CHALLENGES AND OPPORTUNITIES OF BIOPLASTICS FOR SUSTAINABLE DEVELOPMENT

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Abstract: Most plastics that are commercially used today are petroleum based, and can take more than a century to degrade. Under combustion, plastics release cancer causing carcinogenic chemicals that are equally harmful to people and the environment. In this regard, development of "environmental friendly" materials has attracted extensive interest due to increasing environmental and health consciousness. One of the most innovative environmental friendly materials developed recently are 'Bioplastics'. They are formed from renewable biomass composed of biopolymers, starch, cellulose, and a variety of other sources such as sugarcane, wood, waste paper, vegetable oils and fats, bacteria, algae, etc. Its major advantages include lower carbon footprint, energy efficiency, and eco-safety. The global bioplastics market will be growing at a rate of 20%~25% per year. The demand for packaging is rapidly increasing among retailers and the food industry at large scale. Therefore, it is high time that biodegradable plastics (like bags, sacks, films) should be a favored choice for the applications that demand a economic way to dispose of the item after it has fulfilled its job (e.g. for food packaging, agriculture or medical products). For the sustainability within the allied field, recycling systems, production technology and standardization may be developed. Therefore, the main objective of this work is to look at aspects of biodegradable plastics from the perspective of applications, production, types, opportunities and future challenges.

***Keywords* - Bioplastics, Biodegradability, Standards, Sustainable development.**

I. INTRODUCTION

In today's modern society, environment is being depleted of its resources. Since the beginning of the industrial revolution, there has been a considerable amount of change in our global temperatures and weather patterns [1]. Our world has been tackling with many such issues but one such problem which shadows other effects is plastic pollution. Plastics have become an indispensible part of our everyday-life and so versatile in their usage, they cannot be completely avoided. However, they have become a major threat to the environment contributing to a major part of the land pollution [2]. Plastics account for 25% of the total volume of landfills. These plastics showcase slow degradation and these produced in excess are discarded here as landfills. Hence they remain in the landfills for hundreds or even thousands of years [3]. Plastics, since its advent (1907), have crippled our ecosystem and has endangered our marine life. In a long-term study in the North Atlantic, seawater sample contained the equivalent of 580,000 pieces of plastic per square kilometer [4]. Plastic incineration generates toxic emissions such as carbon dioxide and methane. These GHGs (greenhouse gases) contribute to worldwide climate change [5].

These environmental/economic problems and social concerns have triggered developing environmental friendly materials such as bioplastics [6]. These novel materials are of great importance and provides immense applications in the materials world. The biodegradable polymers significantly contribute to material recovery, landfill reduction and renewable resources utilization [7]. The development of biodegradable packaging materials from renewable natural resources has received increased attention and the use of renewable resources has been revitalized [8, 9, 10]. Biodegradability characteristic of bioplastic has been widely publicized due to which the demand for packaging is rapidly increasing at large scale among retailers and the food industry (Figure 1). Bioplastics are made from renewable resources such as corn, sugars, potatoes, etc and they are produced by a range of microorganisms [11, 12]. Plastics have been divided into four characteristics groups i.e plastics that are not biodegradable and are made from petrochemical resources, biodegradable plastics from renewable resources, biodegradable plastics from fossil resources, non-biodegradable plastics from renewable resources [13]. Processing of biobased non-biodegradable plastics and fossil based biodegradable plastics is similar to processing of conventional plastics and can be done on the same processing equipment.

Figure 1: Cutlery at the London Olympic Games made of compostable plastics (BioCycle, 2012).

Bioplastic application ranges from food packaging, catering products, electronic equipments, automotive industry, horticulture and toys to textiles and various other segments (Figure 2). Production of most bioplastics is said to result in reduced carbon dioxide emissions compared to traditional methods. But there are concerns regarding the creation of a global bioeconomy which could drive towards accelerated rate of deforestation. These manufacturing methods also have immense impact on water supply and soil erosion. Packaging films and container bioplastics are particularly interesting, since most of these products have a relative short service life and end up in landfills. Biodegradable bioplastics also find application in biomedical field like preparation of bone plates and screws, in drug delivery carriers and tissue engineering scaffolds [13, 14, 15, 16].

Figure 2: (a) Drug-eluting stents made of bioplastic as replacements for metal stents in cardiovascular and gastrointestinal applications, (b) Rods, pins or screws and implements made of degradable bioplastics, (c) Tests of post-surgical patches, scaffolds and sutures made of bioplastics, (d) External infusion delivery systems made of bioplastics. [17]

Many countries around the world have already begun integrating these materials into their technologies. The global bioplastics market will be growing about 20%~25% per year (Figure 3). Approximately 10%~15% bioplastics of the total plastics market will increase its market share to 30%~40% by 2022. Being an inchoate sector and by providing vast opportunities, more companies are entering and investing in this market. During 20th century the bioplastics production was mainly dominated by the developed countries like North America, Japan, and Western Europe etc. Production of bioplastics will definitely result in reduction in emission of CO_2 compared to traditional plastics.

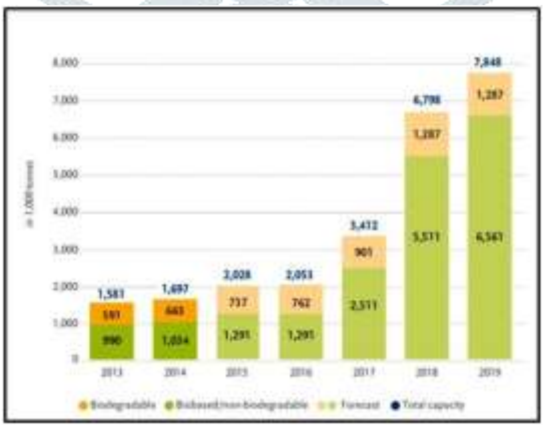

Figure 3: Global production capacity of Bioplastics (European bioplastics 2015)

Due to these advantages, bioplastic production and consumption will grow exponentially in the future. Hence these materials need to be evaluated carefully for sustainability and waste management. The primary drawback of bioplastic is its availability, high costs, recycling problems, lack of legislation etc. If all these disadvantages has been tackled, then the perfect alternative can be found within our nature in the form of bioplastics. The aim of this review is to present about performance of bioplastics, types, applications, their benefits and disadvantages, natural materials for production, opportunities and future challenges.

II. PERFORMANCE OF BIOPLASTICS

Plastics negative impact on the environment is often denounced, such as negatively impacting marine biodiversity and use of fossil fuels to produce them (plastics requires hydrocarbons). Due to these adverse effects scientific community is seeking to offer alternative solutions: “agro-based” or “bio-based” plastics made from natural materials of plant or animal origin, also referred to as bioplastics [18]. Bioplastics vary in raw material usage and their unique characteristics showcase variety of applications (Table 1). With new inventions happening in the field, the list is continually expanding. Bioplastics are mainly used in packaging industry although potential application in automotive industry and electronics sector are well established. Bioplastics also play an important role in increasing the revenue generated from renewable crop production which in turn develops bioeconomy. Therefore it can be stated that., bioplastics is going to dominate the plastics industry in coming days. Developing countries like in India use of bioplastics will create new job opportunities [19]. Bioplastics offering very good properties and new functions are winning over plastics processing industrials and purchasers. For instance, Mitsubishi developed a bio-sourced polymer, which was marketed under the name of Durabio. Its impact resistance is comparable to that of conventional polycarbonate. It has high degree of transparency and displayed excellent optical (resistance to UV yellowing) and surface properties (like hardness, scratch resistance and abrasion-resistance) that surpassed petroleum-based counterparts, and justified its price. Research aimed at removing the obstacles is advancing, and the future looks promising for green plastics processing, as it is driven by application sectors with strong potential.

Table 1: Comparision of conventional plastics and bioplastics

Conventional plastics	Bioplastics
Mainly chemicals	Generally microbes
High Green House Gas emission	Low Green House Gas emission
Non bio-degradable, harmful	Bio-degradable, harmless
Recycling and destroying process is difficult	Recycling and destroying process is less difficult
Low production cost	High production cost

III. ADVANTAGES AND DISADVANTAGES OF BIOPLASTICS

Bioplastics are used in a wide variety of fields. Some of them are:

a. Bags: Bioplastics form excellent replacements to conventional oil based materials in this sector with great performance characteristics, strength, good contact clarity and proven high speed production.

b. Wraps: Bioplastics can be converted into waterproof and fat resistant film for a wide variety of wrapping and packing eco-options.

c. Mulch film: Bioplastics can be converted into much films, which are fully opaque or semi-transparent films that provide the ideal growing environment and can be ploughed into the ground at the end of the growth cycle, resulting in rich soil nutrition for future seasons (Figure 4). Ploughing-in mulching films after use instead of collecting them from the field, cleaning off the soil and returning them for recycling, is practical and improves the economics of the operation.

d. Personal Care and Hygiene: Personal care items like toothbrushes, razors etc can be manufactured from bioplastics. Bioplastics can be blown to form opaque, soft-feel bottles for shampoos and creams. Bioplastic caps can be injection or compression moulded.

e. Electronics: A flame retardant bio-plastic (FRB) developed (Japanese multinational, NEC, 2009) can be used in electronic devices due to its high flame retardancy and processability. The new bioplastic includes <75% biomass components, and can be produced using manufacturing processes that halve the CO2 emissions of conventional processes used to make petroleum-based flame-retardant plastics (PC/ABS plastics).

f. Automobiles: Ford Motor Corp. was the first automaker in the world to use bioplastics in the auto parts manufacturing way back in the 1920s. Recently, Toyota motor corp. employed them in the cover for the spare tire in the Raum, a new model that went on sale this May. The bioplastic used here is polylactic acid (PLA) is made from plants, such as sweet potatoes and sugarcane.

Figure 4: Mulch Films made of PLA Bioplastics

Disadvantages of bioplastics include:

a. High costs: It is acclaimed that bioplastics costs two times more than conventional plastics. However, large-scale industrial bioplastics production with the implementation of cost reduction is expected in the future.

b. Recycling problems: Bioplastic material might actually contaminate the recycling process if not separated from conventional plastics.

c. Reducing raw materials: Bioplastics produced from renewable sources might reduce raw material reserves.

Therefore, based on disadvantages of bioplastics, for the sustainability, several parameters must be considered, including the raw materials from which the bioplastic is generated, the energy consumed during bioplastic conversion and its life cycle assessment analysis from production to ultimate disposal or recycle.

IV. TYPES AND APPLICATIONS OF BIOPLASTICS

Bioplastics are usually categorized into three main groups:

a. Bio-based plastics– These include the bioplastics made out of bio polyesters. Polyethylene (PE), polyethylene terephthalate (PET) and certain polyamides (PA), and polyurethanes (PUR). Biobased Polyesters are used as a feedstock for injection-molding of disposable articles like drinking cups and food containers. Some other applications include soil retention sheething, waste bags, and packaging material in general. Biopolyesters have also found many applications in the medical and pharmaceutical industry, for example, in drug delivery systems, wound closure, surgical sutures, implants, and tissue engineering [20].

b. Bio-based and biodegradable plastics– These include versions like polylactic acid (PLA), polyhydroxyalkanaoates (PHA), polybutylene succinate (PBS). PLA is often used in food handling and medical implants that biodegrade within the body over time. PHAs have excellent biocompostability and biodegradability characteristics and they are widely used for biomedical applications including drug delivery and tissue engineering scaffolds. Bioplastics with high tensile strength, including materials formulated with PHA, show great promise for orthopedic use. In the medical field, PBS could be used as biodegradable drug encapsulation systems, and is also investigated for implants [21].

c. Fossil based but biodegradable plastics- These include PCL, PBAT, etc. PCL has been used as a potential material for bone tissue engineering application where mechanical properties of polymers are very important. It is also used as a plasticizer or as a hydrophobic agent to increase the hydrophobicity of other biopolymers. PBAT serves as bulk of the film with antimicrobial agent being incorporated during processing. The antimicrobial films would be used in food packaging to inhibit bacterial growth, helping to preserve food products safely [22].

V. NATURAL MATERIALS FOR MAKING BIOPLASTICS

Production of bioplastics from waste materials was found to be more prospective especially plant based biodegradable plastic materials offer a wide scope of applications (including medical field). Biodegradable plastics, offer a large range of packaging applications including bags for compost, agricultural foils, horticultures, nursery products, contact articles like disposable containers, toys, and textiles. In this review, bioplastics produced from soybean, banana peel, potato peel, micro algae, sugarcane bagasse and agricultural waste along with their applications and challenges are discussed in detail.

a. Soybean:

Soybeans are a sustainable source of protein and oil, and soy protein and oil are not solely a food source for humans and animals, but they also have an increasing role in industrial applications including the production of soybean plastics. Soybeans, produced by sustainable farming, reduce carbon dioxide emissions. The biodegradable soybean plastics can replace petrochemical products for a "greener" solution for some applications [23] (Figure 5). The two major types of soybean-derived plastics are polyurethane products and polyester thermoset products. Soy polyols, made from soybean oil, are used to make toner, adhesives, sealants, coatings, newspaper ink, automobile panels and urethane foam, including rigid urethane foam insulation. When combined with the appropriate chemicals, soy polyols rival their petroleum counterparts in durability, strength and often cost [24]. Soybean waste consists of proteins and they can be modified by the interaction with formaldehyde, which in turn becomes a bio polymer with plastic characteristics. The applied formaldehyde forms cross links with the protein thus increasing the mechanical strength and resembles the structure of polyethylene [25]. The soybean bioplastics have application in the field of agriculture industry, dairy industry, food and packaging industry. The primary challenge in the production of soybean bioplastic is linked with the raw material, i.e soybean waste, which is unsold due to falling prices or overproduction. The production of bioplastics is not as reliable as synthetic plastics obtained from petroleum products, as they are weather dependent and consumption dependent. Due to such production, the consumption needs to decrease which results in depletion of nutritional value. Furthermore, the worlds agricultural land area has not increased for several years, but the consumption has drastically increased. Hence, the given soybean is recommended to be produced as food crop and reduce the manufacturing of bioplastics and other chemicals from food sources.

Figure 5: Bioplastic from soybean [25]

b. Banana Peel:

Banana peels are rich in fiber and starch content which results in polymeric chain structure that makes them a desirable natural polymer substance for making bioplastics (Figure 6). Banana peels show high flexibility and durability due to the presence of fibers (appr. 65-70%). These fibers aid in the elongation during heavy weight applications. Studies shows that the tensile strength of the bioplastic increases due to presence of starch content and fiber to fiber bonding [26]. Also, its biodegradation was found to be 3-4 months, after which the banana peel bioplastic degraded from the action of micro-organisms. The advantage of banana peel is the reduced time for drying and large quantities of production capacity.

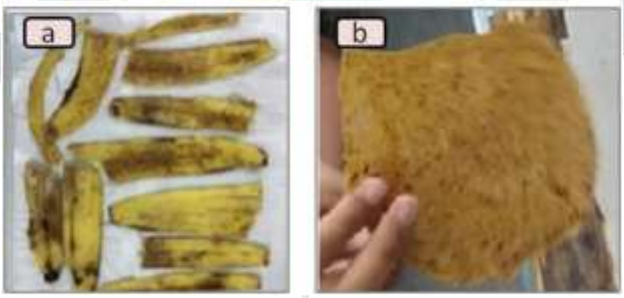

Figure 6: Bioplastic from banana peels [17]

These banana peels are often disposed as waste and there is no inhibition against its use as food source. Since the starch content of banana peel is slightly less in comparision with potatoe peels, it can act as a temporary solution in making plastic bags and tubes. Due to flexibility characteristics, these plastics can be used in various instruments which cannot resist elongation [27]. These banana peels can also be used for food packaging as it enhances food quality [28]. Utilization of banana peel as a reinforcement towards thermoplastic starch matrix to produce biodegradable plastic for planting bag application has been successfully studied [29]. The primary challenge of the production of banana peel bioplastic is that these are weather and time dependent, which indicates that the peels should be collected and processed into bioplastic before they are rotten. Also, the production cost is very high and the availability of large quantities at a single location is difficult. Currently, these challenges restrict the commercialization of manufacturing bioplastics from banana peels.

c. Potato peel:

Potatoes, a major source of nutrients for both humans and animals are most important food sources with 100-180 species and thousands of varieties existing all over the world [30]. Most waste from potato production is made up by peel and damaged potatoes. Potato peels has lot of valuable components, such as phenolic compounds and glycoalkaloids, that can be obtained and after treatment used in food and pharmacy industries. These compounds have antibacterial and antioxidant activities that gives an opportunity to use them as additives in different foods and packing materials [31]. Potatoes contain starch, which is one of the best and variously applicable polysaccharides. Starch consists of amylose and amylopectin. Amylose provides crystallinity and entanglement of starch, highlighting the importance of the amylose/amylopectin ratio during production and leading to improved strength and lowered strain. Starch-based bioplastic serve as a replacement material for existing plastics, leaving no negative effects on the environment. Plastic made from potato peel is compostable and can even be made into an edible product [32, 33] (Figure 7). The production of bioplastics from potato peels reduces the carbon emission by a significant amount, which results in the mitigation of climate change and results in a sustainable world. Even though the raw material is inexpensive, the production process is expensive and time consuming, the present technology is not feasible for commercialization. The harvesting of potatoes is a challenging process & maintaining the required intrinsic conditions like pH, moisture content is a daunting practice.

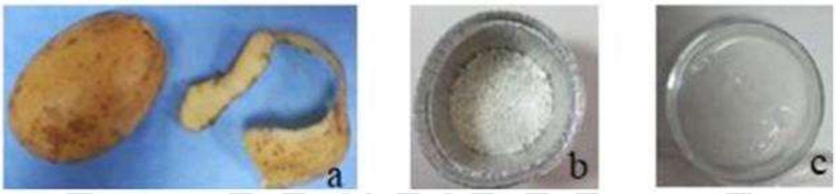

Figure 7: (a) Potato peel; (b) potato starch; (c) bioplastic [34]

d. Orange peel:

According to the researches, there are over 31 million tonnes of orange residue all over the world [26]. The peels that are wasted after juicing, which account for 50 percent of the orange, are usually eliminated by burning, which produces carbon dioxide and other greenhouse gases, or dumping into landfills, where the oil from rotting peels percolates into the soil, harming the plant. Also the percentage of non-biodegradable waste and biodegradable waste increases day by day which may cause soil pollution. Hence a DIY bio plastic using natural materials like orange peels has gained momentum (Figure 8). Orange based plastics are preferred due the presence of a key chemical 'limonene', when extracted and combined with carbondioxide results in bioplastic.

Figure 8: Bioplastic from orange peels [26]

The techniques employed for the breakdown of orange peel requires high power micro waves. Orange peel contains cellulose which has high degree of polymerization. This high chain length relates to high tensile strength. Compared to starch, cellulose is more crystalline, and can take higher temperatures before becoming amorphous in water. These characteristics gives orange peel based bioplastic excellent tensile strength & high temperature resistant [35]. These features enables it have wider industrial applications as material for coatings because of its ability to withstand heat & transparency. It is also utilized as plastic implants. Such plastics may replace conventional plastic bags, bottles, cartons which can dramatically reduce the carbon foot print [36].

e. Micro algae bioplastics:

Micro algae are thick greenish biomass which grow in water resources and can achieve high lipid accumulation. They are perfect alternative for synthetic plastic as they do not act as food source. The micro algae can be used for mass production due to their wide availability and they uptake greenhouse gases while they grow. Approaches for micro algae biomass production includes: (1) blending of microalgal biomass, bio-based polymers and additives, (2) intercellular cultivation of PHB's and starch within microalgal structures [37]. During manufacturing of micro algae bioplastic, a non biodegradable polymer is encapsulated with the structures, which collects the carbon dioxide and will not emit back to the atmosphere. Micro algae consists of high protein and carbohydrate content which makes their structure promising for manufacturing processes. For the production of such algae, harvesting and processing are very crucial. The selection of suitable method is of primary importance as the harvesting process takes 20-30% of the economic cost [38]. These harvesting methods include separation, flocculation, sieving, centrifugation, filtration, flotation and sedimentation [39]. The harvest using centrifuge and separator showcase high efficiency. These harvesting processes increases the uniformity in the liquid medium, which results in an efficient product.

One of the primary advantage of microalgal biomass is its adhesion to any surface. Such algae has the ability to colonize on the surface of polythene present in any water surface and will begin degradation of the synthetic plastic by the production of ligninolytic and exopolysaccharide enzymes [40]. Also, micro algae can be genetically modified to a cell factory which produces and secretes plastic degrading enzymes. Even though, micro algae consists of large prospects, its commercialization and production has many challenges. Initially, the selection of the required biomass based on their intrinsic properties is essential. These selection criteria are also based on biodegradability, feed stock availability, brittleness, consumer acceptability, polymer size and moisture content. Also, during the degradation of microalgal biomass release of harmful greenhouse gases such as carbon dioxide and methane has raised concerns as they can aggravate climate change. Another challenge is the process of harvesting of algae which depends on various factors such as type of harvesting, productivity achieved, cost of harvesting. For such harvesting process greater land area is required, which also poses as a challenge [41]. Some of the applications of microalgal plastics are in the use of cosmetics, food packaging, pharmaceutical industries. These plastics and biomass are also used in conversion into carbon dioxide, water and other biomass products. The obtained carbon dioxide can be pumped underground or can be used as a raw material for other chemical processes [42].

f. Bagasse

Bagasse has emerged as an important ingredient to substitute for petroleum in the production of plastic. These so-called “bioplastics” have the same physical and chemical properties as regular plastic (the most common type is known technically as PET) and maintain full recycling capabilities. From bagasse a polymer is created that’s bio-based rather than oil-based [43]. These sugar cane polymers are a renewable resource and don’t deplete fossil fuels, unlike their oil-based counterparts, which again is of enormous environmental benefit. Each metric ton of bio - polyethylene produced avoids the emission of 2 to 2.5 metric tons of carbon dioxide on a lifecycle basis. Thus lowering the carbon footprint. The key technology in the production process is the binder, a polymer substance that can force the bagasse pulp particles to join together so when it comes to use with food, the product can be heat resistant and waterproof. The pulp is shaped at 180ºC, then passed through a UV-light sterilization process to make sure the food packaging is free from contamination. Bagasse based polythene has a number of uses. It can be used to create bags, covers, tubes, films, wraps and stretch film, which means there are a wide variety of functions to which it can be applied [44].

VI. CHALLENGES AND OPPURTUNITIES OF BIOPLASTICS

Even though biodegradable plastics are considered to be good for the environment, they can harm the nature in certain ways. Emission of greenhouse gases like methane and carbon dioxide, while they are degrading, is very large at landfill sites. This can be handled by designing plastics so that they degrade slowly or by collecting the methane released and use it elsewhere as fuel.

Starch based bioplastics are produced generally from plants like corn, potatoes and so on. This puts massive pressure on the agricultural crops as they have to cater the need of ever growing population. To make plastics, crops have to be grown and this could lead to deforestation. The concept of materials coming from nature with environmental advantages is very attractive to the industry and to the consumers. Bioplastics already play a crucial role in the field of packaging industry, agriculture sector, gastronomy, consumer electronics and automotive industry, but they have a low share of market in the total production of plastics (currently about 1% of the about 300 million tons of plastic produced annually). Biodegradable plastics are often perceived as the possible solution for the waste problem, but biodegradability is just an additional feature of the material to be exploited. They should be used as a favoured choice for the applications that demand a cheap way to dispose of the item after it has fulfilled its job (e.g. for food packaging, agriculture or medical products).

VII. CONCLUSIONS

This paper focuses on the value of biodegradable plastics because of the adverse effects of petroleum-based plastic materialism on the environment. Extensive usage of fossil fuels for the production of synthetic plastics and its disposal is proving to be a hazardous process and extensive research is being conducted to transform the plastic industry and mitigate marine pollution. Mineral oil prices will get increase substantially in the next century, imposing the world to consider alternatives for petrochemical plastics. Thus renewable nature and biodegradability makes bioplastics appropriate resource to substitute synthetic plastics in many applications. Bioplastics can efficiently replace traditional plastics in terms of strength and robustness. They are biodegradable, environmentally friendly, and have low carbon emissions. A bioplastic composite can incorporate petro-based plastic to get the desired value of mechanical properties. Potential applications of bioplastics are promoting in different industries and the field of, medicine. The only disadvantage is the emission of methane during disintegration. But this can be efficiently used as a feed for various chemical processes. The environmental impact assessment shows that the life cycle of a bioplastic will have lesser negative impacts. Therefore, the future of bioplastics depends on the efforts towards fulfilling price as well as performance requirement. It is anticipated that the ongoing marketing activities in several countries will soon make bioplastics available for multiple applications in different areas.

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