Journal of Ecosystem & Ecography

Review Article Open Access

Impact of Biodegradable Plastics: Environmental Hazards

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Received: 21-Jan-2022, Manuscript No. JEE-22-52092; **Editor assigned:** 25-Jan-2022, PreQC No. JEE-22-52092 (PQ); **Reviewed:** 08-Feb-2022, QC No. JEE-22-52092; **Revised:** 25-Aug-2022,QINo. JEE-22-52092 (QI); Manuscript No. JEE-22-52092 (R); **Published:** 22-Sep-2022, DOI:10.4172/2157-7625.1000345

Citation: Dhak P, Banerjee S, Chakraborty S, Kundu A (2022) Impact of Biodegradable Plastics: Environmental Hazards. J Ecosys Ecograph 12: 345.

Abstract

Plastics are ubiquitous in worldwide. They are used almost in every fields of technology due to their longer durability, high tensile strength, elasticity and non-degradable nature. Today's world is known as "the plastic age". Besides improving our lives, they are more harmful for us and for environment. Accumulation of large amounts of plastics in soil and water has shown harmful effects on agricultural plants by inhibiting plant growth and ingestion of micro plastics and Nano plastics through food chain causes dreadful diseases to humans and animals. Prevalence of climate change problem is also due to the accumulation of persistent plastics in environment. One solution for alleviating non-biodegradable plastics is using biodegradable plastics made of biodegradable biopolymers by which extracellular enzymes of microorganisms can utilize them as metabolic products and sole source of carbon and oxygen for the growth of microorganisms. This can help reduce the problems of climate change, micro plastic accumulation and littering. However, biodegradable plastics still lacks complete degradation by microorganisms or arthropods. In depth study is required to unwind complete biodegradation process by some enzymes isolated from plants, bacteria and fungi. This review has also highlighted few putative genes involved in the biodegradation process for further studies. This review highlighted some of the recent assays used to test the biodegradability of plastics and bio-based plastics, their mechanism and applications. Few updates regarding alternatives of plastic are development of bio plastic mulch films for better crop plant yield. Future prospects have highlighted knowledge gaps which are required to study for the development of more alternatives of plastics.

Keywords: Biodegradation; Plastics; Bio plastics; Micro plastics; Nano plastics

Introduction

In the year of 1907 LeoHendrix Baekeland was the first scientist who invented synthetic plastic (Bakelite). He made this plastic in such a way that this Bakelite could be moulded into different kinds of shape. They have remarkable properties in durability, light weight, low-cost, easy production, flexibility and strength. Hyatt's and Baekeland's successful invention of synthetic plastic led to think and develop new plastics composed of non-biodegradable monomer units. It has been reported that extensive use of plastics for various applications in World War II plastic industries gained more attention and thereby expanded its use worldwide. Synthetic polymers include Poly Ethylene Terephthalate (PET), Poly Vinyl Chloride (PVC), Poly Styrene (PS), Poly Ethylene (PE), Poly Urethane (PU), Poly Propylene (PP) and nylons. In the absence of efficient methods for safe disposal of plastic debris, these non-biodegradable synthetic plastic accumulate in the environment posing an ever increasing environmental threat to terrestrial as well as marine living organisms. The major limitation of this kind of plastic is that they are unable to degrade naturally. These are discarded into the environment; they are hydrolysed into the smaller fragments by abiotic stresses and are then left to accumulate for millions of years. Therefore, now plastic pollution is one of the most critical environmental issues in the worldwide. In the year of 2020, more than 380 million tons of plastic wastes were released and found floating in the oceans. In 2019, it was estimated that approximately 368 million tons of plastic production increased worldwide. In 2017, 350 million tons of plastics were produced worldwide and among them only 250 million tons of plastics were released and found floating in the ocean. Whereas, only 236 kilotons of plastic wastes were found floating in the oceans exclusively in the year of 2014. According to recent global assessment, only 9% of plastic waste has been recycled, 12% has been incinerated and 79% has accumulated in the landfills and in the natural environment. In today's world plastics are considered as a celestial part of human life. Plastic debris present in environment is actually the reservoir for the production of more number of secondary pollutants in the environment. Due to the production and persistence nature of micro plastics and other kinds of plastic wastes, researchers are expecting that plastic production in the environment will more likely increase to 34 billion metric tons by the year of 2050. This shows the extensive exploitation of plastics and dependence on plastics for various purposes by humans in their day to day life. As per plastic pollution by country 2021, India is in the 15th position for the production of plastic pollution. While, China ranked 1st, United States ranked 2nd, 3rd position is for Germany, Brazil ranked 4th and Japan ranked 5th. Current meta-analysis reports have shown that plastic components such as, polyester, acrylics, polyethylene, polypropylene, polystyrene and polyurethane are abundantly present in the aquatic environment. In recent years, the term "micro plastics" have gained more attention in the field of biodegradation of emerging pollutants [1-3].

These micro plastics are the small plastic particles less than 5 mm in size. Biodegradation of non-biodegradable plastics or biodegradable plastics releases their small sized secondary pollutants which are smaller in size but they are the components of plastics. These micro plastics accumulate around plant seed pores and results in germination delay and inhibits or slower the growth of terrestrial vascular plants. Plastic debris also has harmful impacts on the composition and activity of microbial communities and taxa except those few microbes which poses the ability to degrade polymers. Long term use of plastic bottles or containers composed of harmful chemical substances is a serious risk factor for human health as well as for marine and terrestrial animals. Bis Phenol A (BPA) which is a significant content of the plastic and these plastics are used for food packaging, perfumes, toys, cosmetics, computers and CDs. BPA is involved in the production of polycarbonate plastics. Long term use of plastics leads to the accumulation of plastic substances in the soil, water, and food. Plastic additives such as, biphenyl A, phthalates, nonylphenols behave as endocrine disruptors. Therefore, through food chain they interrupt living being's ingestion pathways. Harmful impacts of plastics on humans include skin diseases, lung problems, dizziness, birth defects, reproductive defects, cardiovascular problems, genotoxic, gastrointestinal effect, respiratory diseases, vision failure and irritation in the eye, cancer, liver dysfunction and neurodegenerative diseases. Rubber particles are also considered as micro plastics though it is mentioned in few research articles. High-density plastics sink to the sediments whereas low-density plastics float on seawater. The process of degradation may change the density of plastic which leads into the change of buoyancy. Internal tissues can easily absorb small particles of plastics and can cross the blood-brain barrier and enter the brain. Inhalation, dermal contact and ingestion are three most common exposure pathways of micro plastics in aquatic organisms. An ideal additive should be efficient in their function. They should be stable under processing and service conditions. No blooming should occur. They should be non-hazardous and they should be tasteless and odorless. They should be environmental friendly and cost-effective. They should not affect or alter the properties of the polymer [4-7].

Literature Review

In order to mitigate the plastic pollution from the ecosystem, researchers invented degradable plastics. Not all microorganisms have the capability to degrade plastics and not all degradable plastics degrade completely in natural environments. Photodegradable and biodegradable plastics are the two main categories of degradable plastics. Both of them are different based on their mechanism, chemical and physical properties as well as degradability properties. Biodegradable plastics are either completely or partly composed of components which can be degraded either by the action of enzymes secreted by microbes or by non-enzymatic hydrolysis mechanism. While photodegradable polymers are composed of either photosensitive degradable chromophore into the polymer chain backbone or may be composed of an additive into the polymer that facilitates to initiate degradation reaction and photochemical degradation results in hydrolysis of the polymer into non-degradable smaller fragment molecules. Biodegradable plastics are usually composed of raw materials which include lignin, cellulose, starch and bioethanol. Poly Hydroxyl Alkanoate (PHA), Poly Hydroxyl Butyrate (PHB), Poly Hydroxyl Butyrate Valerate (PHBV), Poly Lactic Acid (PLA), Poly Capro Lactone (PCL) are common biodegradable and commercially available natural polymers in the market. The ideal biodegradable plastics are a type of polymer material which has excellent properties and can be slowly biodegraded and exists in environment as a part of carbon cycle. Biodegradable plastics are ultimately not a promising solution to solve the global plastic pollution. Based on the degree and nature of biodegradation, these biodegradable plastics are of two types namely, completely biodegradable plastics and destructive biodegradable plastics. Among these two, destructive biodegradable plastics are not completely degradable [8-15].

Hydrophobic or water-insoluble polymers are very tough to degrade completely. For this reason, biodegradation process is the only technique which converts those hydrophobic polymers into disintegrated hydrophilic monomers and degrades them completely. In this type, natural polymer such as starch or lignin or cellulose is combined with a synthetic polymer where synthetic polymer accumulates in the environmental surroundings. Therefore, to solve the problem of plastic accumulation in the environment, biodegradation of biodegradable plastics, micro plastics, biofilm plastics and synthetic plastics is essential and advantageous and sustainable process over unsustainable disposal methods. Each plastic disposal methods have its own inherent drawbacks. These disposal methods includes, burying in landfill, plastic incineration, chemical and mechanical processing for plastic recycling. Incineration of plastics are involved in the production and release of carbon dioxide, greenhouse gases, heavy metals, toxic carbon-based free radicals, toxic oxygen-based free radicals, PAHs and PCBs to the atmosphere. Plastic biodegradation process is the most convenient, efficient and cheaper alternative to the plastic waste disposal method. This biodegradation process does not release any secondary environmental pollutants. Due to the utilization of microbes especially bacteria and fungi for biodegradation of plastics, the end products released by them are also beneficial for further use. Biodegradation may be defined as the ability of one or more cultures of microorganisms and insects to utilize the synthetic or natural or biodegradable polymers as a sole source of carbon. Researches are currently going on the molecular study of PHA, PHB biosynthesis pathway and production of these biodegradable polymers in transgenic plants and microorganisms. This review highlighted a thorough understanding on the pathways involved in microbial PHA, PHB, PLA and other new polymer synthesis and of some basic plant metabolic pathways that may provide precursors for biodegradable polymer synthesis. In this review we have discussed gene expression of plastic degrading enzymes such as PETase in microorganisms, synergistic biodegradation of some aromatic-aliphatic copolyester plastic by marine microbial consortium, influential factors involved in micro plastic, plastic and other biodegradable plastic biodegradation, phylogenetic distribution of plastic-degrading algae, bacteria and other microorganism and also of insects. The purpose of this review is to provide in depth understanding of polymer degradation pathways, enzymatic expression in order to enhance biodegradation technique more efficiently [16-20].

Chemical structure and types of plastics

Plastics include materials which are made up of some elements such as, carbon, oxygen, hydrogen, nitrogen, chlorine, sulphur.

Plastics are actually the polymeric macromolecules which can easily be molded or shaped in any structure which indicates that they have an excellent plasticity property. These organic polymeric chains consist of several thousands of repeating units formed from monomers. The term "polymer" is coined from two Greek words, poly which means many and mere which means unit or a part. The term polymer is defined as large molecules having high molecular mass. These are also referred to as macromolecules, which are formed by joining of repeating structural units on a large scale. The repeating structural units are derived from some simple and reactive molecules known as monomers and are covalently linked to each other. This process of formation of polymers from respective monomers is known as polymerisation. The transformation of ethane to polyethene and interaction of hexamethylene diamine and acidic acid leading to the formation of Nylon-6,6 are types of polymerization. Plastics consist of a complex mixture of known and unknown chemicals some of which can be toxic for us. Poly Capro Lactone (PCL), and Poly Butylene Succinate (PBS) are referred as petroleum based plastics and microorganisms can easily degrade them. While, PLA, PHB and starch blends are produced from renewable resources and are thus, depending on the degree of acetylation, Acetyl Cellulose (AcC) is either biodegradable (low acetylation rate) or non-degradable (high acetylation rate). Plastics are classified based on their thermal as well as biodegradability properties. Thermoplastics and thermosetting plastics are the two types of plastics based on their thermal properties. On the basis of plastic's design properties includes amorphous plastics, crystalline plastics, and conductive polymers. On the other hand photodegradable bio-plastics, biodegradable bio-plastics, compostable bio plastics and bio-based bio-plastics are the types of plastics based on their degradability properties. These plastics are distinguishable among them on the basis of their weight, hardness, tensile strength, thermal conductivities, dielectric strengths and their resistance properties to environment. Most often the term "engineering plastics" are used by many researchers while discussing about plastics and its types. These engineering plastics actually come under the category of plastics and are used for high-performance applications which include mechanical strength, heat resistance and chemical resistance as well. These types of plastics are much expensive and have weak mechanical strength. In plastic industry, there are some common engineering thermoplastics have been manufactured which includes, ABS, liquid crystal polymers, polybutylene terephthalate, polyamide, polyvinylidene fluoride, thermoplastic polyester elastomer, polycarbonate, polyphthalamide. Different types of plastics are manufactured by using different types of chemical components on the basis of their applications in market. This includes tough and light weight beverage bottles. Plastics or polymers can be classified in other ways too. Based on sources, they are sub categorised as natural polymers, semi-synthetic polymers, and synthetic polymers. Based on polymer structure, linear polymers, branched chain polymers and cross-linked or network polymers. Linear polymers are made of long straight chains. Examples include HDPE, PE and PVC. While, branched chain polymers contain linear chains having few branches such as, LDPE. Cross-linked polymers generally formed from bi-functional and tri-functional monomers and consist of strong covalent bonds between various linear polymer chains for example Bakelite, melamine. Based on mode of polymerisation, addition polymer is also known as homo polymer and copolymer and condensation polymer. Based on molecular forces or interaction, they are sub categorised as elastomers, fibres, thermoplastic, thermosetting plastic. Aliphatic polyesters are one of the most important classes of biodegradable plastics. Some of them are namely Poly Hydro Butyrate Valerate (PHBV), Poly Hydro Alkanoate (PHA), Poly Hydroxyl Butyrate (PHB). There are two types of polymerisation reactions one is addition or chain growth polymerisation and another one is condensation or step-growth polymerization [21-25].

Thermoplastics: Thermoplastic materials are classified into eleven major types such as, polystyrenes, polypropylenes, polyethylene, polycarbonates, polyamides, fluorocarbons, acrylics, acetals, vinyls, cellulosices and Acrylonitrile Butadiene and Styrene (ABS). These are the linear or slightly branched long chain molecules which are capable of repeatedly become soft on heating and hard on cooling. They possess intermolecular forces of attraction intermediate between elastomers and fibres. Thermoplastic elastomers are the materials that combine the properties of rubber-like and thermoplasticity nature.

Thermoset plastics: Thermoset plastic materials are classified into eight types such as, polyester, urethanes, silicones, epoxies, amine, allylics, alkyds and phenolics. These polymers are cross linked or heavily branched molecules, which on heating undergo extensive cross-linking in moulds and again become infusible. These polymers are non-reusable. Common examples are bakelite, urea-formaldehyde resins, etc [26].

Natural plastics: These polymers are biocompatible and bioactive, thus facilitates in enhancement of the cell adhesion and proliferation. Natural plastics are prepared from natural materials such as, oils, salts, fats, cellulose, coal, etc [27].

Synthetic plastics: Synthetic plastics or polymers backbone are made up of long chain of C-C bonds, oxygen, sulphur and sometimes nitrogen as well. These plastics are man-made which are extensively used in daily life as well as in industry. They are often considered as petro-plastics as they are derived from petroleum oil. Examples of synthetic polymers include, nylon, PE, polyester, teflon. Vulcanized rubber is a man-made polymer [28].

Bio-based plastics: Bio-based plastics are prepared by using biological resources such as, starch, cellulose, vegetables instead of fossil based resources. Not all bio-based plastics are biodegradable. Biodegradable and compostable plastics depend on specific environmental parameters to get biodegraded. The terms bio-based and biodegradable plastics are used interchangeably but they are not synonymous. Bio-based plastics are not made from petroleum oil. There are few biodegradable plastics which are produced by using petroleum oils and chemicals. Biodegradable polymers include, Poly Hydro Alkanoates (PHAs), poly (butylene succinate), and Poly Lactic Acid (PLA) [29].

Applications of polymers based on their types: Polymers are becoming rapidly crucial in the field of drug delivery, biomedical application, in nanotechnology, tissue engineering, in construction, laboratory equipment's and in many other fields. Polymers are used as film coatings to disguise the unpleasant taste of a drug, to increase drug stability and permeability. Polymers are now utilized to adjust the device components and structures of solar cells. In perovskite films, polymers are used as additive to enhance its crystallization property. Different kinds of polymers are used in different man-made technologies. Polymers also play an important role in materials and mechanical engineering due to their outstanding tribiological performance. Additives are often heard when we talk about plastics of any types. Additives are therefore one of the reasons why plastics are used for all kinds of applications in daily life and in industries. Additives are chemicals which are blended into plastics to alter their functionality and appearance. Therefore, to develop alternatives of plastics, we need to know more about additives which would be environmental-friendly. Plastics have been divided into several terms based on their particle size, mesoplastic, macroplastics, food chain they interruptliving being's ingestion pathways. Harmful impacts of plastics on humans include skin diseases, lung problems, dizziness, birth defects, reproductive defects, cardiovascular problems, genotoxic, gastrointestinal effect, respiratory diseases, vision failure and irritation in the eye, cancer, liver dysfunction and neurodegenerative diseases. Rubber particles are also considered as micro plastics though it is mentioned in few research articles. High-density plastics sink to the sediments whereas low-density plastics float on seawater. The process of degradation may change the density of plastic which leads into the change of buoyancy. Internal tissues can easily absorb small particles of plastics and can cross the blood-brain barrier and enter the brain. Inhalation, dermal contact and ingestion are three most common exposure pathways of micro plastics in aquatic organisms. An ideal additive should be efficient in their function. They should be stable under processing and service and they should be tasteless and odourless. They should be environmental friendly and cost-effective. They should not affect or alter the properties of the polymer. Biopolymers such as, cellulose, chitosan, starch and gums are present everywhere on earth. They are highly biocompatible. Liposomes are well-known bilayered vesicles produced by dispersion of polar liquids in aqueous solvents. They are as encapsulated form. They are an integral part of delivery vehicles and also aid to protect bioactive compounds from environmental stress conditions. They are used as an effective mode of delivery of pharmaceuticals and neutraceuticals and therefore, they are now used in various domains of food and biomedical sciences. Liposomes are useful in delivery of antioxidants, antimicrobials, flavors, bioactives into the blood stream and body fluids. Liposomes remain viable even when the surrounding environmental and their environmental conditions are distinct. Biopolymer-based liposomes are used as the delivery modalities. Biopolymers provide stability, durability and flexibility to liposomes during drug transport. More researches are required in case of biopolymer applications. Following sections provides a brief discussion regarding the applications of synthetic polymers as well as applications of few biodegradable polymers in different field [30-33].

Poly Styrene (PS): Polystyrenes are long chain hydrocarbon where alternative carbon centres are bound to phenyl groups. Its chemical formula is C_8H_8 .They is synthetic as well as hydrophobic polymer with high molecular weight. They are recyclable to some extent but come under the category of conventional non-biodegradable polymers. PS exists in a form of solid in room temperature. This polymer has been reported as transparent hard plastics and is commonly used as disposable cutleries, cups, plastic models, packing materials and insulation materials. PS is lighter in weight. It imparts a pristine finish. PS foams are widely used in food applications such as in food packaging. It prevents food from spoiling. Electronic goods are packed using PS as it protects from damage during shipping. Molecular mass of PS is 104.1 g/mol. Molecular density is 1.05 g/cm^3. Melting point is approximately 238°C-243°C. PS is soluble in benzene, chlorinated aliphatic hydrocarbons, chloroform. Polystyrene is the product of addition polymerisation between styrene monomers. PS is used to make house hold appliances such as blenders, air conditioners, refrigerators, oven, microwaves and hand-held vacuum cleaners. Polystyrenes are used in kitchen and bathroom accessories, garden, and utensils. It is also used make toys, housing for electronic devices such as, smoke detectors, TV, CD or DVD cases. PS is used in TV cabinets and in video cassette shells. It is also used to manufacture helmets, cameras and is cross-linked to produce extruded bun foams or sheets for footwear portions. It is used to insulate ceilings, walls and floors. PS resins are used in panels, sidings, plumbing fixture, laboratory items such as test tubes, petri plates, trays used in tissue culture assays, diagnostic test equipment's, medical cups, medical keyboards, plastic boxes. It is also used in art and craft projects, models for architectural designs, candle holders, ornaments for Christmas trees. It is also used in food containers, coffee cups, mugs, bowls and cartons [34].

Poly Urethanes (PU): Polyurethanes are the product of the exothermal reaction between a poly-isocyanate and molecules containing one or more than one alcohol groups. Polyurethanes are hydrophilic polymer. Subsequent reaction between prepolymer molecules of PU produces the solid foams and elastomers. Generally they are a high-viscosity liquid. Due to their water-soluble nature, they provide a compatible surface for the aqueous based systems that are common to biochemical research. They are classifies into flexible foams, rigid foams, integral foams, elastomers, surface coatings and adhesives. When a di-isocyanate and a diol react together they form a linear PU. The reaction between di-isocyanate and a polyol lead to a cross-linked PU. Therefore, this polymer is made up of organic units joined together by the urethane links. Most of them are thermosetting polymers. Ester-type and ether-type are the two types of polyurethanes. Many research articles have reported that PUs is impossible to degrade completely by any microorganisms. Researchers are still going on to find out efficient microorganisms or alternatives of microorganisms that can degrade it completely. Polyols are the substances containing more than one functional hydroxyl groups. They often bear ester, amide, ether, metal, acrylic, metallic and other functional groups. They are of two types which include polyether polyols and polyester polyols. PU is highly dependent over the polyols and the isocyanate for its chemical and physical properties. Polyether-based PU has excellent weather durability property. They possess excellent abrasion-resistance property. They are flexible, highly viscous, and have good thermal stability. PU possesses melting temperature of about 300-330 K and glass transition temperature of about 210 K [35].

PU has been widely used in the marine technology. PU-based epoxy used in marine coatings generally protects from corrosion, water erosion and also handles the drag flow of the boat's hull. This is used as anti-fouling, anti-aquatic life and anti-algae to protect the coating of marine boat. PU foams are used in boats and ships to control noise and damping properties. PU provides load bearing capacity even at lower temperature. This is used in marine drive belts, tubing's, wire and cable coatings, for the construction of ships and boats. The application of PU include, the production of cushions, they are used for the manufacture of rubbers. Leathers and adhesives production are also done by using PU. PUs is used in cars especially car seats are made of polyurethane foams. Each part of the vehicles is made of polyurethane. Polyurethanes are used in house constructions. They are used in medical applications as well. They are used in catheter, hospital beds, surgical drapes, wound dressings and in injection-moulded devices. They are used for the manufacture of furniture. Pus is used to remediate unwanted organic compounds, such as phenol, Nile red dye, paraben from water bodies. It has been reported that for the removal of crystal violet dyes, methylene blue, aniline blue and azo dye from laundry wastewater PU polymers have been used. PUs is also used in designing garments. They are converted into thin threads and then incorporated into nylon to make light-weight and stretchable garments. To improve washing time and UV protection of the fabrics, UV quenchers or other groups have been added to the polyurethane dispersions. Low-molecular weight chitosan used for chain extension in PU dispersion was used on plain weave poly-cotton dyed and printed fabrics to improve the stiffness, pilling resistance and its strength. Due to excellent biocompatibility, low-cost, toughness, longevity PU is used in the surgical drapes and other medical applications. PU has been used in drug delivery system for the colon as well as intra-vaginal rings. To prevent HIV-AIDS, PU as a smart vaginal peccaries and microbicides drug delivery system were also synthesized. For cardiac tissue engineering, chitosan-based and biodegradable electro active PU has been used. Use of PU instead of metals in automobile industries is just to reduce the weight of the car and increase the fuel economy. In aircrafts, due to their low-density they are used as interior panels, bumpers. Sealants made of polyurethanes provide remarkable tight seals. They are used in paints and also used as surface coatings. Kitchen sponge is also made of polyurethane foam [36].

Natural rubber and synthetic rubber: Rubber is a natural polymer and possesses elastic properties and also termed as elastomers. It is manufactured from rubber latex. This rubber latex is obtained from the bark of rubber tree and is known as colloidal dispersion of rubber in water. They are also known as cic-1,4-polyisoprene. This rubber becomes soft at high temperature of more than 335 k and brittle at low temperature of 285 k. Tensile strength of NR is about 20 Mpa. NR is chemically cis-1,4-polyisoprene. NR is a natural polymeric product of addition polymerisation of a diene monomer, isoprene (C_5H_8). It is non-polar, polymeric hydrocarbon similar to PE. It is highly elastic. Whereas, synthetic rubbers are either homopolymers of 1,3-butadiene derivatives or copolymers of 1,3-butadiene or its derivatives with another unsaturated monomer. Styrene-butadiene rubber is the example of synthetic rubber [37].

Polyvinyl Chloride (PVC): PVC is a hydrophilic synthetic polymer which is synthesized from the polyvinyl acetate hydrolysis. PVC can either be rigid or flexible. They are highly soft and flexible due to the presence of plasticizers. Use of PVC is based on its low-cost and high versatility. It is a rigid polymer. To increase applicability and flexibility, it is compounded with different additives such as, plasticizers (e.g., phthalates), dioctyl phthalate, ditridecyl phthalate, dibutyl phthalate, addipates and citrates. Stabilizers are used for melt processing and resistance to UV and other environmental factors of degradation. Its melting temperature is 100°C-267°C. It is a good insulator. It is chemically resistant to acids, salts, bases, alcohols and fats.

The rigid form is used in the construction of pipe, windows and doors. It is also used in plastic bottle production, non-food packaging, and food covering sheets. It is used in electrical cable insulation, plumbing. Since, PVC is a water-resistant polymer; it is used for weather proof cloth designing. It is used in catheters, heart-lung bypass sets, tubing, hemodialysis sets. It is used in sewer piping systems. It is used in some paint thinners. PVC films are used in computer-aided printers. It is used for manufacture of blood bags.

Poly Ethylene (PE): It is a wax-like thermoplastic and softening at about 80°C-130°C. It has low density than water. It is tough, but has moderate tensile strength. It is considered as an excellent electrical insulator. It process excellent chemical resistance feature. Its thin films are transparent but in general it is opaque. There are mainly 5 different routes for the preparation of high polymers of ethylene which include high-pressure polymerization, Ziegler-Natta processes, the Philips process, standard oil company process, and metallocene processes. Common additives used in polyethylene includes pigments, rubbers, antioxidants, blowing agents, fillers, flame retardants, slip agents, cross-linking agents, antistatic agents and carbon black. It is a non-polar material. Oxidation of PE *via* the formation of carbonyl groups can increase power factor. Antioxidants are therefore incorporated into the compounds for electrical applications to reduce the effect. PE is a crystalline hydrocarbon polymer. Non-specific interaction occurs. Melting temperature they possess is about 100°C. Low-density polymers dissolve in benzene at 600°C, while high-density polymers dissolve at 20 g/cm^3, 30°C above. Polyethylene is characterized and classified based on the degree of branching and density of the molecules. HDPE and LDPE are such type of poly ethylene. HDPE is a thermoplastic polymer which is produced from the monomer ethylene. It is also known as polythene and HDPE possess 67% crystallite. It is known for its high strength to density ratio. Melting point of HDPE is 120°C-1400°C. Density of HDPE is 0.93 g/cm^3 to 0.97 $g/cm^3$and it possesses higher tensile strength than other forms of polyethylene also resistance to chemicals. LDPE is tough and flexible polymer characterized by longer branches that do not pack well into crystallites. Although, in case of HDPE as the chains become more linear, the molecules are able to pack more closely. Density of LDP is 0.910 g/cm^3-0.925 g/cm^3. LDPEs are gas permeable. HDPE are capable to withstand pressure of 0.6 Mpa-1.0 Mpa. Polyethyleneis cheaper, easy processability, remain flexible and tough even at lower temperatures. Polyethylene is wax-like appearance, they lack rigidity, poor scratch resistance, and they are susceptible to oxidation. LDPE is widely recyclable. It is moisture resistant.

HDPE is used in the production of plastic bottles, in pipes, plastic lumber. It can be used for the production of toys and other equipment. HDPE is used in kitchen wares, cable insulation, used as a food wrapping material. LDPE are used in the production of transparent plastic bags. LDPE is used for trays, long-life bags and sacks, food bags. HDPE film is largely used for grocery, garbage, and deep-freezes bags. It is used for agricultural piping, gas piping and in ink tubes for ball point pens. They are used to manufacture drinking water pipe networks. VLDPEs (Very Low Density Polyethylenes are used in frozen food packaging due to their low-temperature impact properties. HMWPE (High Molecular Weight Polyethylenes are used for packing hazardous chemicals, ore handling, food processing, ropes and also used as a biomedical material. Biodegradable films are made by using Low-Density Polyethylene (LDPE. LDPE are used to make squeeze bottles, chemical tank linings, gas and water pipes, toys, carrier bags [38].

Poly Hydroxyl Alkanoates (PHAs): Lemoigne, a French scientist was the first person who discovered polyhydroxyalkanoate in Bacillus megaterium in the form of poly (3-hydroxybutyrate) in 1925. Polyhydroxyalkanoate is a bio-based biodegradable polyester and are generally produced in nature by bacterial fermentation of sugars and lipids. They are the polyesters of different hydroxyalkanoates. Different hydroxyalkanoates in general are synthesized by many gram-negative and gram-positive bacteria. Non-storage Poly Hydroxyl Alkanoates (PHA) of low-molecular weight have been detected in the cytoplasmic membrane and cytoplasm of *Escherichia coli*. Bacteria store PHAs within the cytoplasm where PHAs exist as granules ranging in size from 0.2 micrometer to 0.5 micrometer. In the case of PHAs, the polyester core inclusion is surrounded by either phospholipids or proteins. It is also a membrane constituent in yeasts, plants, and animals. General functions include, role in voltage-gated calcium channels, DNA transport, protector of macromolecules, to which it is bound, from degradative enzymes. More than 100 various kinds of monomer units have been reported as constituents of the storage PHA. The molecular mass of PHA is in the range of 50,000 Dalton -1,000,000 Dalton and varies with the PHA producer. The monomer units are all in D(-) configuration owing to the stereo specificity of biosynthetic enzymes. PHA are non-toxic, biodegradable, biocompatible thermoplastics that can be produced from renewable resources. They have a high degree of polymerization. They are highly crystalline and are optically active and possess stereo chemical regularity in repeating units. They are piezoelectric in nature. They are hydrophobic in nature. They have sufficiently high molecular mass. These features make PHA as best alternative of petro-chemical derived plastic like Poly Propylene (PP). Poly (3-hydroxybutyrate) is the best characterized PHA. PHA is of three types which include medium-side chain PHA, long-side chain PHA and short-side chain PHA. Formation of these types is based on the growth substrate used. The short-side chain PHAs have less than 5 carbon atoms, medium-side chain PHAs have 5 carbon atoms-14 carbon atoms and long-side chain PHAs have more than 14 carbon atoms. PHA is produced from a wide variety of substrates such as, renewable resources, fossil resources, by-products, chemicals, and carbon dioxide. Renewable resources include sucrose, starch, tri-acyl-glycerols and cellulose. Fossil resources include methane, lignite, hard coal, soft coal, mineral oil. By-products include whey, molasses and glycerol. Chemicals include propionic acid, 4-hydroxy-butyric acid. To date more than 90 genera of both type of bacteria have been detected as PHAs producers under both aerobic and anaerobic conditions.3-hydroxyvalerate and 3-hydroxybutyrate are the examples of short-side chain PHAs, while 3-hydroxydecanoate, 3-octanoate and 3-hydroxyhexanoate are the examples of medium-side chain PHAs. The medium-side chain PHAs were first observed in Pseudomonas oleovorans in the year of 1983. They have good resistance to hydrolytic attack, UV rays, sink in water. These properties facilitate anaerobic biodegradation in sediments. They are chloroform soluble. They are also soluble in other chlorinated solvents. They have shown low permeability for oxygen, CO_2, methanol, isopropyl ether, and carbon tetrachloride. Temperature of glass transition ranges from -500°C to 40°C. Melting temperature ranges from 40°C-180°C. Microorganisms use 8 different metabolic pathways for the synthesis of PHAs. Blend or composite is a homogenous mixture of two or more than two polymers to develop a hybrid material with desirable thermal, mechanical and barrier properties. Examples include PHA-polyolefin blends, PHA-PBS blends, PHA-PLA blends and PHA-PETG blends.

PHA has a broad range of applications owing to their novel characteristics. Based on their piezoelectric nature, they are used as osteon synthetic materials in the stimulation of bone growth, in bone plates, surgical sutures and in blood vessel replacements. Since they are considered as a source for the synthesis of chiral chemical compounds, they are the raw materials used for the production of paints. They can be utilized as biofuels through methyl esterification technique. PHB has been reported to be applicable to use for heart valve tissue engineering. The PHBV microspheres have been reported to support primary neurons when used in tissue engineering of neurons as scaffolds. The PHB based orthopedic bio-implants have been reported to be used in cats and for bone replacement in rabbits. PHAs have also been used as drug delivery carriers due to their biodegradability and biocompatibility properties. PHA microsphere and nano spheres are used as polymers that acts as outer shell in which drugs are incorporated and released when these polymer coatings starts to degrade. PHAs have also been tried on many animals as drug or vaccine delivery carriers such as in mice, dog, sheep, cattle, rabbit and even on humans for the gingivitis treatment. An evidence of using PHBV include, sulbactam-cefoperazone drug loaded rods of PHBV used to treat chronic and implant osteomyelitis. PHAs are used for wound dressings. They are used for repairing damaged nerves. They are used to recover damage of ureter. Development of protein chips using PHAs for specific immobilization of proteins are advancing for specific detection of hepatitis-B virus. PHAs have also been used in ultrasonic imaging. PHB is used in the formation of nano capsules from emulsification or from solvent evaporation. PHA nano fiber scaffolds and films are used for the neural stem cells growth as replacement of natural extracellular matrix as they showed better adhesion of cells and better viability of neural stem cells. They are used to repair damages of spinal cord injuries. PHB has been used for the storage of mayonnaise, margarine and cream-cheese. They have also been used for the packaging of sour cream, meat salad and organic tomatoes. Agricultural nets as we know are essential products for high crop yield, for enhancement of crop quality, to protect crops from meteorological hazards, hailstone, wind, birds and insects, shade crops from sunlight, for broadening of planting period of crops, protect low-light plants, prevent overheating of crops, to reduce chemical input and to replace the lack of natural shade. The biodegradable PHA is currently being used as agricultural nets instead of non-biodegradable and harmful polyethylene made agricultural nets. Biodegradable agricultural netting permits direct disposal of the bio-based plastic in the soil to be composted with organic substances, such as manure, crop remnant and food residue. They decompose into the soil and do not decompose over time. They do not need to be separated from plant residue and hence economically labour free and saves recycling costs. Planter bags which are used to stabilise the temperature in the soil, retain the moisture in the soil, less requirement of crop watering are being made of PHA biopolymers.They are used for the production of sacks, holders, paper coatings, pens, golf tees, razors, ladylike cleanliness items, diaper back sheets, utensils, restorative compartments, jugs, cups and materials for food bundling. Solid- phase denitrification (a process of nitrogen removal from water and wastewater using a solid substrate instead of liquid carbon sources) in which PHAs are used as solid substrate, as PHAs are considered as a microbial storage materials and thus they can be easily metabolized by different microorganisms under denitrifying and aerobic conditions. Poly (3-hydroxybutyrate) is good bacterial polyester applicable in solid-phase denitrification. PHAs does not cause any deteriorate of effluent quality by releasing organic carbon. They serve as solid matrices which are useful for the development of microbial films. Once the PHA is used up, the biofilm can be washed out. They can degrade rapidly inder denitrifying conditions [39].

Poly Capro Lactone (PCL): PCL is a polymer composed of hexanoate repeating units which are included in the class of aliphatic polyesters. PCL degrades at a slower rate than other biopolymers. They also have the ability to form biocompatible blends with other polymers. They are fossil-based biodegradable polymer that can easily be degraded by aerobic and anaerobic microorganisms. They are much expensive than other polymers but they have gained attention due to their flexibility and biodegradability properties. PCL can be star-shaped polymer, dendrimers, or hyper-branched polymers. Another main pathway by which PCL is synthesized includes polycondensation of a hydroxycarboxylic acid: 6-hydroxyhexanoic acid. Melting temperature ranges from 59°C-640°C, glass transition temperature of -600°C. Thus, at physiological temperature, PCL attains a rubbery state resulting in its high toughness, high strength, and high elasticity. They are non-toxic and tissue compatible. They contain 5 hydrophobic

CH_2 moieties in its repeating units. PCLs exhibits slower degradation rate of about 3 years-4 years. Degradation occurs through hydrolytic cleavage of ester groups. The molecular mass of PCL ranges between 30,000 Dalton to 45,000 Dalton.

To potentiate food crops, in adverse environmental conditions, beneficial interactions between rhizobacteria and crop plants are required. Thus, PCL is used as microcapsules in order to maintain the stability and activity of signal molecules in the plant-rhizobacteria interactions. PCL is suitable for controlled drug delivery due to a high permeability to maximum drugs and biocompatibility nature. They are used in drug delivery devices. They are used in dentistry, wound dressings, as well as in sutures. They are also used for making packaging materials. They are used in catheters and blood bags. Tissue engineering strategy is based on the construction of scaffolds containing pores with biodegradability and bio resorb ability of pores to be used as 3D template for supporting cell attachment and subsequent formation of tissue Thus, PCLs are excellent aliphatic polyester used in tissue engineering. PCL is fabricated in the form of micro carriers for sub dermal bioactive drug delivery. PCL also has the capability to form blends with other polymers, which can affect the degradation kinetics. The therapeutic compounds delivery can be hampered due to their hydrophobic nature. They are soluble in chloromethane solvents. PCL are used in dialysis method. Subdermal contraceptive implants utilize PCL homo polymer due to its slower degradation rate as well as its excellent biocompatibility. Recently, PCL microspheres have been used as an injectable implant system for the controlled delivery of contraceptive steroids. They are also used in hormone-replacement treatments, in designing implantable devices. They are used in the design of internal fixation devices. Many researchers have reported the use of PCL for the reduction of mandibular fractures in dogs and in monkeys. Applications of pure PCL in orthopedic field are limited in the current literature. The filling material used in root canal process, a novel PCL composite is used as a root filling and capable of releasing ionic species to enable a predictable sealing. It is used as the thermoplastic synthetic polymer-based root canal filling material. PCLs are used as promising scaffolds for neural tissue engineering [40].

Discussion

Plastic accumulation and its pollution is now a global issue. In environmental conditions the degradation rate of synthetic plastic is much slower due to which long-term exposure to sunlight and physical abrasion leads to the formation of smaller plastic fragments known as microplastics and subsequently even smaller plastic fragments (nanoplastics) formation occurs from the microplastics. Biodegradable plastic is not a solution to combat fully plastic pollution from the environment. Several researchers have reported even these biodegradable plastics are not completely degradable. Microplastics and nanoplastics can also be degraded further by microorganisms. Subsequent metabolic pathways have the potential to remediate plastic polymers and its components from the environment completely. Efficient biodegradation of plastic polymers are first require to cleave into oligomers and eventually dimers and then into monomers to transport them across the cell membrane of the microbial cell. After entering into the microbial cell, these monomers are subsequently metabolized. Degradative polymers intermediate containing carbonyl groups are metabolized inside the microbial cell with the help of beta-oxidation and TCA (Tri Carboxylic Acid) cycle. In plastic biodegradation process two kinds of enzymes plays an important role in it, one is extracellular enzymes such as depolymerases, esterases, lipases, cutinases are important for the cleavage of polymers. Hydrolytic cleavage if occurs at either side of the polymer chain terminus then it is considered as exo-attack. While, hydrolytic cleavage if occurs along the polymer chain then it is known as endo-attack. These two distinct modes of attacks form different products of deteriorated polymers. Exo-attack results in the formation of small oligomers or monomers and assimilates into the microbial cell. While, endo-attack reduces molecular weight of the polymer and requires further degradation. Presence of hydrophilic functional groups in the plastic polymers promotes microbial cell surface attachment. Roughness of the polymeric surface and hydrophilicity of the polymer facilitates stronger adherence and colonisation of microorganisms. Biofilm-forming microorganisms with high hydrophobic cell surfaces have enhanced cell surface attachment to plastic polymers. The intracellular metabolism of polymers intermediate or bio fragmented compounds has not yet been evaluated specifically. Polyethylene biodegradation to form acetate is processed via TCA cycle. Biodegradation of polyurethanes produce adipic acid and 1,4-butanediol which are utilized as source of carbon through TCA cycle. Microorganisms of all classes therefore are in the forefront of preventing accumulation of plastics and its toxic chemical components in the environment. In comparison to other groups of microorganisms, very few researches have been carried out into the potentiality of algae as biodegraders of synthetic as well as bio-based plastic polymers.

Conclusion

Maximum research studies are done on the production of green plastics by using microalgae. Few research articles have only reported that *Chlorella, Nostoc, Spirogyra* and *Spirulina* species can colonise and adheres on the surface of different polymers in aquatic as well as in terrestrial habitats, but there is not reports to show how they metabolize them. Khoironi and Anggoro, 2019 reported that *Spirulina sp.* efficiently biodegraded PET and PP but after 112 days of incubation. Another research study showed that *A. spiroides* efficiently degraded 8.18% of LDPE polymer after 30 days of incubation. In order enhance the production levels and the activities of different plastic degrading enzymes, various kinds of molecular techniques have been employed to manipulate the genes encoding for different enzymes. The substrate specificity of the enzyme has also been engineered and modified to metabolize plastic polymers. The biodegradation of plastics by microorganisms and enzymes works differently under distinct environments such as soil environments and aquatic environments and their degradation rate is highly depends on few parameters such as, polymer characteristics such as type of functional groups, crystallinity, surface area, polymeric surface texture, tacticity, melting temperature, tensile strength, thermal stability. Other parameters include pH, temperature, additives, surfactants, chemical bonds, type of organisms and enzymes. Plastic biodegradation process is a huge process as it is able to remediate plastic contamination from the environment. Moreover we need to biodegrade a plastic polymer into their smaller particles as micro plastics and nano plastics.

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