International Journal of Advanced Research in Engineering Technology & Science
ISSN: 2349-2819
Impact Factor: 7.10
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Email: editor@ijarets.org Volume-12 Issue-4 April-2025 www.ijarets.org

RECENT TRENDS IN THE DEVELOPMENT OF ECO-FRIENDLY BIODEGRADABLE POLYMERS

Rashmi Dubay[1], Abhay Krishna[2],

[1]Dept. of Chemistry, School of Basic Sciences, C. S. J. M. University Campus, Kanpur (U.P) India

[2]Dept. of Applied Sciences & Humanities, K. M. C. Language University, Lucknow (U.P) India

ABSTRACT

The most current advancements, trends, and potential uses of bio-based polymers that are derived from renewable resources are discussed in this article. Because of worries about the environment and the realization that the world's petroleum supplies are limited, bio-based polymers are gaining more and more attention. Not only may bio-based polymers take the place of conventional polymers in a variety of applications, but they also provide novel combinations of features that can be used in alternative applications. This study covers a wide variety of biobased polymers, with a particular emphasis on the general manufacturing processes, characteristics, and commercial uses of these kinds of polymers. The analysis takes a look at the technical and future problems that are covered in the process of bringing these materials to a broad variety of applications, as well as prospective solutions. Additionally, the research addresses the main industry players that are bringing these materials to the market.

Keywords: *Bio-based polymers, Renewable resources, Biotechnologies, Sustainable materials*

INTRODUCTION

Over the course of the previous century, synthetic plastic was seen as the material of the future; yet, in the current day, it is a significant contributor to environmental issues. Synthetic polymers have a number of key drawbacks, the most significant of which are the slow breakdown process and the manufacturing process that relies on non-renewable basic resources. The manufacture of polymers is estimated to use as much as seven percent of the world's oil and gas supply, according to the estimations of experts. Polymers that are either biodegradable or manufactured from renewable sources give an alternate potential that might be considered. Therefore, there is a considerable growth in the manufacture and utilisation of bio-based and biodegradable polymer materials, which may therefore contribute to a reduction in the environmental issues that are associated with waste polymer materials. The utilisation of maize, soy, sugarcane, potato, rice, or wheat, as well as seeds that are an abundant supply of oil or fermentation products, as raw materials for the production of biopolymeric materials is the primary focus of research on renewable resources. The use of biomass for the production of biopolymers offers a significant benefit due to the fact that polymers formed from biomass are both biodegradable and very simple to recycle. As a result of their mostly hydrophilic nature and, in some instances, insufficient mechanical qualities, especially in wet conditions, biodegradable polymers generated from renewable sources have a rapid rate of deterioration, which is one of the most significant drawbacks of these materials. In spite of the fact that they have certain drawbacks, biodegradable polymers have a broad range of benefits to provide since they are manufactured from a variety of plant resources. Because of this, it is no longer essential to make use of the chemical fillers that are integrated into items made of synthetic plastic. Furthermore, throughout the manufacturing cycle of biodegradable plastics, there is a reduction in the amount of energy that is used, and the breakdown process does not result in the release of carbon dioxide into the environment that is not essential. More and more research is being done in the area of novel biodegradable polymers and their enhanced qualities as a result of the fact that the usage of biodegradable goods has the potential to lessen reliance on fossil fuels and, as a result, contribute to a cleaner environment. The purpose of this article is to provide a comprehensive assessment of the most current research on the biodegradable polymers that are often used, to investigate the many applications that may be made of these polymers, and to investigate the prospect of reducing or even eliminating the use of synthetic plastics, which have already created significant environmental issues.

OBJECTIVES

1. Isolation and screening of bacterial species that are capable of generating PHB from sources in the marine environment and organic waste.
2. The extraction of the PHB that was created in the powerful isolates

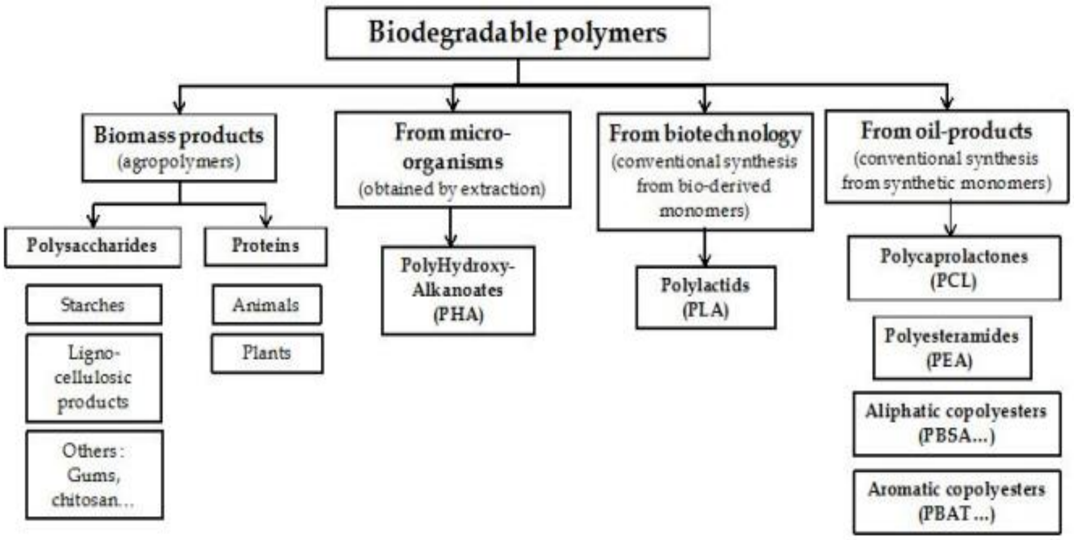
Classification and Properties of Bio-Degradable Polymers

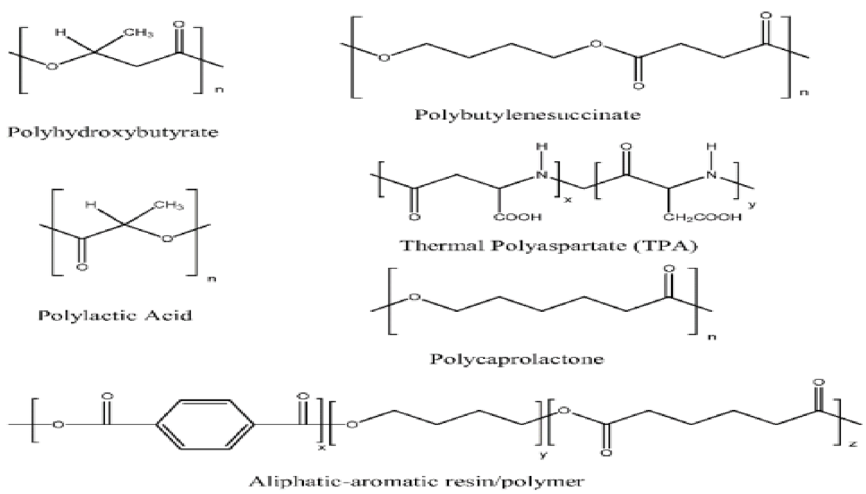
The biodegradable polymers may be categorised in a variety of ways, including their chemical composition, origin and synthesis technique, processing method, economic significance, use, and so on. Generally speaking, biodegradable polymers are divided into two categories based on their origin: natural polymers, which are derived from natural resources, and synthetic polymers, which are manufactured from oil.

Natural Biodegradable Polymers

Natural polymers are another name for biopolymers, which are polymers that are created in nature throughout the growth cycles of all organisms. Biopolymers are also known as natural polymers. The production of these molecules normally requires chain growth polymerisation reactions of activated monomers, which are typically generated inside cells via complicated metabolic processes. These reactions are typically catalysed by enzymes.

Microbiopolymers are biopolymers that are created directly by organisms that are either naturally occurring or genetically engineered. The biosynthetic function of a microbe is responsible for the production of microbial polyesters, which are easily biodegraded by bacteria and inside the bodies of higher animals, including humans.


Biodegradable polymers
Biomass products (agropolymers)
From micro-organisms (obtained by extraction)
From biotechnology (conventional synthesis from bio-derived monomers)
From oil-products (conventional synthesis from synthetic monomers)
Polysaccharides
Proteins
Starches
Ligno-cellulosic products
Others: Gums, chitosan...
Animals
Plants
PolyHydroxy-Alkanoates (PHA)
Polylactids (PLA)
Polycaprolactones (PCL)
Polyesteramides (PEA)
Aliphatic copolyesters (PBSA...)
Aromatic copolyesters (PBAT...)


Polyhydroxybutyrate
Polybutylenesuccinate
Thermal Polyaspartate (TPA)
Polylactic Acid
Polycaprolactone
Aliphatic-aromatic resin/polymer

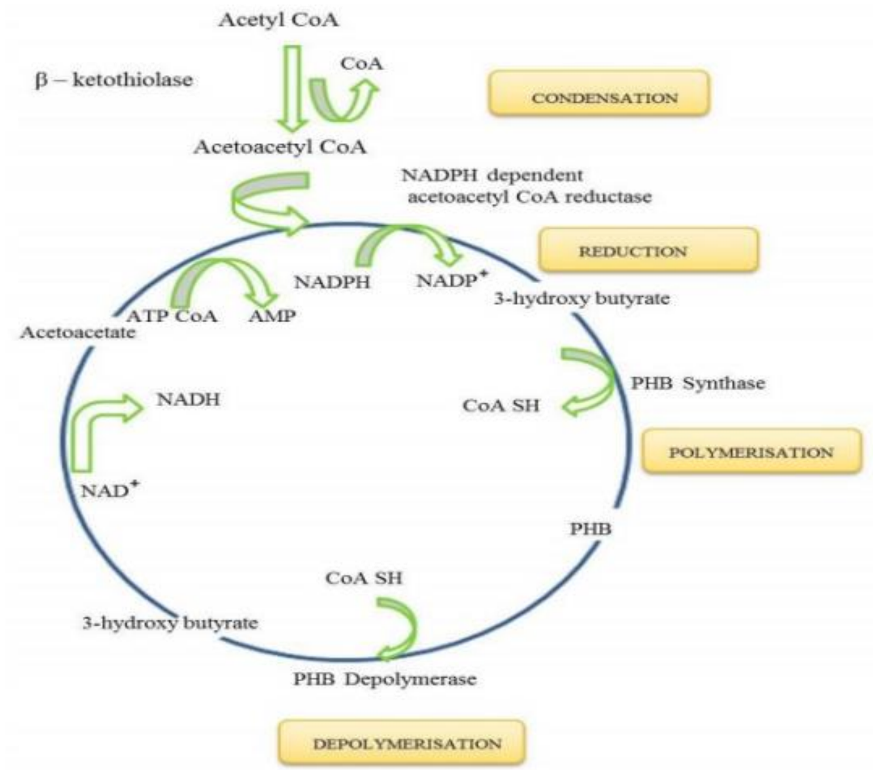


Fig. 1: The cycle representing the synthesis and degradation of poly-hydroxy-butyrate (PHB) Microbes as the bioplastic producers.

Bioplastic: the production of it and the breakdown of it by microorganisms

Among the several kinds of plastics that fall under the category of bioplastics are those that are derived from biomass and are biodegradable. These include cellulose-based plastics, starch-based plastics, and some aliphatic polyester such as polylactic acid (PLA) and poly hydroxyl butyrate (PHB), among others. Poly-3-hydroxy butyrate, often known as PHB, is completely biologically degradable and is manufactured using a variety of renewable resources. Polypropylene and this material have many of the same physical features. The fact that PHB has this quality makes it possible for it to captivate the attention of researchers who are interested in its manufacture and study. The use of these biodegradable and bio-based plastics would unquestionably lessen the pollution that is brought about by the release of carbon dioxide from waste plastics, which is yet another justification for placing focus on this matter. Within the cell, prokaryotic organisms develop intracellular granules known as poly-3-hydroxybutyrate (PHB), which are a polymer of 3-hydroxybutyrate. These granules serve the purpose of storing energy and carbon during times of hunger.

The class of compounds known as polyhydoxyalkanoates includes poly-3-hydroxybutyrate as a member. The existence of an abundance of carbon and a scarcity of nitrogen sources is necessary for the majority of bacteria to accumulate poly-3-hydroxybutyrate.

According to the findings of biochemical research, there are two distinct mechanisms for the production of PHB.

(1) Azotobacter beijerinckii and Zoogloea ramigera are two examples of organisms that exhibit a metabolic pathway that consists of three specific steps. Acetyl coenzyme A (acetyl-CoA) is converted into acetoacetyl-CoA by the enzyme ketothiolase, which is responsible for catalysing the initial step for the reaction. An NADPH-dependent acetoacetyl-CoA reductase is responsible for the further reduction of this intermediate to D-(-)-P3-hydroxybutyryl-CoA (Nishimura et al., 1978; Schubert et al., 1988). It is the enzyme PHB synthase that is responsible for the last step, which is responsible for the head-to-tail polymerisation of the monomer to PHB.

(2) The synthesis of PHB in Rhodospirillum rubrum is accomplished by a five-step synthetic route for the organism. An enzyme called acetoacetyl-CoA reductase, which is reliant on NADH, is responsible for catalysing the synthesis of L-(+)-3-hydroxybutyryl-CoA. This compound is then transformed into D-(-) -P-hydroxybutyryl-CoA by two stereospecific enoyl-CoA hydratases prior to the polymerisation process.

As a result of their remarkable flexibility in a wide range of harsh environmental circumstances, microbes have been reported to be the most powerful producers of PHB. It has been discovered that Bacillus species, Pseudomonas species, and Vibrio species are the most effective for the creation of PHB. This is because these bacteria have a greater level of stability and repeatability when subjected to environmental stress.

Many different kinds of bacteria, including Bacillus species, Pseudomonas species, Cupriavidus species, and Aeromonas species, have been investigated for their potential use in industry, specifically for their ability to manufacture PHA in an effective manner. Researchers are becoming more interested in some bacterial species, such as Bacillus megaterium and Ralstonia eutropha. There have been reports that Bacillus megaterium is responsible for around 84% of the PHB production. Actinobacillus, Azotobacter, Agrobacterium, Rhodobacter, and Sphaerotilius are just few of the bacterial species that have been the subject of research due to their capacity to convert organic waste into bacterial PHA. When it comes to the manufacture of PHB for industrial purposes, some bacterial species, such as Bacillus species, Pseudomonas species, Aeromonas species, and Cupriavidus species, have been used extensively due to their capacity to generate PHB.

The optimum conditions for bioplastic synthesis and influence on changes of parameters

The formation of lipid intracellular lipid granules, also known as PHB, occurs when bacteria are subjected to stressful circumstances, such as a lack of certain nutrients (such as nitrogen, phosphorus, oxygen, etc.) and an overwhelming amount of carbon. In general, the generation of PHB is dependent on a number of other parameters, including the initial culture pH, culture temperature, and rate of agitation, in addition to the presence or lack of nutrients.

Effect of culture pH:

Metabolic activities are dependent on a certain pH, and even a minor shift in pH may have a significant impact on the processes, making them very important. Also, it has been shown that the generation of PHB is at its highest at a pH of 7.0.

Effect of culture temperature:

In addition, temperature is a significant factor in the formation of PHB. At a temperature of 30 degrees Celsius, the PHB production is at its highest.

Effect of Agitation rate:

Additionally, the development of powerful bacterial strains and the formation of PHB are both determined by the agitation rate. When cells are properly agitated, they are prevented from clumping together into big masses, which is beneficial to the growth process. The process of agitation makes it easier for each cell to make use of the nutrients that are present in the culture medium. The agitation rate should be between 150 and 200 revolutions per minute (rpm), and if it is more than 200, the production will drop because of the excessive shear force that is caused by the agitation.

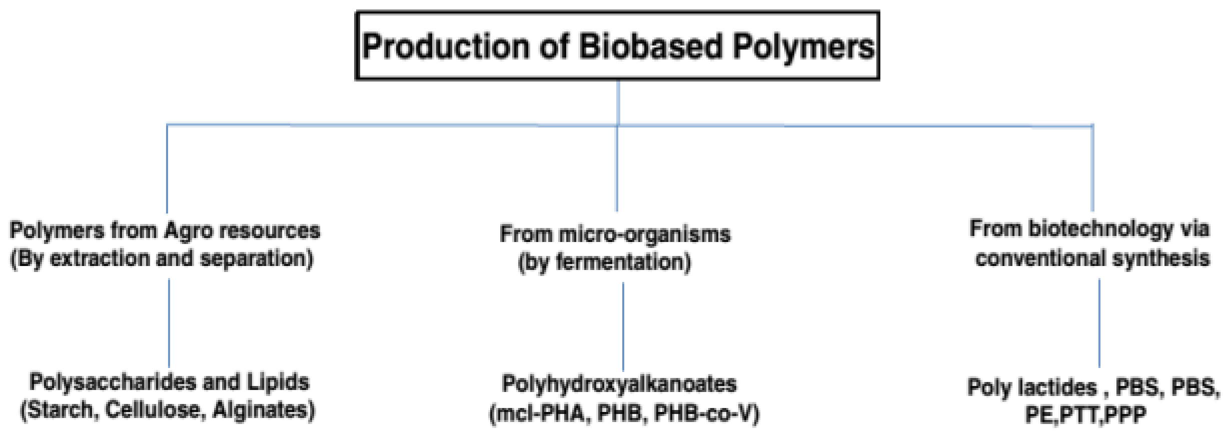


Fig. 2: shows the overview of the types and production of bio-based polymers.

Blending of substrates with polyhydroxybutyrate (PHB), which is a bioplastic, in order to slash manufacturing costs

The cost of industrial production of bioplastics is quite expensive in contrast to the cost of synthetic plastics in the present day. The cost of production is primarily determined by the cost of biomass for fermentation, but it is also vital that bioplastics be produced on a large scale. Consequently, the blending of PHB with other polymers is a method that may be used to minimise the cost to a certain amount. According to the findings of a research, it would be beneficial to minimise the cost of PHB if the ratio of starch blending to PHB was kept at 30:70%.

Biodegradability of Polymers

The biodegradation of polymers is a somewhat complicated process that may take place in a variety of different ways. Degradable plastics are said to undergo a considerable change in their chemical structure when subjected to certain environmental conditions, as stated by the American Society for Testing of Materials (ASTM) and the International Standards Organisation (ISO). The physical and mechanical qualities of the material are diminished as a consequence of these changes, as determined by the conventional techniques. The activity of naturally existing microorganisms, such as bacteria, fungus, and algae, is responsible for the decomposition of biodegradable polymers. Compostable plastics, photo-degradable plastics, oxidatively degradable plastics, and hydrolytically degradable plastics are all types of plastics that may be classified as eco-friendly. Between the months of October 1990 and June 1992, lawsuits were filed about deceptive environmental advertising due to the uncertainty that existed surrounding the real meaning of the term "biodegradable." As a result, the American Society for Testing and Materials (ASTM) and the International Organisation for Standardisation (ISO) realised that there was a need for standardised testing procedures and protocols for biodegradable plastics. There are three basic categories of polymer materials that are now attracting the interest of material scientists. Consumers and businesses alike often refer to these polymer materials as belonging to the category of plastics rather than just plastics. They have a structure that is comparable to that of a composite, in which a polymer matrix, which may be made of plastic or resin, forms a dominating phase surrounding a filler material. The inorganic or organic filler that is reinforced in polymer will improve the material's mechanical qualities while simultaneously lowering the cost of the substance. Following the reinforcement of the composite with phenol-formaldehyde (PF) resin, the physicochemical, thermomechanical, and mechanical strength of the composite was enhanced, as shown in Figure 3 below. Hibiscus sabdariffa (Hs) fibre, also known as Roselle (cellulose rich) fibre, was used.

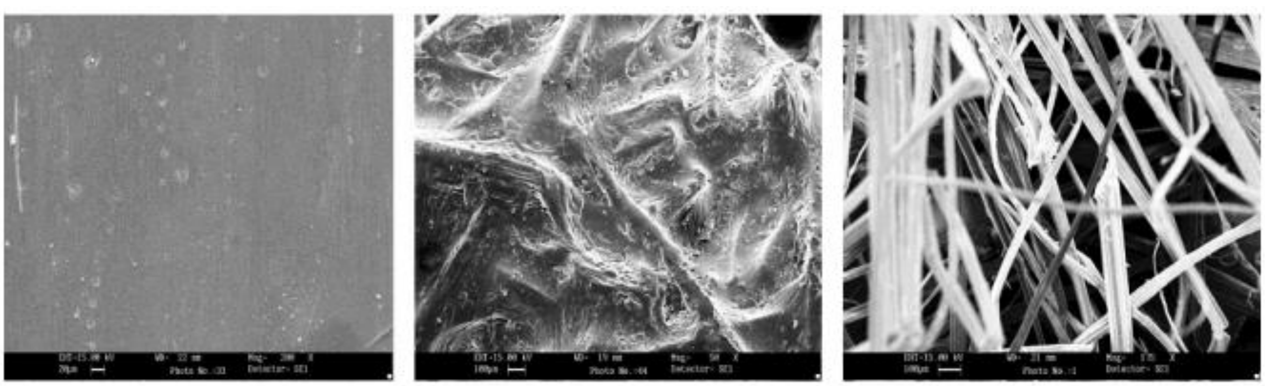


Figure 3: SEM of H.sabdariffa fiber Composite

Because the surfaces of conventional plastics that come into touch with the soil in which they are disposed of are typically smooth, these polymers are resistant to biodegradation. The microorganisms that are present in the soil are unable to ingest a part of the plastic, which in turn leads to a more rapid disintegration of the matrix that contains the supporting elements. This category of materials typically consists of an impenetrable matrix that is derived from petroleum and is reinforced with carbon or glass fibres on the inside. Another kind of polymer materials that are being considered is one that can be broken down into smaller pieces. In comparison to traditional synthetic plastics, they are engineered to degrade at a rate that is far faster than that of the former. When it comes to the production of this category of materials, the normal process involves surrounding naturally generated fibres with a matrix that is manufactured using petroleum. While the plastic matrix is being disposed of, microbes have the ability to eat the natural macromolecules that are contained inside it. A material that is weak and has rough and open edges is the result of this. Any further deterioration might thereafter take place. At the moment, the last category of polymer materials is receiving a significant amount of interest from both the scientific community and the business sector. The development of these polymers has resulted in their total biodegradability. Flax and hemp are examples of typical crops that are used to make fibre reinforcements. The polymer matrix is sourced from natural sources such as starch, cellulose, or polymers that are produced by microbes. These materials may be completely consumed by microorganisms, which will ultimately result in the production of carbon dioxide and water as by-products and waste products. For materials to be considered biodegradable, they must satisfy a set of specified requirements that have been established by the ASTM and the ISO. In general, the structure of the polymer is a significant factor in determining the possibility of microbial assault on a material. When looking at polymer materials from a scientific perspective, there are certain components that are need to be present in order for biodegradation to take place. Active microorganisms, such as fungus, bacteria, actinomycetes, and others, are required to be present at the disposal site. This is the most significant requirement. The temperature at which degradation should take place is typically between 20 and 60 degrees Celsius, and it is determined by the kind of organism. In addition to having a pH that is either neutral or slightly acidic (between 5 and 8), the disposal location must have a high concentration of oxygen, moisture, and mineral nutrients. Several stages are involved in the process of biodegradation of materials. In the beginning, the digestible macromolecules come together to form a chain and go through a direct enzymatic scission. It is then followed by the metabolism of the split parts, which ultimately results in the gradual enzymatic dissimilation of the macromolecule from the chain ends. There is also the possibility that oxidative cleavage of the macromolecules may take place, which will result in the pieces being metabolised. In any case, the chain fragments will ultimately become sufficiently short for microbes to transform them into a different form. In the beginning of their existence, biodegradable polymers that are obtained from plant sources begin as renewable resources, often in the form of starch or cellulose. Innovative research and development of polymers, which ultimately results in the manufacture of plastics on a wide scale by plastic converters. The biopolymers are then transformed into the targeted end products, which are then used by the customer. In an ideal scenario, the biopolymer will be included in a collection of bio waste and then composted at a later time. In the end, this process will result in the production of carbon dioxide and water, both of which are byproducts that are favourable to the environment.

It is anticipated that biodegradable polymers would undergo full mineralisation in an aerobic composting environment, resulting in the production of carbon dioxide and water:

$$\text{Polymer} + O2 \rightarrow CO2 + H2O$$

Fig 4 Applications of Biodegradable Polymers

The research and development process for the introduction of a biodegradable polymer is based on the creation of materials that have a conceptual application. At the same time, it intended to either complement or replace an existing material. The most common applications for biopolymers are in the fields of medicine, agriculture, packaging, and the automobile sector. More attention is being paid to biopolymers that have the potential to be used in packaging than to those that are being researched for other applications. The widespread use of biodegradable packing materials is being supported by all levels of government, notably in China and Germany. This is being done in an effort to reduce the amount of inert materials that are disposed of in landfills, which is a consequence of the limited amount of space available. According to estimates, over 41% of plastics are used in the packaging industry, with almost half of that amount being utilised for the packaging of food goods. For the purpose of further developing biodegradable polymers that are based upon polyester and starch, BASF, a global leader in the chemical and plastic industry, is now working on the project. In 2001, BASF presented customers with Eco-flex, a plastic substance that is completely biodegradable and designed for use in consumer products. In addition to being resistant to water and grease, the material is completely sanitary for use as disposable wrapping and can be composted using standard methods. The result of this is that Eco-flex has discovered a variety of applications that are ideal for use as a packaging wrap. Environmental polymers, located in Woolston, Warrington, United Kingdom, has also produced a biodegradable plastic substance that is called as depart. This polyvinyl alcohol product is suitable for extrusion, injection moulding, and blow moulding. The solubility of Depart in water may be adjusted by the user, and this capacity is governed by the formulation that is used. Some examples are catheter bags, wrap for disposable food service items, and hospital laundry bags that can be rinsed away, allowing for sterile washing. Other examples include wrap for agricultural goods and catheter bags. Because of their renewable and biodegradable properties, biopolymers have the potential to be used in a variety of novel applications, including but not limited to: rubbish bags, disposable cutlery and plates, food packaging, transportation materials, agricultural goods, and research. This is also possible when using sustainable biopolymers like starch as the starting material. An acetylation procedure, chemical treatments, and postextrusion steaming are the methods that are used to manipulate the starch substance. The mechanical qualities of the material are satisfactory, and the material has acquired an effective level of biodegradability.

It is possible to boost the yield of spring wheat by using a transparent plastic mulch cover immediately after sowing, provided that the cover is used for a period of fewer than forty days. As a result, plastic films that begin to disintegrate under soil conditions that are typical after roughly one month are excellent for use as crop mulches. It is not the only use of biopolymers in agriculture; film coverings are also possibilities. Plant pots made of biodegradable materials, as well as composting containers and bags that are disposable, are examples of containers that are of interest. Seeds are planted directly into the soil in the pots, and the dirt is broken down as the plant starts to develop. The use of biodegradable bags for the storage of chemicals and fertiliser is another use that material scientists have investigated. From an agricultural point of view, biopolymers that are biodegradable are essential because they have the potential to enrich the existing nutrient cycle in the soils where the residues are applied. The field of medicine is in a state of perpetual flux, and as a result, the materials that are used by it undergo consistent modifications.

Utilising biopolymers for controlled release medication delivery is yet another significant and crucial use of these materials. The enzymatic breakdown of the bioactive substance determines the pace at which the drug is released from the material. The automobile industry is adjusting its practices in response to the expectations of society and the government for environmental responsibility. Automobiles that are powered by biofuels are lighter, which makes them a more cost-effective option for customers since they use less gasoline. Biopolymers are appealing in all of these sectors because they are derived from renewable sources, which slow the depletion of finite fossil fuel stockpiles. This is the primary reason for their popularity. From the point of view of the business sector, the most significant benefit of using biopolymers that are generated from renewable feed stocks is the cheap cost of these materials. According to first impressions, biopolymers look to be a potentially profitable possibility for both the economy and the environment. However, in order to make judgements that are in the best interest of the economy, it is necessary to take a more in-depth look at the cost-performance ratio of biopolymers. This is also the case with environmental concerns. One of the industries that may reap economic advantages from the use of biopolymer materials is the automobile industry. With regard to the reinforcement of fibres, the typical glass fibres that are extensively used are abrasive and rapidly wear down the processing equipment. Flax fibres have a texture that is less coarse than other fibres, which helps to extend the life of processing equipment. When compared to synthetic fibres, natural fibres have a number of advantages, including the fact that they are more commonly accessible and less costly. The development of biodegradable polymers is still ongoing as a result of the ever-increasing demand for these materials and their successful implementation in a wide range of applications. The biopolymer business has been progressing to the point where it is now economically competitive with the traditional plastic sector. This is a result of several advancements in the industry. The production of synthetic plastics is carried out on a massive scale, while the production of biopolymers is, for the most part, carried out on a rather modest degree.

In light of the fact that feed stocks derived from renewable resources are very affordable, researchers and industry authorities are being encouraged to devote more attention to the development of these methods. There will be an increase in the number of services linked with biopolymers as the manufacturing of biopolymers grows. For the purpose of providing a broad overview, it is possible to assert that the passage of time will result in increased economic power for the assimilation of biopolymer materials into society. A representation of the production or the capacity that is projected for the world's biggest bioplastics manufacturing firms is shown in the figure.

CONCLUSIONS

Biologically degradable polymer materials have the potential to be used in an infinite number of contexts. Polymers that are favourable to the environment are required in a variety of industries, including agriculture, vehicle manufacturing, medicine, controlled medication release, and packaging. It is possible for every sector to develop its own perfect material thanks to biodegradation that may be adapted to unique requirements. Due to the fact that disposal techniques may be adapted to meet the requirements of certain industries, the many modes of biodegradation associated with such materials are also a significant benefit. The concept of environmental stewardship is becoming more significant to commercial enterprises as well as individual customers. This is a significant benefit for people who manufacture products made of biodegradable plastic substances. During the production process, biopolymers reduce the amount of carbon dioxide emissions, and after disposal, they decompose into organic matter. The procedures that include the ongoing development of biopolymer materials via the use of renewable natural resources are the ones that show the greatest promise. In terms of the likelihood of seeing continuous expansion in use, biodegradable polymers that include starch and cellulose fibres seem to be the most plausible candidates. The development of the infrastructure required to commercially extend the use of microbially generated plastics is still considered to be both expensive and cumbersome, despite the fact that these polymers are scientifically sound and represent an innovative approach. It is the ideal moment for scientists and researchers to investigate the untapped potential of natural resources such as polymer and fibre, to make use of these resources, and to produce biodegradable polymer in order to advance scientific and technological advancements while simultaneously maintaining an environment that is free of pollution.

REFERENCES

1. Mulder KF. Sustainable production and consumption of plastics, Technological Forecasting andSocialChange, 1998; 58, 105-124.

2. Subramanian PM. Plastics recycling and waste management in the US, Resources, Conservation, and Recycling, 2000; 28, 253-263.

3. Callister WD. Materials Science and Engineering, An Introduction. New York, N.Y., John Wiley and Sons, 1999.

4. Williams G, Pool R. Composites from natural fibers and soy oil resins, Applied Composite Materials. 2000; 7(5-6),421-432.

5. Bismarck A, Aranberri-Askargorta I, Springer J, Lampke T, Wielage B, Samboulis A, Shenderovick I, Limbach H. Surface characterization of flax, hemp, and cellulose fibers; Surface properties and the water uptake behavior, Polymer Composites, 2002; 23(5):872-894.

6. Grigat E, Kock R, Timmermann R, Thermoplastic and biodegradable polymers of cellulose. Polymer Degradationand Stability, 1998;59(1-3), 223-226.

7. Crawford C, Developing Biobased Industries In Canada. Federal Biomass/ Bio-energy Strategy Framework (AAFC & NR Can) 2001.

8. Ashish Chauhan and BalbirKaith, Novel Materials Procured From Surface Modification of Biomass, Waste and Biomass Valorization, 2012;3 (2), 141- 148.

9. Ashish Chauhan and BalbirKaith, Evaluation of Dynamic Materials procured from waste Biomass, ISRN Material Science, ID 393489, 7., 2011.

10. Ashish Chauhan and BalbirKaith, Sorrel fiber as reinforcement in bio-composite, Journal of Environmental Science and Technology, 2012; 5 (5), 343-353.

11. Ashish Chauhan and BalbirKaith, The Potential Use of Roselle as Novel Graft-copolymer, Journal of Natural Fiber, 2011 8(4), 308-321.

12. Ashish Chauhan and BalbirKaith. Fabrication and Evaluation of Physico-Chemico Thermally Resistant Bio-polymers, International Journal of Polymeric Materials, 2012; 61(12), 893- 905.

13. Narayan R, Pettigrew C. ASTM standards help define and grow a new biodegradable plastics industry. ASTM Standardization News, December, 1999; 36-42.

14. Aminabhavi TM, Balundgi RH, Cassidy PE. Review on biodegradable plastics, Polymer Plastics TechnologyandEngineering. 1990; 29(3):235-262.

15. Ashish Chauhan and BalbirKaith, Physicochemicothermo-mechanical Assessment of H. sabdariffa-reinforced-composites, Journal of Polymer Engineering,2012; 32 (2), 127-133.

16. Ashish Chauhan and BalbirKaith, ThermoChemical Evaluation of the Roselle Graft Copolymers, Polymer from Renewable Resources, 2010; 1(4): 173-187.

17. ASTM Standards, Standard Terminology Relating To Plastics. New York, NY., ASTM, 1998; 08(01) D883-96.