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Role of Novel Biological Agents in Plastic Degradation and Mitigation Approach towards Bioplastics

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Abstract

Plastic has become an important part of modern life, and it is the most commonly used material in every industrial sector. The use of plastic is increasing day by day, and its degradation has become a great challenge. Plastics are characterized into four basic groups on the basis of their point of origin. Plastic that can be degraded by environmental factors is known as biodegradable plastic. Non-degradable polymers tend to accumulate as plastic waste in the environment, posing a major ecological threat. Fossil fuels are utilized to make plastic items, but due to the shortage of natural resources, scientists are finding new alternative ways. Bioplastics have created a revolutionary change in the environment as these plastics are environmentally safe and easy to replenish. Starch is used as a promising biopolymer for plastic synthesis. A polymer undergoes a biological deterioration process by passing through both biotic as well as abiotic mechanisms. Significant attention has been placed on the identification of novel biological agents with degradative potential on plastic material. The microbes can be easily grown on plastic, and the enzymatic process leads to the conversion of plastic into water, carbon dioxide, and methane as a byproduct.

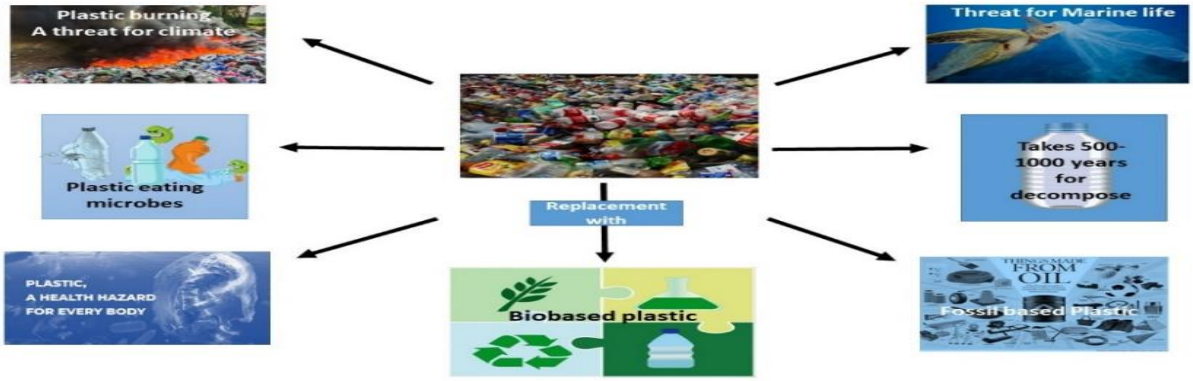
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INTRODUCTION

The most commonly used material in homes as well as in every industrial sector is plastic, which is synthesized artificially and manufactured in massive amounts worldwide. The utilization of plastic is steadily increasing worldwide due to its easily moldable property. The plastic term originates from the Greek word "plastikos," which designates a material that can be formed into any shape. Plastic is chemically synthesized from a high molecular mass containing hydrocarbons that are cross-linked with each other in a long chain. Mainly, Plastic is synthesized from fossil-based petrochemicals such as natural gas, crude oil, cellulose, coal, and salt through a crosslinking process or condensation. The plastics that are synthesized from petroleum products are polyethylene (PE), polyester, polyvinylchloride (PVC), polystyrene, and polyethylene terephthalate (PET) (Geyer *et al.*, 2017). Plastics is used extensively in multiple applications due to their following properties such as strength, lightness, durability, and non-biodegradability. As a result, they have replaced all the packaging materials such as paper and glass, and have become an essential component of practically all sectors (Thakur *et al.*, 2016). Plastics have been used in practically all fields and industries due to their valuable material qualities and inexpensive manufacturing costs, including those in infrastructure, construction, automotive, electrical accessories, and packaging, among others (Al-Salem *et al.*, 2017). Due to the rise in the usage of single-use containers, packaging makes up the majority of the plastic consumed among all of these (Jambeck *et al.*, 2015).

According to research from 2014, the production of plastics utilizes oil as a precursor and produces 311MT of plastic yearly. This production leads to the utilization of world 6% of the total raw oil. Only 5% of the total plastic consumed was recycled for future use, resulting in a loss of £62–92 billion in economic value. Of the entire quantity of plastic consumed, 26% by volume was utilized in the packaging industry. By 2050, it is predicted that the utilization of oil for plastic synthesis will reach up to 20% which is now 6% due to the gradually increasing demand for plastics. Annual plastic manufacturing would be twice up to 2034 and increase up to 1124 MT by 2050 (Lamberti *et al*., 2020).

- Threats of excessive use of plastic and fossil-based plastics were identified.
- Replacement of fossil-based plastic with biobased plastic.
- A variety of starches were identified to be used as a biobased plastic.
- Effect of Novel biological agents on the degradation of plastic was identified
- A variety of plastic-degrading microbial species were identified.



Types of Plastics

Plastics are characterized into four basic groups on the basis of their point of origin and their biodegradability capacity. The following diagrams indicate two types of axis along with basic groups of plastics. Biodegradable and non-biodegradable plastic is represented on the horizontal axis while the vertical axis explains the petroleum-derived and biobased plastics (European Bioplastics, 2011).

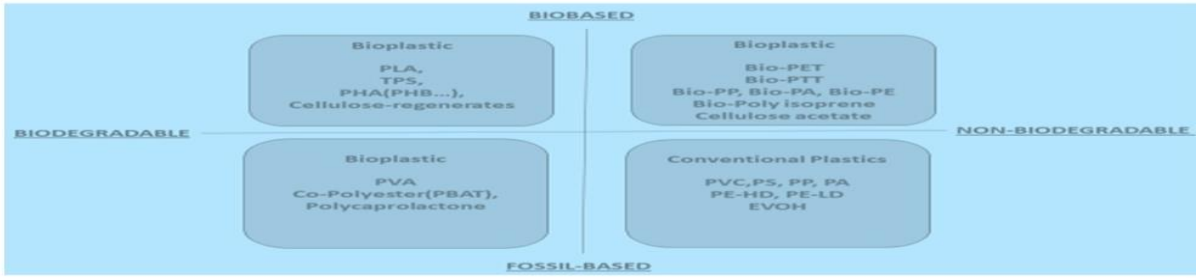


Figure 1.
Plastic classification on the basis of their origin

1. **Petrochemical-based, non-biodegradable plastics**: The most commonly available plastics are polyvinyl chloride (PVC), Polyethylene (PE) and polystyrene are petroleum derived plastics. These plastics are also known as conventional plastics.

2. **Sustainable resource-based biodegradable plastics**: The biobased plastics such as polyhydroxyalkanoate (PHA) and poly lactic acid (PLA) are made from starch based raw material that can be easily degrade in the environment. These biobased

plastics are made of pure starch based particles along with water and other compounds. The carbohydrates include in this are glucose, sorbitol and mannose.

3. **Fossil resource-based biodegradable plastics**: Some plastics which are derived as petroleum based products have the ability to degrade in the environment. These plastic includes poly butylene adipate terephthalate (PBAT), polycaprolactone (PCL) and polybutylene succinate (PBS). These plastics are utilized by combining some quantity of starch polymers along with fossil fuels. Starch and various bioplastics perform better in some applications due to their biodegradable capacity and structural attributes.

4. **Renewable-source polymers that are non-biodegradable**: The plastic which are synthesized by using biobased resources of starch but cannot have degrading capability comes under this type. The most commonly used resources to produce plastic are bioethanol that can be easily formed by using sugar cane as a starch. The ethylene and bio ethylene based plastics comes under this category. Brazil is producing bio-PE polyethylene on a massive scale (Rujnic and Pilipovic, 2017).

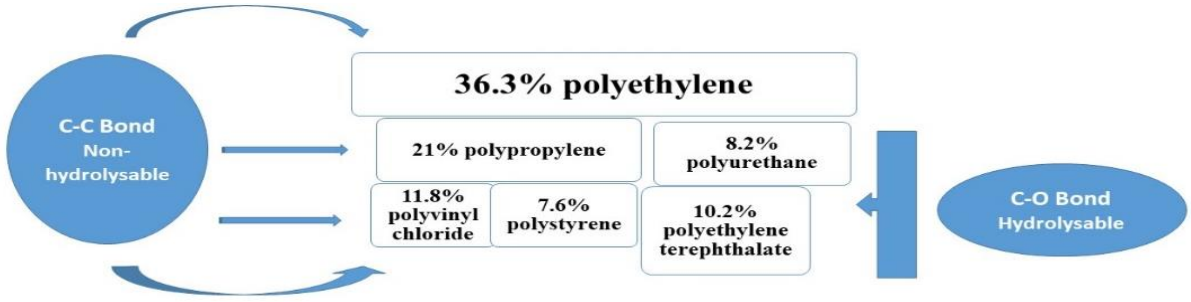


Figure 2.
Market share percentages for several synthetic plastic types.

Petroleum derived Plastics – An environmental hazard

Although Petroleum-derived plastics have numerous advantages, since they cannot degrade, they are significantly damaging the nature. It is now clear how dangerous it is for the oceans, land and waterbodies to become clogged with this very stubborn plastic garbage (Dris *et al*., 2015). According to Rahimi and Garca (2017) worldwide production of plastic waste reaches up to 150 million tonnes annually. In 2015 consumption of plastic reached over 300 MT worldwide. Plastic wastes are present everywhere, including in the oceans, lakes, river and streams as well. The plastic sector also has several drawbacks connected to issues with the economy and the environment (Arikan and Bilgen, 2019).

Due to their inability to biodegrade, they might stay in the environment for a very long time after being disposed of as garbage (Sanyang *et al*., 2016). A tremendous amount of energy is utilized in the production of plastics. They represent a significant environmental danger (Averous and Pollet, 2012). Humans' reliance on plastic causes a variety of problems, including hazards to human and animal health. Issues with sewerage and freshwater pollution are examples of environmental pollution (Al-Salem *et al*., 2017). Plastic pollution is dispersed throughout the world's seas due to the non-biodegradable nature of plastics and their propensity to float in water. It is commonly recognized that marine species, including cetaceans, seabirds, and reptiles, are negatively impacted by plastic pollution as a result of plastic eating and entanglement (Gregory, 2009).

- Due to their inability to biodegrade, they might stay in the environment for a very long time after being disposed of as garbage (Sanyang *et al*., 2016).
- A tremendous quantity of energy is used in the production of plastics.
- They pose a serious threat to the ecosystem (Azahari *et al*., 2011).
- Because of our dependence on plastic, there are a number of issues, including risks to our health and the health of animals.
- Issues with sanitation and groundwater pollution are examples of environmental pollution (Al-Salem *et al*., 2017).
- Plastic contamination has spread over all of the world's oceans since plastics are not recyclable and have a propensity to float in water.
- All the sea creatures such as fishes, seabirds, and other animals die due to entrapment in plastics and its consumption leads to their ultimate death.

Effects of plastic on human health

The consumption of seafood can expose the people to micro-plastics such as by eating fishes and crustaceans, through contaminated air and by utilizing microplastic containing water (Dris *et al*., 2015). Humans are suffering from serious health problems due to its utilization on a daily basis because the size of microplastic is less than 5 millimeter. There are multiple ways by which plastics can adversely affect the health such as toxins produced in the plastic due to chemicals, toxins due to small entrap Particles in plastics, and thirdly the toxins of parasites and microbes in plastics (Vethaak and Leslie, 2016). A research on the toxins generated by particles indicates that microplastic may harm the lungs and small intestines very seriously. These microplastic particles can breach to various parts of the body such as they can cross the placental barrier and enter into the fetus. It can also cross the blood-brain barrier and the plasma membrane that ultimately leads to a number of health issues (Galloway, 2015). Plastic particles are made up to two basic types of molecules that can be micro molecules having low molecular weight and high molecular mass containing macromolecules.

The example of macro molecules include different types of polymers that cross-linked to form a polyester and micro molecules consist of a variety of chemicals used to form plastic and make it resistant to environmental impact. The two most dangerous chemicals that are present in plastics are Phthalates and the second one is Bisphenol A. The Phthalates are such chemicals that makes the plastic more flexible and durable. The adverse effect of these chemicals includes disruption of hormones especially endocrine releasing hormones as well as retardation of growth. Bisphenol A (BPA) are also used in plastic formation especially polycarbonates. This chemical can cause serious health related issues such as heart problems, insulin resistance issues and hormonal problems (Dris *et al*., 2015).

Plastic act a source of nutrients for the growth of microbes (Kershaw and Rochman, 2015). For example plastic is a source of carbon for bacterial growth as well as act a medium for bacterial growth. When these infectious microplastic enters into the sewage and other house hold using water then it ultimately enter into human body and cause serious health hazard diseases. Microplastic can also became a major cause of viral infection. Plastic leads as a microbial growth stimulator in standing water and ultimately this water can spread various diseases in humans such as dengue as well as Aedes mosquito that transmit Zika virus. These mosquito is mostly present on the stagnant water. Due to excessive use of petroleum based products for plastic production the emission of greenhouse gases are continually increasing such as CO_2 and methane gas that leads to more environmental threats. Along with

environmental issues the excessive use of fossils fuel and petroleum products for plastic production make it a finite resource on the earth and its price has been steadily rising, experts are actively looking for suitable replacements for it (Vethaak and Leslie, 2016).

Biodegradable Plastic

Plastic that can be degraded by environmental factors and by other conditions known as biodegradable plastic such as polybutylene succinate (PBS) and poly lactic acid (PLA). In contrast to biodegradable plastic the biobased plastic can be define as such plastic that is produced from raw material such as by using starch and other polymer containing macromolecules (Iwata, 2015). There are many types of macromolecules that make plastic and this specific nature of plastic can be determined by the specific type of enzyme that can degrade the specific polymer (Razza and Innocenti, 2012). Multiple factors are involved that decide the biodegradation period of a plastic such as environmental impacts, the type of material from which plastic is made, the structural properties, the final stages of plastic.

There are two categories of biodegradable plastics:

- The plastic that basically originates from biological macromolecules (carbohydrates and proteins) and lignocellulosic material such as cellulosic based plastic.
- The second group includes such biodegradable plastic that originates from fossil fuels e.g. polycaprolactone (PCL).

Bio-based Plastics

The most significant bio-derived degradable plastics are:

- Thermoplastic starch polymers, which are made of starch (TPS)
- Plastics made from Polylactic acid (PLA)
- PHA-derived plastics such as PHB and PHBV
- Cellulose derived plastics (cellophane)
- Animal waste based Plastic

The primary component for plastic synthesis is a polymer that can be fossil based derived or can be bio-based. Along with it the other necessary components of plastic includes additives (organic or inorganic), colors, lubricating agents, oxidants blockers, and a variety of additional additives. The basic purpose of additives in plastic synthesis is to make the plastic formation process easy and provide physical characteristics and strength. The most important thing about biodegradable plastic is that all the supporting elements for biodegradable polymers should be degradable. The requirements for biodegradable plastics demand that all additives used in the creation of the ultimate plastic product should be tested; neither of the components should have an adverse impact on the recycling procedure (Sprajcar *et al*., 2012).

Thermoplastic starch polymers

Starch is a polysaccharide and is the most plentiful on earth after cellulose. The starch is commonly present in different cereals rice, wheat, bread, tubers and barley etc. The greater portion of starch consists of amylopectin (70 to 90%) while amylose contributes up to 10 to 30% in starch formation (Aung *et al*., 2018).

The utilization of starch for plastic manufacturing is due to its multiple properties such as high accessibility, easily decomposing ability as well as its low price make the starch the best compound for plastic synthesis. Additionally starch do not produce any harsh

chemicals and other compounds after decomposition. Because starch can be easily degrade by specific enzymes present in the environment and glucose monomers are available to be reuse by plants and soil (Araujo *et al*., 2006).

The thermoplastic (TPS) is a basic type of plastic that comes under the category of starch derived plastics. The starch after passing from multiple steps such as heating process, mechanical process and chemical process yields TPS. Thermoplastic has two types of properties as it can be firm like polystyrene and it can be elastic like polyethylene (PE). The starch-based plastics are used to make biodegradable shopping bags, mail bags that comes under loosened wrapping. Starch based plastic are also used to make different sanitation products like babies swaddle and other related products (Sprajcar *et al*., 2012).

Polylactic acid or polylactide

Carothers, a well-known DuPont researcher, created Polylactic acid for the first time in 1932. He produced lactic acid by boiling it under high pressure, but its manufacturing was never widely adopted for commercial use. Glucose, which can be derived from a variety of sugar sources is fermented to form lactic acid. Despite being water resistant, Halogenated hydrocarbons cause Polylactic acid to lose its stability. Its basic purpose is to make the Polylactic acid plastic accessible to decompose within 3 to 4 weeks. The first polymer made from bio-based materials on an industrial basis was polylactide (Sprajcar *et al*., 2012).

Multiple factors are involved in Polylactic acid degradation such as it depends on the size and structure of the material, its monomeric proportion, and the temperature. PLA degrades in the environment over a period of 6 months to 2 years (Xiao *et al*., 2012). Currently, PLA is used for portable dinnerware, injectable stretch blow-shaped bottles, and containers. It is widely used to make sanitary goods (baby diapers), agriculture and kitchenware wrapping paper, and packaging products of kitchen such as bowls, plates, sheets, and food storage boxes (Belard *et al*., 2013).

PHA-derived plastics (PHB and PHBV)

Polyhydroxyalkanoate (PHA) are known as natural degrading polymer as they originate from aliphatic polyesters. Many natural organic molecules such as glycolide (GL) and Lactide (LA) are the main source of aliphatic ester chain that combine to form polyester. Polyhydroxyalkanoate (PLA) comes under the category of natural aliphatic polyesters chain. This type of plastic is formed by fermentation process in which bacteria and other microbes grow on the carbohydrates and lipid molecules. The sugar molecules used for bacterial growth are fructose, glucose and sucrose. In lipids a variety of vegetable oils come under this category. The microbes grow during the fermentation process by utilizing carbohydrates and oil as energy containing molecules. The microbes during growth stages secrete many polymers that can join more than 150 monomeric units to form co polymer chain and homo polymer chain. These polymers are the building block of PLA molecule. Copolymer types have very less crystalline properties as compared to homopolymers. That is the reason copolymer can be easily degrade in comparison of homopolymer (Abreu *et al*., 2017).Polyhydroxyalkanoate are bio based product thus it can be easily degraded in the environment. (Sprajcar *et al*., 2012).

The polyhydroxybutyrate (PHB) are used in many products such as in different packaging process, in different plastic pots formation. PHBV is a Polyhydroxy butyrate -CO- β-hydroxy valerate that is used in different medical application such as making

disposable syringes and in the packaging of papers. The plastic is mainly resistant to the water thus it provides full protection from water vapors. The PHA is mostly used in making packaging plastic. The copolymers is used more commonly as compared to homopolymer due to low tensile strength of homopolymer plastic (Khosravi and Buccib, 2015).

Cellulose-derived plastics

The most prevalent carbohydrate on earth is cellulose. It is a fundamental part of the cell wall of plants. Now the cellulosic material is used to make cellulosic plastic. Plants are the major source of cellulose production. The cellulose in plants is present with different cross linking components such as pectin, hemicellulose and lignin. Therefore purified cellulose is hard to achieve from plants. Beside this the bacteria can also be used for cellulose production. The cellulose made from bacteria is free from any linked compounds. The bacterial specie used for cellulose production is acetic acid bacteria (AAB). Different species of bacteria such as *Komagataeibacter, Acetobacter* and *Gluconacetobacter* are specific species for cellulose production (Valera *et al*., 2015). Different glucose units combine to produce the linear chain polymer known as cellulose. (Moore and Stanitski, 2017). The linkage between the glucose units is beta1-4, glycosidic linkage (Moore and Stanitski, 2017). From plants material the wood of trees and cotton are the main source for textile industry. The cotton is also used to make cellulosic papers and lignocellulose plastic material (Yu, 2009).

Animal waste based plastic

Animal waste-based plastic is counterproductive and under-exploited non-meaty products like skin, blood, and viscera. It is produced by meat refining and animal carcasses that are used to make animal waste-based plastic. The primary significant biopolymers derived from animal products are keratin, myofibrillar protein, collagen, gelatin, and chitosan. They could be utilized to create bioplastics and have a variety of uses in the food and pharmaceutical industries (Kurtela and Antolovic, 2019).

According to studies, animal proteins are highly functional and nutrient-dense (Perez-Andres *et al*., 2019). These proteins are cheap and natural, and can be a great choice for the production of biodegradable films due to their exceptional qualities. Additionally, protein films have an enriching effect on the soil during breakdown because they are biodegradable. The mostly fibrous protein found in skin, bones, ligaments, tendons, cartilage, and aquatic animals such as fish, jellyfish, and sponges is called collagen. According to Avila Rodriguez *et al*. (2018), it displays outstanding viscoelastic behavior with high tensile strength and minimal deformation. When collagen is moderately hydrolyzed, a protein called gelatin is formed. Because of their excellent visibility and impermeable qualities, gelatin films are appropriate for use in food packaging. Other proteins include Myofibrillar Proteins, blood proteins and keratin films were used in film production (Khodaei *et al*., 2020).

Fossils derived biodegradable plastics

Fossil fuel derived plastics are totally inverse of bio based plastics. These plastic types are mostly obtained from fossil based sources such as natural coal, petroleum and natural gases. The plastic produced from this method is resilient to biodegradability. Therefore different types of bonds are added in fossil based plastics to make them biodegradable. The introduction of ester bond, ether bonds and amide bond in the

synthetic plastic make it accessible to cleavage. The term "fossil-based plastic" refers to materials like polybutylene adipate terephthalate (PBAT), polybutylene succinate (PBS), polyvinyl alcohol (PVOH/PVA), oxy-degradable polymer and polycaprolactone PCL (Havstad, 2020).

Polybutylene succinate (PBS)

PBS is a biodegradable plastic that originates from aliphatic chain and their linkages. The synthesis of PBS includes the utilization of an activators that act as a catalyst such as metals (titanium) act as a catalyst. PBS can be synthesized by condensation process. In this process the succinic acid and 1, 4 butanediol link in a long chain and polymerize to give PBS. It can be obtained from petroleum based sources as well as bio derived sources. Mainly its major production comes from fossil based sources. PBS is most widely used in making different plants vessels, plastic films for packing, farming plastic films and sanitary products. It can be utilized in food factory as well as medical fields to make different products. It takes up to 74 days for complete degradation (Havstad, 2020).

Polybutylene adipate terephthalate

One of the fossils derived biodegradable plastic is Polybutylene adipate terephthalate (PBAT) is a. It can be synthesized by combining 3 different componds such as terephthalic acid, adipic acid and last one is butanediol. These compounds combine in a polymerization reaction to give PBAT. The two diacids combine with one molecule of diol to form PBAT. Polybutylene adipate terephthalate is most widely used in different industries due to its numerous qualities such as it has excellent degrading capacity. It has more tensile strength then other polymers and it can undergo processing very easily. The Polybutylene adipate terephthalate (PBAT) is mostly used in making plastic waste bags, farming plastic films and one time use bags. It can be easily modified with bio based plastics to make an excellent biodegradable plastic (Muthuraj *et al*., 2015).

Polycaprolactone

Polycaprolactone is a biodegradable plastic with long aliphatic chain. Its synthesis begins with an opening of a close ring structure of caprolactone. The caprolactone is a close ring structure and after processing it converts into open structure. The polycaprolactone is most widely used in medical fields. It is used to transfer the drugs into human body. It is used to make surgical threads (sutures) that is used after every injury or surgery. It is also used in plant tissue engineering. It can be easily modified with bio based plastics such as (PHA/PLA) to attain the biodegradation property (Muthuraj *et al*., 2015).

Polyvinyl alcohol

Polyvinyl alcohol (PVA) is a hydrophilic polymer. It can be easily undergo biodegradation process. It can be safely used on living tissues and cells. The presence of hydroxyl groups gives it the ability to cross-link. The OH groups are present on the polyvinyl structure as a side chains. Due to hydrophilicity it can be easily soluble and undergo rapid breakdown process. The macromolecules cannot be easily attached with the pure structure of polyvinyl due to its bio-inertness. Due to its hydrophilic property it is used to make plastic films that can be easily dissolvable. The other uses of polyvinyl alcohol includes uses in dyes, different farming chemicals, industry related chemicals and disinfectants (McKeen, 2014).

Oxo-degradable plastics

Oxo degradable plastics are derived from petroleum based products. It can combine with metals so that it can rapidly undergo degradation process. The addition of metals like titanium, copper, tungsten and iron inside the oxo-degradable plastic make it accessible to exposure by light and heat. Poly ethylene (PE) are used to make many products such as plastic films that are biodegradable in nature. These plastic films are also known as oxo degradable plastic.

Oxidation reduction process that is known as redox reaction is the main cause of oxidative degradation by oxo plastics. As the light, heat and other factors act as a stimulant and produce hydro peroxide groups (ROOH). The transition metals such as iron, copper and tungsten act as a redox pair as they can accept the electrons from hydro peroxide groups (ROOH) and convert hydro peroxide group into $RO^{\bullet}$ and OH^{-} groups. These free radicals interact with the plastic polymers and ultimately they interact with themselves to form ketones (carbonyl compounds). The formation of ketones act as a plastic polymer cutter and the plastic is converted into small pieces. The chain breakage leads to the loss of stability as well as mechanical properties of plastic and hence plastic is completely degraded (Deconinck and Wilde, 2013). Oxo plastics that are made of Polyethylene and other petroleum based products are used in agriculture fields as well as in markets as degradable bags that degrade before time (Thomas *et al*., 2012). Along with advantages there are also many side effects of oxo plastics on the marine species. These plastics don't meet the conditions for decomposing and stay in the environment for a very long time (Selke *et al.*, 2015). As these plastic when decompose into small particles then these fragments of plastic remain in the oceans for a very long period of time and ultimately effects the marine environment. The other drawback of oxo plastics is that they cannot be recyclable as these plastic fragments have lost their mechanical strength and hence these remain in the environment without any use. In the Europe the use of oxo plastic is totally prohibited. The use of oxo-plastics, according to the European Parliament and Council (EPC), only contributes to further environmental damage and increase the threat rate for marine life. The parliament of Europe that access the ocean environment has completely declared in March 2019 that oxo plastics cannot be use any more (Aldas *et al*., 2018).

Starch – A Promising Biopolymer

Starch is a promising biopolymer with numerous advantages in plastic production. It is easily available in the plant based food such as cereals rice, bread, grains and legumes. The most commonly available starch supplement is potatoes that is a rich source of starch. Along with its nutritional value starch is widely used to produce bioplastics. The bioplastics made of starch is easily decomposable and eventually recyclable in the environment with no harmful effects (Imre and Pukanszky, 2015). The starch has found its application in many areas such as in food industry, pharmaceutical production, in the agriculture, packing process and many more (Guimaraes *et al.,* 2009). In studies conducted between 2012 and 2018, a variety of starches were utilized to create bioplastics. Working on sago starch started in 2012 to create bioplastics (Zuraida *et al*., 2012). In 2016 Yusoff *et al* worked on the banana peels starch (Yusoff *et al*., 2016). In 2018 Lenz *et al* worked on the maize starch (Lenz *et al*., 2018) and Dawale and Bhagat worked on the sweet potato starch (Dawale and Bhagat, 2018). Cassava starch was used for bioplastic synthesis in 2017 by (Syafri *et al*., 2017).

Banana peels as a starch

The bioplastic can also be produced from banana peels. The peels are the essential components of fruits and vegetables that is rich source of many nutritional compounds. The banana peels are a rich source of starch (20% -30%). These peels are used for the production of bio plastic sheets. A plasticizer (such as glycerol) is used to make bio plastic sheets softer and more elastic (Mishra *et al.,* 2015). Sometimes the microbial resistant compounds were added in it to stop microbial growth such as sodium metabisulphite was used as anti-microbial agent. The banana peels are also widely used to make eatable plastic films. In this the clove oil is also used as a microbial resistant compound and glycerol is used as a plasticizer (Yusoff *et al.,* 2016).

Corn as a starch

The corn is a best source of starch. It is mostly used as a corn flour and corn starch. It is free from protein as it only contain carbohydrate component. Corn starch is widely used to make bioplastic. Along with corn starch many reinforcing components are added to make the plastic more strong and stiff. Reinforcing fillers are the specific material that can be small fibers used to build up or strengthen the metallic compounds and plastic. It can be obtained from natural as well as synthetic sources. The curaua fiber is *a lignocellulosic leaves fiber* stuff that is used as a reinforcing filler in bioplastic synthesis. The corn starch and curaua fibers were undergo different cyclic processes and ultimately give rise to bioplastic. The bioplastic made from this method has very unique chemical and physical properties. In 2018 the corn starch biofilms was introduced with the addition of different algal species (Spirulina) as reinforcing fillers. The addition of fillers enhances the properties of a bioplastic (Lenz *et al.,* 2018).

Cassava as a starch

Cassava starch is also known as tapioca starch. It is obtained from the Cassava plant. The word cassava is derived from the roots of plants and tapioca is the name of starch related compounds. The cassava is used to make bioplastic along with the addition of reinforcing fillers such as cellulose is used as a filler. Sorbitol is used as a plasticizer. The sorbitol has two benefits in manufacturing of bio plastics. Firstly its high concentration makes the bioplastics more elongate. Secondly the sorbitol is used as to accelerate the degradation process in bio plastic.

Rice as a starch

The rice is a natural source of carbohydrate as it consists of both amylose and amylopectin as a component of starch. Recently the use of rice starch for bio-plastic synthesis has gained a lot of attention. The use of rice starch for eatable bio-plastic film synthesis involves the utilization of plasticizer as well as different reinforcing fillers to strengthen the bioplastic (Koller *et al.,* 2010). A plasticizer such as sorbitol and glycerol are used in this process. The bio-plastic characteristics such as chemical and physical properties can be determined by the type of plasticizer. The bio-plastic made from rice starch can undergo biodegradation and their biodegradability can be find out by various tests. In 2010 Naggar and Faraq used different concentration of rice starch to check that which one has best biodegradability rate (Naggar and Farag, 2010). In this process the bio plastic biodegradation was examined by contact of different ultraviolet radiations that ranges from 300 nm to 400 nm. In 2011 bario rice starch was used for bio-plastic synthesis. The use of plasticizer and natural rubber in this process provided the best rice starch based bioplastic (Kiing *et al.,* 2011).

Sago and Tapioca as a starch

The other sources of starch are sago as well as tapioca. The sources of sago starch are palm trees and tapioca starch is obtained from cassava roots. Both types are recently used to make bio-plastic. Tapioca starch is used to make bio-plastic along with Hyacinth fiber pulp (fibers of water hyacinth plant) as reinforcing fillers (Abral *et al.,* 2018). Bio-plastic made from tapioca starch is also investigated by using a plasticizer such as Acetyl Tributyl Citrate. Acetyl Tributyl Citrate is a commonly used plasticizer in bio-plastic synthesis. It is also used in different industries like the paint industry, food industry as well as in skin and nail care cosmetics. It is used in polyvinyl chloride as a safe biodegradable compound and other resins (Judawisastra *et al.,* 2017). Sago starch is commonly used as a food item that has many nutritional benefits. It was investigated to make bio-plastic along with glycerol as a plasticizer. In this different concentration of sago starch along with glycerol was used to make degradable bio-plastic (Zuraida *et al.,* 2012).

Potato as a starch

The potato is a rich and easily available source of starch. Different researches have been investigated to explore the potato starch for making bio-plastic. In 2018 the potato starch was used to make bio-plastic films along with calcium chloride is used as a reinforcing filler. The production of eatable biofilms from potato starch and gelatin starch was investigated (Muneer, 2015)

Bio-plastic can also be produced by combining more than two sources of starch. It is the most recently developed method to make amalgams that is employed to make bio-plastic. Various researchers use different combination of starches to make bio-plastic such as combining rice starch and cassava starch to make bio-plastic (Lopattananon *et al.,* 2012), combining potato starch and wheat gluten protein to make bio-plastic (Muneer., 2015), combining corn starch and banana starch (Sultan and Johari, 2017) and rice starch and sago starch as a composite (Kiing *et al.,* 2011).

The bio-plastic has gained much attention in the past few years. It is the best alternative of fossil fuel to make plastic with best biodegradability rate. The natural sources such as carbohydrates provides excellent use in bio-plastic synthesis. Moreover the bio-plastic can easily undergo degradation and can renewable. It also helps to save cost by minimizing the use of limited petroleum based plastics. So the bio-plastics provide us the future saving promises as well as environmental friendly products (Maulida *et al.,* 2016). However there is also some lack of research regarding the concept of bio-plastic from agricultural resources. There is a need of lot of research and study to utilize the benefits from agricultural field. The starch based sources from agriculture field is available in surplus amount and easily recyclable. There is a need of more research area, opportunities and more experimental techniques to make the bio-plastic a part of our globe (Guimaraes *et al.,* 2010).

Advantages of Bio-Plastics

1. Less harmful run-off is produced by bioplastics
2. In contrast to bioplastics, oil-based polymers don't require fossil fuels.
3. Minimal Greenhouse Gas Production
4. Restricting the use of fossil fuels
5. The decrease of energy consumption
6. It uses less energy.
7. Requiring Less Landfill Space

8. Eco-friendly (Patil and Landage, 2021).

Plastic waste degradation

Plastic waste can decay in two ways:

- Abiotic procedures (Physical and chemical mechanism)
- Biotic process (Biological degradation that is eco-friendly mechanism)

The first stage that is typically thought of as being crucial to any degradation process is the breakdown of the plastic substance by mechanically driven physical forces (Li *et al*., 2019).

Plastics can degrade in the surrounding by any one of the four fundamental techniques, i.e.

1. Photo deterioration
2. Hydrolysis
3. Thermal oxidative decay
4. Biodegradation (Andrady, 2011).

Common plastics like low density polyethylene (LDPE), high density polyethylene (HDPE), and polypropylene (PP) begin degrade in natural circumstances (such as the sea environment) with photodegradation, which is mostly brought on by UV-B radiation. The deterioration then progresses by thermal oxidative mechanism and by hydrolysis to a lesser degree. Plastics become fragmented (broken into smaller pieces) during degradation processes, and the polymer's molecular size (MW) decreases. Microbes can then digest these substances with their low molecular weight (Webb *et al*., 2013).

Biodegradation- A novel Biological Agents

A polymer undergoes biological deterioration process by passing from both biotic as well as abiotic mechanism. The biotic process includes the utilization of plastic polymer as a carbon source for microbes and in turns microbes break down the plastic and produce metabolic excretory products (CO2, biomass, H2O etc.) etc) along with enzyme. Abiotic processes includes (hydrolysis process, oxidation and photodegradation process) (Mohan and Srivastava, 2010). The degradation process of plastic by biotic mechanism rely on characteristics of microbes such as kind of microbe present, their distribution, their growth circumstances (nutrients, temperature, moisture content, oxygen and pH,), and the types of enzymes they utilize (intracellular, extracellular) (Tokiwa *et al*., 2009). Along with nature of microorganism the type and nature of plastic also has a significant effect on biodegradability. The plastic surface conditions such as water loving (hydrophilic) or water hating (hydrophobic), first order structure (molar mass and chemical configuration), and high order structure (melting temperature Tm, Temperature at which glass transitions occur Tg) are all plastic properties that have an impact on rate (Artham and Doble, 2008).

Biodegradation occurs in two discrete stages

1. In the first stage, polymer chains are broken down and shortened by abiotic processes as well as extracellular enzymatic assault; enzymes preferentially break down the less-ordered amorphous portions of a plastic. As a result, a plastic's crystallinity will rise quickly before levelling out close to 100%. (Artham and Doble, 2008).

2. The second step happens when the polymer chains are sufficiently short to be transported into cells of the microorganisms where they can bio assimilate and mineralize (Luckachan and Pillai, 2011).

The degradation rate of bioplastics is defined by various international standards, each of which applies under certain circumstances

Based on the standard EN 13,432:2000, bioplastics must break down by 90% and oxidize in 3 months in an industrial sector between 50 and 60 °C. In theory, it is not essential to dispose of biodegradable plastics because they may be allowed to decompose naturally. This has several benefits including greater soil fertility, less plastic ending up in landfills, and decreased waste management costs (Niaounakis, 2013). However, in practice, the degree of decomposition of a bioplastic may be substantially slower than anticipated, depending on the kind of bioplastic and the compositional circumstances. The loss of any value inherent in the polymer's molecular structure is another drawback of biodegradation.

Factors affecting the degradation rate of plastics

According to Artham and Doble (2008), the degradation rate of plastic is based on the following factors such as exposure of plastic to different abiotic and biotic variables as well as the properties of the plastic polymer itself. This is seen below (Artham and Doble, 2008).

Table 1.
Factors effects plastic degradation

Factors effects plastic degradation	Description	Reference
Carbon chain	As a result of the long repeating unit of carbon, polymeric materials are difficult to biodegrade as in PP. However, the integration of the heteroatoms into the carbon chain makes them vulnerable to light and biological deterioration, much like in the case of polymers that include oxygen (like PU and PET).	(Singh and Sharma, 2008).
Hydrophobicity	The efficacy of plastic breakdown is often influenced by hydrophobic nature, with the degree of degradation rises as hydrophilic property rises.	(Ehrenstein, 2001).
Crystallinity	Plastic degrade at different rate depending on the polymer's crystallinity (Ehrenstein, 2001). Crystalline polymers require more oxygen and moisture in comparison to amorphous polymeric structures, which can start the degradation process. The amorphous regions of a polymer are regarded to be more susceptible to heat oxidation (Li *et al.*, 2019).	(Li *et al.*, 2019).
Molecular weight	The rate of deterioration of the polymer can be influenced by its molecular weight (MW). This theory proposes that the low relative surface area of high MW plastics results in slower degradation.	(Singh and Sharma, 2008).
Morphological characteristics	Degradability is also influenced by the polymer's structural characteristics. Because the formation of biofilm is encouraged by surface roughness more than by surface smoothness due to the large surface area, its degradation rate will rise with surface roughness.	(Booth *et al*., 2017).
Additives	Plastic polymers are made using a variety of techniques and additives, some of which may have an impact on how quickly they degrade. The incorporation of these nanoparticles into the polymeric framework aims to enhance the permeability, structural, thermal, and electrochemical properties of the produced polymer. In order to reduce the rate of deterioration, stabilizers are widely used as additives during the manufacture of plastics.	(Singh and Sharma, 2008)
Sunlight intensity	Kitamoto *et al*. (2011) stated that The amount of sunshine exposure has the most impact on how quickly plastics degrade; this is because more sunlight speeds up the photo-oxidation cycle.	(Kitamoto *et al*., 2011)
Temperature	According to Pischedda *et al.* (2019) the breakdown process of plastic rises with the rise in temperature and the response become	(Pischedda *et al.* (2019)

	doubles after every 10 degrees Celsius. Temperature rises also make the polymer chain more mobile, which has an impact on the enzyme activity of the bacteria during biodegradation. Therefore, it is believed that the environment has a big impact on how naturally plastic waste decomposes.	
Water	The presence of water is another crucial element for the degradation process. Synthetic polymer chain fragmentation is brought about by the hydrolysis of accessible functional groups (Oberbeckmann *et al*., 2016).	(Oberbeckmann *et al*., 2016),
Oxygen availability	Oxygen availability has a favorable impact on the rate of deterioration of plastics. For instance, the increased breakdown of polymers was caused by the faster interaction between carbon-centered radicals and oxygen during the early phases of degradation when oxygen levels were high.	(Price and Horrocks, 2013).

Fungal and bacterial roles in plastic degradation

The degradation of polymeric materials is significantly influenced by fungi. The surface of a polymeric substance can be effectively penetrated by fungi to go deeper within and break down more of the substrate (Sanchez, 2020). Additionally depolymerases is an exoenzyme that is released by the mycelium of fungi that can fragment low molecular weight polymeric substrates into oligomers, dimers, and monomers (Ameen *et al*., 2015). The fungi then take these monomers up and use their internal enzymatic machinery to either absorb or mineralize them. In comparison to bacterial enzymes, fungi manufacture and secrete a large amount of enzymes. According to this perspective, Fungi known to effectively break down polymeric materials include white- and brown-rot fungi. The ability of fungi to degrade polymeric materials are associated with their enzymatic mechanism, which excretes several extracellular enzymes including laccase (Lac), manganese peroxidase (MnP), and lignin peroxidase (LiP), all of which may break down lignin before mineralizing it (Ali *et al*., 2020).

In the same way, bacterial strains in polluted water or soil can break down plastic polymeric materials. According to various research, the biodegradation of plastics by specific bacteria can be an effective bioremediation method for damaged environments (Yoshida *et al*., 2016). According to our analysis of the available literature, Bacterial species including Bacillus specie, Pseudomonas specie and Streptomyces specie degrade various polymeric polymers quickly (Li *et al*., 2020).

Table 2.
Bacteria species for Plastic Degradation

Bacteria species	Enzyme secreted	Plastic type	Reference
Pseudomonas spp	Serine hydrolases, lipases and esterases	Polyhydroxyalkanoate (PHA)	(Bhardwaj *et al*., 2013)
Penicillium, Rhizopus arrizus	Lipase	Polyethylene adipate(PEA), PBS, PCL	(Tokiwa *et al*., 2009)
Firmicutes	unidentified	PHB, PCL, and PBS	(Tokiwa *et al*., 2009)
Rhizopus delemar	Lipase	Polycaprolactone (PCL)	(Tokiwa *et al*., 2009)
Bacillus	lipase, CMCase, xylanase, chitinases, and protease	Polyethylene (PE)	(Yang *et al*., 2014)
Ideonella sakaiensis	Glycoside hydrolases	PE, PET	(Yoshida *et al*., 2016)
Paenibacillus amylolyticus	protease and esterase	PLA	(Teeraphatpornchai *et al*., 2003)

Table 3.
Fungi related microbes for plastic deterioration

Fungi specie	Enzyme secreted	Plastic type	Reference
Basidiomycetes, Ascomycetes and Deuteromycetes	Laccases	PHA	(Rivera *et al.*, 2013)
Aspergillus flavus	Glucosidases	Polycaprolactone(PCL)	(Tokiwa and Calabia, 2009)
Phanerochaete chrysosporium	manganese peroxidases,	Polyethylene	(Gomez *et al.*, 2018)
white-rot fungi, *Pleurotus spp., Phlebia radiata, Trametes versicolor, Bjerkandera adusta, Dichomitus squalens* and *subvermispora*	Lignin peroxidases, manganese peroxidases, multifunctional peroxidases, dye-removing peroxidase	Polyethylene	Ayuso *et al.*, 2017)
Trichoderma reesei	Cutinases	Polybutylene succinate(PBS)	(Chandra *et al.*, 2020)
Acremonium, Aspergillus, Beauveria,, Candida antarctica (CALB) *Fusarium, Geotrichum, Eremothecium, Humicola, Mucor, Ophiostoma, Penicillium, Rhizomucor, Trichoderma and Rhizopus*	Lipases	polyurethane (PUR)	(Singh and Mukhopadhyay, 2012).
Aspergillus flavus, Aspergillus tubingensis		Polyethylene (PE)	(Zhang *et al*., 2021)
Beauveria brongniartii	Polyesterases	PET	(Almansa *et al.*, 2008)

Algal role in breakdown of synthetic plastic polymers

The capacity of algae species to reduce white pollution has only recently been the subject of a small number of studies. The ability of filamentous algae to colonize the surface of trash made of plastic was due to environmental factors, such as sunshine, food, and moisture that are necessary for algal development. (Moog *et al*., 2019). Microalgae are a viable choice since they lack endotoxins and do not require organic carbon sources to develop under photoautotrophic conditions, unlike bacterial and fungal systems that can be seen as biological pollutants because of endotoxins and their need for a rich carbon supply (Yan *et al*., 2016). The ability of certain non-toxic, non-hazardous algae species from the families of Bacillariophyceae. On plastic surfaces, Chlorophyceae and Cyanophyceae can grow and produce algal biofilms in a variety of polluted aquatic bodies, including lakes, and wastewater (Sharma *et al*., 2014). According to Sarmah and Rout (2018), aquatic non-toxic cyanobacteria (Phormidium lucidum and Oscillatoria subbrevis) may colonize on PE surfaces and efficiently break down LDPE without any prior pretreatment (Sarmah and Rout, 2018).

Additionally, Moog *et al.,* (2019) produced a designed PETase that was active against both PET and the copolymer PETG by using the *Phaeodactylum tricornutum* (diatom) as a microorganism factory (polyethylene terephthalate glycol). In addition, Kumar *et al*. (2017) discovered that following algal growth on PE, surface degradation was noticed. Additionally, they discovered that the blue-green alga *Anabaena spiroides*, the diatom *Navicula pupula*, and the green alga *Scenedesmus dimorphus* had

degradation percentages of 3.74, 8.18, and 4.44%, respectively. According to Khoironi *et al*. (2019), *Spirulina species* can reduce PET and PPs mechanical strength by 0.9939 and 0.1977 MPa/day accordingly. Algae may adhere to a surface made of plastic and begin the process of destruction by producing extracellular polysaccharides and lignin-degrading- degrading enzymes (Sarmah and Rout, 2018).

Mechanism of Enzymatic Biodegradation

Enzymatic degradation is the most promising approach to treating plastic trash. Two phases are involved in the breakdown of polyethylene by microbial enzymes. To catalyze a hydrolytic cleavage, the enzyme must first bind to the polyethylene substrate. Fungi and bacteria break down the polyethylene via intracellular and extracellular depolymerases. The accumulating bacteria themselves hydrolyze their endogenous carbon content through intracellular degradation, whereas accumulating microorganisms may or may not use an external carbon source, which results in extracellular breakdown. Short chains of oligosaccharides, dimers, and monomer subunits may pass through bacterial membranes that act as a carbon source. Energy are formed when complex polymers break down. Depolymerisation is the term used for this process. And mineralization is the decomposition process, with water (H2O), methane (CH4) or carbon dioxide (CO2) as the final products. Physical factors such as temperature, pressure, and moisture cause mechanical damage to polymers, which is then triggered by biological forces such as enzymes and other byproducts generated by bacteria. The following flowchart makes it simple to understand how plastics biodegrade (Bhardwaj, 2013).

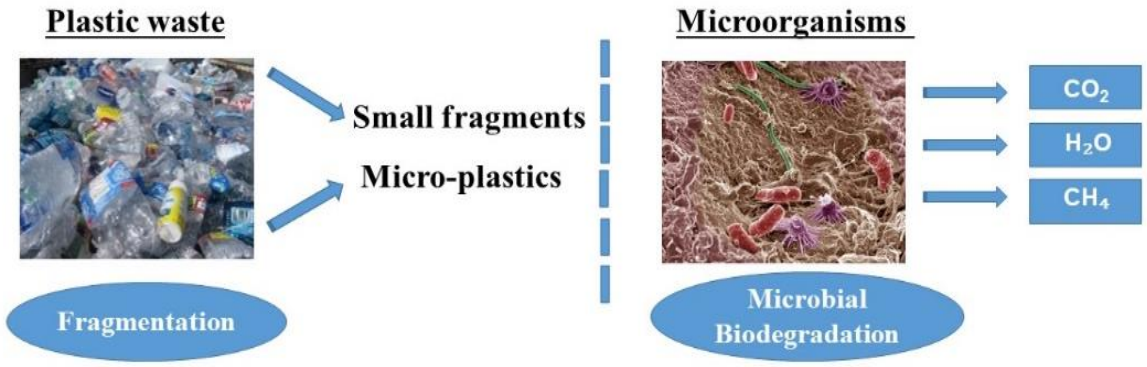


Figure 3.
Mechanism of enzymatic biodegradation of plastic (Shah *et al.*, 2008).

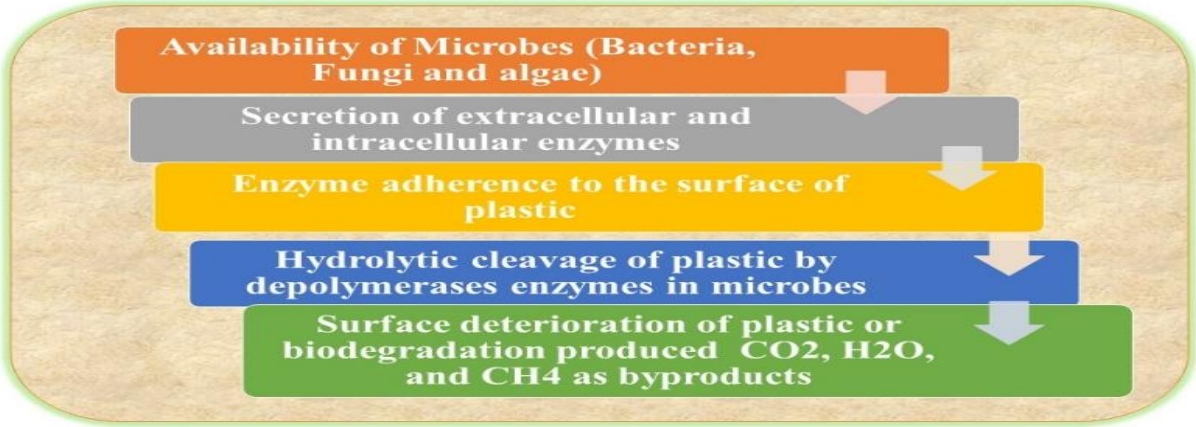


Figure 4.
Summary of microbial degradation (Yuan *et al.*, 2020)

CONCLUSION

As it is plastic age we are using plastic a lot in our daily life, but its excessive use has become a crucial problem for our environment. To clear this hazard people usually bury it in landfills or burn it but these steps are causing great danger to our society. Toxic gasses like furans and dioxins are produced by burning of plastic. Ozone depletion is caused by greenhouse gasses. Human endocrine hormone activity is disturbed by dioxin which is causing serious problem to human health. Soil pollution is also caused by dioxin which is of great concern for worldwide scientists. Fossil based plastic leads to environmental pollution and its excessive use make the fossil fuel a limited non-renewable resource on the earth. The best and eco-friendly method for the production of plastic is bio-based plastic. In bio-based plastic different macromolecules can be utilized such as animal waste based as well as starch based. The most commonly used biobased material is starch based plastic.

The starch based plastic can be easily obtained from lignocellulosic material. The best advantage of biobased plastic is its degradability and easy to obtain. The biobased plastic can be easily degraded by microbes as it is economically feasible to degrade plastic by utilizing it as a microbial food. Hence, under such circumstances degradation of plastic by microbes is one of the eco-friendly and innovative methods. Many fungal genera and bacterial genera have been reported to degrade various kinds of plastics. Information regarding the biobased plastic, fossil based plastic and biodegradation of plastic bags by various novel biological agents is given in this review. It is expected that this review work will encourage young scientists to find out one or more microbial strain from nature for the potential biodegradation of plastic wastes. It also encourages researchers to work on the bioplastic so that environment become safe from dangerous toxins of fossil based plastic.

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REFERENCES

Abral, H., Dalimunthe, M. H., Hartono, J., Efendi, R. P., Asrofi, M., Sugiarti, E. & Kim, H. J. (2018). Characterization of tapioca starch biopolymer composites reinforced with micro scale water hyacinth fibers. *Starch-Starke*, *70*(7-8), 1700287.

Abreu, A. S. L. M., de Moura, I. G., de Sá, A. V., & Machado, A. V. A. (2017). Biodegradable polymernanocomposites for packaging applications. In *Food packaging* (pp. 329-363). Academic Press.

Aldas, M., Paladines, A., Valle, V., Pazmiño, M., & Quiroz, F. (2018). Effect of the prodegradant-additive plastics incorporated on the polyethylene recycling. *International Journal of Polymer Science*, *2018*.

Ali, S. S., Al-Tohamy, R., Xie, R., El-Sheekh, M. M., & Sun, J. (2020). Construction of a new lipase- and xylanase-producing oleaginous yeast consortium capable of reactive azo dye degradation and detoxification. *Bioresource Technology*, *313*, 123631.
Almansa, E., Heumann, S., Eberl, A., Fischer-Colbrie, G., Martinkova, L., Marek, J. & Guebitz, G. M. (2008). Enzymatic surface hydrolysis of PET enhances bonding in PVC coating. *Biocatalysis and Biotransformation*, *26*(5), 365-370.
Al-Salem, S. M., Antelava, A., Constantinou, A., Manos, G., & Dutta, A. (2017). A review on thermal and catalytic pyrolysis of plastic solid waste (PSW). *Journal of environmental management*, *197*, 177-198.
Ameen, F., Moslem, M., Hadi, S., & Al-Sabri, A. E. (2015). Biodegradation of Low Density Polyethylene (LDPE) by Mangrove fungi from the red sea coast. *Progress in Rubber Plastics and Recycling Technology*, *31*(2), 125-143.
Andrady, A. L. (2011). Microplastics in the marine environment. *Marine pollution bulletin*, *62*(8), 1596-1605.
Arikan, E. B., & Bilgen, H. D. (2019). Production of bioplastic from potato peel waste and investigation of its biodegradability. *International Advanced Researches and Engineering Journal*, *3*(2), 93-97.
Artham, T., & Doble, M. (2008). Biodegradation of aliphatic and aromatic polycarbonates. *Macromolecular Bioscience*, *8*(1), 14-24.
Aung, S. P. S., Shein, H. H. H., Aye, K. N., & Nwe, N. (2018). Environment-friendly biopolymers for food packaging: Starch, protein, and poly-lactic acid (PLA). In *Bio-based Materials for Food Packaging* (pp. 173-195). Springer, Singapore.
Averous, L., & Pollet, E. (2012). Biodegradable polymers. In *Environmental silicate nano-biocomposites* (pp. 13-39). Springer, London.
Ayuso-Fernandez, I., Martínez, A. T., & Ruiz-Dueñas, F. J. (2017). Experimental recreation of the evolution of lignin-degrading enzymes from the Jurassic to date. *Biotechnology for biofuels*, *10*(1), 1-13.
Azahari, N. A., Othman, N., & Ismail, H. (2011). Biodegradation studies of polyvinyl alcohol/corn starch blend films in solid and solution media. *Journal of Physical Science*, *22*(2), 15-31.
Belard, L., Poncin-Epaillard, F., Dole, P., & Avérous, L. (2013). Plasma-polymer coatings onto different biodegradable polyesters surfaces. *European polymer journal*, *49*(4), 882-892.
Bhardwaj, U., Dhar, P., Kumar, A., & Katiyar, V. (2013). Polyhydroxyalkanoates (PHA)-cellulose based nanobiocomposites for food packaging applications. In *Food additives and packaging* (pp. 275-314). American Chemical Society.
Booth, A. M., Hansen, B. H., Frenzel, M., Johnsen, H., & Altin, D. (2016). Uptake and toxicity of methylmethacrylate-based nanoplastic particles in aquatic organisms. *Environmental toxicology and chemistry*, *35*(7), 1641-1649.
Chandra, P., Singh, R., & Arora, P. K. (2020). Microbial lipases and their industrial applications: a comprehensive review. *Microbial Cell Factories*, *19*(1), 1-42.
Dawale, S. A., & Bhagat, M. M. (2018). Preparation and characterization of potato starch based film blended with CaCO3 nanoparticles. *International Journal of Engineering Science*, *8*(2), 16013.
De Araujo, M. C. B., Santos, P. J., & Costa, M. F. (2006). Ideal width of transects for monitoring source-related categories of plastics on beaches. *Marine Pollution Bulletin*, *52*(8), 957-961.
Deconinck, S., & De Wilde, B. (2013). Benefits and challenges of bio-and oxo-degradable plastics. *Study DSL-1, Final Reports, on behalf of Plastic Europe AISBL, Brussel*.
Dris, R., Gasperi, J., Rocher, V., Saad, M., Renault, N., & Tassin, B. (2015). Microplastic contamination in an urban area: a case study in Greater Paris. *Environmental Chemistry*, *12*(5), 592-599.
Dris, R., Imhof, H., Sanchez, W., Gasperi, J., Galgani, F., Tassin, B., & Laforsch, C. (2015). Beyond the ocean: contamination of freshwater ecosystems with (micro-) plastic particles. *Environmental chemistry*, *12*(5), 539-550.
Ehrenstein, G. W. (2012). *Polymeric materials: structure, properties, applications*. Carl Hanser Verlag GmbH Co KG.

El-Naggar, M. M., & Farag, M. G. (2010). Physical and biological treatments of polyethylene–rice starch plastic films. *Journal of Hazardous Materials*, *176*(1-3), 878-883.

European Bioplastics (2011) Fact sheet. European Bioplastics. Available at: http://en.european-bioplastics.org/wp-content/uploads/2011/04/fs/ Bioplastics_eng.pdf (accessed 28 August 2015).

Galloway, T. S. (2015). Micro-and nano-plastics and human health. In *Marine anthropogenic litter* (pp. 343-366). Springer, Cham.

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science advances*, *3*(7), e1700782.

Gomez-Mendez, L. D., Moreno-Bayona, D. A., Poutou-Pinales, R. A., Salcedo-Reyes, J. C., Pedroza-Rodríguez, A. M., Vargas, A., & Bogoya, J. M. (2018). Biodeterioration of plasma pretreated LDPE sheets by Pleurotus ostreatus. *PloS one*, *13*(9), e0203786.

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2013-2025.

Guimaraes, J. L., Frollini, E., Da Silva, C. G., Wypych, F., & Satyanarayana, K. G. (2009). Characterization of banana, sugarcane bagasse and sponge gourd fibers of Brazil. *Industrial Crops and Products*, *30*(3), 407-415.

Guimaraes, J. L., Wypych, F., Saul, C. K., Ramos, L. P., & Satyanarayana, K. G. (2010). Studies of the processing and characterization of corn starch and its composites with banana and sugarcane fibers from Brazil. *Carbohydrate Polymers*, *80*(1), 130-138.

Havstad, M. R. (2020). Biodegradable plastics. In *Plastic waste and recycling* (pp. 97-129). Academic Press.

Imre, B., & Pukánszky, B. (2015). From natural resources to functional polymeric biomaterials. *European Polymer Journal*, (68), 481-487.

Iwata, T. (2015). Biodegradable and bio-based polymers: future prospects of eco-friendly plastics. *Angewandte Chemie International Edition*, *54*(11), 3210-3215.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A. & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768-771.

Judawisastra, H., Sitohang, R. D. R., & Marta, L. (2017, July). Water absorption and its effect on the tensile properties of tapioca starch/polyvinyl alcohol bioplastics. In *IOP conference series: materials science and engineering* (Vol. 223, No. 1, p. 012066). IOP Publishing.

Kershaw, P. J., & Rochman, C. M. (2015). Sources, fate and effects of microplastics in the marine environment: part 2 of a global assessment. *Reports and Studies-IMO/FAO/Unesco-IOC/WMO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Eng No. 93*.

Kershaw, P., Katsuhiko, S., Lee, S., & Woodring, D. (2011). Plastic debris in the ocean. United Nations Environment Programme.

Khodaei, D., Oltrogge, K., & Hamidi-Esfahani, Z. (2020). Preparation and characterization of blended edible films manufactured using gelatin, tragacanth gum and, Persian gum. *Lwt*, *117*, 108617.

Khoironi, A., & Anggoro, S. (2019). Evaluation of the interaction among microalgae Spirulina sp, plastics polyethylene terephthalate and polypropylene in freshwater environment. *Journal of Ecological Engineering*, *20*(6).

Khosravi-Darani, K., & Bucci, D. Z. (2015). Application of poly (hydroxyalkanoate) in food packaging: Improvements by nanotechnology. *Chemical and Biochemical Engineering Quarterly*, *29*(2), 275-285.

Kiing, S. C., Ee, S. Y., Wong, S. C., Rajan, A., & Yiu, P. H. (2011). Development of Biodegradable Plastic from Sago and Bario Rice Starch Blend. *Journal of Polymer Materials*, *28*(3), 457.

Kitamoto, H. K., Shinozaki, Y., Cao, X. H., Morita, T., Konishi, M., Tago, K. & Tsushima, S. (2011). Phyllosphere yeasts rapidly break down biodegradable plastics. *AMB express*, *1*(1), 1-11.

Koller, M., Atlić, A., Dias, M., Reiterer, A., & Braunegg, G. (2010). Microbial PHA production from waste raw materials. In *Plastics from bacteria* (pp. 85-119). Springer, Berlin, Heidelberg.

Kumar, A., Alam, A., Rani, M., Ehtesham, N. Z., & Hasnain, S. E. (2017). Biofilms: Survival and defense strategy for pathogens. *International Journal of Medical Microbiology*, *307*(8), 481-489.
Kurtela, A., & Antolović, N. (2019). The problem of plastic waste and microplastics in the seas and oceans: impact on marine organisms. *Croatian Journal of Fisheries*, *77*(1), 51-56.
Lal Bhardwaj, R. (2013). Effect of mulching on crop production under rainfed condition-a review. *Agricultural Reviews*, *34*(3).
Lamberti, F. M., Román-Ramírez, L. A., & Wood, J. (2020). Recycling of bioplastics: routes and benefits. *Journal of Polymers and the Environment*, *28*(10), 2551-2571.
Lenz, D. M., Tedesco, D. M., Camani, P. H., & dos Santos Rosa, D. (2018). Multiple reprocessing cycles of corn starch-based biocomposites reinforced with Curauá fiber. *Journal of Polymers and the Environment*, *26*(7), 3005-3016.
Lenz, D. M., Tedesco, D. M., Camani, P. H., & dos Santos Rosa, D. (2018). Multiple reprocessing cycles of corn starch-based biocomposites reinforced with Curauá fiber. *Journal of Polymers and the Environment*, *26*(7), 3005-3016.
Li, J., Kim, H. R., Lee, H. M., Yu, H. C., Jeon, E., Lee, S., & Kim, D. H. (2020). Rapid biodegradation of polyphenylene sulfide plastic beads by Pseudomonas sp. *Science of the Total Environment*, *720*, 137616.
Li, Y., Wang, X., Fu, W., Xia, X., Liu, C., Min, J. & Crittenden, J. C. (2019). Interactions between nano/micro plastics and suspended sediment in water: Implications on aggregation and settling. *Water research*, *161*, 486-495.
Lopattananon, N., Thongpin, C., & Sombatsompop, N. (2012). Bioplastics from blends of cassava and rice flours: the effect of blend composition. *International Polymer Processing*, *27*(3), 334-340.
Luckachan, G. E., & Pillai, C. K. S. (2011). Biodegradable polymers-a review on recent trends and emerging perspectives. *Journal of Polymers and the Environment*, *19*(3), 637-676.
Maulida, S. M., & Tarigan, P. (2016). Production of starch based bioplastic from cassava peel reinforced with microcrystalline celllulose avicel PH101 using sorbitol as plasticizer. In *J. Phys. Conf. Ser* (Vol. 710, No. 1).
McKeen, L. W. (2014). Plastics used in medical devices. In *Handbook of polymer applications in medicine and medical devices* (pp. 21-53). William Andrew Publishing.
Mishra, R. S., Kumar, N., & Komarasamy, M. (2015). Lattice strain framework for plastic deformation in complex concentrated alloys including high entropy alloys. *Materials Science and Technology*, *31*(10), 1259-1263.
Mohan, S.K., Srivastava, T. (2010). Microbial deterioration and degradation of polymeric materials. J Biochem Techol, 2, 210-215.
Moog, D., Schmitt, J., Senger, J., Zarzycki, J., Rexer, K. H., Linne, U. & Maier, U. G. (2019). Using a marine microalga as a chassis for polyethylene terephthalate (PET) degradation. *Microbial cell factories*, *18*(1), 1-15.
Moore, J. W., & Stanitski, C. L. (2017). Lengthening the chain: polymers in general chemistry. *Journal of Chemical Education*, *94*(11), 1603-1606.
Muneer, F. (2015). Biocomposites from natural polymers and fibers.
Muthuraj, R., Misra, M., & Mohanty, A. K. (2015). Hydrolytic degradation of biodegradable polyesters under simulated environmental conditions. *Journal of Applied Polymer Science*, *132*(27).
Newson, W. R. (2012). Protein based plastics from the residuals of industrial oil crops.
Niaounakis, M. (2013). *Biopolymers: reuse, recycling, and disposal*. William Andrew.
Oberbeckmann, S., Osborn, A. M., & Duhaime, M. B. (2016). Microbes on a bottle: substrate, season and geography influence community composition of microbes colonizing marine plastic debris. *PLoS One*, *11*(8), e0159289.
Patil, V. N., & Landage, A. B. A Review on Bioplastics: Applications and Current Scenario.
Pérez-Andrés, J. M., Álvarez, C., Cullen, P. J., & Tiwari, B. K. (2019). Effect of cold plasma on the techno-functional properties of animal protein food ingredients. *Innovative Food Science & Emerging Technologies*, *58*, 102205.
Pischedda, A., Tosin, M., & Degli-Innocenti, F. (2019). Biodegradation of plastics in soil: The effect of temperature. *Polymer Degradation and Stability*, *170*, 109017.

Price, D., & Horrocks, A. R. (2013). Combustion processes of textile fibres. *Handbook of Fire Resistant Textiles*, 3-25.

Rahimi, A., & García, J. M. (2017). Chemical recycling of waste plastics for new materials production. *Nature Reviews Chemistry*, *1*(6), 1-11.

Razza, F., & Innocenti, F. D. (2012). Bioplastics from renewable resources: the benefits of biodegradability. *Asia-Pacific Journal of Chemical Engineering*, *7*, S301-S309.

Rivera-Hoyos, C. M., Morales-Álvarez, E. D., Poutou-Piñales, R. A., Pedroza-Rodríguez, A. M., RodrÍguez-Vázquez, R., & Delgado-Boada, J. M. (2013). Fungal laccases. *Fungal Biology Reviews*, *27*(3-4), 67-82.

Rujnic-Sokele, M., & Pilipović, A. (2017). Challenges and opportunities of biodegradable plastics: A mini review. *Waste Management & Research*, *35*(2), 132-140.

Sanchez, C. (2020). Fungal potential for the degradation of petroleum-based polymers: An overview of macro-and microplastics biodegradation. *Biotechnology advances*, *40*, 107501.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Sahari, J. (2016). Effect of plasticizer type and concentration on physical properties of biodegradable films based on sugar palm (Arenga pinnata) starch for food packaging. *Journal of food science and technology*, *53*(1), 326-336.

Sarmah, P., & Rout, J. (2018). Efficient biodegradation of low-density polyethylene by cyanobacteria isolated from submerged polyethylene surface in domestic sewage water. *Environmental Science and Pollution Research*, *25*(33), 33508-33520.

Selke, S., Auras, R., Nguyen, T. A., Castro Aguirre, E., Cheruvathur, R., & Liu, Y. (2015). Evaluation of biodegradation-promoting additives for plastics. *Environmental Science & Technology*, *49*(6), 3769-3777.

Shah, A. A., Hasan, F., Hameed, A., & Ahmed, S. (2008). Biological degradation of plastics: a comprehensive review. *Biotechnology advances*, *26*(3), 246-265.

Sharma, B. K., Moser, B. R., Vermillion, K. E., Doll, K. M., & Rajagopalan, N. (2014). Production, characterization and fuel properties of alternative diesel fuel from pyrolysis of waste plastic grocery bags. *Fuel Processing Technology*, *122*, 79-90.

Singh, A. K., & Mukhopadhyay, M. (2012). Overview of fungal lipase: a review. *Applied biochemistry and biotechnology*, *166*(2), 486-520.

Singh, B., & Sharma, N. (2008). Mechanistic implications of plastic degradation. *Polymer degradation and stability*, *93*(3), 561-584.

Sprajcar, M., Horvat, P., & Kržan, A. (2012). Biopolymers and bioplastics: plastics aligned with nature. *Ljubljana: National Institute of Chemistry*.

Sultan, N. F. K., & Johari, W. L. W. (2017). The development of banana peel/corn starch bioplastic film: A preliminary study. *Bioremediation Science and Technology Research*, *5*(1), 12-17.

Svistunov, A. A., Tarasov, V. V., Shakhmardanova, S. A., Sologova, S. S., Bagaturiya, E. T., Chubarev, V. N., ... & Aliev, G. (2018). Urotensin II: Molecular mechanisms of biological activity. *Current Protein and Peptide Science*, *19*(9), 924-934.

Syafri, E., Kasim, A., Abral, H., & Asben, A. (2017). Effect of precipitated calcium carbonate on physical, mechanical and thermal properties of cassava starch bioplastic composites. *International Journal on Advanced Science, Engineering and Information Technology*, *7*(5), 1950-56.

Teeraphatpornchai, T., Nakajima-Kambe, T., Shigeno-Akutsu, Y., Nakayama, M., Nomura, N., Nakahara, T., & Uchiyama, H. (2003). Isolation and characterization of a bacterium that degrades various polyester-based biodegradable plastics. *Biotechnology Letters*, *25*(1), 23-28.

Thakur, M. K., Thakur, V. K., Gupta, R. K., & Pappu, A. (2016). Synthesis and applications of biodegradable soy based graft copolymers: a review. *ACS Sustainable Chemistry & Engineering*, *4*(1), 1-17.

Thomas, N. L., Clarke, J., McLauchlin, A. R., & Patrick, S. G. (2012, August). Oxodegradable plastics: degradation, environmental impact and recycling. In *Proceedings of the Institution of Civil Engineers-Waste and Resource Management* (Vol. 165, No. 3, pp. 133-140). ICE Publishing.

Tokiwa, Y., Calabia, B. P., Ugwu, C. U., & Aiba, S. (2009). Biodegradability of plastics. *International journal of molecular sciences*, *10*(9), 3722-3742.
Valera, M. J., Torija, M. J., Mas, A., & Mateo, E. (2015). Cellulose production and cellulose synthase gene detection in acetic acid bacteria. *Applied microbiology and biotechnology*, *99*(3), 1349-1361.
Vethaak, A. D., & Leslie, H. A. (2016). Plastic debris is a human health issue.
Webb, H. K., Arnott, J., Crawford, R. J., & Ivanova, E. P. (2013). Plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). *Polymers*, *5*(1), 1-18.
Xiao, X., Cheng, Z., Meng, H., Khan, M. A., & Li, H. (2012). Intercropping with garlic alleviated continuous cropping obstacle of cucumber in plastic tunnel. *Acta Agriculturae Scandinavica, Section B–Soil & Plant Science*, *62*(8), 696-705.
Yan, C., Wang, R., Wan, J., Zhang, Q., Xue, S., Wu, X. & Cong, W. (2016). Cellulose/microalgae composite films prepared in ionic liquids. *Algal research*, *20*, 135-141.
Yusoff, R. B., Takagi, H., & Nakagaito, A. N. (2016). Tensile and flexural properties of polylactic acid-based hybrid green composites reinforced by kenaf, bamboo and coir fibers. *Industrial Crops and Products*, *94*, 562-573.
Zhang, K., Hamidian, A. H., Tubić, A., Zhang, Y., Fang, J. K., Wu, C., & Lam, P. K. (2021). Understanding plastic degradation and microplastic formation in the environment: A review. *Environmental Pollution*, *274*, 116554.
Zuraida, A., Yusliza, Y., Anuar, H., & Muhaimin, R. M. K. (2012). The effect of water and citric acid on sago starch bio-plastics. *International Food Research Journal*, *19*(2), 715.

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