Journal Of Research Technology & Engineering
www.jrte.org
ISSN 2714-1837

Bioplastics for sustainable future

*G.A.I.M Bandara, A.M.A.R.B Alahakoon, P.G.R.L.P Senarath, T.M.T.N Thennakoon, D.M Weerarathna, H.T.M Hewage, W.M.V.A Jayathma, D.G.M.L Gamage, L.G.T Sulaksha

Faculty of Technology, University of Sri Jayewardenepura
* g.a.i.m.bandara@gmail.com
Received:22 March 2023; Revised: 26 March 2023; Accepted: 28 March 2023; Available online: 10 April 2023

Abstract: Bioplastics are a type of material that can decompose or come from renewable sources, such as plant starch and Cellulose. These materials show great potential as an eco-friendly alternative to regular plastics because they assist in minimizing the adverse effects that plastic manufacture, use, and disposal have on the environment. Furthermore, bioplastics may significantly reduce our reliance on oil-based plastics that contribute to climate change and are not renewable. This summary examines the present state of the bioplastics study, exploring subjects such as their manufacture, features, uses, and probable environmental consequences.

Index Terms: Bioplastics, Ecofriendly, Sustainable, Renewable, Biodegradable.

1 INTRODUCTION

Plastics are artificial or semi-artificial materials made of different polymer materials that can be moulded into various shapes and forms. They have softness, heat sealability, excellent strength-to-weight ratio, and transparency. Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVC), Polyurethane (PUR), Polyethylene Terephthalate (PET), Polybutalene Tereptheline (PBT), Nylon as well as other petrochemical-based plastics, are used in everyday life because of qualities like adaptability, durability, lightweight, affordability, and corrosion resistance [1,2,3]. Synthetic or semi-synthetic compounds significantly impact the ecosystem. Worldwide, millions of tons of plastic are used. Oceans and the earth both contaminate large amounts of plastic. According to this information, burning plastics releases harmful chemicals like methane, CO2, and other greenhouse gases. It immediately impacts the retreating glaciers and climate change [4]. Records show that burning 1 kilogram of plastic releases about 2.8 kilograms of carbon dioxide into the atmosphere [5]. Many metric tons of plastic are made yearly, but only 7% are recycled; the remaining 93% end up in landfills and the ocean [6,7]. In a water sample taken from the North Atlantic Ocean, long-term research discovered the equivalent of 580,000 pieces of plastic per square kilometre [8]. Bioplastics can replace synthetic polymers. The use of bioplastics produced from biological materials has gained popularity worldwide [4]. In 2022, 2.22 million metric tons of bioplastics were produced worldwide, as shown in Fig.1. Biodegradable and non-biodegradable bioplastics are available in two varieties [9]. Currently, bioplastics are one of the innovative materials made from waste, biomass, and renewable resources such as food waste, waste banana peels, waste potato peels, algal biomass, coconut husk fibre, bacterial strains, microorganisms, wastewater sludge, jackfruit seeds, waste cooking oil, rice straw, agricultural waste, corn starch, cassava peel, and avocado seeds Globally, the focus has been on increasing the production of bioplastics. Many types of waste can be used as raw materials in the production of bioplastics [7]. This review goes through bioplastics, raw materials, classification, processing, biodegradation and standardization, life cycle, advantages and disadvantages, and applications.

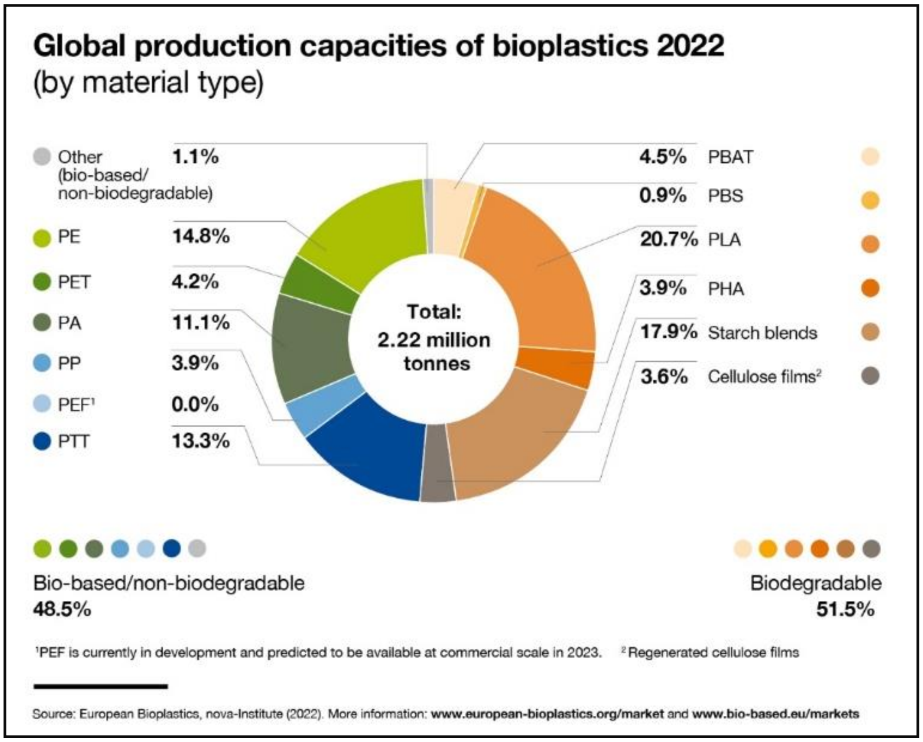

Fig. 1. Global production capacities of bioplastics 2022. [9]

2 WHAT ARE BIOPLASTICS

Bioplastics are defined as "plastic based on renewable resources or plastics that are biodegradable and/or compostable" by the European Bioplastics Organization (EBO). These bioplastics decompose naturally or when stimulated, primarily through the enzymatic activity of microorganisms, into CO_2, H_2O, organic compounds, or biomass. The following four requirements must be met to qualify as a bioplastic polymer.

- Chemical characteristics: Organic matter must comprise at least 50% of the end composition.
- Biodegradation: Under conditions promoting composting, the developed polymer should degrade by at least 90% of its weight or volume in six months.
- Disintegration: Under controlled composting conditions, the bio-based polymer should, at the very least, fragment microscopic, undetectable components (2mm) within two months.
- Eco toxicity: After biodegradation for six months, non-degradable biopolymer residues should not pose a danger to plant growth [10].

Many polymers, like Cellulose or chitin, which are either made naturally or by microorganisms during their growth cycles, are included in the growing field of biodegradable polymers. Bio-based plastics (biodegradable bioplastics) and non-biodegradable bioplastics are the two categories into which bioplastics fall. Although produced from renewable resources, bio-based plastics may not always be biodegradable. On the other hand, biodegradable plastics are made to decompose rapidly in the environment [11]. Bioplastics are growing in popularity as an environmentally favourable substitute for traditional petroleum-based plastics made from nonrenewable resources. They can take hundreds of years to decompose in landfills. Bioplastics provide a more environmentally friendly option because they can be made from renewable resources and biodegrade rapidly, minimizing the environmental impact of plastic waste. It is crucial to note, though, that not all bioplastics are created equal. In some environments, bioplastics may not degrade correctly and may still take a long time to break down. In order to prevent environmental pollution, it is also crucial to ensure that bioplastics are disposed of correctly, such as in composting facilities [7,11,12].

3 BIO-WASTE FOR PRODUCTION OF BIOPLASTICS

Most of the raw materials used to make bioplastic come from agricultural products. Lands that can be farmed are necessary for creating raw materials; otherwise, they should have been used for food production. As a result, the rivalry for arable land prompts ethical questions about the expansion of bioplastics. Additionally, the expense of growing those crops and the following processing of those crops make bioplastics an expensive endeavour. Bio-waste, including agricultural waste, food industry biomass waste, peel waste, seed waste, waste oil, bio-waste from effluents, domestic wastewater, and municipal solid waste, among others, can be used there to address these issues while minimizing environmental impacts. The table below (Table 1.) overviews the different types of waste used to turn bio-waste into bioplastics [13].

Table 1. Type of waste, for example, bio waste, type of plastics produced

Types of waste	Examples of bio-waste	Type of plastics produced
Lignocellulosic bio-waste	Sugar cane bagasse, cotton linter, corn cob, corn husk, rice husk, rice straw, wheat barn	Cellulose Based bioplastic and PHB polymers
Food industry biomass waste	Peel waste: Cassava, potatoes, pineapple, orange and banana peels	Starch-based bioplastics and Cellulose based bioplastic, PLA and PHB polymers
	Seed water: Mango, Date, Avocado, jackfruit	Lipid-based bioplastic, starch-based bioplastic, PHB polymers
	Crustertaceans shells waste: shells waste from squillas, shrimp, crabs, lobs, and prawns like crustaceans	Chitin-based bioplastic and PHA polymers
	Waste oil: Waste frying oil, Non-edible oil like Castor and Jatropha	Lipid-based bioplastics and PA polymers
Biowaste from effluents	Domestic wastewater, food and dairy industry wastewater, wood mill effluent, Oil industry effluent	PH, PHA, poly-3-(hydroxybutyrate-co-hydroxyvalerate) and PHA polymers
Miscellaneous waste	Municipal solid waste, Feather quill, Paper waste	PHA, Protin based bioplastics, PLA polymers

4 CLASSIFICATION OF BIOPLASTICS

In addition to being produced from fossil or bio based materials, bioplastics can be biodegradable. While bioplastics can be made entirely of green resources, biodegradable plastic is either made of fossil-based polymers or a mix of both renewable and fossil resources. Bioplastics come in three major categories as follows [14].

- Biodegradable and bio based bioplastics
- Biodegradable and fossil bioplastics

- Non-biodegradable and bio based bioplastics

The examples for the above categories are shown in Fig. 2. and Table 2.

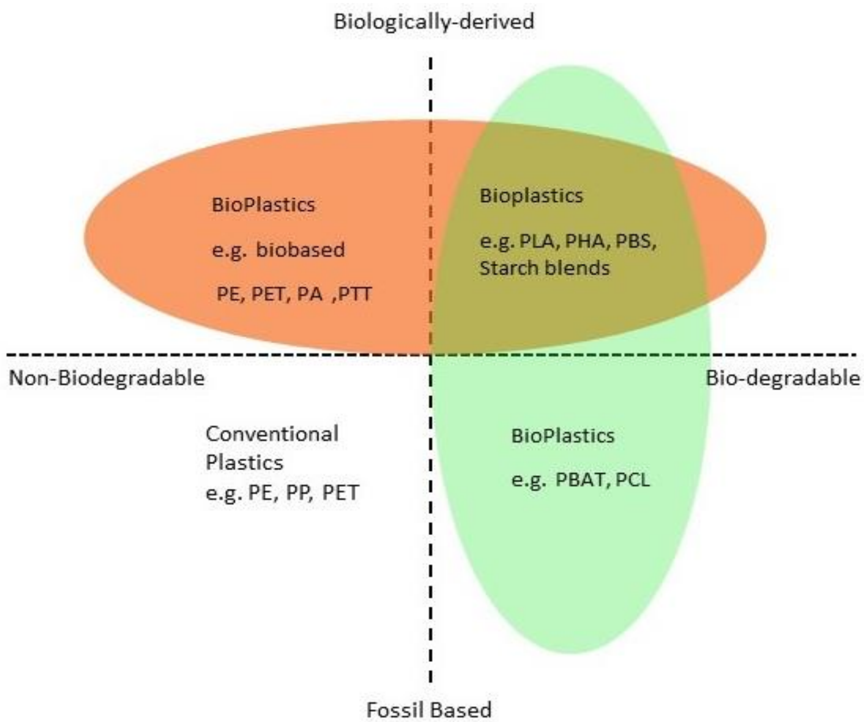

Table 2. Types of bioplastics

	Bio-based	Petroleum-based	Reference
Biodegradable	Bioplastics e.g.:-Starch, Cellulose, Polyhydroxy alkanoates, Polylactic acid	Bioplastics e.g.:-Polycaprolactone, Polybutylene succinate, Polybutylene adipate Terephthalate	[14,16,17,18]
Non-biodegradable	Bioplastics e.g.:-Bio-polyethylene, Biopolypropylene	Conventional Plastics, e.g.:-PVC Polypropylene Polyethylene	[17,18,19]

5 Process of Bioplastics Production

The selection, processing, and modification of raw materials are just a few processes in creating bioplastics. Starch-based and non-starch-based materials are the two major groups into which the raw materials for the production of bioplastics can be divided. Because they are simple to make and have solid mechanical qualities, materials based on starch are frequently utilized to make bioplastics. Lignin and Cellulose, which are not based on starch, are being researched as potential raw ingredients for creating bioplastics. The extraction of the raw materials, followed by their alterations to produce the necessary qualities, is the first

step in the manufacturing of bioplastics. This may entail physical alteration, such as introducing Nano fillers to increase strength and durability, or chemical modification, such as using plasticizers or crosslinking agents [20].
These are the main steps of bioplastic production:

Raw Material Preparation:
Bioplastics can be made from various sources, including cornstarch, sugarcane, Cellulose, and vegetable oils. The first step in the manufacturing process is to extract and prepare the raw materials for use.
Fermentation:
In this process, the raw material is fermented, and the sugar in the raw material is converted to lactic acid.
Polymerization:
Lactic acid is polymerized into polylactic acid (PLA), a biodegradable and compostable plastic.
Moulding:
The PLA is then moulded into the desired shape using injection, blow, or thermoforming techniques [21,22].
Completion:
After the bioplastic product is formed, the excess material is trimmed off, and the edges are smoothed and finished.
Quality Management: The final step in the production process is quality control of the finished bioplastic product to ensure it meets the required specifications and standards. It is important to note that the specific details of the bioplastic manufacturing process may vary depending on the type of raw materials used and the desired end product [23,24,25].

The manufacture of bioplastics can be better understood by looking at the accompanying Fig. 3. Process flow diagram and Fig. 4.

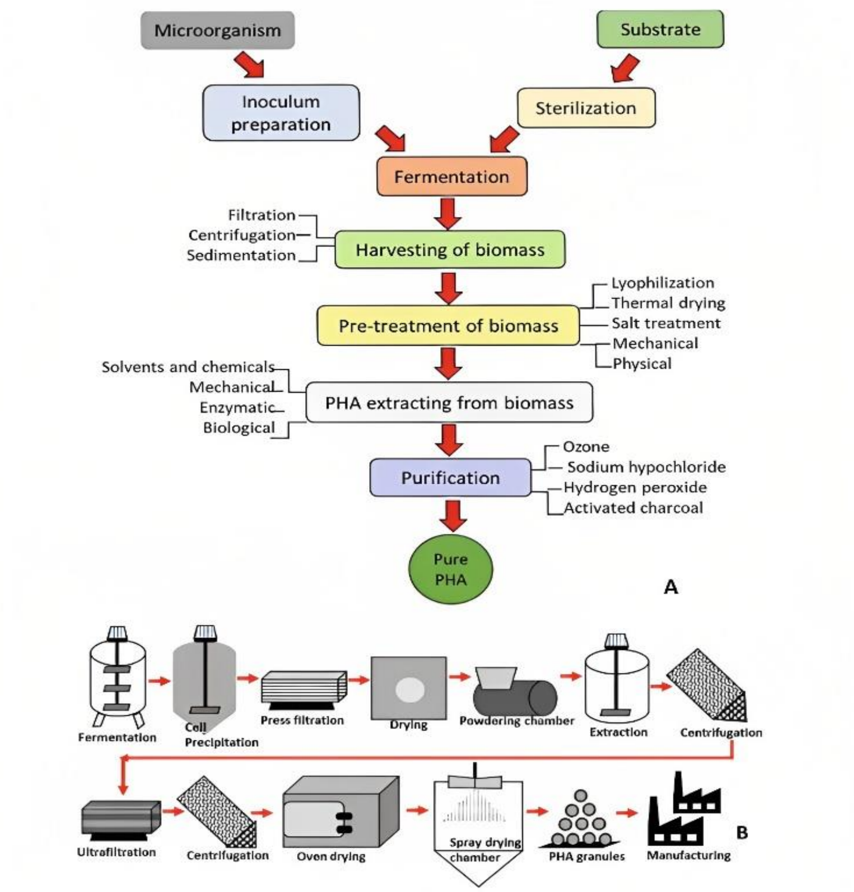

Fig. 3. (A) Basic Production steps, (B) Industrial production steps of Bioplastics. [21].

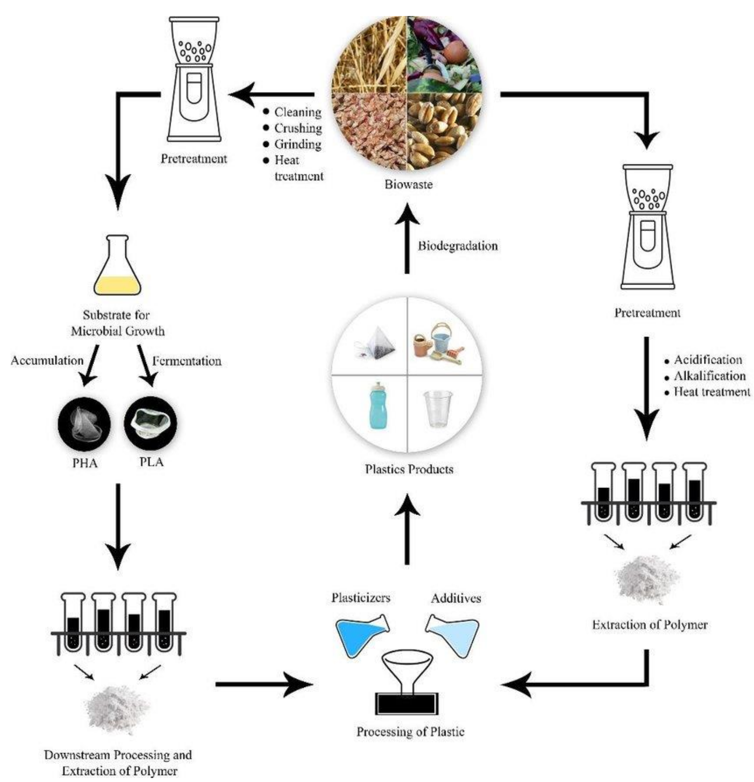

Fig. 4. Production of bioplastics[13].

6 BIODEGRADATION OF BIOPLASTICS

"biodegradation" refers to the process of microorganisms (such as fungi, bacteria, and archaea) mineralizing organic matter to produce carbon dioxide and water as the end products under aerobic conditions. Organic and inorganic metabolites, or transformation products, are created when mineralization is incomplete [26]. The rise in the production of bioplastics and their promising applications in the market has spurred interest in assessing the biodegradation of these materials within the context of waste treatment processes for organic municipal solid waste. Various studies have followed established standards, such as those set by the American Society for Testing and Materials (ASTM), International Organization for Standardization (ISO), and European Standards (EN), which guide factors such as environmental conditions, testing timeframes, and testing scales. These studies have yielded a series of analyses, mainly at the laboratory scale, considering different factors such as waste treatment simulation duration, bioplastic types, film thicknesses, and temperature variations. The outcomes of these studies, however, are heavily influenced by the combinations of these factors affecting the biodegradation of bioplastics[27]. The use of bioplastics as a substitute for fossil-fueled plastics is increasing in popularity. Biodegradable bioplastics, in particular, offer an added advantage as they can generate biogas once utilized[28]. When there is a lack of oxygen, the biodegradation process generates biogas, water, hydrogen sulfide, and ammonia. It is digested due to the activity of microorganisms. In contrast to aerobic composting, organic materials, including bioplastics, deteriorate in anaerobic conditions, particularly in an AD (anaerobic digestion) facility, offering various benefits. These advantages include reducing odour emissions, using the generated methane as an energy source, and providing nutrient-rich digestate that can serve as a fertilizer[29].

7 LIFE CYCLE OF BIOPLASTICS

The Life Cycle of bioplastics involves several steps, beginning with the extraction of the raw materials, refinement, manufacturing, disposal, and ending with composting and renewal. Biodegradable bioplastics, one of the two kinds, go through their entire life cycle, as shown in Fig. 5. Other bioplastics are not biodegradable despite being made from plant-based raw materials. Pollution is being removed from the atmosphere. At the same time, the plants develop, giving bioplastics their "green" appeal [14].

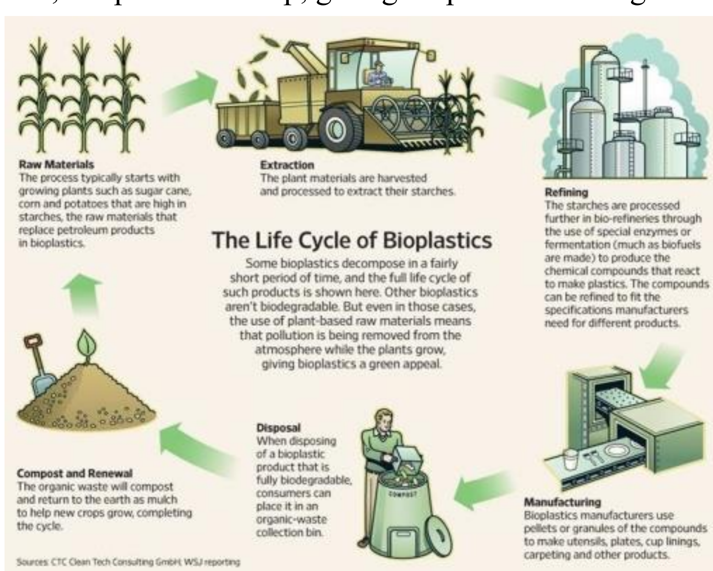

Fig. 5. The life cycle of bioplastics (https://www.sciepub.com/reference/84613)

8 ADVANTAGES OF BIOPLASTICS

8.1 Benefits of Using Biodegradable Bioplastics for Waste Management

To limit the quantity of plastic trash produced by society, grocery store chains, the food service business, and the agricultural sector have successfully implemented bioplastic packaging. Managing biological waste is made simpler by biodegradable plastics. For instance, catering businesses, which dispose of much garbage, including plastic tableware, have started using biodegradable flatware. This has increased the pace of composting and reduced the amount of rubbish gathered and dumped in landfills[30].

8.2 Bioplastics' Carbon Neutrality

Since global warming has become a significant worry, bioplastics have gained more attention as a way to reduce society's overall carbon dioxide (CO2) emissions. Whereas making regular plastics necessitates the net addition of carbon to the atmosphere, the CO2 released by BPs originates from biomass. It may therefore be carbon neutral throughout its existence. Even if the BPs feedstock may be carbon-neutral, bioplastics processing may still be powered by fossil fuels[30].

8.3 Possibility of A Much Smaller Carbon Footprint

It should be noted that whether or not a bioplastic permanently stores the carbon drawn from the air by the growing plant significantly impacts its carbon footprint. A synthetic material derived from living organisms sequesters the CO2 the plant takes during photosynthesis. This sequestration is undone if the resulting bioplastic reverts to CO2 and water. However, a permanent bioplastic that resembles polyethylene or other common plastics can permanently store CO2. The CO2 initially removed from the atmosphere is still trapped in the plastic, even after it has been recycled numerous times[31].

8.4 Reduction in Energy Use (Less Petroleum Dependence)

Possible petroleum shortages are now a significant worry. Compared to the production of conventional plastics, the production of bioplastics uses less fossil fuel. Multilayer films made of polylactic acid had a life cycle assessment that revealed their environmental impact was almost half that of films made of petroleum[30].

8.5 Manufacturing Will Pay Less for Energy

Nevertheless, just 4% of the oil consumed worldwide yearly is used to make plastics. Plastic production is more vulnerable to price fluctuations due to the lack of oil[31].

8.6 Avoid using Limited Crude Oil

In comparison, producing one kilogram of plastic often takes more energy than producing one kilogram of steel or 20 kilowatt hours. About all of this is derived from fossil sources[31].

8.7 Utilizing Biodegradable Bioplastics Results in A Decrease in Litter and An Increase in Composability

The decrease in the persistent litter is the benefit of biodegradable bioplastics that is most understood. Using single-use shopping bags is the most prominent illustration of how plastics may persistently and significantly damage the environment. Disposable plastic bags account for a significant portion of the trash in our waters. Towns and nations worldwide are fighting litter, sometimes by outright banning non-biodegradable plastic bags[31].

8.8 Reduction of CO_2 Emissions

Between 0.8 and 3.2 tons less carbon dioxide is produced per ton of bioplastics than petroleum-based plastics[32].

8.9 Benefits for Rural Economy

As nations worldwide hunt for alternatives to oil to protect the environment and achieve energy security, the price of crops like maize has increased significantly. This is because a growing interest is in manufacturing biofuels and bioplastics worldwide [32].

9 Disadvantages of Bioplastics

9.1 High Production Cost

The cost of producing bioplastics is higher than that of traditional plastic. If the usage of bioplastics on a large industrial scale spreads, it will likely result in cost savings. The cost of producing bioplastics is more than twice as high as that of ordinary plastics. Several studies have supported this assertion[33].

9.2 Bioplastics Have Weak Mechanical Properties

Packaging materials comprised of starch and cellulose-based plastics have low long-term stability, poor processability, brittleness, and inferior mechanical properties because of their hydrophilic nature. The limited mechanical strength of bioplastics frequently restricts their use. It uses other environmentally hazardous components such as carbon, glass, nano clay, fiber, and nanoparticles[33].

9.3 Uncertainty Among Consumers

Most bioplastics' labels and identifications do not give customers enough information. This creates uncertainty and makes it challenging to handle bioplastics correctly. This results from the manufacturers' inadequate information delivery[33].

9.4 The Stockpiles of Raw Materials Used to Make Bioplastics Can Decline

In order to reduce energy consumption during the production of bioplastics, prevent potential competition with agricultural resources for food, and provide new sources of raw materials, it is also becoming more popular to utilize food byproducts[34].

9.5 Isolated Recycling

A contamination issue may be if bioplastic material is recycled with regular plastics[32][34].

9.6 Toxins Can Be Formed

The inefficient breakdown of plastic caused by improper disposal of biodegradable plastics can result in the release of pollutants (such as carbon dioxide and methane) into the environment[33][34].

10 Applications of Bioplastics

When made into hydrophilic matrices, natural polymers and polysaccharides are well-liked in biomaterials for controlled-release dosage forms because they lengthen release dosage form[7]. The construction and building business has been one of the significant areas of exciting bioplastic investigation. Using bioplastics for various items, such as a fence, decking, and other uses, is appealing to builders and homeowners[7]. Bioplastics are used in electroacoustic device manufacturing firms as a membrane for high-quality sound. The benefit of using this type of material is that it produces a sound that is as delicate and fast-moving as one made of titanium or aluminium. Also, it creates bass notes that are incredibly deep and trebles that are brilliantly pure[7]. Many biomedical applications, such as bone plates, screws, tissue engineering scaffolds, and drug delivery systems, utilize biodegradable bioplastics[32]. Packaging made of plastic is more durable and thinner than more recent alternatives. Unfortunately, the short packaging lifespan (usually six months) results in significant waste. Biodegradable packaging helps reduce the overall environmental impact[35].

11 Future prospects

Bioplastic has emerged in recent years as an innovative and eco-friendly material. While it is widely viewed as a promising alternative to traditional chemical-based plastics, several challenges still need to be addressed. These include improving mechanical properties such as heat and shock resistance, enhancing processability, expanding the range of applications, developing industry standards, and reducing production costs. Researchers are currently studying ways to overcome these obstacles, including exploring new plasticizers and creating composite polymers to improve mechanical properties. A fundamental way to increase the sustainability of the production process is to identify suitable biological sources - particularly from waste products. If these efforts are successful, bioplastics could be extended across various industries, leading to rapid growth in this sector.

12 Conclusions

To sum up, the rise of bioplastics is a hopeful advancement in the pursuit of sustainable materials. By utilizing renewable resources, they have the potential to decrease the ecological effects of conventional plastics. Nevertheless, it is crucial to note that not all bioplastics are alike. Further investigation is necessary to identify the optimal materials and manufacturing methods. Although bioplastics are replaced with traditional chemical-based plastics, there is no point if people's mindsets do not change. Moreover, it is essential to dispose of bioplastics correctly to prevent harmful environmental consequences. While facing severe concerns regarding climate change and resource exhaustion, bioplastics could be a valuable step towards achieving a more sustainable tomorrow.

13 References

[1] Kumar Y, Shukla P, Singh P, Prabhakaran PP, Tanwar VK. Bioplastics: A perfect tool for Eco-friendly food Packaging: A Review. Journal of Food Product Development and Packaging. 1(1), 01-06, 2014.

[2] Gadhave, R. V., Das, A., Mahanwar P. A., Gadekar, P. T. Starch Based Bio-Plastics : The Future of Sustainable Packaging. Open Jounal of Polymer Chemistry. 8, 21–33, 2018.

[3] Gadhave RV, Das A, Mahanwar PA, Gadekar PT. Starch-based bioplastics: The Future of Sustainable Packaging. Open Journal of Polymer Chemistry. 2018; 8(2): 21-23

[4] Ezgi Bezirhan Arikan and Havva Duygu Ozsoy. A Review: Investigation of Bioplastics. Journal of Civil Engineering and Architecture 9, 01-04, 2015.
DOI: 10.17265/1934-7359/2015.02.007

[5] S. Thakur, J. Chaudhary, B. Sharma, A. Verma, S. Tamulevicius, V.K. Thakur, Sustainability of Bioplastics: Opportunities and Challenges, Current Opinion in Green and Sustainable Chemistry (2018),
DOI: 10.1016/j.cogsc.2018.04.013.

[6] Sushmitha, B. S., Vanitha, K. P., Rangaswamy, B. E. Bioplastics - A Review. International Journal of Modern Trends in Engineering and Research. 3 (4), 411–413, 2016.

[7] Izathul Shafina Sidek, Sarifah Fauziah Syed Draman, Siti Rozaimah Sheikh Abdullah, Nornizar Anuar. CURRENT DEVELOPMENT ON BIOPLASTICS AND ITS FUTURE PROSPECTS: AN INTRODUCTORY REVIEW. i TECH MAG. 1,

01-03, 2019.
DOI: http://doi.org/10.26480/itechmag.01.2019.03.08

[8] Law, K. L. "Plastic Accumulation in the North Atlantic Subtropical Gyre." Science 329: 1185-8. 2010.

[9] European bioplastics conference, Bioplastics development update 2022. December 2022. Online available at: https://docs.european-bioplastics.org/publications/market_data/2022/Report_Bioplastics_Market_Data_2022_short_version.pdf

[10] SATISH KUMAR, KS THAKUR. Bioplastics - classification, production and their potential food applications. Journal of Hill Agriculture 8(2): 118-129, April – June 2017
DOI 10.5958/2230-7338.2017.00024.6

[11] Oberti, I.; Paciello, A. Bioplastic as a Substitute for Plastic in Construction Industry. Encyclopedia 2022, 2, 1408–1420. https://doi.org/10.3390/ encyclopedia2030095

[12] Di Bartolo, A.; Infurna, G.; Dintcheva, N.T. A Review of Bioplastics and Their Adoption in the Circular Economy. Polymers 2021, 13, 1229. https://doi.org/10.3390/ polym13081229

[13] George N, Debroy A, Bhat S, Singh S, Bindal S. Biowaste to Bioplastics: An Ecofriendly Approach for A Sustainable Future. J Appl Biotechnol Rep. 2021;8(3):221-233. doi:10.30491/JABR.2021.259403.1318

[14] Manali Shah, Sanjukta Rajhans, Himanshu A. Pandya and Archana U. Mankad. Bioplastic for future: A review then and now. World Journal of Advanced Research and Reviews, 2021, 09(02), 056–067
Article DOI: https://doi.org/10.30574/wjarr.2021.9.2.0054

[15] Arnab Chatterjee, Sumitava Khan. Bioplastics: A Sustainable and Environment-Friendly Alternative to Plastics. World Journal of Environmental Biosciences. Volume 11, Issue 4: 16-19
DOI: https://doi.org/10.51847/cHZ39jkw1g

[16] Ilyas RA, Sapuan SM, Sanyang ML, Ishak MR. Nanocrystalline Cellulose reinforced starch-based nanocomposite: A review Conference: 5th postgraduate senior on natural fiber composites. At University Putra Malaysia. 2016; 82- 87.

[17] Soykeabkaew N, Tawichai N, Thanomsilp C, Suwantong O. Nanocellulose Reinforced Green Composite Materials. Walailak Journal Science & Technology. 2017; 14(5): 353- 368

[18] Lackner M. Bioplastics – Biobased plastics as renewable and/or biodegradable alternatives to petroplastics. Kirk-Othmer Encyclopedia of Chemical Technology. 2015.

[19] Emadian SM, Onay TT, Demirel B. Biodegradation of bioplastics in natural environments. Waste Management. 2017; 59(1): 526-536.

[20] Chethan V Ghorpade, Swathi K S, Sai Charitha Shetty M M, Chetan C J, T P Krishna Murthy. Bioplastics Production and Applications: A Mini Review. International Journal for Scientific Research & Development| Vol. 10, Issue 2, 2022 | ISSN (online): 2321-0613

[21] Arikan, Ezgi & Bouchareb, Esma & Bouchareb, Raouf & Yagci, Nevin & Dizge, Nadir. (2021). Innovative Technologies Adopted for the Production of Bioplastics at the Industrial Level. 10.1007/978-981-16-1823-9_3.

[22] Dr.-Ing. Andreas Schütte. Processing of Bioplastics - a guideline. 1st English edition, September 2016. Online Available at: https://www.ifbb-hannover.de/files/IfBB/downloads/EV_Processing-of-Bioplastics-2016.pdf

[23] Senem Onen Cinar, Zhi Kai Chong, Mehmet Ali Kucuker , Nils Wieczorek , Ugur Cengiz, Kerstin Kuchta. Bioplastic Production from Microalgae: A Review. In*ternational Journal of Environmental Research and Public Health.* 2020, 17, 3842; doi:10.3390/ijerph17113842

[24] Neudecker, Marco & Endres, Hans-Josef. (2015). Bioplastics injection moulding Closing the knowledge gap in bioplastics injection moulding operations. Bioplastics Magazine. 18-19.

[25] Rolf Koster, Kim Ragaert. Bioplastics Injection Moulding And Modern Mould Opportunities. PMI 2007

[26] Emma M.N. Polman , Gert-Jan M. Gruter , John R. Parsons , Albert Tietema. Comparison of the aerobic biodegradation of biopolymers and the corresponding bioplastics: A review. Science of the Total Environment. Volume 753, 20 January 2021, 141953.

[27] Federica Ruggero , Riccardo Gori ,Claudio Lubello. Methodologies to assess biodegradation of bioplastics during aerobic composting and anaerobic digestion: A review. Waste Management & Research. 2019, Vol. 37(10) 959–975. https://doi.org/10.1177/0734242X198541.

[28] Ankita Shrestha , Mieke C. A. A. van-Eerten Jansen , Bishnu Acharya. Biodegradation of Bioplastic Using Anaerobic Digestion at Retention Time as per Industrial Biogas Plant and International Norms. Sustainbility. 21 May 2020

[29] Adele Folino , Aimilia Karageorgiou , Paolo S. Calabrò ,Dimitrios Komilis. Biodegradation of Wasted Bioplastics in Natural and Industrial Environments: A Review. Sustainability. 27 July 2020.

[30] Eri Matsuura, Yan Ye, Xiaoxuan He. Sustainability Opportunities and Challenges of Bioplastics. School of Engineering Blekinge Institute of Technology Karlskrona, Sweden. 2008

[31] BIOPLASTIC: A BETTER ALTERNATIVE TO PLASTICS. IMPACT: International Journal of Research in Applied. 2347-4580 Vol. Aug 2014, 115-120

[32] R. Laxmana Reddy, V. Sanjeevani Reddy, G. Anusha Gupta. Study of Bio-plastics As Green & Sustainable Alternative to Plastics. International Journal of Emerging Technology and Advanced Engineering. Volume 3, Issue 5, May 2013.

[33] Yusuf Sarkingobir,Abdulmudalib Abdullahi Lawal. Bioplastics: Their Advantages and Concerns. STM JOURNALS. Volume 11, Issue 1, 2021. DOI (Journal): 10.37591/JoMME.

[34] Arnab Chatterjee, Sumitava Khan. Bioplastics: A Sustainable and Environment-Friendly Alternative to Plastics. World Journal of Environmental Biosciences. Volume 11, Issue 4: 16-19. 2014.

[35] Taofeeq D. Moshood,Gusman Nawanir,Fatimah Mahmud,Fazeeda Mohamad,Mohd Hanafiah Ahmad,Airin Abdul Ghani. Expanding Policy for Biodegradable Plastic Products and Market Dynamics of Bio-Based Plastics: Challenges and Opportunities. Sustainability. 30 May 2021. https://doi.org/10.3390/su13116170