International Journal of Advanced Biochemistry Research

Toxicity and environmental plastic disposal, its death and survival rate

Isaac John Umaru, Emmanuel, Askeb-nde Joel, Bilyaminu Habibu, Kerenhappuch Isaac Umaru and Barrah Collins Chizaram

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2019; 3(2): 64-75
www.biochemjournal.com
Received: 03-06-2019
Accepted: 04-07-2019

Isaac John Umaru
Department of Biochemistry,
Federal University Wukari,
Taraba State, Nigeria

Emmanuel
Department of Biochemistry,
Federal University Wukari,
Taraba State, Nigeria

Askeb-nde Joel
Department of Biochemistry,
Federal University Wukari,
Taraba State, Nigeria

Bilyaminu Habibu
Department of Biochemistry,
Federal University Wukari,
Taraba State, Nigeria

Kerenhappuch Isaac Umaru
Department of Biochemistry,
Federal University Wukari,
Taraba State, Nigeria

Barrah Collins Chizaram
Department of Biochemistry,
Federal University Wukari,
Taraba State, Nigeria

Corresponding Author:
Isaac John Umaru
Department of Biochemistry,
Federal University Wukari,
Taraba State, Nigeria

DOI: https://doi.org/10.33545/26174693.2019.v3.i2a.136

Abstract

Plastics are synthetic organic polymer materials that are widely utilized in homes, hospitals, and a variety of other settings, including the manufacture of water bottles, medical equipment, clothes, food packaging, electronic products, and construction materials. The majority of plastics in use are manufactured from organic polymers derived from petroleum-based sources. High density polyethylene, polypropylene, polyethylene terephthalate, high density polyethylene, polyvinyl chloride (PVC), low density polyethylene, are the major examples of plastics found in the marketplace. Numerous chemicals and toxic materials, including poly-fluorinated compounds, brominated flame retardants, and bisphenol A (BPA), which pose major risks to human and animal health and the environment, are present in plastics. Landfilling and the implementation of government usage restrictions on plastics are two ways to manage the disposal of plastics. The incineration and recycling of waste are further control methods. The impact of plastic trash on animals, people, and the ecosystem has drawn public attention, which necessitates the need to protect the environment. Despite the fact that plastic items are widely used every day, the hazardous chemicals used in their production must be limited in order to protect the environment, human and animal health. Microorganisms destroy complex polymers by a variety of processes, such as the direct use of plastic fragments as food or the indirect action of numerous microbial enzymes.

Keywords: Toxicity environmental, plastic, disposal, death, survival

1. Introduction

Plastics are synthetic materials made of organic polymers that are widely utilized in homes, hospitals, and a variety of other settings, including the manufacturing industries, water bottles, clothing, food packaging, electronics, and construction materials (Proshad *et al*., 2018) [1]. Pollution of the environment as a result of plastic wastes is now widely acknowledged to be a significant environmental burden (Rochman *et al*., 2013a) [2], particularly in the aquatic environment where plastics undergo prolonged biophysical breakdown (Derraik, 2002; Thompson *et al*., 2004) [3, 7].

There had been international awareness about pollution arising from over usage of plastic in almost every level of the society. This was aided by the rapid spread of information through social media and information technology, in schools, media and up to the international lawmakers. They are now aware that the plastic contamination of the planet is a massive problem (Derraik, 2002; Thompson *et al* 2004) [3, 7].

The majority of this plastic pollution is visible, including the plastic bags that litter the environment and are particularly harmful to marine life because they are entangled in it (plastic nets) and rivers that have been contaminated with this plastic product. Recent research, however, has revealed that this is only one aspect of the issue with these minute particles of plastics poisoning the entire earth world, down to the deepest waters (Andrady, 2011; Bakir *et al*., 2014) [4, 5].

1.1 Plastics in a Global Circular Economy

A progressive counterbalance to a linear economy is the idea of a circular economy, in which material resources are continuously cycled through a value chain of production, consumption, and recycling in order to optimize their usefulness and prevent the extraction and use of virgin materials.

In the classic linear economy, raw materials are taken out of the environment, refined, and processed into goods that are subsequently used up and thrown away. They are eliminated either by burying or burning or removed from the inventory of resources that are available to create new products. Even worse, the effects of burying or burning those resources include pollution of the air, soil, and water, exposure of people to harmful emissions and waste, and long-term effects on biodiversity and climate.

However, the continuous burning of wastes generated by plastic materials results in the destruction of the resource itself and in addition, leads to the production of harmful solid and air pollutants. The petrochemicals that were used to produce the plastic as well as the "embedded energy" in the plastic objects will all be destroyed in the process. The energy required for oil extraction, petrochemical synthesis, polymer production, and transportation between each step, including delivery to market, all fall under the category of embedded energy. For the incinerator to extract the meager quantity of "calorific energy" created when the plastic object is burned, all of that embedded energy is obliterated in a matter of seconds.

1.2 Types of Plastics

Depending on the components and materials utilized in their production, there are several varieties of plastics, as explained below:

1.2.1 Polyethylene Terephthalate (PET)

The term "stomach plastic" refers to polyethylene terephthalate (PET), a smooth, translucent, and thin variety of polythene. Due to its known anti-inflammatory and entirely liquid, polyethylene terephthalate is frequently used to package foods and snacks including salad dressing, juice, mouthwash, vegetable oil, cosmetics, soft drinks, margarine, and water bottles. It was discovered that polyethylene terephthalate acts as an anti-air, keeping oxygen from penetrating it (Proshad *et al.*, 2018) [1]. To stop the leaching of some harmful chemicals including acetaldehyde, antimony, and phthalates, high temperatures must not be applied to PET plastics. Antimony remains a carcinogenic agent detrimental to the life of humans. (Proshad *et al*. 2018) [1].

1.2.2 High-density polyethylene

Large number of people in the world use polyethylene, however high density polyethylene, a heat-resistant plastic made from petroleum, is still the only type of plastic used as packaging bags.

Additionally, it is a key component of many household items, including refrigerators, detergent bottles, toys, milk containers, and several types of plastic grocery bags. No phthalates or BPA were reportedly discovered in high-density polyethylene. Despite evidence that prolonged exposure to sunlight can be harmful, high density polyethylene containers have been considered acceptable for use as drink and food containers because they pose no health risks (Proshad *et al*. 2018) [1].

Fig 1, 2, 3 & 4: Polyethylene Terephthalate (PET); High density polyethylene; Polyvinyl Chloride; Low-density polyethylene.

1.2.3 Polyvinyl Chloride (PVC)

Another form of heat-resistant polymer employed in packaging drinks, particularly in the food industry, is Polyvinyl Chloride (PVC). The presence of chemical entities such as heavy metals, dioxins, BPA, and phthalates makes polyvinyl chloride very toxic to life existence. The presence of phthalates makes PVC flexible depending on non-plasticization. Phthalates are considered harmful to people. The use of this type of polymer in the food industry has significantly decreased since it is believed to pose serious dangers to the environment and public health throughout the full PVC life cycle, which includes production, use, and disposal. PVC, however, is the most widely used material in the manufacture of consumer items because of its affordability and adaptability.

1.2.4 Low-density polyethylene

Low-density polyethylene was also said to be heat resistant, brittle, flexible, and rigid. Juices, milk, and frozen foods are frequently packaged using this type of polymer. LDP has no components that are toxic to humans. This makes it safe for use in the food industry (Proshad *et al*. 2018) [1].

1.2.5 Polypropylene

Polypropylene is a semi-transparent, tough, and rigid plastic. In addition, it is heavier and more powerful than polyethylene. For the packaging of medicines, beverages, etc., the pharmaceutical and food industries utilize this type of plastic. Like polyethylene, polypropylene plastics are deemed safe for use by humans in food and beverage packaging since they contain no toxic constituents (Proshad *et al*. 2018) [1].

Fig 5, 6, 7 & 8: Polypropylene, Polystyrene, Polycarbonate, and land pollution of plastics

1.2.6 Polystyrene

Polystyrene remains that petroleum-based plastic that has as its components human system-carcinogenic chemical benzene (Proshad *et al*. 2018) [1]. Majority of the time, polystyrene is utilized to make insulation and packaging materials. Styrene-derived products are unhealthy. Small amounts of styrene can have cytogenetic, carcinogenic, and hematological consequences after being exposed for a long time (Dowty *et al*., 1976). According to the International Agency for Research on Cancer (IARC), styrene causes cancer in humans (Proshad *et al*. 2018) [1].

1.2.7 Polycarbonate

Among the examples of plastics is polycarbonates. It is a polymer used for packaging consumer items like reusable bottles. When exposed to high temperatures, polycarbonates, which contain BPA, through percolation can leach into the food or drink that is stored in them. The use of polycarbonate plastics has decreased as a result of the health danger associated with BPA being reported in various instances (Proshad *et al*. 2018) [1].

2. Causes of Plastic pollution

Plastics of all sizes, ranging from large to very microscopic ones, are the causes of plastic pollution. Plastics come different forms. They exist based on their precursors and polymerization process. The main factors that contribute to the issue of pollution via plastics are fishing nets, old trash, manner in which plastics (packages and garbage) are disposed.

2.1 Fishing Nets

One component of an agricultural activity that is typically carried out on a global scale is fishing. People consume fish for their daily living and to maintain a healthy, balanced diet as a result of the commercial fishing industry, which is a necessary economic activity. The fishing industry's contribution to plastic contamination in the ocean has caused a variety of issues. Plastic materials are usually utilized to make the nets for large-scale fishing operations. These fishing nets are initially immersed in water; after a period of time, the toxin is released voluntarily. Later, the breakdown into smaller particles that find their way into aquatic animals, and finally to the final consumers. This results in vast contamination of water bodies and aquatic animals of the area affected.

According to a representative for the ocean cleaning, Chinese cargo ships are to blame for the plastic contamination in the ocean. It is estimated that up to 80 to 90 percent of the plastic trash in some places comes from fishing gear, including nets and traps, which is the main source of plastic pollution in the ocean. According to statistics, storm-water runoff and direct discharge into coastal waters are the main ways that continental plastic waste enters the ocean. It has been demonstrated that plastic in the ocean follows ocean currents, eventually forming what are known as Great Garbage Patches. According to estimates, plastic contamination in the oceans causes more than 400,000 marine creatures to die each year. In abandoned or improperly disposed fishing gear, such as ghost nets, marine species are caught. In order to increase the buoyancy and durability of fishing gear, synthetic materials like nylon manufactured from polyethylene are frequently utilized to make the ropes and nets that are employed in these activities. These organisms can become entangled in circular plastic wrapping occasionally, and if they keep expanding in size, the plastic may cut into their flesh. Coral reefs can be harmed as a result of equipment like nets dragging along the seafloor.

2.1.1 Plain Old Trash

Plastics are ubiquitous on the streets and in every nook of Nigerian communities, which makes them messy. Some products, like canned food, drinks, and beverages, have plastic linings inside their cartons to enable correct packing. Participants and invited guests discard plastic drinking bottles, water bottles, straws, and stirrers used for soft drinks in hotels, restaurants, and event spaces for entertainment during conferences, seminars, symposiums, wedding receptions, Annual General Meetings (AGMs), etc. while disregarding the environmental impact. Even microscopic plastic beads may be present in some of these goods. These kinds of waste materials are washed down the drain, where the hazardous contaminants endanger the ecosystem and cause injury. Landfills and trash dumps pose serious issues because they allow contaminants to leak into the ground, damaging groundwater and animals.

The land is threatened by plastic pollution, which also endangers the flora, animals, and people that live there. Between four and twenty three times as much plastic is estimated to be present on land than in the ocean overall. More plastic is piled up on land than in water bodies, and it's also more concentrated.

2.1.2 Disposing of Plastic and Garbage

Plastics have a complicated chemical make-up. This makes them strong and difficult to degrade or easily break down. Depending on their chemical makeup, plastics and resins have various pollutant absorption and adsorption characteristics. Due to salty surroundings and their cooling effect, polymer breakdown occurs slowly in seas and oceans. These are variables that contribute to plastic debris's persistence in some ecosystems. The marine scientists' research has enabled them to forecast the speeds at which certain plastic items will degrade. A plastic beverage holder is predicted to endure 400 years, a foam plastic cup 50 years, a diaper 450 years, and fishing line 600 years to decompose. Plastic is poisonous when burned, harming the environment and increasing the risk of fatal illness. In landfill, the release of toxins is continuous. The majority of plastic waste in landfills comes from packaging and other single-use items. This type of disposal or discarding of plastics causes buildup. However, there are space restrictions at the landfills, and incineration poses a greater danger of gas emissions than landfill disposal. Another thing to keep in mind is that the liners that operate as barriers between the environment and landfills may crack, allowing toxic substances to leak out and contaminate the nearby soil and water. Plastic recycling alone won't be able to get rid of all the trashed plastic that exists now. Plastic irritants and hazardous compounds may be released into the environment during plastic recycling.

2.1.3 Over-Utilization of Plastics

This alludes to the excessive use of plastics. In this state, it lasts longer and costs less. These make it possible for both rich and less privileged members of society to purchase plastic goods and other things. It is currently one of the most frequently used and accessible materials in the entire globe. Plastics are difficult to decompose and, when burned outdoors, they damage the surrounding area's air, land, and ecosystem when disposed of or abandoned with the environment. Additionally, improperly dumped plastic goods can be transported to oceans by storm waters.

2.2 Environmental effect of plastic disposal and pollution

Plastics contain significant harmful chemicals that have the potential to seriously endanger the environment through air, water, and land contamination. Due to the non-biodegradable status of plastics, it can devastate the environment and cause long-term problems for people, animals, and plants. Urban regions, shoreline geography, trade routes, wind and ocean currents, and other variables all affect where plastic waste is found. In some places, the human population is another important factor. Plastic is typically found in enclosed spaces, like the crevices of cities and towns, having an impact on the environment. This contributes to the spread of creatures to distant shores that are not their unique natural habitats. Groundwater pollution, disruption of the food chain, animal deaths, land pollution, toxic potential, air pollution, and cost are a few consequences of plastic pollution on our habitats.

2.2.1 Groundwater Pollution

Water that is found underground in rocks or other non-stratified materials is known as groundwater. Surface water systems and the components of the Earth's crust are connected via groundwater (McConnel, 2010) [8].

In most places, groundwater is relatively contaminant-free when in its natural state. Being a popular source of drinking water, its contamination will definitely pose a serious issue man and animals. Drinking water comes from groundwater or streams and lakes on Earth's surface, whether it is obtained from the tap or bottles (McConnel *et al.*, 2010) [8].

This demonstrates how the leakage of wastes and plastics puts the world's water in grave peril. When it rains, all of these landfills, garbage dumps, and plastic wastes that litter the earth leach into the groundwater, contaminating this source of our drinking water. Groundwater and reservoirs can leak environmental contaminants, causing the water to become poisoned. The world's oceans are now contaminated and strewn with plastic, which has negative consequences on it. This has had disastrous environmental repercussions on numerous marine species, having a negative impact on those who eat fish and other marine creatures for their nutrition (Carlson *et al.*, 2010) [9].

2.2.2 It Upsets the Food Chain

In an ecosystem, the order of who eats whom is called the food chain. Different species frequently belong to multiple food chains, especially when their feeding level is modest (Starr and McMillan, 2007) [10]. An ecosystem is made up of one or more colonies of species interacting with the environment and one another. Some species in an ecosystem have their own place in a feeding/tropical level hierarchy. Energy transfer from one of an ecosystem's feeding levels to another is a crucial aspect of its operation (Starr and McMillan, 2007) [10].

There are producers, consumers, and decomposers in the food chain. The majority of the organisms in the food chain eat plastic wastes. Plankton, the smallest organism in the planet, are being harmed by plastic pollution as a result. Plastics become eaten and poisoned when these species, who are producers, feed on them, which creates issues for the higher animals, who are consumers and rely solely on them (the primary producers) for food in the food chain. The food chain and ecosystem as a whole are hampered as a result of this pollution by plastic wastes. Additionally, through the food chain, this may result in a significant amount of very dangerous compounds and carcinogens being ingested by plankton, fish, and mostly people (Starr and McMillan, 2007) [10].

2.2.3 Killings of Animals

A number of animals, including ducks, dolphins, fish, fowl, turkeys, and tortoises have died as a result of being trapped in or poisoned by plastic wastes due to their availability in the nooks and crannies of their natural habitat. This is because these wastes, such as plastic bags, containers, and different shaped ring can-holders, are being discarded every day. This has negative consequences on the wildlife in the area, which has an impact on the ecology. Many marine animals, including fish, turtles, birds, and others, have died as a result of becoming entangled in plastic trash. These creatures die or suffocate after becoming trapped in the rubble along the journey. They die from being unable to flee from predators as a result of their incapacity to disentangle themselves. They can also die due to starvation. Severe abrasions and ulceration are additional common side effects of being entangled. In the 2006 research titled Plastic Waste in the World's Oceans, it was estimated that at least 267 different animal species had experienced harm through entanglement and ingestion of plastic garbage (Uwaegbulam *et al.*, 2018) [11].

2.2.4 Land pollution

Typically, plastic garbage is disposed of in landfills. When this happens, dangerous compounds are created as a result of the waste contact with water. The quality of water declines as these contaminants seep underground. Wind carries and deposits plastic from one location to another, contributing to plastic pollution. With this, there is now more land litter. Also susceptible to becoming stuck are trees, fences, towers, poles, traffic lights, rooftops, and other structures. The majority of American municipalities chose to dispose of their urban waste in landfills due to the availability of open land and a free-market system for waste collection and disposal (Fellman *et al*., 2005).

A threat to public health and an eyesore on the landscape in earlier times, most of these were just open dumps on the soil. The sanitary landfill was seen to be a more environmentally friendly method of trash disposal, and stricter Federal rules started to mandate its use in the 1960s. This entails placing waste in a depression in the ground or a trench that has been dug, compacting it, and sealing it with dirt each day. In 1976, open dumping became illegal. The majority of the municipal waste in the nation is dumped in landfills. There was a genuine concern in the 1970s and 1980s that if landfill sites were less readily available, more expensive, or allowed, the expense of disposing of solid waste would skyrocket. Over half of the East Coast's cities were without any local dump sites by the middle of the 1990s, and about two-thirds of all landfills that were in use in the late 1970s had failed and shut down by 1990. But those early worries turned out to be unfounded due to developments in waste economics during the 1990s.

Land-based plastic pollution is a serious threat to the plants, animals, and people that live there, making the environment uncomfortable for everyone. From 60% in East Asia and the Pacific to 1% in North America, plastic garbage that has been improperly managed. Between one third and one half of the total unmanaged wastes for that year end up in the ocean each year as plastic marine debris due to improperly managed plastic garbage. Chlorinated plastic can leak dangerous chemicals into the soil nearby, which can then seep into nearby water sources like the groundwater and threaten the global ecology. The species that use water may suffer severe injury as a result of this.

When harmful chemicals from plastic garbage interact with water and seep into the soil, they render the soil infertile and have an adverse effect on plant growth. Due to the ease with which the waste can be picked up and carried to the ocean by wind or smaller waterways like rivers and streams, landfills that are close to oceans frequently contribute to ocean debris. Ineffectively treated sewage water that is eventually transferred to the ocean through rivers can also result in marine debris (Miller *et al*. 2010) [12].

2.2.5 Air Pollution

This denotes the existence of chemicals in the atmosphere at higher concentration levels that can harm living things, ecosystems, or things manufactured by humans (industrialization), as well as alteration of the climate. Since atmospheric circulation carries pollutants freely across political boundaries, communities far from the polluting source may suffer from the effects of air pollution today. Toxic/harmful chemicals are emitted when plastics are burned outdoors, in landfills, or in incinerators, which damages the environment. Additionally, when inhaled, discarded plastics contribute to greenhouse gas emissions that have a negative impact on both people and animals. As a result, breathing in polluted air can have a negative impact on an animal or human's health and lead to respiratory and endocrine issues, among other issues (Fellman *et al* 2013) [13].

2.3 Health Effects of Plastic pollution and Waste

Although it is generally accepted that plastic polymers are inert and pose minimal threat to public health, it is possible that certain additives and leftover monomers from these polymers are to blame for the alleged health hazards (Araujo *et al*., 2002). Microplastics are significant pollutants that pose a concern to the public's health since they can bioaccumulate in the food chain after being consumed by a variety of freshwater and marine life (Galloway, 2015). Consuming animals that have been exposed to microplastics and plastic additives can be harmful to humans. Through the assessment of environmental pollutants, biomonitoring investigations on human tissues have demonstrated that plastic constituents persist in the population of humans (Brydson, 1999).

Fig 9: Health Effects in Plastic

Fig 10: Plastic disposal on animal

Plastic pollution is when plastic builds up or gathers in a place and starts to have a harmful impact on the ecosystem, posing issues for both flora and wildlife as well as the human population. As a result, local animals and people are put in danger and plant life is killed. Although it is produced of harmful chemical compounds that can make people sick, plastics are an extraordinarily valuable material in both smaller communities and more developed nations.

According to a 2017 study, plastic contaminants were found in 83 percent of tap water samples from throughout the world. The United States has the most polluted tap water, with an increased contamination rate of 94%, followed by Lebanon and India in this study's first examination of the global problem of plastic pollution of drinking water. The lowest contamination rate was seen in European nations like the United Kingdom, Germany, and France, yet the levels stood high at 72%. This implies that people may consume between 3,000 and 4,000 microscopic plastic particles annually from tap water. Particles larger than 2.5 microns, or 2500 times larger than a nanometer, were discovered through the examination. Based on current study, it is unclear if this contamination is harmful to human's health, but in instances where non-particle pollutants are also identified in the water, there may be negative consequences on people's overall wellbeing, according to reports by scientists concerned with the study.

Carcinogens and hormonal growth disruption are as a result of the effects of plastic. The chemicals used to make the primary feedstock for plastics have some recognized negative effects on human health, including neurological, cancer, reproductive, and developmental toxicity, immune system damage, and birth defects. According to research, the production of plastic has complex, significant, intersecting, and adverse effects on human health. These effects can be found at every stage of the plastic lifecycle, from the wellhead to the refinery, from store shelves to people's bodies, and from waste management to more recent effects like water, air, and soil pollution. Exposure of the human body to the poisons generated by plastics is unhealthy. The safety of the additives (such as bisphenol A (BPA) and a group of compounds called phthalates) that are incorporated into plastics during the manufacturing process, which makes them more flexible, resilient, and transparent, is a major problem in the production of plastics.

2.4 Effect of plastic disposal/waste on Animal

Food supply chain for humans is bound to experience striking setbacks if animals are poisoned by prevailing toxic substances found in plastic wastes and other plastic products (Daniel, 2004) [14]. Great amounts of plastic garbage entering the world's oceans have been reported to pose a serious threat to the survival and livelihood of large marine creatures (Karleskint *et al*. 2009) [15].

Majority of ocean animals mistake plastic debris thrown into the water for food and subsequently, ingest them (Daniel, 2004) [14]. Due to this confusion, jellyfish, sea turtles and other aquatic species whose primary food source is jellyfish are significantly endangered by marine pollution caused by plastic wastes. Similar circumstances frequently occur with fish and seabirds, both of which can mistake plastic debris for their natural prey (Gregory, 2009) [16].

Ingesting plastic wastes has the dire potential to physically harm and impede a bird's alimentary canal, which would decline the system's capacity for digestion and finally results to famine, malnutrition, and most of the times, leads to death. Entanglement of plastic garbage in animals has caused several birds, turtles, fish, seals, and other marine species to drown or suffocate to death. In an estimated 243 species of marine life, entanglement has been shown to pose health hazards that frequently result in fatalities. Predator deaths also result from animal entrapment in plastic wastes since the animals are unable to free themselves and flee (Hammer *et al*. 2012). Dragging nets and other plastic items down the sea floor has harmed coral reefs (Gregory, 2009) [16].

3. Recycling of Plastics

Recycling of plastics is the process of converting waste or scrap plastic into products that can be utilized again. The majority of plastics are not naturally biodegradable. Reducing trash emissions, managing it well, and recycling the garbage that results from the use of plastics are the main work. (Padanyi and Foldi, 2014; Foldi, 2009) [18, 17].

Plastic recycling is frequently more difficult due to low density and low value as compared to the profitable recycling of metal (equivalent to the low value of recycling glass materials). When recycling plastic, there are various technical challenges to overcome. When different plastic kinds melt together, they frequently separate into layers similar to how oil and water do. The structural fragility of the final product(s), caused by the ensuing phase barriers, has restricted the use of certain polymer blends. This is true of the two plastics that are most frequently created, polyethylene and polypropylene, which has limited their utility in recycling. Block copolymers have recently been proposed as a type of macromolecular welding flux or molecular stitches to get around the problem of phase-separation during plastic recycling (Creton, 2017). (Eagan *et al*. 2017).

3.1. Types of plastic recycling

It has been suggested that the following established and new techniques to managing plastic wastes are remedies to the lingering plastic waste issue:

3.2 Chemical Recycling

In chemical recycling process, plastic polymers involved are broken down into smaller and more usable parts like monomers. This indicates that the polymer structure is generally modified chemically to produce liquids and gases that are utilized as raw materials to make additional petrochemicals and plastics (Al-Salem *et al*., 2009).

3.2.1 Chemical Recycling Techniques

The three main classes of chemical recycling techniques are:

3.2.2 Chemical Depolymerization

This technique is best adapted to PET and pure terephthalic acid (PTA), but it can also be used with PA, PU, PLA, PHA, PEF, and PC, as well as a variety of polyesters. It only functions effectively with very selective inputs, necessitating rigorous source segregation. In contrast to solvent-based regeneration procedures, which generate a purified polymer ready for conversion to plastic products, depolymerization results in monomers that must be re-polymerized together with additions to replace those lost. Colorants, additives, and other impurities can be entirely separated at the molecular level during depolymerization and solvent regeneration (provided procedures are carried out in accordance with rigid guidelines), and the product is then of high purity (Crippa *et al*., 2019) [23].

3.2.3 Solvent Based Regeneration

High quality, nearly virgin polymers are produced through solvent-based purification and depolymerization. This is an illustration of a solvent regeneration method. Without the need for the depolymerization procedures necessary for monomers produced during depolymerization operations, the solvent-regenerated polymer is prepared to be transformed directly into a plastic product. The majority of impurities, coloring agents, and other additives are eliminated at the molecular level without changing the structure of the target polymer. To duplicate the target product's attributes as they were with the original product, additional additives can be needed. Solvent-based purification typically involves dissolving the polymer in a particular solvent, removing impurities like additives, pigments, and Non-Intentionally Added Substances (NIAS) through filtration or phase extraction, and then precipitating the polymer using an anti-solvent that the polymer is insoluble in (Crippa *et al*., 2019) [23].

3.2.4. Thermal Depolymerization

The output of plastic pyrolysis and gasification cannot (PMMA and PS waste can be subject to pyrolysis to produce monomers, but only with heterogeneous feedstock and carefully controlled conditions.) be used directly to produce polymers. The outputs are char, oil, tars, and gas with mixed hydrocarbon molecules containing a range of contaminants, which must be subject to much the same processes and refinement as crude oil requires before it can be developed into polymers. Therefore, these processes essentially generate raw hydrocarbon feedstock to manufacture polymers, rather than monomers or polymers directly. However, as previously mentioned, economic factors typically prevent the use of these raw hydrocarbons as a new feedstock for petrochemicals or polymers, instead leading to their sale and burning as a form of reconstituted fossil fuel made from plastic waste. (Gleis, 2012) [24].

3.2.5 Depolymerization Using Bacteria

The bacterial enzyme is based on naturally occurring bacteria that scientists later modified to process PET more effectively, claiming a 90% depolymerization within 10 hours (Tournier *et al*., 2020). To scale up bacterial production using fungi to an industrial scale, Carbios has partnered with an enzyme manufacturer, Novozymes. According to reports, this enzyme has a high efficiency and can produce 16.7 grams of terephthalate per liter per hour for only 4% of the price of virgin plastic derived from oil. How the bacteria respond to additives and contaminants, as well as the dangers of the waste stream created after the PET has been separated from the plastic waste, are still open questions. The results of scaled-up trials and the lengthy wait before the product is commercially available may not accurately reflect the technique's early promise. Pseudomonas bacteria are now frequently used to break down polyurethane (Espinosa *et al*., 2020).

3.3 Mechanical recycling

This type of recycling reprocesses plastic waste only mechanically, and it typically entails collection, cleaning, drying, clipping, sizing, coloring, clumping, extrusion, and manufacturing (Francis, 2016).

3.3.1 Technical Processes Involved in Mechanical Recycling.

3.3.2 Collection

Source separation and collection systems from public, commercial, and industrial sources are crucial for an effective and profitable mechanical plastic recycling system. Curbside collection, drop-off sites, buy-back, and deposit-refund schemes are the primary collecting strategies employed in many industrialized nations. These concentrate on consumer goods and plastic packaging. Due to the lack of contamination from mixing with organic wastes, industrial waste plastics (cut offs and scraps) obtained straight from companies can be particularly beneficial. The cleaning phase is less resource-intensive following how clean the incoming plastic waste is. The gathering, sorting, and cleaning procedures are less complex and carry more dangers for employees in low-income nations, but they may also be quite effective.

3.3.3 Cleaning and sorting

Mixed plastics must be sorted, segregated, and cleaned in order to assist mechanical recycling since they are frequently contaminated with organic matter and other materials when they arrive at the mechanical recycling plant. The first phase is the elimination of non-plastic components including paper, metal, and wood. To aid with separation, shredding could take place throughout the nest phases. Following the divide into colorful and clear plastics, rigid plastics are separated from non-rigid plastics (such as foils and chip packages). Polymer kinds must then be divided into various fractions. Magnets and eddy currents can be used to extract metals. Blowers and wind sifters can be used to separate non-rigid polymers. The optical color recognition sensors separate colors (Delva *et al*., 2019).

3.3.4 Polymer Sorting

Mixed polymers reduce the value of recycled material and help the end products' strength and other attributes deteriorate. They also make processing more challenging since they have varying melting points. It is possible to sort polymers directly or indirectly. Direct approaches include density separation, although owing to density overlap, more sophisticated procedures such flotation or froth flotation (Burat *et al*., 2009), use of centrifuges, or hydro cyclones may be required for mono separation (Pascoe, 2006). Utilizing optical scanners to identify and classify different polymer kinds is a part of indirect approaches. The FT-NIR (Fourier Transform Near-Infrared) sensor is the most widely utilized technology, however it has the potential to mistakenly detect impurities and black polymers. The sensor industry is expanding quickly, and PVC and black plastic sensors are currently in use. Concerns regarding contamination of the recycling chain and potential incompatibility with polymers derived from fossil fuels have lately been highlighted by the advent of bioplastics (Alaerts *et al*., 2018).

3.3.5 Remelting and Extrusion

After being sorted, cleaned, and shredded, the polymers can be remelted (apart from thermoset plastics) and extruded to create bulk pellets (nurdles), which are then sold to companies that make plastic products. Solid-state polycondensation (SSP) in a vacuum at particular temperatures (180-240 °C) is applied to various polymers, such as PET, causing post-consumer impurities to rise to the surface of the PET and be removed by the vacuum force (Cruze and Zanin, 2006).

3.3.6 Toxic Additives Challenge Mechanical and Chemical Recycling

In addition to the many institutional, economic, and policy issues that have previously been raised in this paper, there are also technological issues with the separation and processing of post-consumer polymeric materials. A key issue is the thermo-degradation of polymers throughout the recycling process as a result of heat and mechanical shear (Delva *et al*., 2019). The output recycled product may have suffered further types of deterioration before it arrived at the recycling plant, including exposure to heat, light, oxygen, and moisture (Ragaert, 2016).

3.4 Biological recycling

This is a technique for recycling biodegradable plastics. Tertiary recycling includes biological recycling. These polymers are susceptible to microbial assault and can degrade quickly, entering the biological cycle (Hopewell *et al*., 2009) [21].

3.4.1 Biodegradability of plastics

Microorganisms destroy complex polymers by a variety of processes, such as the direct use of plastic pieces as food or the indirect action of numerous microbial enzymes. The most often utilized bacterial and fungal strains for the biodegradation of polymers are *Penicillium simplicissimum*, *Pseudomonas fluorescens*, and *P. aeruginosa* (Norman *et al*. 2002; Singh and Sharma 2008; Raziyafathima *et al*. 2016) [25, 27].

3.5 Classification of Plastics Based on Biodegradability

In terms of biodegradability, plastics may be divided into two categories: non-biodegradable plastics and biodegradable plastics.

3.5.1 Non-Biodegradable Plastics

Polymers derived from fossil fuels and biological sources are both non-biodegradable plastics. The majority of currently used non-biodegradable plastics are fossil-based synthetic polymers made from petroleum and hydrocarbon derivatives (petrochemicals). Due to the numerous times that tiny monomer units are repeated, they have a large molecular weight (Ghosh *et al*. 2013) [28]. These polymers are quite stable and don't easily interact with the biosphere's cycles of deterioration (Vijaya and Reddy 2008). The majority of commercial polymers used today are either non-biodegradable or degrade at rates that prevent total disintegration. Many commonly used plastics, such as PVC, PP, PS, PET, PUR, and PE, are non-biodegradable. They have collected in the environment in large quantities and have become a menace to the planet as a result of inadequate waste management and littering (Krueger *et al*. 2015) [30].

3.5.2 Biodegradable Plastics

Depending on the level of biodegradability and microbial absorption, biodegradable plastics may contain both bio-based and fossil-based polymers. Enzymatic and non-enzymatic hydrolysis are both involved in the biodegradation of polymers. The type of organism, pretreatment method, and polymer properties are some of the variables influencing how well biodegradation processes work (Wackett & Hershberger 2001) [31]. Additionally, some crucial factors for the degradation of plastics include mobility, crystallinity, type of functional groups, tactility, chemical components, molecular weight, and additives included in polymers (Artham and Doble 2008) [32]. Exo-enzymes, which are secreted by microorganisms during degradation, break down polymer complexes into simpler molecules like dimers and monomers. Therefore, a bacterial cell's semi-permeable membranes can accommodate even smaller molecules, which it uses as both a source of energy and carbon (Gu 2003; Jayasekara *et al*.2005) [33, 38]. Anaerobic and aerobic processes are both involved in biodegradation reactions (Shah *et al*. 2008) [34].

3.6 Classification of biodegradable plastics

3.6.1 Bio-based biodegradable plastics

Since they may totally disintegrate biologically, bio-based biodegradable polymers are desirable in some industrial applications from an environmental standpoint because they are made from renewable resources (Kale *et al*., 2007).

Bio-based polymer are frequently used to make biodegradable plastics. Starch is often used to create bio-based, biodegradable polymers because of its availability, affordability, abundance, and propensity to degrade under certain environmental circumstances (Chattopadhyay *et al*. 2011; Kyrikou and Briassoulis 2007; Nanda *et al*., 2010; Jayasekara *et al*., 2005) [36, 37, 38].

3.6.2 Fossil-Based Biodegradable Plastics

Fossil-based biodegradable polymers have been used in a variety of applications, particularly in the packaging sector. The bulk of fossil-based plastics, however, are non-biodegradable and provide a significant challenge for their waste management systems (Hoshino *et al*. 2003; Vert *et al*., 2002) [40, 41].

Non-biodegradable polymers derived from fossil fuels degrade very slowly.

3.6.3 Microbes and Their Mechanisms for Plastic Biodegradation

Extracellular enzymes produced by bacteria and fungi help break down a variety of bio and fossil-based polymers (Shah *et al*. 2014) [42].

These polymers are broken down by bacteria and fungi into CO_2 and H_2O through a variety of metabolic and enzymatic processes. Depending on the microbiological species and even within the strains, different enzymes have different characteristics and catalytic activities. Different enzymes are known to breakdown distinct forms of polymer due to this selectivity. For instance, the bacteria *Bacillus spp*. and *Brevibacillus spp*. create proteases that help break down different types of polymers (Sivan 2011) [43].

Microbes adhering to polymers and then colonizing surfaces is the main process of plastic biodegradation. Two processes are involved in the hydrolysis of plastics using enzymes: Enzymes first connect to the polymer substrate, then hydrolytic division occurs (Fig. 1). Oligomers, dimers, and monomers are examples of polymer degradation products that have significantly lower molecular weights and are eventually mineralized to produce CO2 and H2O. (Tokiwa *et al*. 2009) [44]. By using oxygen as an electron acceptor and then synthesizing smaller organic molecules, bacteria create CO2 and water as their final products in an aerobic environment (Priyanka and Archana 2012) [45]. Microorganisms break down polymers in the absence of oxygen. Anaerobic bacteria employ sulfate, nitrate, iron, carbon dioxide, and manganese as electron acceptors when anaerobic conditions exist (Priyanka and Archana 2012) [45].

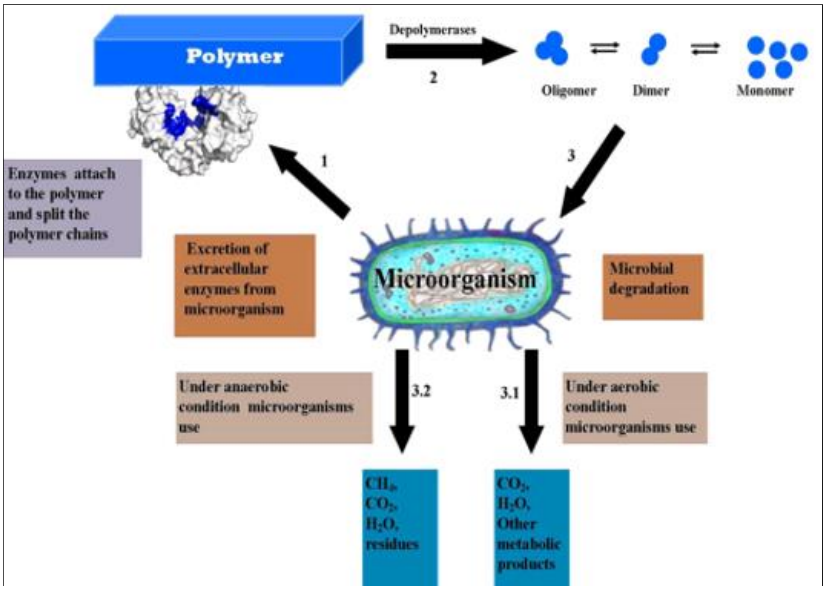

Fig 11: Microbial enzymes and pathway (Priyanka and Archana 2012) [45].

3.7 Factors Affecting Plastic Biodegradation

The features of the enzyme, the exposure circumstances, and the polymer properties all have an impact on the biodegradation process. Below is a list of a few of these elements.

3.7.1 Moisture

Given that bacteria need water to thrive and reproduce, moisture can have a variety of effects on polymer biodegradation. As a result of quick microbial action, polymer breakdown speed is increased in the presence of enough moisture (Ho *et al*. 1999) [46]. Furthermore, moisture-rich environments promote the hydrolysis process by increasing the number of chain scission processes.

3.7.2 PH and Temperature

By adjusting the acidic or basic conditions, the pH can alter the pace of hydrolysis processes. For instance, the rate of PLA capsule hydrolysis is best at pH 5. (Auras *et al*., 2004; Henton *et al*., 2005) [47]. Different polymer breakdown products change the pH levels, which thus affect the rate of degradation and microbial development. The softening temperature of the polymer also has a substantial impact on its capacity to be broken down by enzymes. Polyester with a high melting point is less likely to degrade biologically. As temperature rises, potential enzymatic degradability declines. As an illustration, pure R. delemar lipase effectively degraded polyesters like PCL, which had low melting points (Tokiwa and Calabia 2004; Tokiwa *et al*. 2009) [49, 44].

3.7.3 Enzyme Characteristics

It was discovered that the extracellular enzymes, involved in the depolymerization of PHB (depolymerase), degrade PHB by distinct mechanisms depend on the specific microbially produced depolymerase. Different enzymes possess unique active sites and have the ability to biodegrade various types of polymers (Yamada-Onodera *et al*. 2001) [50].

Due to their hydrophobicity and three-dimensional structure, plastics made from petrochemical sources are unable to decompose easily in the environment (Yamada-Onodera *et al*. 2001) [50]. In addition, PE's hydrophobic properties interfere with the development of a biofilm of microorganisms to slow down biodegradation (Hadad *et al*. 2005) [48].

3.8 Management of Plastic Disposal

Waste management is crucial in lowering the damaging impacts of plastic wastes on the environment and public health. The collection, handling, and disposal of plastic trash must be improved for a global reduction in litter and ocean pollution (Jambeck *et al*., 2015) [19]. Inadequate landfill management will allow dangerous chemicals contained in plastic garbage to leak into the environment and contaminate the soil, air, and subterranean water. Micro-plastics won't get into the ecosystem from landfills if wastewater is managed properly. There is a need for a prohibition, such as Annex V to the International Convention for Prevention of Pollution from Ship (MARPOL) agreement, which will limit the disposal of plastic trash into the sea as the majority of treated wastewaters are released into rivers or seas (Mouat *et al*., 2011).

Both public awareness and education of the populace has to be made to keep them aware of the possible negative effects that plastic wastes pollution might have on the environment and public health. This will significantly lower the rate of pollution and protect the environment's quality. People need to be aware of the chemical components of plastic items and how they affect human health. The knowledge on waste management and methods for reducing plastic pollution must be included in educational curricula at all levels. Landfilling, education and public awareness, plastic incineration, and plastic recycling are some methods for managing plastic disposal.

3.8.1 Land filling

Plastics make up around 10% of household garbage and are primarily disposed of in landfills. Even though landfilling is the most widely used traditional waste management strategy in many nations, there is a growing problem with the lack of available land for them. For instance, landfilling has historically been popular in the UK since it is affordable and straightforward and doesn't always require treatment, cleaning, or separation. In Western Europe, landfilling of plastic trash accounted for 65 percent (8.4 million tons annually) of the total amount of recoverable plastics in household garbage in 1999 (APME, 2002), however it is now the least preferred waste management strategy in the UK. Due to the types, amounts, and potential for leaking of harmful substances into landfill sites, there is rising environmental and public health concern over the consequences of landfills (Miller, 2005).

With 60 percent of England's municipal waste still being sent to landfills, compared to 20 percent in Germany and 37 percent in France, it has been challenging for the UK government to implement its policy to reduce the amount of waste that is landfilled (see, for example, the Landfill Directive European Commission 1999/31/EC). If landfills are properly managed, environmental pollution and dangers to public health can be minimized, while there is a chance that disintegrating plastic residues and additives could contaminate soil and groundwater in the long run (Oehlmann *et al*. 2009 and Teuten *et al*. 2009).

3.8.2 Plastic incineration

The burning of plastic wastes offers an alternative to landfilling, but there are rising worries about the possible atmospheric emission of dangerous chemicals during the process. For instance, the burning of plastics releases furans, dioxins, and polychlorinated biphenyls (PCBs) into the environment along with halogenated compounds and polyvinyl chloride (Gilpin, 2003).

The drawback of burning plastics is that the toxic gases emitted into the environment cause air pollution. When plastics are burned, they irreversibly destroy the combustion heater of the flue systems, and the byproducts of this combustion are harmful to both people and the environment. Low molecular weight substances can pollute the air by vaporizing into it directly. Depending on the substance, certain low molecular weight substances may also produce flammable mixtures, while others may oxidize into solid form. Plastics are typically coked during incineration, and the amount of the coking depends on the burning circumstances (Nagy, 2016).

When plastic and plastic composite items are burnt, hazardous gases are released. When plastics are incinerated, soot, ashes, and other powders are created. These materials eventually land on plants and soil and have the potential to go into aquatic environments. Rainfall can cause some of these harmful substances to dissolve into the soil, contaminate the groundwater, or be absorbed by the plants that thrive there. They also find their way into the food chain. Some of these chemicals for burning plastic can chemically react with water, and the resultant substances can modify the pH of the water, which can impact how aquatic ecosystems function. In compared to recycling and landfilling, plastic incineration is used less for waste management because of the possible environmental damage. European nations with large incinerator plants for handling urban solid waste, including plastics, include Sweden and Denmark as well as Japan. Nevertheless, nations like Hungary have passed rules (29/2014). The Ministry of Agriculture has regulations on waste incineration that only permit licensed plastic waste incineration facilities to burn plastics; all other types of burning plastic trash are prohibited (Nagy, 2016). Energy recovery from plastic trash is a benefit of plastic incineration (Hopewell, 2009) [21]

4. Conclusion

Public concern over the impact of plastic waste and disposal on people, animals, and the environment at large necessitates the need to save the ecosystem. Despite the fact that plastics are quite beneficial in daily life, it is important to closely monitor the harmful chemicals used in manufacture to protect the environment and human health. Additionally, microorganisms employ a variety of ways to break down complex polymers, including direct feeding on plastic pieces or indirect action from a number of microbial enzymes.

4.1 Recommendation

Governmental organizations and health authorities must move quickly to implement environmental regulations that will keep tabs on the nation’s plastic manufacturing, usage, and disposal. Policies must be appropriately implemented in order to counteract and stop the environmental damage caused by plastics.

5. References

1. Proshad R, Islam MS, Kormoker T, Haque MA, Mahfuzur R. Toxic effects of plastic on human health and environment: A consequences of health risk assessment in Bangladesh. Inter Journal of Health. 2018;6(1):1-5.
2. Rochman CM, Browne MA, Halpern BS, Hentschel BT, Hoh E. Policy: Classify plastic waste as hazardous. Nature. 2013a;1(494):169-171.
3. Derraik JG. The pollution of the marine environment by plastic debris: A review. Marine Pollution Bull. 2002;1(44):842-852.
4. Andrady AL. Micro plastics in the marine environment. Marine pollution bull. 2011;62(2011):1596-1605.
5. Bakir A, Rowland S, Thompson R. Transport of persistent organic pollutants by micro plastics in estuarine conditions. Estuarine Coast. Shelf Science. 2014;140(2014):14-21.

6. Nelms SE, Barnett J, Brownlow A. Micro plastics in marine mammals stranded around the British coast. Science Rep. 2019;1(9):1075.
7. Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ. Lost at sea: Where is all the plastic? Science. 2004;1(304):838.
8. McConnell D, Steer D, Knight C, Owens B. The Good Earth: Introduction to Earth Science, Second Edition. McGraw-Hill Companies, New York, 2010, 316.
9. Plummer CC, Carlson DH, Hamersley L. Physical Geology, Thirteenth Edition. McGraw-Hill Companies, New York, 2010, 292pp.
10. Starr C, McMillan B. Human Biology, Seventh Edition, Thomson Brooks/Cole, Belmont, California. 2007;464(466):481-482.
11. Uwaegbulam C, Nwannekanma B, Gbonegun V. Producers' Responsibility and Plastic Pollution Crisis, The Guardian Newspaper. 2018;35(14350):32-33.
12. Miller Tyler JRG, Spoolman SE. Environmental Science, Thirteenth Edition, International Edition, Brook/Cole, Belmont, California, 2010, 370, 412.
13. Fellman JD, BJelland MD, Montello DR, Gettis A, Gettis J. Human Geography: Landscapes of Human Activities, Twelfth Edition, McGraw-Hill Companies, New York, 2013, 431.
14. Daniel DC. Creating a sustainable future. Jones and Bartlett Learning. Environ Science. 2004;8:517-518.
15. Karleskint G, Small J, Turner R. Introduction to marine biology. Ceng Learning, 2009, 536.
16. Gregory MR. Environmental implications of plastic debris in marine settings--entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos Trans. R. Soc. Lond. B. Biol. Sci. 2009;364:2013-2025.
17. Foldi L, Halasz L. Környezetbiztonság. Complex KiadóKft, Budapest, Hungary, 2009.
18. Padanyi J, Foldi L. Environmental responsibilities of the military soldiers have to be Greener Berets. Ecology Manage. 2014;2:48-55.
19. Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M. Plastic waste inputs from land into the ocean. Science. 2015;347:768-771.
20. Hardesty BD, Good TP, Wilcox C. Novel methods, new results and science based solutions to tackle marine debris impacts on wildlife. Ocean & Coastal Management. 2015;115:4-9.
21. Hopewell J, Dvorak R, Kosior E. Plastics recycling: Challenges and opportunities. Philos Trans. R. Soc. Lond. B. Biol. Sci. 2009;364:2115-2126.
22. Bradley EL, Coulier L. An investigation into the reaction and breakdown products from starting substances used to produce food contact plastics. CSL York, 2007.
23. Crippa M, De Wilde B, Koopmans R, Leyssens J, Linder M, Muncke J, *et al*. A circular economy for plastics: Insights from research and innovation to inform policy and funding decisions. European Commission EC, 2019.
24. Gleis M. Gasification and pyrolysis - reliable options for waste treatment? In: Thomé-Kozmiensky, Thiel, S. (Eds.), Waste Management 3. Vivis, TK Verlag, 2012, 403-410.
25. Singh B, Sharma N. Mechanistic implications of plastic degradation. Polymer degradation and stability. 2008;93(3):561-584.
26. Ahmed T, Shahid M, Azeem F, Rasul I, Shah AA, Noman M, *et al*. Biodegradation of plastics: current scenario and future prospects for environmental safety. Environmental Science and Pollution Research. 2018;25(8):7287-7298.
27. Raziyafathima M, Praseetha PK, Rimal Isaac RS. Microbial degradation of plastic waste: a review. J Pharma Chem Biol Sci. 2016;4:231-242.
28. Ghosh SK, Pal S, Ray S. Study of microbes having potentiality for biodegradation of plastics. Environmental Science and Pollution Research. 2013;20(7):4339-4355.
29. Reddy RM. Impact of soil composting using municipal solid waste on biodegradation of plastics, 2008.
30. Krueger MC, Harms H, Schlosser D. Prospects for microbiological solutions to environmental pollution with plastics. Applied microbiology and biotechnology. 2015;99(21):8857-8874.
31. Wackett LP, Hershberger CD. Biocatalysis and biodegradation: microbial transformation of organic compounds (No. QP517. B5 W33). Washington, DC: ASM press, 2001.
32. Artham T, Doble M. Biodegradation of aliphatic and aromatic polycarbonates. Macromolecular bioscience. 2008;8(1):14-24.
33. Gu JD. Microbiological deterioration and degradation of synthetic polymeric materials: recent research advances. International Biodeterioration & Biodegradation. 2003;52(2):69-91.
34. Shah AA, Hasan F, Hameed A, Ahmed S. Biological degradation of plastics: a comprehensive review. Biotechnology Advances. 2008;26(3):246-265.
35. Kale G, Kijchavengkul T, Auras R, Rubino M, Selke SE, Singh SP. Compostability of bioplastic packaging materials: an overview. Macromolecular bioscience. 2007;7(3):255-277.
36. Chattopadhyay SK, Singh S, Pramanik N, Niyogi UK, Khandal RK, Uppaluri R, *et al*. Biodegradability studies on natural fibers reinforced polypropylene composites. Journal of Applied Polymer Science. 2011;121(4):2226-2232.
37. Kyrikou I, Briassoulis D. Biodegradation of agricultural plastic films: a critical review. Journal of Polymers and the Environment. 2007;15(2):125-150.
38. Jayasekara R, Harding I, Bowater I, Lonergan G. Biodegradability of a selected range of polymers and polymer blends and standard methods for assessment of biodegradation. Journal of Polymers and the Environment. 2005;13(3):231-251.
39. Kasirajan S, Ngouajio M. Polyethylene and biodegradable mulches for agricultural applications: a review. Agronomy for Sustainable Development. 2012;32(2):501-529.
40. Hoshino A, Tsuji M, Ito M, Momochi M, Mizutani A, Takakuwa K, *et al*. Study of the aerobic biodegradability of plastic materials under controlled compost. In Biodegradable Polymers and Plastics. Springer, Boston, MA, 2003, 47-54.
41. Vert M, Santos ID, Ponsart S, Alauzet N, Morgat JL, Coudane J, *et al*. Degradable polymers in a living

environment: where do you end up? Polymer International. 2002;51(10):840-844.

42. Shah AA, Kato S, Shintani N, Kamini NR, Nakajima-Kambe T. Microbial degradation of aliphatic and aliphatic-aromatic co-polyesters. Applied microbiology and Biotechnology. 2014;98(8):3437-3447.
43. Sivan A. New perspectives in plastic biodegradation. Current Opinion in Biotechnology. 2011;22(3):422-426.
44. Tokiwa Y, Calabia BP, Ugwu CU, Aiba S. Biodegradability of plastics. International Journal of Molecular Sciences. 2009;10(9):3722-3742.
45. Priyanka N, Archana T. Biodegradability of polythene and plastic by the help of microorganism: a way for brighter future. J Environ Anal Toxicology. 2011;1(4):1000111.
46. Ho KLG, Pometto AL, Hinz PN. Effects of temperature and relative humidity on polylactic acid plastic degradation. Journal of Environmental polymer Degradation. 1999;7(2):83-92.
47. Auras R, Harte B, Selke S. An overview of polylactides as packaging materials. Macromolecular Bioscience. 2004;4(9):835-864.
48. Hadad D, Geresh S, Sivan A. Biodegradation of polyethylene by the thermophilic bacterium *Brevibacillus borstelensis*. Journal of Applied Microbiology. 2005;98(5):1093-1100.
49. Tokiwa Y, Calabia BP. Review degradation of microbial polyesters. Biotechnology Letters. 2004;26(15):1181-1189.
50. Yamada-Onodera K, Mukumoto H, Katsuyaya Y, Saiganji A, Tani Y. Degradation of polyethylene by a fungus, *Penicillium simplicissimum* YK. Polymer Degradation and Stability. 2001;72(2):323-327.
51. Hadad D, Geresh S, Sivan A. Biodegradation of polyethylene by the thermophilic bacterium *Brevibacillus borstelensis*. Journal of Applied Microbiology. 2005;98(5):1093-1100.