Review Paper:

Development of an eco-friendly biodegradable plastic from various biomass materials and its characterization: A review

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Abstract

The synthetic and conventional plastic production and use have become one of the driving forces behind environmental change due to unparalleled world pollution of land and sea The synthetic plastic has been used in variety of benefits due to inexpensive, robust, aesthetically pleasing, lightweight and it comes in various shapes, sheets, panels, films. These plastics cause harm to the people and environment due to the nature of its non-biodegradability. It takes more than 500 years to degrade and will become toxic in nature after decomposed. There is a need of development of sustainable material as biodegradable plastic. The study focuses on producing bioplastics from biomass and proves to be an innovative solution to protect humans and the environment. The objective of the current study is to produce biodegradable plastic from various biomasses as an alternative for the synthetic plastic and to prove that the various biomasses could be used in the production of the biodegradable plastic, which can provide a sustainable and eco-friendly alternative to conventional plastics. Bioplastics, derived from renewable sources such as fruit waste, are biodegradable, compostable and can reduce carbon footprint.

The main objective of the present study is to know the properties of bioplastic of its strength, chemical compositions and physical properties and characterization using FTIR (Fourier Transform Infrared Spectroscopy), Scanning electron microscope (SEM) analysis, one of the most significant results obtained such as tensile properties, elongation at break, the bioplastic's modulus obtained during the research is degradation tractability nature of the bioplastic. The data obtained was used to determine suitability for different types of industrial and commercial use.

Keywords: Biomass, Biodegradable plastic, Eco friendly.

Introduction

Plastics, synthetic and semi-synthetic materials, are primarily composed of polymers, long-chain molecules from fossil fuels. These chains, which can be branching or straight, are determined by their joining pattern. Due to their adaptability and diverse uses, plastics are versatile material with a wide range of applications due to their unique chemical structure[28]. Plastic is lightweight, durable and adaptable, making it ideal for long-lasting appliances and furniture. Its shape-changing potential allows for versatile construction. Plastic can withstand water, making it suitable for items in or near water. Additionally, it is less expensive to produce, making it an affordable choice for various uses[7].

Uses of Plastics: Plastic's lightweight, strength and adaptability make it a popular material for packaging. It is employed in the packaging of food products, drinks, medications, cosmetics etc. Products' shelf lives are extended, contamination is avoided and freshness is maintained with the use of plastic packaging. Plastic is utilized in the construction sector for a variety of purposes including windows, floors, roofing, insulation, fittings and pipelines. Plastic materials are suited for construction because of their flexible, inexpensive, corrosion-resistant and simple-to-install qualities[2]. A vast range of components, including dashboards, bumpers, interior trims, external panels and under-the-hood elements, are made from plastic in the vehicle sector. They contribute to lighter vehicles, more safety, better fuel economy and more design freedom.

In the electronics business, plastics are used to make connections, casings, enclosures and insulating materials for a wide range of electronic products including computers, televisions, cell phones and appliances. In addition to being lightweight and flexible in design, plastic materials provide electrical insulation. Plastics are used in the production of medical equipment, disposable syringes, bags, surgical tools, prosthetic devices and pharmaceutical packaging. Plastic materials are appropriate for use in medical applications because of their chemical resistance, sterility and flexibility. Plastic is utilized in the manufacturing of a large variety of consumer products including kitchenware, toys, furniture, appliances, bottles and containers. Plastic materials are popular alternatives for consumer items because they are inexpensive, long-lasting and versatile in design[19].

Plastic impacts ecosystems through direct and indirect effects, causing life-threatening situations like bird consuming plastic pellets and environmental imbalances caused by invading species[11]. Plastic, used for short-term purposes, often ends up in landfills due to UV breakdown and microbiological degradation. Microplastics penetrate soil, form barriers and potentially cause plant extinction. Marine creatures, crustaceans and corals ingest microplastics, leading to ingestion, bleaching and bioaccumulation in higher predators[24].

What is Bioplastic?
Biodegradable polymers derived from renewable resources are known as bioplastics. Potato starch, maize starch, pineapple fibers, jute, hemp, banana stems, cassava, newspaper pulp, wastepaper, Prosopis Juli flora, citrus waste, cyanobacteria, *Pseudomonas putida* and Bacillus sp. are examples of renewable sources. It has been highly encouraged in recent years to use innovative methods for producing bioplastics that stimulate sustainable solutions and cut down on plastic waste. Corn is a major source of starch, although starches from potatoes, wheat, rice, barley, oats and other plants are widely utilized nowadays. It is possible for bacteria, fungus and algae to break down bio-based polymers. These polymers are significant new materials of the twenty-first century. These are now utilized as packing materials, but they will also be employed in the future to manufacture other things including car components and electronics[5].

Properties of bioplastic: One of the main benefits of bioplastics is their capacity to break down naturally under specific circumstances, in contrast to traditional plastics made from petroleum. The material and ambient conditions affect biodegradability. Under industrial composting settings, some bioplastics, such PLA (polylactic acid), can biodegrade[28]. Corn, sugarcane, or wood pulp cellulose are examples of renewable biomass sources that are commonly used to make bioplastics. This use of renewable resources can lessen the carbon footprint brought on by the manufacture of plastic[13]. Tensile strength, flexibility and durability are just a few of the many mechanical qualities that bioplastics may display. These characteristics, however, might differ greatly based on the precise composition and processing techniques applied[4].

Certain bioplastics can be used in packaging because of their ability to function as a barrier against oxygen, moisture and other environmental elements, protecting food and other perishable items[25]. Bioplastics are quite straightforward to incorporate into current manufacturing processes since they can frequently be processed utilizing the infrastructure and equipment already in place in the plastics sector[15].

Biomass to produce bioplastic: Bioplastics may be made by cultivating algae. Because of their quick development and little resource needs, algae-based bioplastics have the potential to be a more sustainable biomass source than certain other biomass sources[29]. Oils from soybeans may be converted into bioplastics. Applications for soy-based bioplastics are numerous, ranging from automobile parts to packaging[26]. Another popular source for bio-plastic production is sugarcane. Bioplastics made from sugarcane are frequently utilized in packaging and throwaway goods[9]. Plant cell walls include lignin, a complex organic polymer. It is a byproduct of several industrial operations, including the manufacturing of paper and biofuel. Because they make use of a waste product, lignin-based bioplastics have the potential to be more ecologically beneficial[17].

Fruits used to produce bioplastic
1. Orange peels: Orange peels, rich in cellulose, hemicellulose, lignin and pectin, are a good source of natural substances, making them ideal for producing bioplastics[18]. The process of extracting cellulose from orange peels involves cleaning and drying the peels, followed by mechanical or chemical procedures to isolate the cellulose fibers. Mechanical techniques like grinding or milling are used to disintegrate the peels. The cellulose fibers are then transformed into bioplastic materials by mixing them with biopolymer matrices like starch, polylactic acid, or polyhydroxyalkanoates, which act as binding agents, creating a durable bioplastic material[10].

2. Banana peel: Bananas, with 102 million tons of fresh fruit produced annually, make up 35% of the fruit's weight. With 26 million tons produced annually, banana peels have potential for future use due to their high nutritional value. The majority of banana peels are water and carbohydrates, with starch as a carbohydrate. Biodegradable polymers can be made with a significant amount of starch content. Overripe peels release glucose, while underripe peels retain high starch content but become rigid[6].

3. Cassava starch: Cassava starch, abundant and affordable, is an eco-friendly, biodegradable and versatile resource grown in tropical locations. It can be converted into various bioplastics with unique properties like flexibility, transparency and water resistance. Cassava starch can also be easily combined with other biodegradable polymers or additives to enhance its mechanical properties such as tensile strength. This makes it an eco-friendly alternative to traditional plastics[1].

4. Pomegranate peel: Pomegranate peels, rich in polyphenolic substances like flavonoids and tannins, have been studied for their potential as antibacterial and antioxidant agents in various applications including plastic manufacturing. Dietary fibers can influence the mechanical properties of bioplastics, as reinforced bioplastics exhibit greater strength and stiffness compared to conventional plastics. Pomegranate peels, as organic materials, can biodegrade in the right environment and their inclusion in bioplastics could enhance their environmental friendliness and biodegradability[14].

Methods of production of bioplastics
Chemical-based bio plastic: Chemical processing is crucial for extracting cellulose from banana peels and producing bioplastics. Alkaline therapy breaks down lignin and

hemicellulose components, leaving cellulose. This process separates cellulose fibers from other organic substances. Acid treatment, such as sulfuric acid, hydrolyses hemicellulose and other constituents, facilitating the separation of cellulose fibers. After both treatments, a hydrolysis phase occurs, where cellulose fibers are separated from the organic substances. This process is essential to produce bioplastics[21].

Natural based bio plastics: Bioplastics that are based on natural resources including plants, algae, or even animal waste, are known as natural-based bioplastics. They provide a greener substitute for conventional plastics made from petroleum. Polylactic acid (PLA) is a popular natural-based bioplastic derived from sustainable sources like sugarcane or maize starch. It has strong mechanical properties and can be composted for industrial use. Starch-based bioplastics, produced from potatoes, wheat and maize, are often combined with other biodegradable polymers for enhanced mechanical properties. They are used in industries like packaging, textiles and 3D printing. Cellulose-based bioplastics are based on naturally occurring polymers[23].

Testing method

1. Tensile test: Tensile test was carried out using universal tensile testing machine to determine numbers of factors such as strength, elongation, Young's modulus. The results are calculated automatically using software. It can be calculated manually using the formulas[24]:

Tensile strength (N/mm^2):

$$\sigma\gamma = F / Ao \tag{1}$$

where F is force required to break (N) and A is cross sectional area(mm2).

Elongation:

$$\% E = (L_f) - (L_o) / (L_o) \times 100\% \tag{2}$$

where L_f is Final length (mm) and L_o is Original length (mm).

Young's modulus(N/mm^2):

$$E = \sigma / \varepsilon \tag{3}$$

where σ is Tensile stress and ε is Tensile strain.

Water solubility:

$$solubility\ \% = \frac{initial\ mass - mass\ after\ test}{initial\ mass} x100 \tag{4}$$

2. Water Absorption: Water absorption measures how much water is absorbed under specified conditions and parameters. The bioplastic's concentration of corn starch utilized correlated with how much water it absorbed.

3. Biodegradability: The ability of organic materials to be biologically broken down by living things is known as biodegradability. The time it takes for bioplastic to decompose may vary depending on the materials and manufacturing processes used. The maximum level of biodegradability is exhibited by bioplastic, which breaks down before it can perform its whole purpose.

Mechanism

- Hydrochloric acid is utilized to hydrolyse amylopectin, which aids in bioplastic production by forming H-bonds between glucose chains in starch. Amylopectin inhibits film formation[16].
- In this experiment, sodium hydroxide is used to neutralize the medium's pH[12].
- Plasticizers, often known as dispersants, improve a material's plasticity or fluidity. Plastics, namely PVC, glycerol and sorbitol, are the most common uses[22].

Discussion

The bioplastic based on chemicals was shown to have a greater tensile strength. Because of the high starch content, natural based bioplastic has a poor tensile strength. Tensile strength drops with increasing starch content because of the filler-filler interaction being more pronounced. A combination of chemicals and banana peels can be used to increase the tensile strength. This behavior may also be due to variations in the plasticizer's concentration[20]. Materials derived from natural sources have a higher modulus of elasticity than those derived from chemicals. It demonstrates how much greater the natural-based composite stiffness was than the chemical-based one. One can say that the propagation of stress, which results in an increase in stiffness, is involved in the increase in Young's modulus. This is most likely a result of the composites made with natural ingredients having a larger amount of starch.

The polymer chain in the composites has a stronger bond because of the increased starch content[27]. The inclusion of glycerol increases the percentage elongation of chemical-based bioplastic because the plasticizer enhances the plastic's plasticity behavior[29]. Bioplastic samples derived from both natural and chemical sources were collected. Natural materials were far less expensive than chemical materials. It was also easier to get than a chemical, which is difficult to find and is possibly dangerous. Bioplastic composites made with natural materials are robust and durable, whereas those made with chemicals are delicate and fragile.

Conclusion

Fruit peels can be used to produce biodegradable plastic, which is a possible solution to various environmental problems. Bioplastics derived from chemical and natural sources exhibit varying tensile strength, with chemicals having greater strength and natural-based bioplastics having poorer strength due to high starch content. Natural-based materials have a higher modulus of elasticity, likely due to increased starch content and stronger bonds in polymer chains. Chemical-based bioplastics have a higher percentage elongation due to plasticizer enhancement. Natural materials are less expensive and easier to obtain than chemical materials, making bioplastic composites more robust and durable.

The process of turning fruit peels into biodegradable plastic shows great promise, while research is still underway. With more developments in process optimization, material property enhancement and production scaling, this technology has the potential to become a major weapon in the fight against plastic pollution and the pursuit of a more sustainable future.

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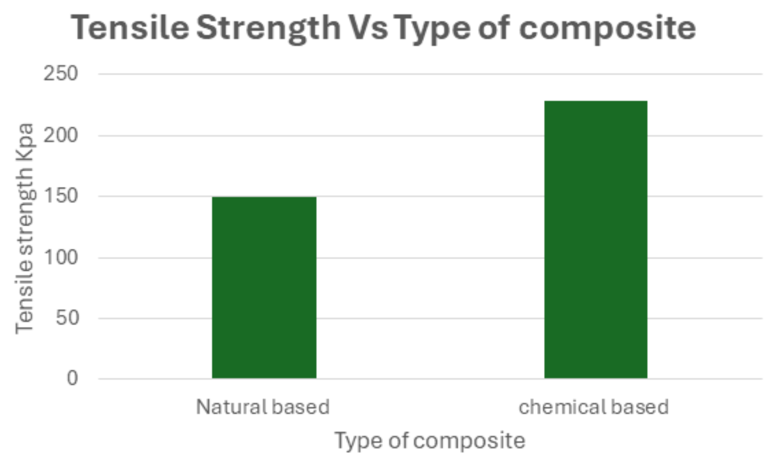

Fig. 1: The effect of tensile strength Vs the type of composite

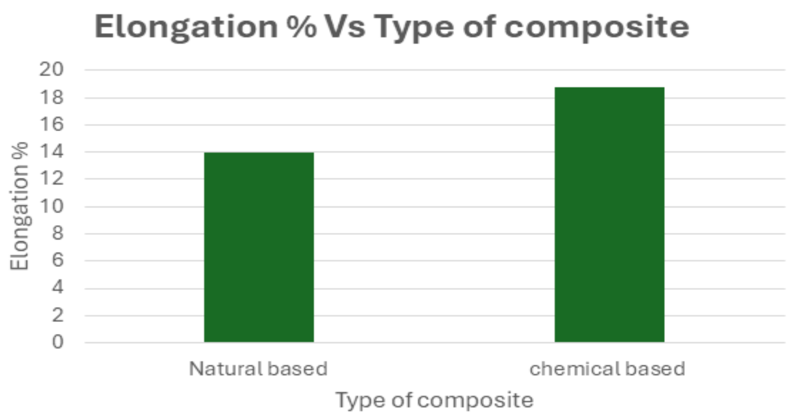

Fig. 2: The effect of percentage of elongation Vs the type of composite

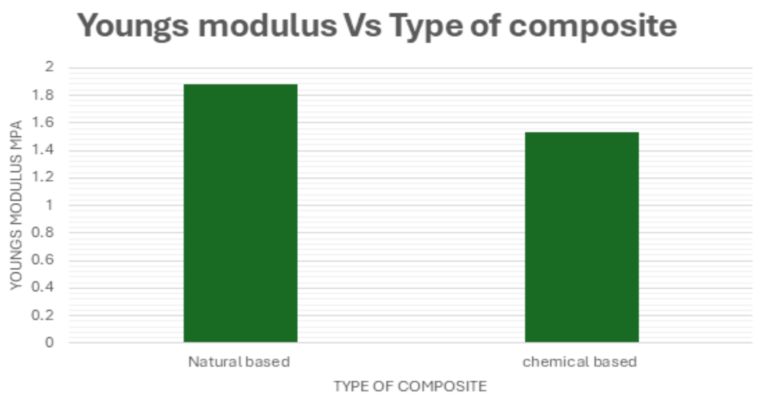

Fig. 3: The effect of Young's Modulus Vs the type of composite

References

1. Abidin N.D.Z., Azhar N.S., Sarip M.N., Hamid H.A. and Nasir N., Production of bioplastic from cassava peel with different concentrations of glycerol and $CaCO_3$ as filler, AIP Conference Proceedings **(2021)**

2. Avella M., De Vlieger J.J., Errico M.E., Fischer S., Vacca P. and Volpe M.G., Biodegradable starch/clay nanocomposite films for food packaging applications, *Food Chemistry*, **93(3)**, 467- 474 **(2005)**

3. Azkiya N.I. et al, The Potential of Cassava Peel Waste as a Material of Biodegradable Plastic using Calcium Silicate Filler, *Journal Teknik Kimia dan Lingkungan*, **7(2)**, 85-91 **(2023)**

4. Banerjee Amrita, Mitra Debanjan, Das Biswajit, Das Mohapatra Pradeep Kumar and Samanta Saptadip, Molecular Characterization of Alpha-Amylase of *Aspergillus flavus* and *Aspergillus oryzae*: An *In Silico* Study, *Res. J. Biotech.*, **19(3)**, 76-85 **(2024)**

5. Bezirhan Arıkan and Bilgen, Production of bioplastic from potato peel waste and investigation of its biodegradability, *International Advanced Research and Engineering Journal*, **3(2)**, 093-097 **(2019)**

6. Cadenas-González M.T., Leo-Avelino G. and Hernández-Córdova R., Mechanical and thermal properties of bioplastic film obtained from orange peel, *Research Square*, https://doi.org/ 10.21203/rs.3.rs-1950220/v1 **(2022)**

7. Campos K., Castro Y., Castañeda C., Valverde J. and Benites E., Carya illuminances shell for made biodegradable food-safe packaging, Congreso Internacional de Innovation y Tendencies en Ingenerate (CONIITI), Bogota, Colombia, IEEE Xplore, Proceeding, 1-4 **(2021)**

8. Chandarana J. and Chandra S., Production of Bioplastics from Banana Peels, *International Journal of Scientific Research & Engineering Trends*, **7(1)**, 131-133 **(2021)**

9. Gaonkar M.R., Palaskar Prashant and Navandar Rishikesh, Production of Bio plastic From Banana Peels, *International Journal of Advances in Science Engineering and Technology*, **6(1)**, 36-38 **(2018)**

10. Kshirsagar A.B., Production of biodegradable plastics from different crops, Research Gate **(2021)**

11. Listyarini R.V., Susilawati P.R., Nukung E.N. and Yua M.A.T., Bioplastic from Pectin of Dragon Fruit (Hylocereus polyrhizus) Peel, *Journal Kimia Sains Dan Aplikasi*, **23(6)**, 203–208 **(2020)**

12. Marsi N., Huzaisham N.A., Hamzah A.A., Zainudin A.Z., Rus A.Z.M., Leman A.M. and Darlis N., Biodegradable plastic based on orange peel for packaging application, *Journal of Design for Sustainable and Environment*, **1(2)**, 1- 6 **(2019)**

13. May Zon Kyawt Oo, Myo Thu and Zin Nyi Nyi Tun, Bioplastics from Fruit Waste, *International Journal of Advances in Scientific Research and Engineering (IJASRE)*, **5(8)**, 209-215 **(2019)**

14. Menaka Priya Balaji and Devi Rajeswari V., Endothelial Dysfunction associated with Diabetes Mellitus linked to extracellular signal-regulated kinase and inflammatory pathways, *Res. J. Biotech.*, **18(1)**, 135-146 **(2023)**

15. Nishi K.A., Orange is the new plastic: biodegradable plastic from orange peel, Research Gate **(2021)**

16. Nur Athirah Huzaisham and Noraini Marsi, Utilization of banana (musa paradisiaca) peel as bioplastic for planting bag application, *International Journal of Advanced Research in Engineering and Technology (IJARET)*, **11(4)**, 108-118 **(2020)**

17. Nur Farhana Fadzil and Siti Amira Othman, Preparation and Characterization of orange peels for Commercial plastic: a review, *International Journal of Advanced Research in Engineering Innovation*, **3**, 97–102 **(2021)**

18. Orencia R.M., A Wahida Abdul Rahman, Muhammad Syafiq Kamaruddin1, Noradurrah Samsudin, Nur Azfira, *Azizan Scientific Research Journal*, **20**, 55-74 **(2023)**

19. Pavithra Amritkumar and Jeenusha K.S., Production of biodegradable food packaging material from Musa (Banana plant) leaves by eco-friendly methods, *IOSR Journal of Environmental Science, Toxicology & Food Technology*, **14(4)**, 01–05 **(2020)**

20. Razak S.N.A., Yahaya N.A., Rohmadi R.N.A. and Nordin N.S., Biodegradable Banana Peels-Based Plastic – A Review, *Multidisciplinary Applied Research and Innovation*, **1(1)**, 38-44 **(2020)**

21. Reshmy R., Philip E., Vaisakh P.H., Raj S., Paul S.A., Madhavan A. and Pandey A., Development of an eco-friendly biodegradable plastic from jack fruit peel cellulose with different plasticizers and Boswellia serrata as filler, *Science of the Total Environment*, **767**, 144285 **(2021)**

22. Rizwana Beevi K., Sameera Fathima A.R., Thahira Fathima A.I., Thameemunisa N., Noorjahan C.M. and Deepika T., Bioplastic Synthesis Using Banana Peels and Potato Starch and Characterization, *International Journal of Scientific & Technology Research*, **9(1)**, 1809-1814 **(2020)**

23. Rusianto T., Yuniwati M., Wibowo H. and Akrowiah L., Biodegradable plastic from Taro tuber (Xanthosoma sagittifolium) and Chitosan, *Saudi J. Eng. Technol*, **4(1)**, 16-22 **(2019)**

24. Samira Syed, The Development of Bio-composite Films from Orange Waste, *Chemical Engineering – Applied Biotechnology*, DOI:10.13140/RG.2.2.30520.21760 **(2021)**

25. Sharmila S., Teja P.R., Gupta D., Lakshmi P.K., Kamalambigeswari R. and Rebecca L.J., Bioplastic production using corn starch with natural fillers & its semeds report, *Plant Archives*, **21(1)**, 286-289 **(2021)**

26. Senem Onen Cinar, Zhi Kai Chong, Mehmet Ali Kucuker, Nils Wieczorek, Ugur Cengiz and Kerstin Kuchta, Bioplastic Production from Microalgae: A Review, *International Journal of Environmental Research and Public Health*, **17**, 3842 **(2020)**

27. Tuates Jr. A.M. and Caparino O.A., Development of biodegradable plastic as mango fruit bag, *International Journal on Advanced Science and Engineering*, **6(5)**, 799-806 **(2016)**

28. Yaradoddi J.S. et al, Bio-based material from fruit waste of orange peel for industrial applications, *Journal of Materials Research and Technology*, **17**, 3186-3197 **(2022)**

29. Zhao X., Wang Y., Chen X., Yu X., Li W., Zhang S., Meng X., Zhao Z., Dong T., Anderson A., Aiyedun A., Li Y., Webb E., Wu Z., Kunc V., Ragauskas A.J., Ozcan S. and Zhu H., Sustainable bioplastics derived from renewable natural resources for food packaging, *Matter*, **6(1)**, 97–127 **(2023)**.

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