind [17].

iv. Radioactive waste: waste generated as a result of radioactive treatments like laser treatments, cancer therapy, etc.

c. *Agricultural waste:* The unwanted and discarded materials produced wholly from the agricultural practice example, manures and other waste from poultry farms, pesticides, agricultural runoff, harvest waste etc.

d. *Industrial waste:* The waste produced by industrial activities like mining, manufacturing, coal combustion, oil and gas production, which includes materials that are produced during manufacturing processes such as that of factories, mills mining, etc. It also includes waste such as chemical solvents, paints, sand paper, industrial by-products, paper products, metals and radioactive waste, etc. These industrial waste includes toxic pollutants that needs to be treated thoroughly before releasing it out in the environment [18].

e. *Electronic waste:* E-waste or electronic waste are actually the unwanted electronic devices which are discarded for recycling, reuse or refurbishment example, computers, VCRs, DVD players, televisions, stereos, copiers, fax machines etc. [19]. The electronic waste has turned out to be a major problem for mankind. When these wastes are dumped into landfills, toxic substances such as mercury, lead, cadmium, etc. leach out into the soil and water and as a result affect the human race and animals.

f. *Waste from constructions and demolitions:* Whenever any kind of constructions or demolitions of buildings, roads, fly-over, bridges, and subway, etc. or remodeling of these structures takes place, a lot of waste is generated out. This includes metal, wood, plastics, concrete materials, plasters, etc. It consists of 10-20 % of the municipal solid waste.

g. *Commercial source:* As a result of the greatest advancements and modernization in the cities, industries and automobiles generates a large amount of waste of daily bases from commercial enterprises. These may include food products, disposable medical items, textiles and much more.

Biodegradable and non-biodegradable waste

We can totally agree that technology has enhanced the quality of life and has given birth to innovation in various fields. This has created an erratic impact on mankind and the environment and also other lives on the planet. As for the plastic water bottles that are very convenient to use but might take around thousands of years to decompose but its degradation is a test to nature. Now there are huge amount of waste/garbage that can be decomposed or non- degraded. And whether it is biodegradable or non-biodegradable, all garbage is harmful to human life and a loss to the environment. These are classified below:

Biodegradable waste

Materials and substances can be termed as biodegradable if they are easily decomposed by bacteria and other natural organisms and do not contribute to pollution. Biodegradable waste is easily found in municipal solid waste like kitchen waste, green waste, food waste, paper waste, etc which are usually degraded by microbes (bacteria, fungi, etc.), abiotic components like temperature, UV, oxygen, etc. They are broken down into carbon dioxide, methane, water and other basic natural mixes by various processes like fertilizing the soil, aerobic digestion, anaerobic processing or comparative ways. It additionally incorporates a few inorganic compounds like gypsum and its products which can be broken down by the microorganisms. Biodegradable waste affects the environment only when they are present in excess. They can generate are large quantity of microbial population around the waste which can cause many communicable diseases to humans, animals, etc., it can generate bad odor, release certain gas on the process of burning, dumping grounds can act as a breeding ground for certain vectors or carriers like mosquitoes and rats which ultimately can various harmful diseases. Biodegradable waste can also be utilized as a source of heat energy, power and fills by methods anaerobic digestion or burning [20].

Non-biodegradable waste

Waste or materials which cannot be degraded or decomposed by the biological processes or broken down by natural organisms and add up to the pollution are referred to as non-biodegradable waste. This waste cannot be taken care of. It remains on earth for thousands of years without being decomposed. Hence, they are more dangerous than the biodegradable waste. Extreme use of such waste, for example, chemical fertilizers and pesticides makes the soil more acidic or alkaline, thus affecting the growth of plants and the fertility of the soil. From the fields, these harmful chemicals might wash off into the nearby water bodies thereby disturbing the aquatic life and endorsing the algal bloom causing eutrophication. Most of the non-biodegradable waste can enter the food chains or biological cycles and since humans occupy the highest tropic levels at any of these cycles, therefore most of the harmful chemical concentrations are found in the human bodies. A usual example of this is the plastic which is found in every area. In order to give plastics more durability and better outcome, better quality plastics are being used. Other examples include metals, cans, industrial trash, chemicals from agricultural fields, etc. These are the major causes of air, soil and water pollution and causes deadly diseases like cancer [21].

Plastics: Invented in the late 19th century, this miracle material has made modern life easy and sustainable. "Plastic" initially signified as “pliable and easily molded.” It is derived from a class of materials called polymers which signifies “of numerous parts,” and these polymers are made of long chains of natural cellulose molecules, the insoluble substance that constitute the main part of plant cell walls and of vegetable fibers such as cotton. Other examples of polymer are polyethylene, PVC, nylon, etc. Since the dawn of history, humankind has endeavored to develop material offering benefits that are not easily found in natural materials. The development of plastics started with the use of natural materials that had intrinsic plastic properties in them such as shellac and chewing gum. The next step in the evolution of plastics involved the chemical modification of natural materials such as rubber, nitrocellulose, collagen, galalite, etc. Finally, a wide range of completely synthetic materials recognized as modern plastics started to develop around 100 years ago.

Plastic categorization: Plastics are an essential component of many products such as water bottles, combs, beverage containers, bags etc. The types of plastics include:-

i. Polyethylene Terephthalate (PETE/PET): - This was introduced by J. Rex Whinfield and James T. Dickson in 1940. It is one of the most commonly used plastic in the world. Knowingly, it took almost 30 years before it was used for crystal-clear bottles such as beverage bottles used in Pepsi and Coca Cola.

ii. High- Density Polyethylene (HDPE): - Produced by Karl Ziegler and Erhard Holzkamp in 1953. They used low pressure and catalyst to create high density polyethylene. It is used for manufacturing a wide variety of products today. It was first used for pipes in drains, culverts, etc. It does not break under the exposure of extreme heat or cold. Around 12 % of all the HDPE are being recycled every year.

iii. Polyvinyl Chloride (PVC): - It is one of the oldest synthetic materials used in industrial production. PVC was accidentally discovered twice: first discovered by a French physicist named Henri Victor Renault in 1838 and again by a German chemist named Eugen Baumann in 1872. Both of them found the PVC inside vinyl chloride flasks which was left exposed to the sunlight. In general, PVC is one of the least recycled plastic; less than 1 % is being recycled each year. PVC consists of numerous toxins and is harmful to human health and the environment and hence it is called as the “poison plastic”.

iv. Low- Density Polyethylene (LDPE): - LPDE is considered to be the grandfather of the material as it was the first polyethylene to be produced. It has less mass as compared to high density polyethylene and hence it is considered as a separate material for recycling. Containers and packaging that are made from LPDE make up to 56 % of all the plastic waste. 75 % of this waste come from the residential households. But luckily many newer recycling programs are evolving to handle these products.

v. Polypropylene (PP): - In 1951, Paul Hogan and Robert L. Banks of Philips Petroleum Company discovered polypropylene. During this time, they were actually trying to convert propylene to gasoline but instead they ended up discovering a new catalytic process for making plastic. Only a small portion of this plastic is being recycled every year. In the USA, only 3 % of the polypropylene products are being recycled.

vi. Polystyrene or Styrofoam (PS): - While preparing medication, German apothecary Eduard Simon accidentally discovered polystyrene in 1839. He discovered it from natural resin and didn't realize yet. Later, German chemist Hermann Staudinger took research on it and expanded on its usage. Polystyrene is lightweight and easy to form and hence it breaks effortlessly, making it more and more harmful for the environment. It accounts for about 35 % of US landfill cover.

vii. Miscellaneous Plastics: - Polycarbonate, polylactide, acrylic, acrylonitrile, butadiene, styrene, fiberglass and nylon are the remaining plastics. Also, there are many differences in the plastics under the recycling programs. These plastics are not very easy to break down unless they are being exposed to high temperature which makes it nearly impossible for them to be recycled [22].

Throughout the only remaining century and half human race have figured out how to make engineered polymers, here and there utilizing normal substances like cellulose and also the petroleum products and oils have frequently provided carbon sources that are being utilized thoroughly. The Synthetic polymers comprise of long chains of repeating units. And as the result the polymers are solid, lightweight, sturdy and adaptable.

In 1869, John Wesley Hyatt introduced the principal manufactured polymer as an ivory substitute. By treating the cellulose which was gotten from cotton fiber, with camphor, Hyatt was capable to find a plastic that could be made into a wide range of shapes and made to copy the characteristic substances like tortoiseshell, horn, material, and ivory. Plastic flotsam and jetsam in the seas were first seen during the 1960s. As the mindfulness about natural issues began spreading, the constancy of plastic waste started to inconvenience humanity. There is another arrangement of plastics called microplastics. They are little plastic circles utilized in face washes, beauty care products, and toothpastes to shed or clean and are normally made out of polyethylene (or polypropylene, polyethylene terephthalate, or nylon) yet the category of plastics that are under 5mm long are specified by NOAA (National Oceanic and Atmospheric Administration) of the USA[23, 24]. When these synthetics are inside us, it can cause different cancers, a debilitated safe framework, conceptual issues and then some. Microplastics can taint the air, tap and filtered water, food and beverages, including salt, fish, nectar and lager. A wide range of ocean animals do ingest microplastics, and as they climb to the natural cycles, these plastics will unavoidably wind up in the people's circulatory framework.

Notwithstanding developing issues, plastics are urgent to present day life. Plastics made conceivable the improvement of PCs, mobile phones, and a large portion of the lifesaving propels in medication. They are lightweight and useful for protection, plastics help spare non-renewable energy sources that are utilized in warming and in transportation. Maybe generally significant, reasonable plastics increased the expectations of living and made materials all the more promptly accessible. Since unmistakably plastics have a significant spot in our lives, a few researchers are endeavoring to make it more secure and increasingly manageable. Some inventors are creating bioplastics, which are produced using plant crops rather than non-renewable energy sources, to make substances that are increasingly ecological well-disposed [25, 26].

Despite the upcoming problems and human activities, plastics have proof to be one of the key elements for modern life. Plastics have made conceivable the improvement of PCs, mobile phones and the vast majority of life saving advances in medication. They are lightweight and useful for protection; plastics help spare non-renewable energy like fossil fuels. Perhaps most significantly, cheap or inexpensive plastics have increased the expectations of living and made materials all the more promptly accessible. A few researchers are endeavoring to make it more secure and increasingly practical. Some inventors are creating bioplastics that are obtained or produced from plant crops instead of petroleum products, to create substances that are progressively ecologically and harmless. Unfortunately, most bioplastics do not break down easily in home composts, landfills, or loose in the environment. Most of them require commercial composting facilities, which aren't always available to the consumers. Many companies have been working on fully compostable (in some cases edible!) packaging. Here are some examples already on the market:

i. Mushroom packaging: Fungi, unlike mushrooms, the type of fungi used for structural design aren't edible. However, it is a beneficial replacement for plastic. By using different techniques to culture the fungi, it is possible to grow reproductions of several materials, such as wax, and even cork. The micro-organisms are first neutralized before the product is sold, so you don't need to worry about the chair growing green stuff. A combination of agricultural waste and mycelium (mushroom) root, this home compostable product is "grown" on a hemp-flour mixture, and dried to stop the growth process. It is most commonly used to replace Styrofoam plastics.
ii. Liquid wood: Liquid wood is a biopolymer. These are substances that look and act just like polymers but are biodegradable. It is manufactured by mixing lignin (a plant byproduct of the paper manufacturing process) with water and then subjecting this mixture to heat and pressure. What comes out is a strong, flexible, composite non-toxic material which can be used to create anything from toys to T-shirts.
iii. Seaweed-based packaging that comes in edible and biodegradable grades.
iv. Pressed hay is being used as egg cartons, packaging in Poland.
v. Banana Leaves: In Thailand, one supermarket has opted to go plastic-free in favor of banana leaf-and-bamboo packaging as to reduce the use of plastics. And while banana leaves may only be practical where they're readily available, this does reinforce the idea of using local, compostable materials.

Glass: Glass has been around for a long, long time. Sure, plastic is lighter. But on the flip side, glass won't melt easily. And glass is much easier to recycle then plastic. Glass doesn't leach harmful chemicals into anything. It doesn't take polluting materials or manufacturing processes: glass is made from sand and could be a better alternative to plastic.

Alternative packaging material

Biodegradable plastics (BDP): Biodegradable plastics or (BDPs) are not an alternative to plastic in the conventional sense because they are plastic. The only thing is that they are biodegradable. Materials such as starch, milk or cellulose, etc. are capable of breaking down completely are classified as biodegradable (or biodegradable) which break down into tiny particles, over months, or bio-compostable which can be composted with other compostable. Both must end up by the enzymatic activity of microorganisms into inorganic mass, H_2O, CO_2, CH_4 etc.

Types of BDP: They may be classified as bio-based, or petrochemical-based.

The bio-based type is produced from plants, animals or microbes, which produce polysaccharides like starch, lignin or cellulose, lipids such as animal fats or from plants, and proteins such as gelatin, gluten or casein. Natural rubber, polyhydroxyalkanoates, and poly-3-hydroxybutyrates (both from microbes or plants), polylactic acid (PLA) which comes from a bio-based monomer, lactic acid, etc. are also included.

Petrochemical-based BDPs include aliphatic polyesters such as polyglycolic acid, polycaprolactone (PCL) and aromatic copolyesters like polybutylene succinate terephthalate can be biodegraded. Polycaprolactone is an aliphatic polyester which is made from fossil fuels, can undergo complete breakdown in six weeks.

It is already being used in stitches for precision and the main reason why it has not been adopted on a wider scale is because of its high manufacturing cost. However, combining it with cornstarch can cut down these problems.

Many BDPs today contain a mixture of both categories for increased performance or cost-effectiveness [27-30].

Microbial degradation of plastics

Many modern biotechnological techniques such as the development of synthetic microbial consortium, genetic engineering and systems biology are being applied to overcome the associated limitations of conventional burning and land filling methods. Genetic engineering has been useful in manipulating the genetic structure of microorganism to enhance their ability in degradation of plastic contamination. Systems biology provides related information on the expression of DNA along with RNA and metabolites produced too. The natural microbial consortium is manipulated in the sense of their genetic potential to obtain synthetic microbial community [31].

There are many steps in the microbial degradation of plastics and have certain terminologies by which they can be identified.

i. Bio-deterioration**-** It defines the action of certain organisms that are responsible for the physical as well chemical decomposition of the plastics. This results in a surface degradation that alters the properties of the plastic including mechanical, physical and chemical properties.
i. Bio-fragmentation- It refers to the certain catalytic actions that breaks down the polymeric plastics and converts it into respective oligomers, dimers or monomers by x free-radicals or ecto-enzymes that the microorganisms release.
ii. Assimilation**-** It is the getting together or union of the constituent molecules transported in the cytoplasm in the metabolic pathways or strategies of microbes.
iii. Mineralisation**-** In this process, the molecules are degenerated in a way that results in their total deterioration and excretion of fully oxidized metabolites like CO_2, N_2, CH_4 and H_2O.

These terms are further described as follows-

1. *Bio-deterioration:* This process is a superficial or surface degradation that modifies all the properties of plastic including physical, chemical and mechanical properties. Mostly, the abiotic parameters help to weaken the polymeric structure of plastic. Sometimes, these abiotic parameters may prove to be useful either as a symbiotic factor, or as an initiator of the biodegradation process.

   The formation of a microbial biofilm initiates the process of bio-deterioration. This biofilm grows on the surface and also within the plastic. The manner in which the biofilm develops depends on two factors: the conditions of the surrounding environment and the structural make-up of the plastic [32]. PS and PE plastic polymers are hydrophobic. Thus, if the bacterial surface is hydrophobic only then will there be the formation of a stable biofilm. Here, we can cite the example of the biofilm of *Rhodococcusruber C208* formed on polyethylene that showed high level of activity. Even after being incubated for 60 days, it adhered to the polyethylene without any supply of external carbon.

   A high level of physical and chemical deterioration, is seen to be caused by the microbial biofilm:

   i. *Physical deterioration:* The adhesion to the surface of the plastic and cohesion of the biofilm are emphasized by extracellular polymeric substances (EPS). These substances are in this way, linked to the process of the microbial biofilm forming. They then enter the pores that leads to the growth of microorganisms inside the pores. Thus the pore size increases resulting in cracks. These cracks are responsible for weakening the physical properties of the plastic [33].
   ii. *Chemical deterioration:* There may be different microbial groups that develop on plastic [34] and the biofilm that forms on it may discharge acid compounds. For example, nitric acid (e.g. *Nitrobacter* spp.), nitrous acid (e.g. *Nitrosomonas* spp.) or sulphuric acid (e.g. *Thiobacillus* spp.) by chemolithotrophic bacteria. Some chemoorganotrophic communities also release various organic acids such as glyoxalic, citric, fumaric,

gluconic, glutaric, oxalic and oxaloacetic acids. The release of all these acids inside the pores alters the pH, which is followed by a gradual degeneration that modifies the microstructure of the plastic matrix.

2. *Bio-fragmentation:* There may be different origins of breaking down of plastic polymers into its constitutional oligo- and monomers that include mechanical, thermal, UV radiation, chemical and/or biological origin. The biological aspect is the main focus here.
   Plastics, being polymers, have high molecular weights. Their movement across the cell wall is not possible. There are specific extracellular enzymes (exoenzymes) secreted by microorganisms that target the perimeter of the plastic polymer and catalyze the chemical reactions there. There is a requirement of an unequal electric charge to perform disintegration reactions by these enzymes even after being able to perform numerous other chemical reactions. The major drawback of bio-fragmentation is that the plastic polymers are constituted by a long chain of carbons and hydrogens that contains very balanced charges that make them stable. The local electric charge needs to be destabilized for the bacteria to act on them. For this purpose, bacteria contain certain enzymes called oxygenases that add oxygen to a long carbon chain thus producing unequal charges and allowing the bacteria to degrade the plastic. Mono-oxygenases and di-oxygenases include, respectively, one and two oxygen atoms, forming alcohol or peroxyl groups. These groups are more manageable for biodegradation. The transformations other than these are then catalyzed by endopeptidases for amide groups, or by esterases and lipases after the formation of carboxylic groups [35].
3. *Assimilation and mineralisation:* Assimilation by microorganisms is not assured merely by the formation of monomer. To go across the cell wall and/or cytoplasmic membrane they have to use certain carriers. A few of the monomers may remain freely in the surrounding of microbial cells without being absorbed. Catabolic pathways inside the cells are used to oxidize the plastic monomers, producing energy, cell structure and new biomass. There exist three essential catabolic pathways for the production of the energy to maintain cellular activity, structure and reproduction based on whether the microbes can grow in aerobic or anaerobic conditions: fermentation, anaerobic respiration and aerobic respiration. There may be incomplete degradation of the monomers even after the absorption of atoms inside microbial cells. This integration or joining results in the formation of a lot of secondary metabolites. In the microorganisms that cannot metabolize or do not need to store these metabolites, the metabolites are carried outside them. If any other cell that can perform additional degradation then they may then use the secondary metabolites which were excreted earlier. The mineralization indicates to the total degeneration of primary and secondary metabolites that further results in the excretion of fully oxidized metabolites (CO_2, N_2, CH_4 and H_2O) [36].

Non-microbial degradation of plastics

The mechanisms by which plastics degrade in the environment excluding microbial degradation are photo-degradation, thermo-oxidative degradation and hydrolytic degradation. Generally speaking, natural degradation of plastic begins with photodegradation, which leads to thermooxidative degradation. The activation energy which helps in the commencing of the inclusion of oxygen atoms into the polymer is supplied by the UV radiations emitted by the sun. When this happens, the plastic becomes fragile enough to be broken down into smaller and smaller pieces. This goes on until the polymer chains reach a molecular weight that is low enough so that the microorganisms could break them down or metabolize them. These microbes result in either incorporation into biomolecules or conversion of the carbon in the polymer chains to carbon dioxide. However, this entire process is very slow, and it can take 50 or more years for plastic to fully degrade. This is not aided by the fact that the photodegradative effect is significantly decreased in seawater due to the lower temperature and oxygen availability and that the rate of hydrolysis of most polymers is insignificant in the ocean [37].

Challenges faced during microbial degradation

The process of degradation of plastic pollutants depends on a number of factors like molecular weight, surface area, functional groups, melting point, temperature, hydrophilic and hydrophobic characters, chemical structure, crystallinity, etc. the molecular weight of the polymers tends to affect the degradation process by comparatively reducing the solubility and the degradation rate. Moreover, the reduction in solubility usually makes the plastic polymer less vulnerable to microbial attack because they are assimilated by the microbes through the cell membrane. It is also seen that the crystalline nature of plastic polymers makes it less accessible for microbial enzymatic action and hence the degradation rate of plastic decreases with increase in the crystalline nature. Additionally, the hydrophobic nature of plastic polymers restricts the microbial action by inhibiting water absorption that can be reused by biofilm formation. So, it can be concluded that degradation of most polymers depends on suitable factors. Up to date, screening of microbes or enzyme production helps in degradation of polymers [38].

Case studies

1. *Mysterious Worms Eat Plastic And Excrete Alcohol:* In Brandon University in Manitoba, Canada, a study was conducted that found waxworms usually living in beehives and feeding off of wax for survival, can also survive on polyethylene—the type of plastic that is mostly used in day to day lives. This is due to the presence of intestinal microbes. The waxworms after consuming a meal of plastics excrete glycol which scientists have yet to confirm its use.
   More than 30 square cents of a plastic bag could be consumed by around 60 waxworms in the laboratory within a period of seven days. But this does not give us a solution to the issue of plastic. Compared to letting the worms to feed directly on plastics, the efficiency of a species of intestinal bacteria in the worms which would very well survive by having plastic as the sole supply of food for quite a long duration of time was quite less.
   The fact that waxworms could consume plastics was recognized earlier in 2017 in the U.K. by some university researchers. But the researchers also state that "the contribution of its intestinal micro-biome remains to be poorly understood and contested". Further in a series of experiments, the researchers presented confirmation of a sophisticated relationship between biodegradation of low-density polyethylene (LDPE), a micro-biome that is fully unscathed and the production of glycol as a by-product after metabolism. The information gathered from these experiments will allow them to establish tools which can be used to help eliminate plastic waste without needing live waxworms, which may cause inconvenience for large-scale plastic waste removal [39].

2. *'Plastic-eating' bacteria found in Zambales:* Philippines has a problem associated with plastics. Besides being named one of the top five countries that contribute to half of the world's plastic pollution, a study done in 2015 revealed over 6,237,653 kg of plastic is wasted each day. So the discovery of bacteria which can overcome the resistance of plastic degradation can be a revolution.
   In 2018, strains of bacteria were discovered in Poon Bato Spring, Zambales, which were found to be capable of "eating" or biodegrading plastic, according to researchers of the University of the Philippines-Baguio.
   Out of the original nine strains that were taken from the spring, a total of four strains of bacteria could biodegrade low-density polyethylene (LDPE), commonly used in plastic bottles, bags and other such containers.
   The ultimate goal is to check whether these bacterial strains are capable of degrading plastic in a large scale and economical way [40].

3. *A chemist explains the working of a plastic-eating bacteria:* Lately scientists have discovered a particular strain of bacteria that can actually eat the plastic which is used for making bottles, and have now enhanced it so that it can function more proficiently. The results are unassertive – it is not a comprehensive key to eradicate plastic pollution – but it does portray how we can take the help of bacteria to produce recycling that would be more environment-friendly.
   Plastics are a type of complex polymers. They are constituted by long and repeating chains of molecules which do not get dissolved in water. As these chains are tough, plastic can last longer meaning that it takes a very long time to degrade by nature itself. But these segments could be accumulated to form new plastics if they were to be fragmented down into small and soluble chemical units.
   Various bacteria were collected by scientists from a bottle recycling plant in Japan in the year 2016. They discovered that a specific bacteria, *Ideonellasakaiensis*201-F6 could break down polyethylene terephthalate (PET), the plastic used to make bottles. Its action on plastics was due to the release of an enzyme known as PETase. The PETase split certain ester linkage in PET, producing smaller molecules which could then be absorbed by the bacteria, making use of the carbon in them as a source of food.
   Even though there were other bacterial enzymes which were already known to be capable of digesting PET, the new enzyme had supposedly evolved particularly for this job. This suggested that it might be more efficient and could be potentially used in bio-recycling.
   This research helps us perceive how this hopeful enzyme could degrade PET and gives us further clues about how we could make it work rapidly by exploiting its active parts, even when the improvements to the PETase activity were not remarkable.
   The enzymes that have evolved naturally cannot be devised to make them work better. It is clearly indicated by the fact that the bacteria using PETase have evolved not long ago to be able to sustain on this synthetic plastic. This may prove to be an important piece of information and a breathtaking opportunity for scientists to surpass evolution by engineering enhanced forms of PETase.
   Yet there is one concern. The fact that the modified bacteria could evolve to decompose and devour plastic suggests this material that we are dependent on so much may not be as sturdy as

we thought, even though any of the modified bacteria used in bioreactors are very much regulated.

If more number bacteria started eating plastic in the wild, then products and structures which were originally designed to last for years could be at risk. The plastics industry would be facing the serious challenge of preventing its products from becoming polluted with ravenous micro-organisms [41].

4. *Biodegradable plastic could be just as harmful, study says:* The United Nation's top environmental scientists deliberated a research to understand how biodegradable plastics would affect the environment. Researchers established these type of plastics are just as harmful to different habitats with common plastic products.

   In the last decade a great amount of 'green-peace' campaigns have been made in developed countries. Reducing the use of common plastic bags and switching to recycled bags or biodegradable bags was the main target. But a team of the UN's most recognized environmental scientists proved that biodegradable plastic bags and recipients are just as harmful as common plastic to marine habitats.

   Thus it can be concluded that biodegradable plastics may not be as useful or eco-friendly as they are thought to be [42].

Discussion

Plastics are convenient in our everyday life because of their ease of manufacturing process, low costs, high durability and flexibility, indestructibility during transportation, etc. Its utilization is increasing step by step and its debasement is turning into an extraordinary danger. In the regular habitat, various types of microorganisms undertake a significant task in different advances engaged with the degradation of plastics. Considering the synergism between those microorganisms will give a knowledge for future endeavours toward the biodegradation of plastic materials. The plastics are found to have high-atomic weight and have hydrophobic surfaces, making it difficult for the microorganisms to form stable biofilms and break them into small sub-atomic oligomers.

Different plastic-degrading techniques are accessible, yet the least expensive, eco-accommodating, adequate technique is degradation utilizing microorganisms. The microorganisms discharges the extracellular catalysts to degrade the plastic with the complex enzymatic response, however, further examination despite everything needs to be done. Usage of atomic strategies to identify explicit gatherings of microorganisms included in the degradation procedure will allow a superior comprehension of the association of the microbial network to engage with the materials. The portrayal of effective plastic-degrading organisms at the atomic level is not yet accessible, so examine ought to be engaged in the field of genomics and proteomics, which could accelerate the degradation.

Conclusion

Taking into account the ecological cordial and practical advantages of utilizing microorganisms in the degradation and disposal of the waste generated in various nations, some proposals like pertinent government parastatals ought to combine in their activities and ventures occupants on authentic ways to deal with administrative waste, and management of waste assortment. This was given by the Integrated

Solid Waste Management System (ISWM). Garbage partition at the source ought to be done to take into account increasingly compelling and proficient waste assortment and management. Microbiological strategies for waste, the executives ought to be created and used, for environmental cleanup as well as for the worth included advantages of such methods. Also the existing plastic waste or similar materials can be degraded with the help of suitable microorganisms and utilization of synthetic and semi- synthetic biodegradable materials should be the preference for future aspects. Lastly, waste assortment frameworks ought to be improved for manageable and increasingly sterile natural.

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