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# A REVIEW OF BIODEGRADABLE PLASTICS IN NIGERIA

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## ABSTRACT

*Synthetic polymer materials since their inception have seen vast functionality in every discipline of human endeavor indicating their importance and significance in our diurnal life. These man-made macromolecular materials are petroleum-based and most conventional ones are considered to be non-biodegradable or non-degradable, and some pose arduous to salvage or recycle considering that they are materials of intricate composition having varying levels of contamination – by biological substances and food. Petroleum resources are limited, and severe environmental effects have come into being due to the ever-growing use of non-biodegradable polymers which is a serious source of pollution affecting both fauna and flora. Furthermore, these conventional polymers, non-biodegradable polymers typically made for the long haul persist many years after disposal thus making them unsuitable for temporary use. This review focuses on biodegradable polymer alternatives as a suitable replacement for petroleum based plastics.*

**Keywords:** Synthetic Polymer, Environmental effects and Plastic in Nigeria

**Cite this Article:** Abioye, O. P, Abioye, A. A, Afolalu, S. A, Akinlabi, S. A and Ongbali, S. O, A Review of Biodegradable Plastics in Nigeria, International Journal of Mechanical Engineering and Technology, 9(10), 2018, pp. 1172–1185.

<http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=10>

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## 1. INTRODUCTION

Polymers are macromolecular substances composed of a multitude of recurring units called mers. Several organic (i.e. naturally occurring) substances like rubber and a range of substances composed primarily on glucose, viz. the polysaccharides cellulose and starch (in plants) and glycogen (in animals) are polymers. Nucleic acids, proteins, and inorganic macromolecular substances, like silicates, are also some examples. Carbon usually forms the backbone of the chain linking with other elements such as hydrogen, nitrogen, oxygen, sulphur, and chlorine.

Plastics are typically organic polymers of high molecular mass. Most commonly derived from petrochemicals thus making them synthetic, conversely a range of variants are made from renewable stock such as Polylactic acid from corn or Cellulosics from cotton linters. Plastics more accurately referred to as polymers – in engineering – are materials comprising of an extensive range of organic compounds which can be either synthetic or semi-synthetic and are pliable and easily shaped into various solid forms. Synthetic polymers are produced by chemical reactions known as polymerization in which individual molecules (monomers) join to form larger units – the polymer chains found in nature are much shorter than these synthetic ones. It is the length of these chains and their unique structures that makes polymers strong, lightweight, and flexible. Simply put, it's what renders them so plastic. People have been utilizing naturally derived plastics for far longer than one might envision. For instance, medieval artisans made lantern windows from translucent slices of animal horn, which is composed of keratin – a blended carbon-nitrogen polymer – a similar stuff that skin and hair, as well as fleece, is made of.

By making use of various natural or synthetic materials, catalysts and polymerization methods, various types of plastics have been produced and added to the vast catalogue of plastics available for industrial use since the onset of the 21st Century. And, this variety of plastics have found application in a multitude of industries, their usefulness and significance have become of such great importance that it is almost impossible to envision modern life without them.

Nearly all contemporary plastics are petroleum-based; manufactured via chemical extraction and synthesis giving rise to materials that are low cost, easily manufactured, versatile, impervious to water, and some possess the added capability of being resistant to corrosive chemicals. Plastic is amazing because of its durability and is likewise dreadful because of said durability. Almost every piece of man-made synthetic plastic ever produced is largely non-biodegradable and tend to remain in the natural environment in one form or the other (Gertz, 2016).

## **2. THE PROBLEM OF PLASTICS**

Over the past decade, man has manufactured more plastic than we did in the century before that. Plastics production worldwide increased from 322 million tonnes in 2015 to 335 million tonnes in 2016 alone (Plastics Europe, 2017). Half of all plastics produced are considered as disposable due to being single-use plastic products and packaging materials. But think about it, how can a one-use item be made of a material that been specifically engineered to be “indestructible”, where does it go?

After their service life is exhausted and the plastic product becomes waste, most of these plastic wastes are not dropped off in garbage cans for consequent removal to incinerators, recycling centres, or landfills. Rather, they are indiscriminately discarded in proximity to where their useful life ends abruptly. Discarded on the ground, tossed out of a moving vehicle, piled up on a gorged garbage bin, or stolen away by a current of wind, they immediately become an aesthetic problem and pollute the local ecosystem. Increasing accumulation of these plastics in the environment has become a worldwide problem and severe threat to the planet.

Almost 10 percent by weight of municipal garbage content are plastics (D'Alessandro, 2014). In contrast to materials that have seen widespread use since the onset of the 20th century, like aluminium, glass, and paper, plastics iron, plastics have a low retrieval rate. Thus, making it problematic to reuse or recycle considering that they are complex composites having varying levels of contamination – by food and other biological substances. Recycling rates, however, vary considerably across nations. With European Countries achieving rates of

50 percent or higher, by 2016 for the first time, less plastic waste was dumped in landfills than was recycled (Plastics Europe, 2017). Plastic pollution comes from improper disposal of plastic materials, hence, recycling which deals with “properly” dispensed waste does not really tackle plastic pollution in actual sense.

The plastics that are not recycled or incinerated for electricity generation end up accumulating and sitting in landfills for hundreds even thousands of years without decomposing. Synthetic plastics do not degrade, and most of the time we say it breaks down, but that is not an accurate way to depict the process either. Plastics break up, that is, it is proliferated in a multitude of tinier bits such that pieces from a one-litre bottle could end up on every mile of beach throughout the world. These plastics in landfills and the environment; discharge toxic pollutants which contaminate groundwater and the soil; cause changes in the carbon dioxide (CO<sub>2</sub>) cycle; some plastics like Styrofoam (foamed polystyrene) bring about a release of neurotoxins at high doses when temperatures hike. Plastics bags, bottles, films, and other items also clog drainage systems causing flooding. Terrestrial wildlife might also ingest this plastic matter leading to intestinal blockage and inherently death. And as waste dumps enlarge due to accumulation taking up useful space in municipal areas, piles of residual plastics form a foundation for the domiciles of the scavenging poor.

In the sea, plastics are as dreadful as they are on land. The ocean receives a great deal of the plastic waste generated on land. In excess of 80 percent of ocean plastic is leaked from land-based sources, plastic garbage generated by in-landers irrespective of proximity to the sea still finds its way to the sea (D’Alessandro, 2014). Nearly 8 million tonnes of plastic leaks into oceans every year from coastal cities, through channels, and then down large rivers. More than 50 percent of marine debris including plastic sink to ocean’s sediment (70% of all ocean plastic sinks) (Leeson, 2016). The oceans are driven by five major circular currents or gyres which represent forty percent (40%) of the world’s oceans, and floating plastic waste has been shown to accrue and converge within these gyres. Scientists estimate that there are more than 5 trillion pieces of plastic afloat in our oceans worldwide. These create a kind of plastic smog (D’Alessandro, 2014). These tiny pieces of plastic that are floating on the surface of the ocean come from larger pieces. Over time, the sun’s ultraviolet light, ocean wave action, and salt break it up into smaller pieces called “microplastics” – These microplastics have rough, pitted surfaces. Plastics have been revealed to concentrate waterborne chemicals from industry and agriculture in exponential levels than in surrounding seawater, making them toxic poison pills to the species that ingest them. In the Western Mediterranean, recent findings show a 1-to-2 ratio of plastic to plankton – and these plastics are being eaten by marine life. Plastic pollution in oceans cause harm and even kill marine mammals through entanglement, these aquatic life also die from indigestion upon ingesting these plastics. Studies have shown that all species of sea life regardless of size are safe from the hazard that plastic debris in their habitat pose. Humans are not left out of the oceanic havoc because marine life ingesting these harmful toxic plastics affects the food chain thereby causing reproductive problems, hormonal problems, kidney damage, nervous system damage, and cancer in humans (Plastic Oceans Foundation, 2016).

Presently, most plastics are obtained from fossil feedstocks such as natural gas, oil or coal. Around eight percent of the world’s oil and gas production is used in the production of plastic (Brown, 2018). Petroleum resources are insufficient as they are continually being depleted, this poses an additional problem for petroleum-based plastics. Yearly, 35 billion barrels of oil are used worldwide (Biello, To, LaRosa, & Anderson, 2017). This massive scale of fossil fuel dependence would not last forever and it causes pollution on a massive scale. Scientists estimate that 40 percent of the world’s oil reservoirs have already been consumed, and at

current consumption rates, all known sources of petroleum on the planet would be exhausted before the end of the 21st century.

As the demand for plastic products continues to climb, the compulsion to discovering more ecologically safe alternatives to orthodox petroleum-based plastics also intensifies. The search for more environmentally friendly alternatives has prompted scientists to develop bio-based or biodegradable polymers which are capable of degradation in certain controlled environments (Fialho e Moraes et al., 2017; Lu, Xiao, & Xu, 2009; Makhtar et al., 2013). The development of biodegradable plastics is an effort towards achieving the Sustainable Development Goals (SDGs) – Goal 11 (Sustainable cities and communities), Goal 12 (Responsible consumption and production), Goal 13 (Climate action), Goal 14 (Life below water), and Goal 15 (Life on land) – as set by the United Nations Development Programme (UNDP) (UNDP, 2016).

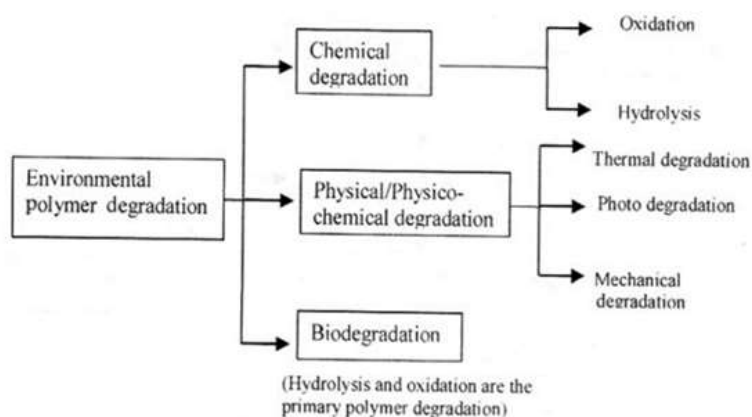
### 3. BIO-PLASTICS

There are various misconceptions of the term “Bio-plastic.” Bio-plastic, however, comprise bio-based plastics or biodegradable plastics.

- Bio-based bioplastic has some or all its content or carbon produced from a renewable source (animals, plants, or micro-organisms).
- Biodegradable plastics degrade into methane (CH<sub>4</sub>), carbon dioxide (CO<sub>2</sub>), water (H<sub>2</sub>O), and biomass in a defined timescale and in defined environments – soil and marine environments, anaerobic digestion, and composting – through biological action.

A common misunderstanding exists between “bio-based” and “biodegradable” polymers as they are inappropriately always linked, there is a fine distinction as they are not, given that a biodegradable bioplastic may not be bio-based [e.g. polybutylene adipate-co-terephthalate and polycaprolactone] and a bioplastic that is bio-based may not essentially be biodegradable [e.g. polyethylene-terephthalate and biopolyethylene] (Babu, O’Connor, & Seeram, 2013; Mashek, Krieger, & Martin, 2016; Tokiwa, Calabia, Ugwu, & Aiba, 2009).

Biodegradation takes place in two steps. Initial step is the disintegration (n.b. disintegration is a physical process, while biodegradation is a chemical process. But, both must occur together for complete decomposition to occur) of the polymers under suitable conditions into lower-molecular weight varieties by means of either biotic reactions, i.e. photodegradation, hydrolysis or oxidation. Closely followed by mineralization of the polymer remains by microbes i.e. degradations by microbes or abiotic reactions.



**Figure 1** Mechanisms of polymer degradation (Vasile as cited in Arutchelvi et al., 2008)

### 3.1. Characterizing Biodegradability of Polymers

During examination of the biodegradability of a material, results cannot depend solely on chemical analysis of the polymer. The effects of the environment also should be considered. For simplification, biodegradation environments can be separated into environments where; oxygen is absent (anaerobic), and oxygen is present (aerobic). These are then further subdivided into terrestrial and aquatic environments. Microbial action and hence biodegradability is affected by the:

- Oxygen uptake rate
- Thermal conditions
- Availability of water
- Chemical environment
- Predominance of microorganisms

Several analytical approaches have been established to measure the extent and nature of biodegradation. These characterisation systems are intended to study the physical, chemical, and mechanical properties of the polymer before and after degradation, which will aid in understanding the degree in addition to the mechanism of degradation. Since the characteristic exposure setting involves incubation of a polymer substrate with enzymes or microbes. Measurements are hence limited as regards the reactive products, to the microorganisms, or to the substrates.

Universal approaches existing for the study of biodegradation processes include:

- Monitoring reaction products
- Monitoring the depletion of substrates
- Monitoring microbial growth
- Monitoring changes in substrate properties

### 3.2. Factors Affecting Biodegradability

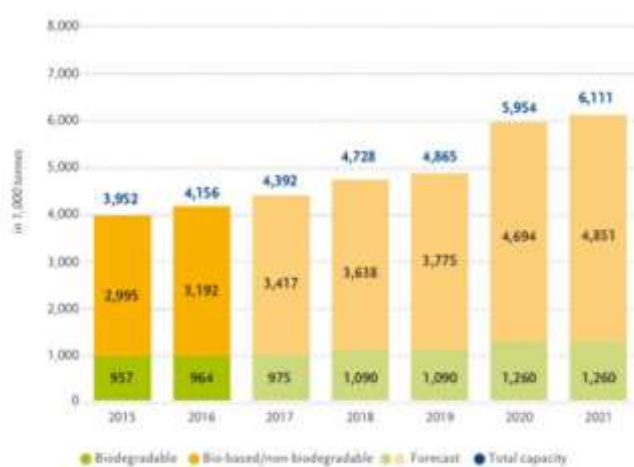
Some factors affecting biodegradability including physical and chemical characteristics are listed below, however some research has shown many variants from this norm. Platt (2006), Tokiwa et al. (2009), and Arutchelvi et al. (2008) gave these factors as:

- The surface presented for attack and physical state of the plastic
- Crystallinity and amount of amorphous regions
- Hydrophilic nature of the polymer
- Pendant groups, their chemical action and their position
- Chemical linkages in the polymer backbone
- Density, molecular weight, and size of the polymer
- Melting temperature
- Chemical activity of end-groups
- Stereo-chemistry of the monomer units along the polymer chain
- Interaction with other polymer blends
- Glass transition temperature

### 3.3. Production of Bio-Plastics

Biodegradable plastics expand the scope of waste handling options over conventional fossil-fuel polymers, which are supported by Life Cycle Assessment. Municipal and domestic composting are the most favoured end-of-life disposal options for these materials as opposed to the landfill which is the least favourable. Therefore, biodegradable polymers can make substantial impact towards utilization of renewable resources, reduction of landfill, and material recovery (Mostafa, Farag, Abo-dief, & Tayeb, 2015).

At present, bioplastics equate to about one percent (1%) of approximately 300 million metric tons of plastic manufactured annually. Although as customer base is expanding and with more products emerging, applications, and high-tech materials the market is already burgeoning at a rate of 20 to 100 percent annually. European Bioplastics (2016) in line with their recent market data, forecasts that the volume of bioplastics produced worldwide will grow by 50% in the medium term, from approximately 4.2 million tonnes in 2016 to about 6.1 million tonnes in 2021.



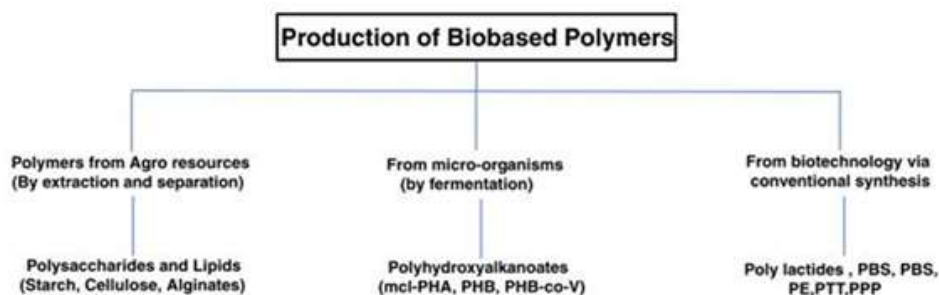
**Figure 2** Volume of bioplastics produced worldwide (European Bioplastics (2016) [www.european-bioplastics.org/market](http://www.european-bioplastics.org/market))

The fascination with bio-based polymers has accelerated globally in recent times due to the need and desire to discover and harness non-fossil-fuel-based polymers. Bio-based polymers proffer vital contributions by diminishing the reliance on petroleum and through the interrelated positive ecological impacts such as lessened carbon dioxide emissions. The premier generation of bio-based polymers utilized agricultural feedstocks for their production. Bio-based polymers which bear similarity with traditional polymers are formed by means of bacterial fermentation which synthesize the monomers from renewable resources including lignocellulosic – a strengthening substance composed of lignin and cellulose, found in woody tissues of plants (starch and cellulose), organic waste, and fatty acids. Another class of bio-based polymers which occur naturally exists with examples such as: nucleic acids, proteins, and polysaccharides.

Babu et al. (2013) states, there are three fundamental ways of producing bio-based polymers using renewable resources:

- Utilizing natural bio-based polymers with partial modification to meet the requirements
- Producing bio-based monomers through conventional chemistry or fermentation followed by polymerization (e.g. polybutylene succinate, polylactic acid, and polyethylene)

- Producing bio-based polymers via bacterial action (microorganisms) or in genetically modified crops (e.g. polyhydroxyalkanoates).



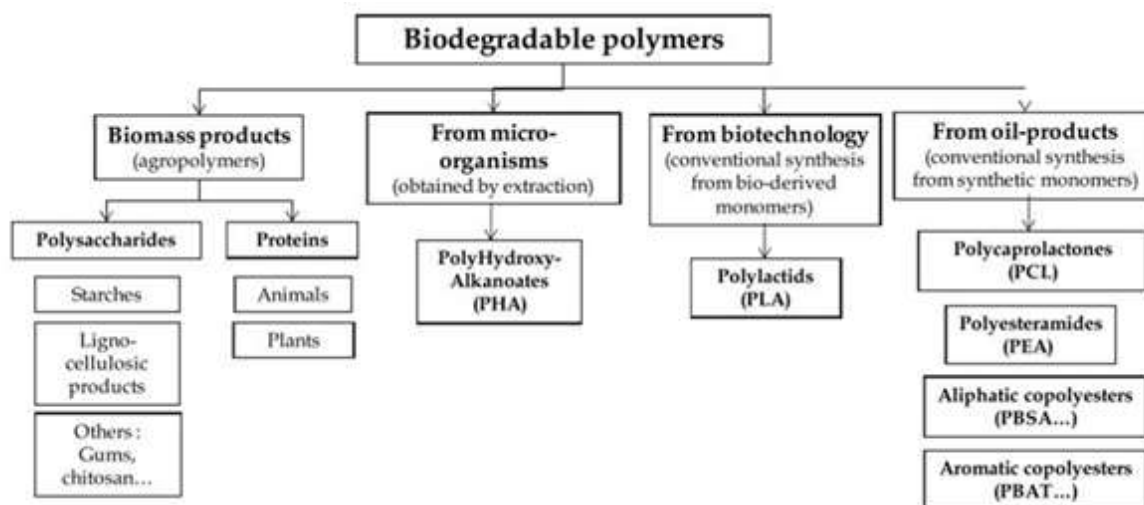
**Figure 3** Categories of bio-based polymers produced by various processes (Luc and Eric (2012) as cited in Babu et al., 2013)

Guilbert (2000) in Vilpoux & Averous (2002) however defined three kinds of biodegradable materials:

- Agricultural polymers blended with biodegradable synthetic polymers or used in its lonesome.
- Microbial polymers, formed by the fermentation of agricultural products which acts as the substrate. Within this class exists polyhydroxyalkanoates (PHA) – its most common derivative being polyhydroxybutyrate covalerate (PHBV) (Averous, 2002)
- Oligomers or monomers obtained from the fermentation of agricultural raw materials (substrate) and polymerized via common established chemical processes. Poly(lactic acid) (PLA) being the most recognised material within this class.

Averous (2002) included a fourth class to the above-mentioned definitions by Guilbert (2000):

- Derivatives from fossil-fuel produced by means of synthesis. Polycaprolactone (PCL); polyester amide (PEA); aliphatic co-polyester or polybutylene succinate adipate (PBSA); aromatic co-polyester, such as the polybutylene adipate-co-terephthalate (PBAT).



**Figure 4** Classification of biodegradable polymers (Averous (2004) as cited in Anne, 2011)

This review concentrates on the advances, technical and social challenges, and ecological advantages of biodegradable plastics. It goes ahead describe the highly favourable biodegradable polymers which are either being developed or as of now promoted.

### 3.3.1. Biodegradable Plastics from Starch and Cellulose

Starch is a low-cost, annually replenished material which occurs widely as an energy store in the form of carbohydrate in most plants, particularly in the seeds, roots, fruits, shoots, and leaves. The decomposition of starchy crops reuses environmental CO<sub>2</sub> caught by starch-creating plants. Starches obtained from various sources contain amylopectin and amylose, at proportions which differ with source. This disparity gives a characteristic instrument to varying starch material properties.

Starch is one of the most utilized and researched biodegradable substance for bio-plastic production. Starch begins to show plastic properties when mixed with plasticizer. In attempts to improve the properties of starch-based polymeric materials with minimal effects on degradation, starch is usually copolymerized and mixed, with cellulose fibres, chitosan, lipids, and cereal proteins.

Novamont under the Mater-Bi trademark has successfully created Starch-based biodegradable polymers by mixing or blending them with artificial polymers. By changing the artificial blend part and its miscibility with starch, the compositional structure and consequently the properties can be managed effectively and productively. Blends comprising thermoplastic starch (TPS) might be grafted or blended with decomposable poly-esters [such as polycaprolactone (PCL)] to increase moisture resistance and plasticity. Blends containing more than eighty-five percent (85%) starch are utilized in injection moulding and foaming. The foams which possess a typical density of 6 to 8 kg/m<sup>3</sup> (Gross & Kalra, 2002, p. 803) are consequently utilized as loose-fill in preference to conventional polystyrene. These starch-based loose fill materials are usually hydrophilic. However, upon mixing TPS with cellulose derivatives, dimensionally stable and firm injection-moulded articles result (Fialho e Moraes et al., 2017, pp. 932–933). It is worth noting that plastic-grade cellulose acetates which were believed to be non-biodegradable in the mid-1990s have proven to be biodegradable in simulated compost environments. This, however, applies to cellulose acetates possessing degrees of substitution from 2.5 to 1.7. Fully biodegradable cellulose acetates which are commercially feasible were manufactured by Fialho e Moraes et al. (2017) using flat die extrusion-calendering process. This can be applied in biomedicine, agriculture, or short-term packaging.

It should be noted that thermoplastic starch is not an authentic thermoplastic, but, in the presence of a high temperatures (90 – 180°C), plasticizer (water, glycerine, acetyl tributyl citrate, etc.), and shearing, it dissolves and fluidizes, making possible its utilization in blowing, extrusion, and injection equipment, like those for synthetic plastics. To obtain a thermoplastic starch, it is a prerequisite that the starch behaves in a way similar to that of a melted thermoplastic and maintain its semi-crystal granular structure (Vilpoux & Averous, 2002).

**Table 1** Amylose and Amylopectin (%) content in starch obtained from different sources (Carvalho (2013) as cited in Eva, 2015)

Starch	Amylose (%)	Amylopectin (%)
Wheat	30	70
Corn	28	72
Potato	20	80
Cassava	16	84



### 3.3.2. *Biodegradable Plastics from Polyesters*

Poly( $\epsilon$ -caprolactone) was found to be completely degradable when disposed in bioactive environments such as soil (Tokiwa et al., 2009). This and associated polyesters are hydrophobic and may be melt-extruded into sheets, bottles, and a variety of discrete shaped articles, thus making this class of plastics principal targets for use as biodegradable plastics.

Polyhydroxyalkanoates are biodegradable polyesters that can be created directly from renewable resources by both synthetic and bacterial courses. The most widely recognized polymer is poly(3-hydroxybutyrate) (PHB), a semi-crystalline isotactic polymer that experiences surface disintegration because of its crystallinity and the hydrophobicity of the backbone. PHB has a glass change temperature of about 5 °C and a dissolving temperature range of 160 – 180 °C. The hydrolytic debasement of PHB brings about the arrangement of D(-)- 3-hydroxybutyric acid, a typical constituent of blood. The degradability, processibility, and biocompatibility of PHB make it an incredible contender for deployment in long-haul tissue designing applications. Tragically, the stability of PHB makes it a poor contender for controlled delivery applications. The biodegradability and physical properties of PHAs can be regulated by blending with natural or synthetic polymers. Zeneca PHBV Biopol<sup>®</sup> a copolymerization of PHB with 3-hydroxyvalerate has received great attention and has also been utilized in tissue engineering of tendon, bone, nerves, cartilage, and skin. However, although the addition of HV content enhances the biomaterial capability of PHB, the degradation rate remains drastically low for other biomedical applications. (Lenz, 2017; Ulery et al., 2011).

Poly(lactic acid) (PLA); Carothers in 1932 pioneered the production of polyester from lactic acid which was consequently further developed by Dupont and Ethicon (Gross & Kalra, 2002). Until recently, restrictive costs of production confined the suitability of these polymers other than in the medical field. From that point forward, significant leaps forward in process technology, combined with diminished expenses of organically created lactic acid, have prompted the industrial-scale generation of bio-plastics from lactic acid for nonmedical applications. This incorporation of chemistry and biotechnology is an essential system that will be essential to enhancements in numerous other synthetic processes in the future. PLA transparency, crystallization rate, crystallinity, and degradation rate of products are regulated by the copolymerization of chosen L-to D-isomer proportions of lactic acid or lactide.

Cargill Dow LLC utilizes a solvent-free continuous process and a novel distillation method to convert lactic acid to high molecular weight PLA which has been used to form fibres for clothing. Conversely, Mitsui Toatsu uses a solvent-based process with azeotropic removal of water by distillation (Gross & Kalra, 2002). Upon discarding, PLA essentially decomposes by hydrolysis, not microbial assault. Thus, with high levels of atmospheric moisture, it is exceptional to experience microbes contaminating high molecular weight PLA. This unordinary characteristic for a bio-plastic is appealing for applications in which they are in coordinate contact with sustenances for prolonged periods. PLA can be changed into compost in municipal compost facilities.

Poly( $\epsilon$ -caprolactone) (PCL) and poly(alkene succinate)s; PCL is a thermoplastic biodegradable polyester produced by ring-opening polymerization preceded by chemical conversion of crude oil. PCL has good solvent, oil, water, and chlorine resistance, low viscosity, and a low melting point, and is easily processed thermally. PCL may be blended with starch to scale-down manufacturing costs. By blending PCL with fibre-forming polymers (such as cellulose), bandage holders, incontinence products, scrub-suits, and hydroentangled nonwovens (in which bonding of a fibre web into a sheet is realized by interweaving the fibres by water jets) have been produced.

A series of biodegradable aliphatic polyesters have been developed on the basis of traditional polycondensation reactions as compared to PLA, PCL, from lactide, and PHAs. Most renowned are the array of poly(alkene succinate)s trademarked Bionolle produced by Showa Denko. Certainly, their development is the brain-child of lessons learned in working with PCL. The aforementioned polyesters possess properties that mimic those of traditional plastics such as low-density poly(ethylene) (LDPE). Their biodegradation mechanisms and physical properties are dependent on the choice and composition of the diacid/diol building blocks (Gross & Kalra, 2002). Currently, Bionolle is employed in the manufacture of bottles, fibres, cutlery, and films. Bionolle plastics have been found to decompose in activated sludge, moist soil, seawater, fresh water, and compost.

#### *3.3.2.1. Increasing the strength of biodegradable polyesters*

Aliphatic polymers may be strengthened by substituting a fraction of the ester links with amide groups, which increase interchain hydrogen bonding and, therefore, material strength. Bayer innovated BAK 2195 – an injection-mouldable grade of poly(ester amide), built from butanediol, diethylene glycol, adipic acid, and hexamethylene diamine. Of recent, the company stopped producing and selling this product. Polyester bio-plastics can also be strengthened by replacing some aliphatic diacid building blocks with more rigid/solid aromatic diacids. BASF and Eastman Chemical Company have developed such aliphatic/aromatic resins that retain their biodegradability (Gross & Kalra, 2002, pp. 805-806).

### **3.4. Review of Past Research**

Brandelero, Grossmann, & Yamashita (2011) studied the impact of blend production method on the structural and mechanical properties of biodegradable starch films manufactured through blown extrusion. Two discrete methods were used to produce the blends, D1 and D2. Method D1 involved mixing starch granules with glycerol in various proportions and consequent extruding to generate thermoplastic starch (TPS) pellets. Then these pellets were extruded alongside PBAT pellets and films were produced via blown extrusion. In method D2, glycerol, granular starch, and PBAT were mixed, and pellets extruded. Production process for films was the same as method D1 but with reduced processing cost.

Results revealed that production method of biodegradable films influenced the micro-structural impediment to water vapour, and the structural and mechanical properties of blends produced by blown extrusion. Films produced via method D1 possessed better mechanical properties when PBAT concentration was equal to fifty percent (50%). Blends can be produced utilizing method D2 (granular starch) – with increased concentration of starch (>50%), with only one extrusion phase without the loss of mechanical properties, resulting in lower production cost.

Cho, Moon, Kim, Nam, & Kim (2011) investigated the biodegradation speed and biodegradability of poly(butylene succinate) (PBS) and poly(caprolactone) (PCA)/starch (consisting of 30% starch, aliphatic polyesters, and 55% PCL) under conditions without oxygen (anaerobic) and with oxygen (aerobic). After 80 days, biodegradability of PBS was merely 31% under aerobic conditions, and showed a  $0.01 \text{ day}^{-1}$  biodegradation rate, meanwhile PCL/starch effortlessly degraded, showing a biodegradation rate of  $0.07 \text{ day}^{-1}$  having 88% biodegradability after 44 days under same conditions. Under the influence of anaerobic bacteria, the PCL/starch blend was well degraded – 83% biodegradability in 139 days, however as compared to cellulose which was employed as control, its rate of biodegradation was slow ( $6.1 \text{ mL CH}_4/\text{g-VS day}$ ). Under anaerobic conditions, two percent (2%) biodegradability after 100 days was realised for PBS. This study points out that anaerobic digestion, landfilling and composting are viable options for managing waste

generated from PCL/starch blend while there is a need for further research into methods for containing waste from PBS.

Makhtar et al. (2013) investigated the use of *Tacca leontopetaloides* starch plasticized using glycerol and crude palm oil (CPO) as an alternative for traditional plastics. The developed samples were compared with a conventional bio-plastic sourced from Maribumi Sdn. And, subjected to various tests and analysis including; Fourier Transform Infrared (FT-IR) Analysis, Thermogravimetric Analysis (TGA), Morphological Analysis, and Degradability Test.

The FT-IR analysis – which was performed before and after degradability test – revealed that glycerol TPS promoted degradability when no longer in use, while the CPO TPS did not undergo much change after degradability, which might be because of high thermal stability of the CPO formulated sample. TGA indicated that CPO TPS starts degrading at 430°C, and leaves 25% sample residue at 500°C. Glycerol TPS begins to degrade at 70°C, and experiences broad weight decrement between 110 - 260°C and a drastic decrement at 290°C leaving 20% sample residue. Meanwhile, conventional bio-plastic begins degrading at 110°C, and broadly undergoes weight loss at 240°C and left 15% residue at the end of 500°C which was the least amount of all 3 samples. However, glycerol TPS undergoes a faster rate of mass change in comparison to CPO TPS and conventional bio-plastic – which indicates easier thermal degradation. Morphological Analysis done using SUPRA 40VP field emission scanning electron microscopic (FESEM) before and after degradation test showed that glycerol TPS and conventional bio-plastic can be even further degraded. The morphological structure of CPO TPS remained unchanged, due to its high thermal stability. This study supports the use of *Tacca leontopetaloides* starch in bio-plastic development.

Wan Zakaria, Nor Azura, Hakimah, & Muthmirah (2014) conducted a study of hygrothermal effect on the mechanical properties of starch filled polypropylene composites exposed under hygrothermal conditions at various temperatures. Polypropylene (PP) was compounded with different starches; Sago (S), Tapioca (T), and Corn (C) at 20 wt.% using Brabender Plasticoder machine at the temperature of 170°C and a rotary speed of 50 rpm and, the composite samples were prepared by utilizing compression moulding technique.

Melt Flow Index (MFI) results revealed that MFI values of PP/starch (i.e. Corn, Sago, and Tapioca) composites were lesser as compared to Pure PP. For the Moisture Absorption test, the samples were dried in an oven for 24 hours at 70°C, and then immersed in distilled water at room temperature, 40°C, and 70°C. Results showed that percentage of moisture absorbed ( $M_t$ ) at 70°C rapidly increased in PP/starch composites with respect to pure PP. Proving that the degradability of the PP/starch under hygrothermal conditions were accelerated at high temperatures of 70°C as compared to room temperature and 40°C. Mechanical characterization showed that PP/starch composites had lower flexural strength compared to Pure PP before being exposed to the hygrothermal conditions described above, these properties decreased further with time and temperature upon immersion. However, the flexural modulus of PP/starch composites were slightly higher than Pure PP at all testing temperatures. The reduction of mechanical properties of formulated samples across the various testing temperatures indicates the presence of a weak adhesion between the starch and matrix. Morphological Analysis results revealed that PP/20T composite was found to be more stable under hygrothermal conditions due to better flexural properties as compared to PP/20C and PP/20S.

Mostafa, Farag, Abo-dief, & Tayeb (2015) investigated the viability of an efficient manufacturing method of producing cellulose acetate from cotton linters and flax fibres, which are both cheap resources. The resultant of the acetylation of 35g of each raw-material was plasticized with polyethylene glycol 600 to produce the final polymer. The samples were

then examined and assessed for resistance to salts, alkalis, and acids, molecular weight, crystalline structure, and biodegradability. Investigational outcomes revealed that based on the weight of the cellulosic residue used, the yield of cellulose acetate was 54% and 81% from cotton linters and flax fibres respectively.

Molecular weight distribution was obtained using a Gel Permeation Chromatograph (GPC) and this revealed that formed CA was adequately homogenous and the average molecular weight for cotton linters and flax fibres was 1674 and 1607 Daltons respectively. Biodegradation tests showed that rate of biodegradation of cellulose acetate produced from flax fibres was better compared to that from cotton linter. But, they had almost the same chemical resistance, however the formed CA proved to be analogous with polypropylene and polyethylene with respect to its resistance to 40% NaOH and 30% sulfuric acid. The produced CA samples showed no reduction in weight when mixed in sodium chloride, lead acetate, solid ferrous sulphate, and tri-sodium orthophosphate salts for a period of 5 days, with intermittent weighing each day. The researchers garnered that the satisfactory total performance, shown by produced CA samples, makes it a fit material for fibre, plastic tools manufacture, salt containers, and packages.

Fialho e Moraes et al. (2017) carried out a study into the production of new, marketable, biodegradable sheets by flat die extrusion-calendaring process generated from thermoplastic starch/plasticized cellulose acetate/poly(butylene adipate-co-terephthalate) (TPS/PCA/PBAT) and thermoplastic starch/plasticized cellulose acetate (TPS/PCA) blends, and to evaluate the effects of thermal properties, morphological traits, and composition and processing state.

It was revealed that processing temperature and composition equally had great effects on the properties of TPS/PCA and TPS/PCA/PBAT biodegradable sheets produced. PCA and TPS showed excellent compatibility mainly at higher processing temperatures in the TPS/PCA blends as revealed by the morphological characteristics and thermal properties, while a heterogeneous structure evolved in the TPS/PCA/PBAT blends due to components being incompatible. The mechanical properties of TPS/PCA blends processed at higher temperatures were promising, which make them probable as a new sustainable, economically feasible substitute for conventional non-biodegradable plastics.

### **3.5. Loopholes in Commercialization of Biodegradable Plastics**

Although still in research phase, biodegradable plastics can easily substitute petroleum-based plastics, but this has not been the case, due to the major fact that the cost of producing biodegradable plastics is very high compared to the regular plastic, most plants used for development of bioplastics are generally modified which is a very costly process.

The manufacture of PLA is costly because of the intermediary steps. “To start with, lactic acid is delivered to the reactor and transformed into a form of pre-plastic in a vacuum under high temperature (Sels, 2012). The pre-plastic which is a low-quality plastic is then broken down into building blocks for PLA. Despite PLA being considered an eco-friendly plastic, the various intermediary steps in the production process still require metals and produce waste. Another major setback is the achievement of the optimal mechanical properties of the plastic for its purpose, this challenge is affiliated with food packaging, PET bottles, and general use plastic i.e. crates, plates, cutlery, etc.

Most polymers do not have sufficient mechanical strength and functionality for specific electrical and thermal conductivity applications. Thus, ninety-five percent (95%) of polymers are compounded with inorganic/organic additives to form composites. Generally, no one polymer has the required properties for whatever application it is to be employed in, the conversion, combination of these polymers, blend with plasticizers and other materials to

form the optimal composite has not been perfected. These make the cost of producing bioplastics much more than the petroleum-based plastics.

## REFERENCES

- [1] Anne, B. (2011). Environmental-Friendly Biodegradable Polymers and Composites. *Integrated Waste Management*, 1, 341–364. <https://doi.org/10.5772/16541>
- [2] Arutchelvi, J., Sudhakar, M., Arkatkar, A., Doble, M., Bhaduri, S., & Uppara, P. V. (2008). Biodegradation of polyethylene and polypropylene. *Indian Journal of Biotechnology*, 7(1), 9–22.
- [3] Babu, R. P., O'Connor, K., & Seeram, R. (2013). Current progress on bio-based polymers and their future trends. *Progress in Biomaterials*, 2(8). <https://doi.org/10.1186/2194-0517-2-8>
- [4] Biello, D., To, M., LaRosa, S., & Anderson, A. (2017). How long will human impacts last. TED-Ed. Retrieved from <https://ed.ted.com/lessons/how-long-will-human-impacts-last-david-biello#review>
- [5] Brandelero, R. P. H., Grossmann, M. V. E., & Yamashita, F. (2011). Effect of the method of production of the blends on mechanical and structural properties of biodegradable starch films produced by blown extrusion. *Carbohydrate Polymers*, 86(3), 1344–1350. <https://doi.org/10.1016/j.carbpol.2011.06.045>
- [6] Brown, P. (2018, February 22). Plastic Threatens to Swamp the Planet. Retrieved March 24, 2018, from <https://www.ecowatch.com/plastic-pollution-oceans-2538009649.html>
- [7] Cho, H. S., Moon, H. S., Kim, M., Nam, K., & Kim, J. Y. (2011). Biodegradability and biodegradation rate of poly(caprolactone)-starch blend and poly(butylene succinate) biodegradable polymer under aerobic and anaerobic environment. *Waste Management*, 31(3), 475–480. <https://doi.org/10.1016/j.wasman.2010.10.029>
- [8] D'Alessandro, N. (2014, April 7). 22 Facts About Plastic Pollution. Retrieved March 24, 2018, from <https://www.ecowatch.com/22-facts-about-plastic-pollution-and-10-things-we-can-do-about-it-1881885971.html>
- [9] European Bioplastics. (2016). Bioplastics Market Data. Retrieved October 13, 2017, from <http://en.european-bioplastics.org/market/>
- [10] Eva, Y. O. (2015). Preparation and Properties of Starch – Lignosulfonate Blends for Food Packaging Applications. *Kungliga Tekniska Hogskolan*.
- [11] Fialho e Moraes, A. R., Pola, C. C., Bilck, A. P., Yamashita, F., Tronto, J., Medeiros, E. A. A., & Soares, N. de F. F. (2017). Starch, cellulose acetate and polyester biodegradable sheets: Effect of composition and processing conditions. *Materials Science and Engineering C*, 78, 932–941. <https://doi.org/10.1016/j.msec.2017.04.093>
- [12] Gertz, J. E. (2016). The Earth Is Becoming a Plastic Planet. Retrieved November 8, 2017, from <http://www.takepart.com/article/2016/01/29/earth-becoming-plastic-planet>
- [13] Gross, R. A., & Kalra, B. (2002). Biodegradable Polymers for the Environment. *Science*, 297(5582), 803–807. <https://doi.org/10.1126/science.297.5582.803>
- [14] Leeson, C. (2016). A Plastic Ocean. Netherlands. Retrieved from <http://www.imdb.com/title/tt5203824/>
- [15] Lenz, R. W. (1995). Biodegradable Polymers and Plastics in Japan: Research, Development, and Applications. (A. J. Holloway, Ed.). Baltimore, Maryland.
- [16] Lu, D. R., Xiao, C. M., & Xu, S. J. (2009). Starch-based completely biodegradable polymer materials. *Express Polymer Letters*, 3(6), 366–375. <https://doi.org/10.3144/expresspolymlett.2009.46>
- [17] Makhtar, N. S. M., Rais, M. F. M., Rodhi, M. N. M., Bujang, N., Musa, M., & Hamid, K. H. K. (2013). *Tacca leontopetaloides* starch: New sources starch for biodegradable plastic. *Procedia Engineering*, 68, 385–391. <https://doi.org/10.1016/j.proeng.2013.12.196>

- [18] Mashek, W. B., Krieger, P., & Martin, K. (2016). *Watching: Bioplastics*. Plastics Market Watch. Washington, DC. Retrieved from [http://www.plasticsportal.net/wa/plasticsEU~bg\\_BG/function/conversions:/publish/common/upload/biodegradable\\_plastics/plastics\\_market\\_watch\\_bioplastics.pdf](http://www.plasticsportal.net/wa/plasticsEU~bg_BG/function/conversions:/publish/common/upload/biodegradable_plastics/plastics_market_watch_bioplastics.pdf)
- [19] Mostafa, N. A., Farag, A. A., Abo-dief, H. M., & Tayeb, A. M. (2015). Production of Biodegradable Plastic from Agricultural wastes. *Arabian Journal of Chemistry*, (April 2015), 4–11.
- [20] Plastic Oceans Foundation. (2016). *InfoGraphic: How Ocean Pollution Affects Humans*. Retrieved February 22, 2018, from <https://www.plasticoceans.org/infographic-ocean-pollution-affects-humans/>
- [21] Plastics Europe. (2017). *Plastics – the Facts 2017*. <https://doi.org/10.1016/j.marpolbul.2013.01.015>
- [22] Platt, D. (2006). *Biodegradable polymers: Market Report*. Shropshire, UK: Smithers Rapra Limited. Retrieved from <http://books.google.com/books?hl=en&lr=&id=Jtt2MFkYiP0C&oi=fnd&pg=PA1941&dq=Biodegradable+Polymers+Market+Report&ots=NDKXR5Fyb6&sig=Z2U9bQLrzMsLr9qAj0bcfMhvGyE>
- [23] Tokiwa, Y., Calabia, B. P., Ugwu, C. U., & Aiba, S. (2009). Biodegradability of plastics. *International Journal of Molecular Sciences*, 10(9), 3722–3742. <https://doi.org/10.3390/ijms10093722>
- [24] Ulery, B. D., Nair, L. S., & Laurencin, C. T. (2011). Biomedical applications of biodegradable polymers. *Journal of Polymer Science, Part B: Polymer Physics*, 49(12), 832–864. <https://doi.org/10.1002/polb.22259>
- [25] UNDP. (2016). *Sustainable Development Goals*. Retrieved October 13, 2017, from <http://www.undp.org/content/undp/en/home/sustainable-development-goals.html>
- [26] Vilpoux, O., & Averous, L. (2002). Starch-based plastics. *Technology, Use and Potentialities of Latin American Starchy Tubers*, 521–553.
- [27] Wan Zakaria, W. N., Nor Azura, A. R., Hakimah, O., & Muthmirah, I. (2014). Mechanical Properties of Starch Filled Polypropylene Under Exposure of Hygrothermal Conditions. *The Malaysian Journal of Analytical Sciences*, 18(2), 434–443.