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ADVANCES AND CHALLENGES IN PLASTIC BIODEGRADATION: A COMPREHENSIVE REVIEW

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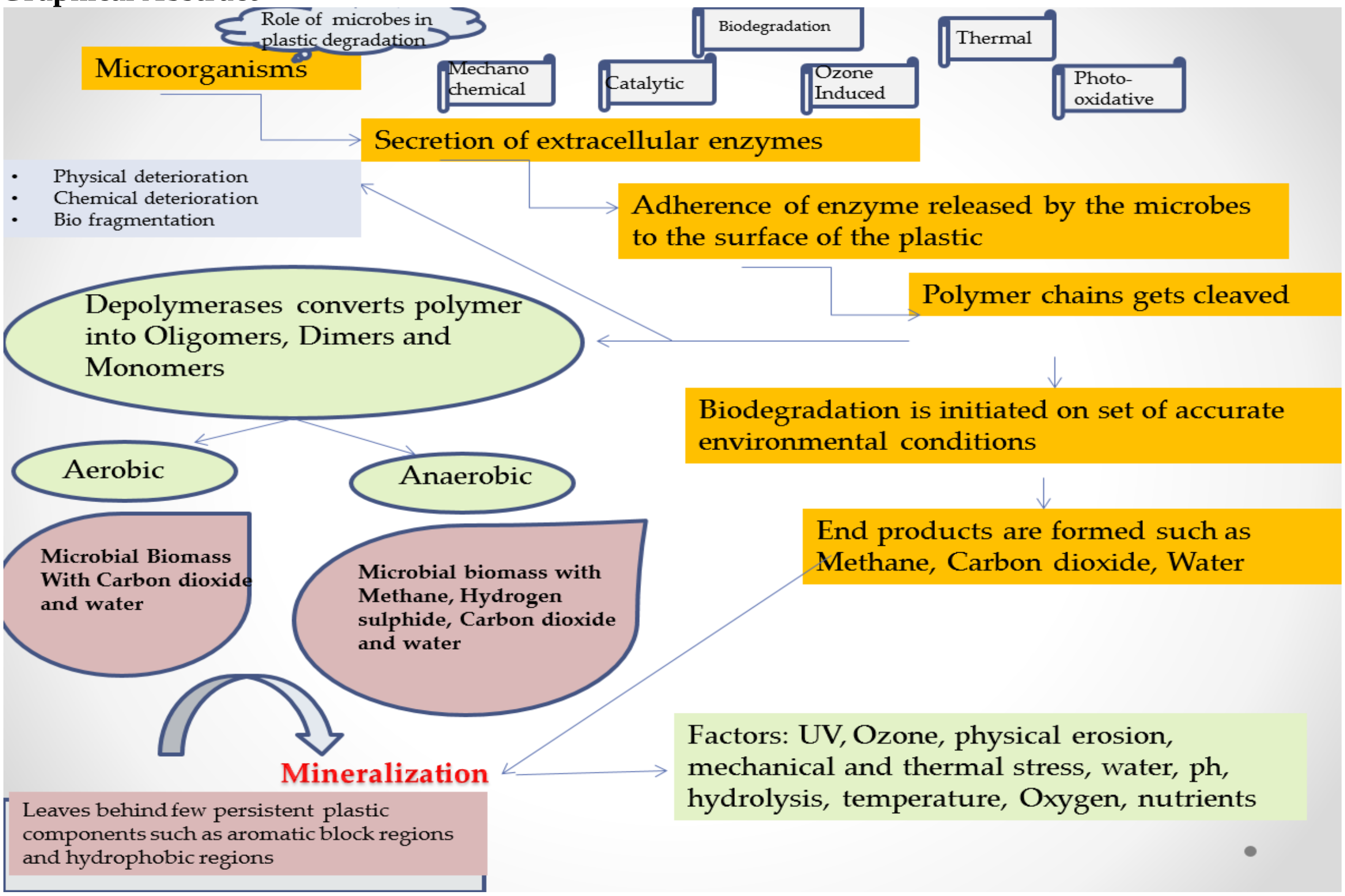
Abstract:

Plastics play indispensable role in our life. It is one of the most widely used products owing good tensile strength, lightness, resistance to water and multipurpose usage. Plastics being recalcitrant to degradation take decades to be degraded on its own. Its accumulation is an inevitable threat to the environment and mankind. Plastic pollution has become one of the most pressing environmental concerns of our time. The ever-increasing production and consumption of plastics have led to a significant accumulation of plastic waste in various ecosystems, posing severe threats to wildlife, human health, and the overall health of the planet. In recent years, extensive research has been dedicated to understanding plastic degradation mechanisms and developing sustainable solutions to address this global crisis. Microbial plastic degradation is an effective remediation method, where desired strains of organism are involved where they adopt a series of mechanisms to convert the toxic, recalcitrant, polymers into simpler, non-toxic monomers. This, inturn, paves way for bio mineralization and assimilation in soil leading to increased soil fertility. This review paper provides an in-depth analysis of the challenges associated with plastic degradation, explores the various degradation mechanisms, and discusses promising future perspectives for mitigating plastic pollution. Also itanalyses the recent knowledge about biodegradation of artificially synthesized plastics and the mechanism in which it happens by certain bacteria, fungi and actinomycetes are clearly explained.

Key words: Polyethylene, microorganisms, biodegradation, mineralization.

Graphical Abstract



1. Introduction

The word plastic is framed from a Greek term "plastikos" which signifies 'able to mold in different shapes'. Plastics are artificially synthesized lengthy chained complex polymer. It's been half a century that plastic has started to play a vital role in the day to day life now plastic has become an inevitable part of our lifestyle (Venkateshet al., 2021). Commercially available plastics are a formulation of carbon, oxygen, nitrogen, silica and chlorides and the raw material is believed to be cellulose, coal, natural gas, salt and crude oil. As an end product plastics are obtained after the process of through a polymerization or poly-condensation (Ahmed et al., 2018). Plastic, a multipurpose 'manmade' substance in the 19th centuries is now an essential component of our daily life especially in the industrial and technological revolutions. Foodstuffs, sartorial, housing, transport, edifices, pharmaceuticals, recreation industries, food and agricultural industries etc are now unimaginable without plastic, it is now an inevitable dependency (Rolf-Joachim Mueller et al., 2006). These artificially synthesized polymers are generally highly recalcitrant and least susceptible for microbial attack, even if it does it takes minimum 400 years to degrade plastic naturally (Masayuki Shimao et al., 2001). There are also petroleum based synthetic polymers available which produces which contributes majorly a remarkable amount of polymer burden in the environment. Applicatory aspect of the synthetic plastics are versatile, used 30% for packaging alone. Its physical and chemical properties have made it potential and user friendly with reference to its tensile strength, flexibility, stability, durability,water repellant nature and resistance to ware and tare.They are also light, cost effective, anti-corrosive in nature and insulated in nature (Roth et al., 2014).

2. Types and Uses of polyethylene

There are two types of plastics as follows;

Thermoplastics: These are rigid plastics that doesn't change its chemical properties and their composition when they are subjected to high temperature.

Thermosets: Processes infinite molecular weight. Made up of chains of many repetitive subunits derived from monomers. Each monomer may repeat over thousand times. Monomers which constitute to long polymer chain may be of same kind or of different kinds of monomers.

Chemicals in plastic which give them the rigidity is contributed by certain chemicals such as flame retardants, bisphenols, phthalates and other carcinogenic chemical complexes. Living organisms especially marine animals are affected the most. Humans are also affected by plastic pollution where they are highly carcinogenic and also disruption of various hormonal mechanisms (Tokiwa et al., 2004)

There are various types of plastics such as polypropylene (PP), polyethylene (LDPE, MDPE, HDPE and LLDPE), polystyrene (PS), poly (butylene terephthalate) (PBT), polyurethane (PUR), polyvinyl chloride (PVC), poly (ethylene terephthalate) (PET), nylons are most widely (Sabir et al., 2004). Their favorable and thermal properties makes it user friendly both in large scale and small scale .One third of the plastic produced are single use plastic which is exclusively used for packaging purpose are readily being disposed once used (Thompson et al., 2009). They are believed to be less than 40microns, can neither be reused nor recycled, they are the major contributors of pollutants in the environment which includes from the terrestrial land to marine ecosystem (Anantharam et al., 2018). The rate of accumulation is directly proportional to the shore use, a concentrated settlement, region of the Earth's surface that wind blows primarily from a specific bearing (Tokiwa et al. 2009).

TABLE 1:TYPESOFPLASTICSUSED.

Plastic types		Uses
Polypropylene terephthatate	PETE	beverage bottles, oil cans, syrup bottles etc.
High density polythylene	HDPE	Soap bottles, health care product bottles.
Plyvinyl chloride	PVC	Food packaging, sweets and fruits tray, food foils.
Low density Polyethylene	LDPE	Bags, Food warps and packages , carry bags
Polypropylene	PP	Toys, kids items, external lining on auto mobiles, travel bags.

Polystyrene	PS	Computer hardware's, storage devices of computer, electro appliances like refrigerator, switch boards
Nylon	Nylon	Auto mobile and computer hardware materials, Medial appliances, kitchen appliances, clothes, jackets and shoes
Glass fibers	GF	Aerospace, paper industry, food processing, automobile hardware's , towers, oil/ gas pipes.
Polylactic fibers	PLF	Automobiles, electronic gadgets, textile industry , cosmetics, Food packaging, single use bottles, plates, spoons.
Polycarbonate	PC resins	Space craft hardware's, constructions, travel bags, medical Equipment, surgical materials.

Thebelowpointsexplainsthevariousfieldsinwhichplasticsareusedmostextensively

•**Containers:** It is polyethylene packaging and containers (PE) that are useikadzd forthe transportation of any packages product. Even packaging the product is done using PE.Polyethyleneispreferredsinceithaslightweight,doesn'ttransmitodour,tasteoranyflavour.
•**Transportation:** In any means of transport in which the material is transported plasticincluded.This is dueto its good quality
•**Medicine:** Devices or materials like syringes, capsules, prosthesis, bags of serum, gloves admany morearemadeofplastic.
•**Electronics:**Theyareverygoodinsulators.Materialslikecables,Computers,fixedtelephones,mobilephones aremanufactured byPolyvinylchloride (PVC)
•**Agriculture:**Agriculturaltechnologyandharvestingmethodshavedrasticallyimprovedinthatplastic plays a major role. They are most commonly used in greenhouse, pipes for irrigation,tunnelsof cropping etc(Swift G et al., 1997).

Generally pure plastics have low toxic content because of its low solubility in water and itschemicalinertness.Fewplasticshavehightoxiccontentinthemduetothesyntheticadditiveslike plasticizer (adipates and phthalates) in them. The compounds in the plastic may cause hormonefunctions and suspected to be carcinogen as well. But a finished plastic is non-toxic though, themonomers which makes up the polymer may be toxic. In order to synthesis finished plastic quitefastercertainadditives are added suchas polyvinyl chloride (Shimpi et al., 2012)
Synthetic fibers: They are purely artificially synthesized by man. A synthetic fiber is composed of chain ofsmall units that together forms a long fibers. These small units could be chemicalsubstances.Manysuchunitsjoinswithlargeunitscalledaspolymers (Sharma et al., 2017).

3. Effects of Polyethylene

The dependency on plastics has transmuted our lifestyle completely. As there is high demand, the production and availability of plastic is also sufficient enough hence the usage is to its peak (Ward at al., 2006). The demand has raised the production of plastic from 0.5 million tons to 260 million tons when compared in the year 1950. The annual production on an average have raised 46.6% from the survey from 2002 to 2013 (Bollinger et al., 2018).

Terrestrial habitats are the hot spots showing a steady decline in the native species population (Wallace et al., 2017). Marine ecosystem on the other hand reflects a serious negative impact on the aquatic fauna and flora. The latter being non-biodegradable remains static when ingested or remains tangled on the body for years disrupting its movement and metabolism also leads to bioaccumulation. New pelagic layer is formed as a new habitat made up of millimeter-sized plastics (Ren et al., 2019) (Benachour et al., 2009). There are many primitive algae, cyanobacteria, protozoans, fungi and bacteria seen residing on it (Benachour et al., 2015).

As per International Agency for the Research on Cancer (IARC) Vinyl chloride is considered carcinogenic and it also mimics human hormones, proved to be causing human and animal mammary cancer. PVC being widely used all sorts of cosmetics and body care products for kids and adults is again proved to cause various health issues and turns carcinogenic when used extensively. Styrene again being classified as carcinogenic agent by IARC also induced tumor formation and endocrine disorders (Mohanan et al., 2020a) (Mohanan et al., 2020b). BPA is directly associated with under-intrauterine development, underdeveloped new born and especially postpartum preeclampsia, high usage may show an impact on the sex hormones in females to be particular (Chua et al., 2003). Incineration of plastic is not an acceptable way of plastic management or disposal as it releases lethal greenhouse gases could induce ozone layer depletion and increase gaseous toxicity in the atmosphere. Dioxin on a serious note causes endocrine hormonal issues and also contributed for soil pollution. . Phthalates, Bisphenol and others causes thyroid gland related issues (Shah et al., 2008). Chemicalsinplasticwhichgivethemtherigidityiscontributedbycertainchemicalssuchasflameretardants, bisphenols, phthalates and other carcinogenic chemical complexes.Livingorganismsespecially marine animals are affected the most.Humans are also affected by plastic pollutionwheretheyarehighlycarcinogenicandalsodisruptionofvarioushormonalmechanisms (Jayasekara et al., 2005)

This drastic increase in the availability and usage of plastics have paved way for a serious treat for the environment. Huge accumulation of plastic wastes from various sources (Abrusci et al., 2013). Have become a stubborn trouble to face, as these commercial polymers are highly recalcitrant and lacks readiness to degrade easily (Alvarez H. M. 2003).This massive waste thus produces creates a negative impact on the cities, forests and wildlife as well. Proper plastic waste disposal plays a vital role to control the pollution stress to hinder the potential harm on mankind and ecology. Burning was always a concerned method to treat plastic waste, stubborn organic pollutants known as furans and dioxins (Gu, J.D. 2003). Even during the production of plastic at various stages quite good amount of polymer wastes are produced which should be taken into consideration. There are few plastics such as polyurethane, polyester, polyethylene with starch blend that are susceptible to biodegrade but the commercially available plastics takes eras to reduce(Webb et al., 2013). This has elevated as an emerging worry about degradable polymers and raised research movement overall to either hoistbiodegradability or to foster novel choices that are degradable by any or the accompanying instruments as a whole: biodegradation, photodegradation, natural disintegration and warm corruption (Andrady A. L. 2011).

4. Biodegradation of plastic

In 1980′s, researchers began to look on the off chance that plastic may become helpless to microbial assault, making them deteriorate in a microbial dynamic climate. Biodegradable plastics paved the way for new contemplations of plastic leftover administration methodologies as these materials were intended to corrupt the ecological circumstances (Kenny et al., 2008). Recycling of plastics is not a cost effective methodology to eliminate plastic from the ecosystem, that case biodegradation of plastics becomes handy to eliminate plastic in an eco-friendly manner. Plastics can be converted as composts with other degradable waste and use them inturn to increase soil fertility (Yang et al., 2018).

Any structural or compound variation in polymer because of natural properties, like light, heat, dampness, synthetic circumstances or organic action (Weiland et al., 1995). Processes enacting changes in polymer properties (decay of support) by virtue of compound, physical or typical responses factors resulting in bond scission and coming about substance changes have been delegated polyethene degradation. Debasement has been replicated in changes of physical properties like mechanical, optical or electrical characteristics, in maddening, breaking, deterioration, staining, stage segment or delamination. The movements integrate security scission, manufactured change and plan of new helpful social events (Yang et al., 2015).Plastics can be degraded via various methodologies such as by chemical deterioration, thermal decomposition, photo or biological degradation (Gu et al., 2000). Any physical or chemical change changes the complete conformation of the polyethene sheet like reduction in the weight, loss of tensile strength, like gas production as a byproduct of the reaction signifies the biological degradation by microorganisms (Urbanek et al., 2018). There are list of factors that should be favorable for the degradation to occur which includes optimum temperature, humidity, water activity, oxygen concentration and desired living organisms (Albinas et al., 2003).

Factors affecting biodegradation of plastic

Temperature: Rate of biodegradation increases as temperature increases that a is it is believedtheenzymaticactivityisinitsoptimumrangeof30ºCto40ºC.,increasedsolubilityandavailabilityof less soluble hydrophobicsubstances also play animportant role.

Oxygen: Initial steps of biodegradation are the catabolic reaction ofaliphatic and cyclic hydrocarbonsand at times also involves aromatichydrocarbonsbybacteriaandfungi.Itinvolvestheoxidizing protocol upon plasticbyoxygenase whereit requires molecular oxygen.

Essentialelements: AlongwithCarbontherearemanyotherelementsthatareessentialthey arefound to be H_2, N_2, O_2, Phosphorous and also Sulphur. They play a vital role indegradation.

Salinity: Rateofbiodegradationinfreshandmarinewatershowssignificantdifferences.Microorganismsinhighlyhalophilicconditionsareveryless.Itisanalyzedthatrateof biodegradationofplasticgraduallydecreasesassaltconcentrationincreases.Itdecreasesintherangeof 3.3-28.4%.

Pressure: Basophilesareorganismswhichcanresistabout700atmosphericpressure.Theygreatlycontribute during biodegradation ofplastic.

pH: SoilpH varieshighly withtime totimeranging from202 inminerefuseto 11.0inalkalineexerts.Many bacteriaand fungi work is pH 7.

Bioticfactors: Bacteria, fungi,algaeandotherprotozoamajorlycontributestoBiodegradationofplastic (Gamerith et al., 2016) (Gnanavel et al., 2012)

Areplasticsbiodegradable?

Yes,definitely.Plasticsthatcanbedecomposedordegradedbyfewlivingorganisms.

•Plasticsarethepolymerwhichbecomesmobileorliquidfluidlikewhenitisheatedtoaparticulartemperature. Andthentheyarecastedintodesiredshape.Theyalsocontainnon-metalliccompounds. Plastic causes a serious threats to environment and as well to the living forms duringitssynthesis and disposal.

•The amazing fact is the certain microorganisms are capable of degrading plastics over 90 generafrombacterialike*Baccilusmegaterium*,*Pseudomonassp*,*Azotobactersp*,*Ralstoniaeutrophs*,*halomonasspe*tc. Evencertain fungi are capable of doing so. These bacteria tend to cleave thepolymerchainofplasticusingtheuniqueenzymesitproduces.Thesepolymersathenhydrolysedsimple monomers and oligomers.Simply they are converted to inorganic components is calledMineralization.Theseuniquemicroorganismscanbio remediateplasticwastes.Microbialactivitycanbeenhancedby strain improvementand genetic modifications (Premraj et al., 2005).

•A special type of microbial community that develops on plastic are highly diverse and couldproducebiofilmanditreleasesaspecialtypeofcompoundssuchasnitrousacid (Eg.*Nitrosomonasspp)*,nitricacid (Eg.*Thiobacillus spp.)* bychemolithotrophicbacteria. (Alvarez H. M. 2003).

5. Organisms involved in biodegradation of polyethylene

Biodegradation is the cooperation by which normal substances are isolated by carrying on with living things. The term is commonly used relating to science, waste the board, ecological remediation in account of their extensive future .Regular material can be defiled energetically, withor without oxygen. In this case, synonym of biodegradation is bio-mineralization, in which regular matter is changed over into minerals (Kijchavengkul T et al., 2008). Plastics are observed to be biodegradedin nature, anaerobically present in landfills and midway vivaciously, generally fertilizes the soil. Simple not toxic byproducts are produced during high-influence biodegradation.Carbon dioxide, water and methane are conveyed during anaerobic biodegradation (Silva et al., 2011).Usually, the cleavage of toxic, complex polymers intosimple carbon dioxide (mineralization) requires consortium of particular organisms, wherethere is serial reduction of polymer into its constituent monomers, to include the thus produced monomers to less perplexing nontoxic simple waste combinations (Takei et al., 2008).

Since microorganisms are good for spoiling most of the regular and inorganic materials, there is a lot of interest in the microbial defilement of plastic and polythene waste material.Microorganisms such as bacteria, fungi and actinomycetes degrades both natural and synthetic plastics The richness of microbes able to degrade polythene is so far limited to 17 genera of bacteria and 9 genera of fungi (Wei et al., 2014). Microbial degradation of plastics is caused by oxidation or hydrolysis using microbial enzymes that leads to chain cleavage of the large compound polymer into small molecular monomer by the metabolic process. The microbial species associated with the degrading materials were identified as bacteria, fungi, actinomycetes sp. and *saccharomonospora*genus (Vega et al., 1999).

The microorganism's growth is influenced by several factors including the availability of water, redox potential, and temperature carbon and energy source (Zimmermannet al., 2011).Microorganisms secreted by both exoenzymes and endoenzymes that are attached to the surface of large molecular substrate and cleave in to smaller segments (Juan-Manuel Restrepo-Flórez et al., 2014). Recently reported, degrading enzymes are produced by several microorganisms. Microorganisms recognize polymers as a source of the organic compounds (Zeenat et al., 2021).

Both natural and manmade plastics are subject to deterioration by microorganisms including bacteria and fungi (Pramila et al., 2011). Because the microorganisms responsible for the degradation are distinct from one another and each has its own preferred growing conditions in the soil, the biodegradation of plastics progresses actively under various soil conditions depending on their qualities. Heterotrophic bacteria may be able to grow on polymers, particularly plastics. The qualities of the polymer, the type of organism, and the method of pretreatment are some of the variables that influence biodegradation. Degradation of a polymer is greatly influenced by its properties, including its mobility, tactility, crystallinity, molecular weight, kind of functional groups and substituents present in its structure, and plasticizers or additives added to the polymer(Sowmya et al., 2015)

The tedious conversion of complex, toxic, recalcitrant polymers into simple, non-toxic, biodegradable monomers leads to mineralization. This process of depolymerization is occurs under various parameters, and in order to be absorbed as a mineral by the organisms this breakdown is a must. As believed small the minerals higher is the absorption rate by the microorganisms. There are n number criteria involved in this process of degradation which includes physical and biological processes (Halt et al., 2004). Mechanical detoriation first leads to consistency change of plastic sheet which becomes brittle and cracks which is artificially done heating/ drying/ freezing (Oliveira et al., 2020). There are certain fungi in favor with its morphology pierces through the polymer sheet and causes wear and tear (Shinozaki et al., 2013). Many synthetic polymers can be degraded using microbial enzyme leading to straight reduction of molecular weight of the polymer sheet (Ikada et al., 2000). Abiotic hydrolysis is an essential reaction to reduce the synthetic polymers occurs in the environment. Thus produced monomers, dimers and oligomers are readily minerilizable and no longer toxic (Tomita 1999). Enzyme produced by the organisms are the ground work to include the degradation process, once subjected with the polymer there is an attack on the polymer bonds making it more susceptible for degradation. But high molecular weight and rigidity of the bonds keeps them static for any sort of enzymatic encroachment. But when the polymer is subjected to extracellular and intracellular depolymerases enzyme especially for a prolonged period of time in harmony with other essential parameters then the degradation can be successful (Verce et al., 2000)

In past years polyethylene degrading bacteria has been reported as per the table

TABLE 2:LIST OF ORGANISMS INVOLVED IN PLASTIC DEGRADATION

LIST OF ORGANISMS INVOLVED IN PLASTIC DEGRADATION	
Arthrobacterviscosus	*Corynebacyerium sp.,*
Pseudomonas spp.,	*Arthrobacterglobiformis*
Viscosus spp.,	*Rhodobacterruber*
Acinetobacterbaumannii,	*Micrococcus lylae*
Bacillus, Thuringiensis	*Pseudomonas putida*

Streptococcus sp.,	*Pseudomonaaeruginosa*
Ralstonia spp.,	*Serratiamarcescens*
Bacillus brevies	*Micrococcus letus*
Pseudomonas fluorescens	*Proteus vulgaris*
Diplococcus sp.,	*Streptococcus lactis*
Rahnella, Lylae,,,	*Aspergillusversicolar*
Staphylococcus cohnii	*Aspergillusflavus*
Micrococcus luteus	*Chaetomiumspp*
Bacillus sp.,	*Mucorcircinellodies*
Micrococcus sp.,	*Aspergillusniger,* *A. cremeus, A. flavus, A. candidus and glaucus*
Moraxella sp.	*Flavobacterium spp.,,*
Paenibacillusmacerans,	*A. ornatus, A nidulans*
Staphylococcus sp.,	*Rhodococcuserythropolis*
Delftiaacidovorans	*Pseudomonas aeruginosa,*

(Browne et al., 2015)

It is found that long chain of polymer in the plastic is broken down into simpler smallmoleculessuchasoligomers,dimersandmonomerswhichissimplysaidasconversionoftoxic form to nontoxic from. They monomers or dimers which are formed are found to beso small that they can enter the bacterial cell that is it can enter the semi-permeablemembrane of the microorganisms and then utilized as they essential elements such asCarbonand other energysource (Zeenat et al., 2021). Bacteria involved could be Gram positive or Gram negative (classification of bacteria based on their cell wall composition) and also few species of fungi are found to have capability to degrade plastic onset of favourable condition over a course of time. Most often involved common species are Streptococcus, Pseudomonas, Micrococcus, *Aspergillusglacus* and *Aspergillusniger*. These are commonly occurring microorganisms in soil contributes majorly towards degradation of polymer like plastic, which converts the long chain polymer into simple monomers on set of favorable conditions which are no longer found to be toxic (Fontanella et al., 2010).

TherearespeciesofmicroorganismsidentifiedwhichareabletodegradePLA,PCLandPBSsuchas actinomycetes. Sample containing PLA film was reduced by nearly 60% with the help of PLAdegradingactinomycetes and*Amycolatopsisspecies*.Straini.e.100mgPLAfilmafter14daysofincubation in liquid culture at 30˚C. Several plastic degrading actinomycetes were reported suchasAmycolatopsisspecies 3118,*Streptomycesbanladeshensis*77T-,*Streptomycesthermoviolaceus species*,*Thermoviolaceus76T-2 (*Di Gennaro et al., 2019).

6. Mechanisms involved in degradation of polyethylene

Syntheticplasticsareevolvingecologicalcontaminants, foundtobeaccumulating is a very large quantity. They are highly recalcitrant and not highly susceptible toget degraded. Burning or burring of this pollutant would cause serious bad impact on to theenvironment.Theyreleaseharmfultoxicmaterialswhichcontributestoincreasedlevelofharmfulgases in the environment(Fontanella et al., 2010). Plastic is a material which contains synthetic orsemisynthetic organic complexes that are molded in different forms as per required. Theseorganicpolymersareofhighmolecularmass.Itcanasbemanufacturedusingpolylacticacidfromcorn or cellulose from cotton linters.Since they are of low cost, versatility, ease to manufacture and impervious to waterthey are used so widely from packing the food stuff to spacecraft (Fratzke et al., 2021). Biodegradable plastics are environmental friendly; currently certain enzymesrealized bythe microorganisms used to degrade this recalcitrant contaminant.UK and Brazil, engineeredan enzyme that candigest Polyethylene terephthalate(PET) and convert them into simpler products. It is a main primary constituentutilizedto manufactureplasticmaterials which is usedextensively(Wallace et al., 2017).

TheenzymeinvolvedisfoundtobePETase,anaturallyoccurringenzymerecentlydiscoveredbythe bacterium *Ideonellssakaiensis*to degrade plastic as a food source. In order to obtain 3Dstructure ofPETase, Professor McGeehan and colleagues used the diamond light source thatproduces extensive high beam of X-rays 10billion times brighter than a sun(Tokiwa et al., 2009). Under the influenceof exoenzymes and endoenzymes, there is a chemical reaction that is carried out and therebyinitiatingthebiodegradationofpolymer.Itistheprogressofbreachingthepolymerchainand oxidation is carried out (Crabbe et al., 1994). This has a result there are many moreenzymes comes into action due to formation of their favorablecondition this enters the cellularmetabolismpathway,whichresultsinreleaseofbyproductssuchaswater,carbon dioxide,biogaslikeMethaneandotheressentialbyproductswhichareinvolvedinbiodegradationofpolymer (HerreroAcero et al., 2011). It isa best way to decompose such resistant contaminates which appears in high concentration in theenvironment. Credit to this process is that it produces bi products which are nom-toxic and arefoundtobeecofriendlyortheelementsentersthebiogeochemicalcycles (Lim et al., 2002)

Because plastic is one of the most dangerous contaminants, it is a technology whose benefits should be well understood. Plastic also comes in a variety of forms, is very refractory, and is not particularly prone to degrading. Today, it is very difficult to find a replacement for plastics, which are utilized for many different things. Two to three million tons of plastic are used annually in the agricultural business alone. In some industries, its 10 to 30 times higher or even higher (Numata et al., 2009)

However, their principal drawback is that they are difficult to degrade in the environment or by the enzymes produced by bacteria, and they pollute the ecosystem by leaving behind trash. Plastics are notoriously recalcitrant because they are often composed of carbon, nitrogen, oxygen, chlorine, and bromine. The amount of plastic waste in landfills can be decreased by using compostable and biodegradable polymers (Vatseldutt et al., 2014).

Photodegradation: Plastics which are extensivelysubjected to high intensity of solar radiationforalongperiodoftimeundergoesdegradationbytheUltra-violetcomponentpresentinthesolarradiation that ranges the wavelength 0.295 to 0.400um. This radiation is absorbed by theplasticand breakage of bonds in the polymers is achieved. This leads to photo-oxidation (Gajendiran et al., 2016).

Thermaldegradation: The molecular weight of the polymer and plastic qualities including ease to mold texture and embrittlement, chalking, color changes, cracking, and a general decrease in their physical properties are typically affected (Grima et al., 2000)

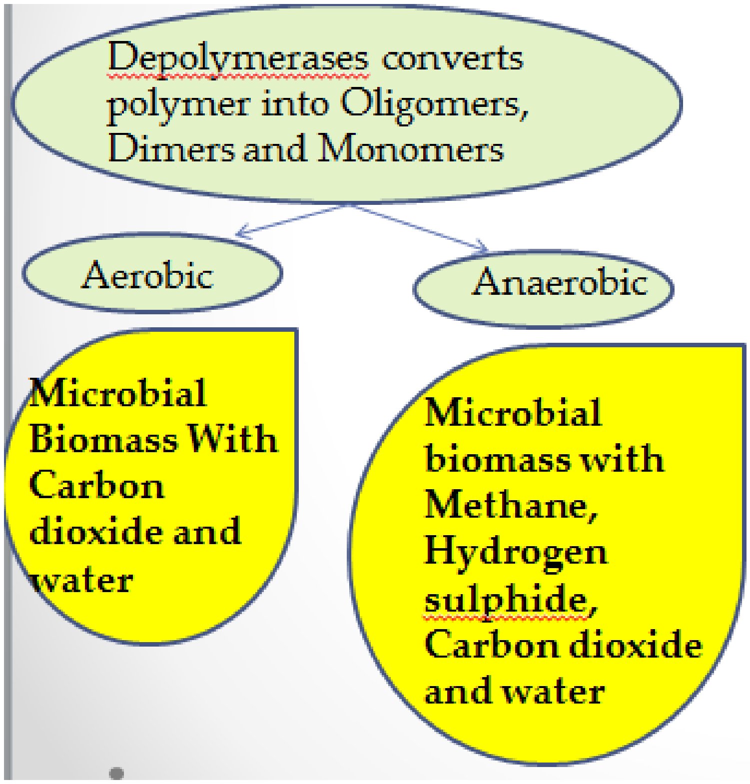
Itinvolvesthreemechanisms;

Initiation: Here there is loss of hydrogen atoms from the long chain polymer under the influence of light.
Propagation: Itinvolvesvarietyofreactionsandthemostimportantoneiswherefreeradiclereactswithanoxygenmoleculetoformaperoxyradical,whichcompletely eliminates the hydrogengroups frompolymerchaintoforma Hydrogenperoxideandthisregeneratesfreeradicleagain.Thishydrogenperoxide can thus produce new free radicals which will continue to repeat the reactionwhichwill attack otherpolymer.
Termination: It is achieved when the free radicals tend to produce inert products which cannotfuture be affected by any free radicals. This happens naturally when the free radicals combines oritcan bemadedifficult by additionofstabilizers inthe plastic (Shah et al., 2006).
Biodegradationisoftwotypes:

Aerobicandanaerobicbiodegradation

•Aerobic are mostly involved in scavenging of contaminants. They use oxygen as an electronacceptorandmineralizationtakesplace.Carbondioxideandwaterareobtainedas mainproducts.
•Anaerobicbiodegradationoccursinthe anaerobic or micro aero condition. TheyuseNitrate,Manganese,Iron,SulphateandCarbondioxideastheirelectronreceiver andmineralizationtakesplace (Shilpa et al., 2022).

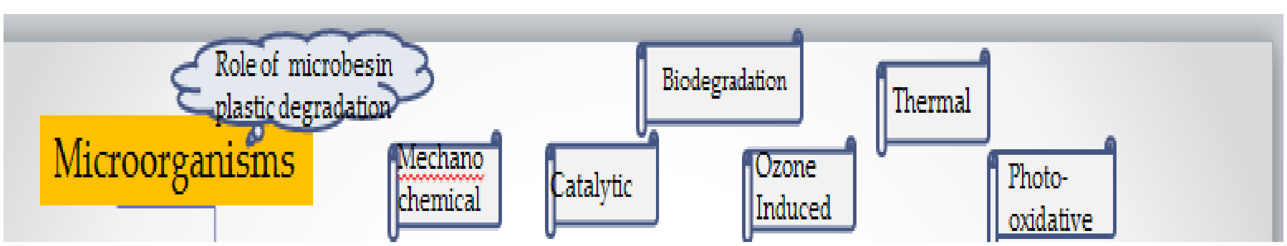
FIG 1: TYPES OF DEGRADATION



Factorsaffectingthebiodegradationofplasticsbymicrobes.

•Structural andorganicpropertiesofplasticsmainlyinfluencethebiodegradationcapacity.
•Physiochemicalnaturelikesurfacearea, molecularweight,hydrophilicandhydrophobicity,chemicalstructure, meltingtemperature,crystallinityetcplays majorrole.
•Molecularweightalsoplaysmajorrolebecauseitidentifiesthepolymerpresentintheplastic.
•Greaterthemolecularweightofpolymerlowerwillbethedegreeofcrystallinity.Amorphous domain part of the polymer is more susceptible for degradation.
•Lowertherate oftranslucentpart ofpolymer increasestherate ofbiodegradation (Bhardwaj et al., 2012).

FIG 2: ROLEOFMICROBESIN PLASTICDEGRADATION



Severalstepsinvolvedinplasticbiodegradationisexplainedusingsimpletermsasfollows;

•Bio-deterioration is defined as the action of microbial population and others decomposers thatareresponsibleforthestructuralandelementalfactorsthatresultinthesuccessivedegradationofplastics usingits properties.

•Biofragmentationreferstothecatalyticactionofthemicrobialenzymethatwillcleavethepolymer of the plastic into simpler oligomer or monomers. Usually freeradicals areusually secreted to performthedesired action.

•Mineralization is a prior step where complete degradation takes place where complexpolymers are gradually broken down into simple monomers, dimers and oligomers andcomplete oxidized metabolites are released such as carbondioxide, water and methane (Chee et al., 2010)

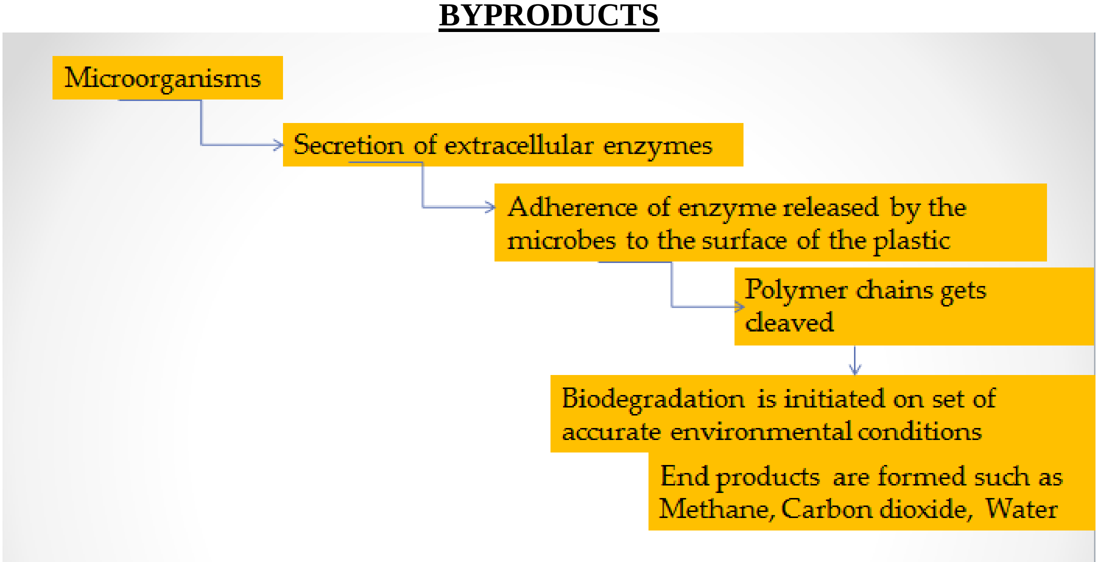
Physicaldeterioration: Formationofthemicrobialbiofilmdependsonthesecretion(EPS). TheseEPSentersthepores andgrowsinsidetheplastic.This increases the pore size and leads to cracking thereby leading to complete destruction ofphysicalproperties the plastic.

Chemical deterioration: Diverse group of microorganisms contribute to the biofilm and releasediverse group of acidic compounds like Nitrous acid, nitric acid or sulphuric acid by certainchemolithotrophs and organic compounds. Results in pH change inside theporesof theplasticis then modified (Eyheraguibel et al., 2017).

Bio-fragmentation:

Fragmentationofplasticpolymersintosimplemonomerscanbeachievedbymechanicalor chemical process,thermal, UV radiation and biological method. Synthetic polymers are of high molecularweight hence it cannot cross the cell wall. Hence certain exoenzymes are released that catalyzesthe reactions in boundaries of the plastic polymer.These enzymes need to have imbalancedelectrical charge to perform lysis. In order to stabilizethe native electrical charge, bacteria that can reduce plasticusuallysecretes enzymescalledoxygenase(monoordi)whichaddsupoxygentolong carbonchain (Li et al., 2019) (Rose et al., 2011)

FIG 3: ROLE OF MICROORGANISMS TO DEGRADE PLASTIC TO SIMPLER BYPRODUCTS



(Hayase et al., 2004)

7. Conclusion

Biodegradingbacteriaplays a harmonized role intheenvironmentwith respective to plastic degradation andsecretesbothendo-enzymesandexo-enzymesthatattackthesubstrateto cleavethemolecularchainsintosimplemonomersineco-friendlyway.Enzymesareproteinsmadeupof-COOH,-OH,-NH2whichhelpsthe enzyme to cleave the polymer. Certain factors such as temperature, water availability, pH,oxygen supply and redox potential. Thesebiodegradingbacteriadoesn't produceanytoxicsubstancestotheenvironment.Theinitialbreakdownisduetoseveralphysicalandbiologicalforcesthatcouldbewetting,heating,cooling can causepolymeric cracking (Kim et al., 2015) (Pramila et al., 2011).

The conclusion summarizes the key findings discussed throughout the paper and emphasizes the urgency of concerted efforts to address the plastic pollution crisis. It emphasizes the importance of interdisciplinary collaborations, technological innovations, and sustainable practices for effective plastic degradation and a cleaner, healthier future. Attention to be given on recent advancements in enzyme engineering, biotechnological approaches, nanomaterial-based degradation, and the potential of circular economy principles. It also highlights the importance of policy interventions, waste management strategies, and public awareness in mitigating plastic pollution (Sowmya et al., 2015) (Bonhomme et al., 2003) (Pagga et al., 2001) (Peng et al., 2019).

Alternativeisfoundto beNaturalplastics

They are synthesized from renewable sources that are completely biodegradable in their native form and they are found to be nothing but the components of plants, animals, and algae. Main advantage of these natural plastic over normal plastics is that the natural plastic is found to be biodegradable. There are many archaea and bacteria synthesizes biodegradable plastics which are also polymers but they are found to be biodegradable, eco-friendly and biocompatible (Ramis et al., 2004). The properties of PHA are also just like polyethene and polypropylene. Many microorganisms accumulate PHA and carbon inclusion as its native intracellular energy and store ns. There are many other nutrient elements that are present such as Nitrogen, sulphur, Oxygen and phosphorous. It's observed that there are different types of PHA (Rajashree et al., 2015). The study of these special bacteria which has capability to biodegrade plastics in a given reasonable time interval. The above study is trying to conclude the following;

- Certain microorganisms make a drastic changes in degradation of plastic which is one of the recalcitrant contaminant present in the atmosphere and are very resistant to undergodegradation.
- Degradation is carried out by the enzymes released by the microorganisms.
- Not all bacteria have the potential to biodegrade plastic. And it is observed that the potential at a given period of time to biodegrade plastic varies widely from species to species. .
- Degradation of polymers are increasingly used hence natural plastics are found to be the alternative which is found to be biodegradable. .
- This biodegradation process is successful under natural environment or even in lab conditions. But the estimated results are found to be different at different conditions.
- Production of enzymes of these bacteria increases the rate of biodegradation. (Nechwatal et al., 2006) (Motta 2009)

8. References

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