

Exploring Jackfruit (*Artocarpus heterophyllus*) Peel Waste for Eco-Friendly Bioplastics: A Sustainable Substitute for Traditional Plastics

Veena Somannagari¹, M.E Rani²

^{1,2}Department of Chemistry, Rayalaseema University, Kurnool- 518007, Andhra Pradesh, India

Abstract

As concerns about the environmental impacts of traditional plastics increase, sustainable alternatives are growing in popularity. A possible way to reduce plastic waste and its negative effects on the environment is to use bioplastics, which are made from renewable sources. In this talk, the manufacture of bioplastics from jackfruit peel—a plentiful agricultural byproduct—is the main topic. Due to its size and variety of culinary uses, jackfruit (*Artocarpus heterophyllus*) creates a significant amount of peel waste, creating a potential opportunity for value addition. These lignin-, polysaccharide-, and cellulose-rich peels are used as a feedstock to make biopolymers. Biopolymer films have increased flexibility and tensile strength because to the plasticizer glycerol. The bio-based origin of these films is confirmed by characterizing methods such X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and scanning electron microscopy. Understanding their interaction with soil microorganisms is essential for biodegradation, which affects the nitrogen cycle in the soil. In conclusion, using jackfruit peel as a bioplastic feedstock offers viable route toward eco-friendly plastic substitutes.

Keywords: Biopolymers; Jackfruit waste; Biodegradable; Soil microbes; Environment.

1. INTRODUCTION

The need for sustainable alternatives to traditional plastics has never been greater than it is now, when plastic pollution is a prevalent and growing concern for the whole world community[1]. Plastic garbage is clogging up landfills, seas, and ecosystems all around the world as a result of the pervasive use of single-use plastics in daily life. The search for environmentally sustainable solutions has significantly accelerated in response to this challenge[2]. Bioplastics have evolved as one of these alternatives that shows promise for reducing the negative effects of plastic usage on the environment[3].

This study explores the creative synthesis of bioplastics made from jackfruit peel waste, a plentiful and underused resource. The major goal of this work is to manufacture biodegradable and environmentally friendly polymers by using the jackfruit peel's natural biopolymer content through an acidification process and the addition of a suitable plasticizer, such as glycerol[4]. The urgent need to reduce the usage of single-use plastics and switch to sustainable, bio-based alternatives is the main driving force behind this study.

Tropical fruit known as jackfruit (*Artocarpus heterophyllus*) is popularly consumed around the world and is prized for its delectable pulp. The peel, which is typically thrown out as garbage, contains important biopolymers that may be turned into bioplastics that have the potential to solve a number of

pressing environmental problems[5]. Jackfruit peel-based bioplastics have several benefits over their traditional equivalents. One of their most noticeable benefits is their quick decomposition rate, which considerably lessens the ongoing issue of plastic waste[6]. Traditional plastics have a long shelf life in the environment, while jackfruit peel-based bioplastics degrade considerably more quickly, minimizing their environmental impact.

The entire process of creating jackfruit peel-based bioplastics will be examined in this research paper, including the extraction and modification of biopolymers, the addition of glycerol as a plasticizer, and the characterization of the material's physical and mechanical characteristics[7]. The project will also examine how these bioplastics affect the environment and how quickly they degrade, giving important insights into whether they may replace single-use plastics in sustainable ways. In conclusion, the creation of bioplastics from discarded jackfruit peels is an important step toward a future that is more ecologically conscious and sustainable[8].

2. MATERIALS AND METHODS

2.1 Materials and composition

The skin of the jackfruit, known as the peel, is covered in a pattern resembling spikes. It is non-edible and regarded as the fruit's trash, usually being dumped or utilized as fertilizer. Because it is said to have significant levels of carbohydrate (24%), protein (8.7%), and fiber (17.3%), it is typically given to cattle in communities[9]. Functional components include steroids, triterpenoids, saponins, alkaloids, glycosides, tannins and phenolic compounds, flavonoids, proteins, and carbohydrates are found in jackfruit peel[5]. The jackfruit peel's regular contact with the extrinsic domain may be related to the peel's higher concentration of polyphenols. The synthesis of polyphenol is triggered by abiotic stress factors like as sunshine, UV radiation, and climate throughout the peel. Antioxidants contain bioactive components that aid in bodily chemical processes that counteract the harm caused by oxidation reactions. The peel is a valuable source of the polysaccharide since it has between 8.94 and 15.14 percent of pectin in dry matter. Pectin's serve as emulsifiers, binders, stabilizers, and other agents in the food industry as well as in other industries including medicines and cosmetics. The biochemical makeup of jackfruit and its waste revealed that it can have positive effects on health as well as serve as a sustainable raw material for the creation of a variety of priceless bio products[10]. Due to the significant amounts of vital Phyto-nutrients and Phyto-chemicals present, jackfruit is widely regarded by researchers, the food industry, and consumers.

Table: 1 Chemical constituent typically found in jackfruit peel

S.No	Chemical Constituents	Approximate Proportion (%)
1.	Cellulose	20-30
2.	Hemicellulose	20-30
3.	Lignin	15-25
4.	Starch	10-20
5.	Pectin	5-10
6.	Protein	2-5
7.	Lipids (Oils and Fats)	1-3
8.	Sugars (mainly sucrose)	1-3

9.	Water	10-15
----	-------	-------

The exact composition of jackfruit peel may vary depending on factors such as the ripeness of the fruit and environmental conditions[11]. The proportions provided here are approximate and can serve as a general guideline for the chemical constituents found in jackfruit peel.

2.2 Preparation of biopolymer film

The bio film from jackfruit peel waste must be produced in a number of processes. To get rid of undesired elements like dirt and soluble sugars that are present in the jackfruit peels, the harvested peels must be washed and left to soak in tap water for a whole night. Smaller fragments of the moist peels were separated by filtering. After that, the jackfruit peels were macerated for around 40 minutes in the sodium metabisulfite solution. After that, a sterile strainer was used to remove the peels. As part of the mechanical crushing technique, which aids in removing the polymeric materials from the fruit peels, the crushing was carried out using a pestle and mortar. The peels were then roasted for approximately 10 min at 120 °C in a hot air oven to eliminate extra moisture.

30 gms of the peel paste were selected for further processing. The sample was subjected to a sequence of steps: first, 6 ml of 0.5 N HCl was meticulously introduced and mixed by gently stirring with a glass rod. Following this, 2.5-3 ml of glycerol was judiciously added to the mixture, ensuring thorough blending. A modest amount of distilled water was then gently introduced, and the amalgamated mixture was thoroughly kneaded and compressed using a mortar and pestle. The resulting uniform paste was subsequently poured into molds to achieve the desired shape, while a portion of the sample was cast onto a glass arbor and left to incubate at room temperature (RT) for approximately 48 hours. Upon completion of the incubation period, the sample could be easily removed from both the glass arbor and molds.



Fig. 1 Synthesis of bioplastic from jackfruit peels.

2.3 Characterization Techniques

ATR-FTIR spectrophotometer (Perkin-Elmer) was used in the region of 4000-400 cm^{-1} to record the spectrum with a resolution of 4 cm^{-1} and 32 scans. Crystallinity studies of the samples were examined through XRD pattern (Bruker, Germany) measured using Cu-K α irradiation in the scanning range of $2\theta = 10\text{--}90^\circ$ and scanning speed of 8.5° min^{-1} . FE-SEM (Quanta 250 FEG) was utilized to examine the morphology of the bioplastic jackfruit peels.

3. MATERIALS AND METHODS

3.1. Fourier transform infrared spectroscopy (FTIR)

Fig. 2a shows FTIR spectrum of the bioplastic synthesized from jackfruit peels. The primary bands in the peels' FTIR spectra were found to be in the region of 2864 cm^{-1} carboxylic acids (-OH), 3952 cm^{-1} alcohols -H-bonded (-OH), and typical "polymeric" OH stretching, whereas alkene, aromatic acids, and amino acids (C-double bond C) are represented by the band at 1614 cm^{-1} . The degree of esterification may be determined by the ratio between the bands. According to the degree of esterification, intense asymmetric stretching occurs at 1614 cm^{-1} for the absorption spectra of jackfruit peel material extracted with highly esterified pectin, and the carbohydrate groups have a second weak stretching group at 1378 cm^{-1} .

3.2. X-ray diffraction (XRD) analysis

Fig. 2b shows FTIR spectrum of the bioplastic synthesized from jackfruit peels. XRD analysis provides detailed information of the nature of the developed sample. It is a rapid analytical technique used primarily for phase identification of the crystalline and amorphous nature of the biopolymer. XRD analysis of the jackfruit peel shows peaks at 29° , corresponding to 16.19° , 18.61° , and 27.71° . In the XRD analysis of the developed jackfruit peel film, only one broad peak is observed at $29 \approx 24.71^\circ$, confirming the amorphous nature.

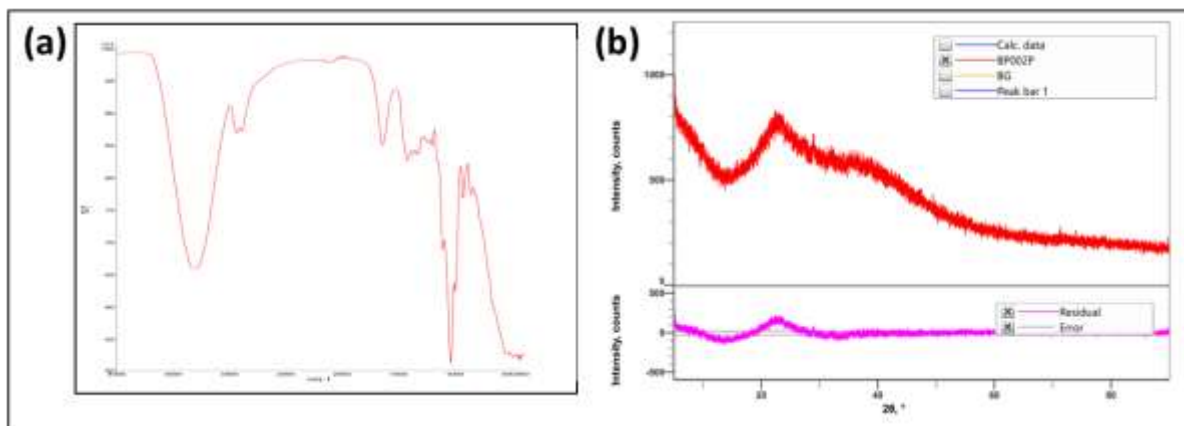


Fig. 2 (a) FT-IR and (b) XRD Spectra of bioplastic synthesized from jackfruit peels, respectively.

3.3 SEM Analysis

Fig. 3a-c shows the SEM images of bioplastic synthesized from jackfruit peels at different magnifications. The images show the surface microstructure of starch bioplastics as well as 3D AFM micrographs with RMS roughness. Granules on the surface, which are the remaining component of the starch particle, are an indication that the starch was not fully gelatinized during manufacture. The starch granule expansion's insoluble by products are seen in the SEM images. There were also some visible

gaps on the broken surface (black dots in the image), which might have added to its low impact and tensile strength.

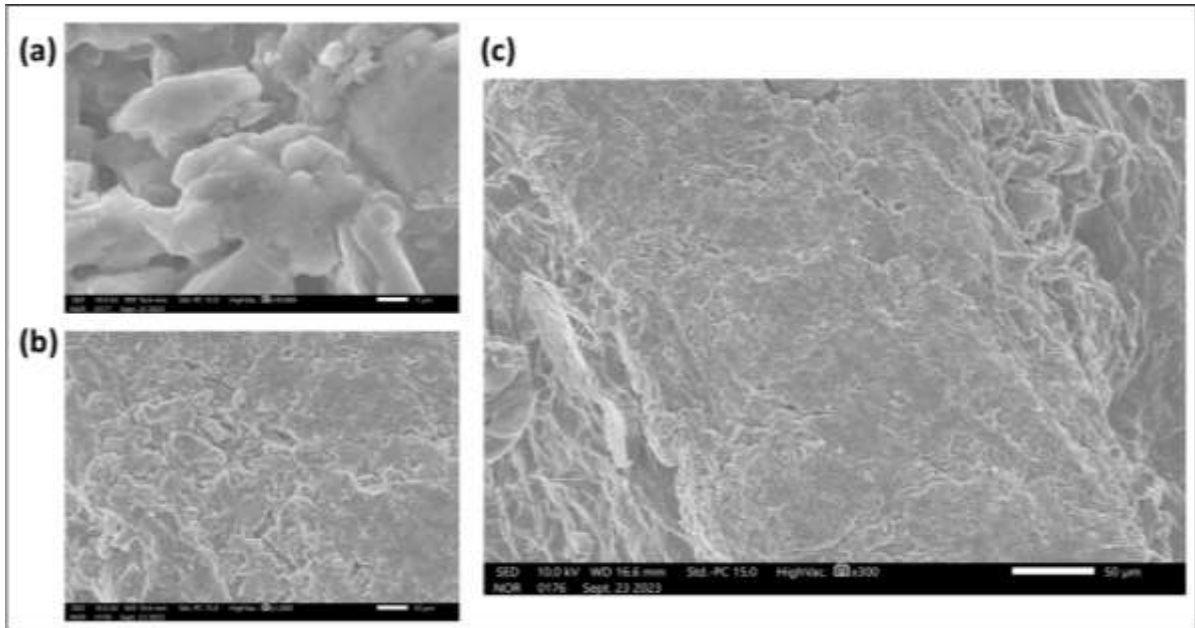


Fig. 3. (a-c) SEM images of bioplastic synthesized from jackfruit peels at different magnifications, respectively.

3.4 Solubility tests for synthesized bioplastic

The bioplastic material arranged was intentional for their solubility. The solubility test was completed activity to check steadfastness of these bioplastic fabrics by following the process.

Table: 2 Solubility tests of synthesized bioplastic in different solvents

S. No	Names of the Solvents used	Solubility Test		
		Insoluble	Partially soluble	Completely soluble
1.	Acetone	Yes	No	No
2.	Acetic acid	Yes	No	No
3.	Ammonia	Yes	No	No
4.	Ethyl alcohol	Yes	No	No
5.	Sulphuric acid	No	No	Yes

4. APPLICATION STUDIES

4.1 Soil degradation studies and microbial activity

To examine how bioplastic degrades in real-world settings including soil, moisture, and dryness. Bioplastic samples (1x1) were placed in soil at a depth of 8 cm, and then incubated for 10 days at room temperature with sampling intervals every two days. The samples that were buried were cleaned and weighed.

$$\text{Degradation \%} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial weight}} \times 100 \quad \dots\dots (1)$$

Initially the weight of the sample bio-plastics is 1.04 gms. After a week of decomposition, the weight has been reduced by 0.5 gms. It weighed 0.9 gms Here by using the above-mentioned Formulae, the percentage of soil degradation for bio-plastics is observed as 28.83%. In the degrading process a biodegradable plastic can be converted to carbon dioxide (CO₂) and water and composting. After microbial degradation, the soil microbial species were identified through serial dilution method for isolation and morphology through staining technique. **Fig. 4** depicts the process of biological degradation of biodegradable polymers.

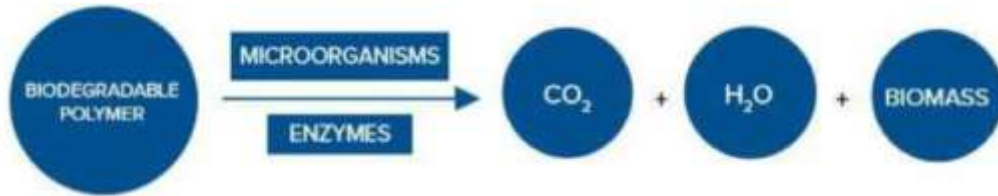


Fig. 4 The process of biological degradation of biodegradable polymers.

The bioplastic synthesized from fruit waste i.e., jackfruit peels is buried in soil in a depth of 100 cm and then left for a week. The results showed that the biopolymer film has turned to brownish black as the time increases. Its texture has become brittle and delicate. The weight of the bioplastic is also decreased with increase in days. This degradation in soil is depicted in the table below.

4.2 Microbial degradation of jackfruit peel

Any physical and chemical change in a material caused by the action of microorganisms is called biodegradation. Natural and synthetic plastics are degraded by the action of microorganisms such as bacteria, actinomycetes and fungi.

Aerobic biodegradation: In this type of degradation, microorganisms break down large organic compounds into smaller compounds by using oxygen as an electron acceptor. The by-products of this process are carbon dioxide and water. Whereas in anaerobic biodegradation, it does not require oxygen for the breakdown of compounds by microorganisms. Oxygen is an important component for natural attenuation of contaminants at hazardous waste sites. Anaerobic bacteria use nitrate, iron, sulphate, manganese, and CO₂ as electron acceptors instead of oxygen to break down large organic compounds into smaller compounds.

Fig. 5a, b shows the population of bacterial colonies and purple stained bacterial species observed. All polymers are huge in size and not water soluble, which prevents them from being immediately carried into the cells of microorganisms through their cell walls. By secreting extracellular enzymes, microorganisms can utilize these polymers as a source of energy. These enzymes break down polymers outside of bacterial cells. Enzymes play a part in the intracellular and extracellular biodegradation of polymers. The two processes that are involved in the biological deterioration of polymeric polymers are depolymerization and mineralization.

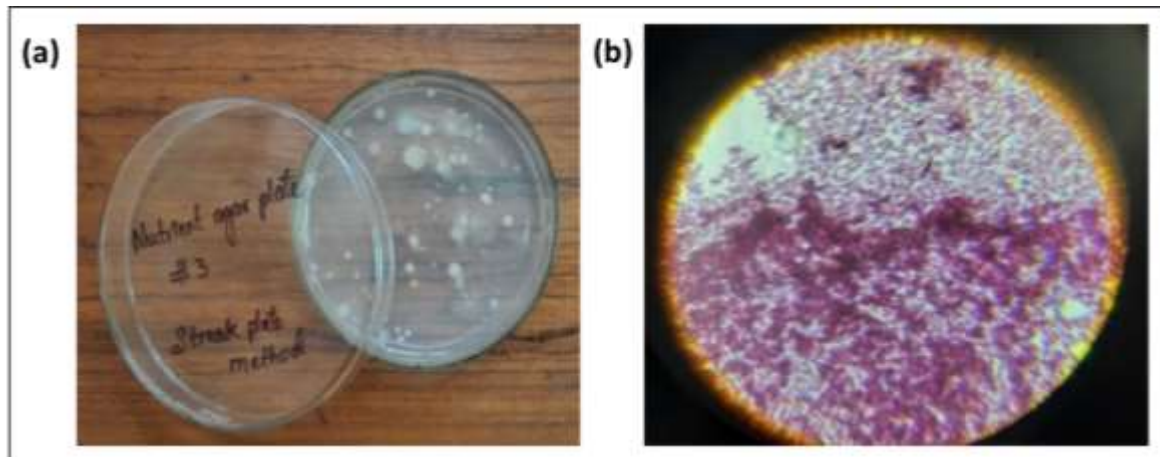


Fig. 5 (a) Population of bacterial colonies and, (b) Purple stained bacterial species are observed.

4.3 Test with microorganisms

The identification and characterization of bacteria depends on its shape, size and arrangement of the isolates and their differentiation into gram negative or gram-positive bacteria were found. The bacterial isolates were characterized biochemically by Grams staining technique. Hans Christian Gram, a Danish bacteriologist, introduced the common, significant, and widely used differential staining method known as "Gram staining" in 1884. This test helps to classify and differentiate microorganisms by dividing bacteria into Gram Positive and Gram-Negative Bacteria. Here the bacteria are able to preserve the primary stain, while others are decoloured by alcohol. The bacteria are stained with the primary stain Crystal Violet and fixed by the mordant. So, it is Gram positive bacteria which have low levels of lipid and a thick covering of peptidoglycan, a protein-sugar complex. The cell's thick cell wall becomes dehydrated and shrinks as a result of decolorization, which seals the cell wall's pores and keeps the stain from leaving the cell. As a result, the Crystal Violet-Iodine combination, which is coloured blue or purple and linked to the gram-positive bacteria's thick layer of peptidoglycan, cannot be removed by ethanol. Gram positive bacteria like Actinomyces, Bacillus, Clostridium, Corynebacterium, Enterococcus, Lactobacillus, Mycoplasma, Staphylococcus, Streptococcus, Streptomyces, etc. are involved in degrading the bioplastic synthesized from the peels of jackfruit.

5. CONCLUSION

The recent investigation into the physicochemical properties of the biodegradable plastic film has demonstrated the significance of the potential usage of the unique kind of materials for numerous industrial applications. The present work is highly innovative for the industries since it includes two stage procedures. The approach utilized in the study is credited with making it noteworthy since it calls for the utilization of naturally available resources like organic waste materials like jackfruit peel, which may be converted into riches technology. To ascertain whether functional groups were present in the film, the FTIR analysis was performed. In addition, it was found that the substance lacks any ingredients that may be harmful. The resulting material is therefore safe for the environment. The presence of carboxylic acids necessitates their use in pharmaceutical formulations. The plasticizers have improved the tangibles of the film's content. The ability to turn such materials into bio fertilizers and animal food makes garbage disposal one of the main advantages of employing them in public. The two most important components of the bio-based plastic, pectin and cellulosic fibers, gave it the required strength

and ensured biodegradability, enabling it to be used as a short-term packaging medium. The found bio-based material seems promising, even if more characterization and improvements are needed to obtain the necessary features, such as hydrophobicity. We can create a society that is cleaner, greener, and more sustainable by using bio-based polymers with better degrading capabilities in place of a greater amount of traditional plastics. Through the presentation of a novel method for the synthesis of bioplastics, this research aims to make a positive contribution to the fight against plastic pollution.

Acknowledgements:

I extend sincere acknowledgment to Andhra Pradesh Pollution Control Board (APPCB), Vijayawada for giving financial assistance in the form of Research Fellowship (RF) which supported the study.

References

1. Filho WL, Salvia AL, Bonoli A, et al (2021) An assessment of attitudes towards plastics and bioplastics in Europe. *Sci Total Environ* 755:142732. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.142732>
2. Atiwesh G, Mikhael A, Parrish CC, et al (2021) Environmental impact of bioplastic use: A review. *Heliyon* 7:.. <https://doi.org/10.1016/j.heliyon.2021.e07918>
3. Veena S, Rani ME (2022) Bioplastics from banana peels and biodegradation by micro organisms. *IJCRT* 10:8.
4. Yadav A, Kumar N, Upadhyay A, et al (2021) Edible Packaging from Fruit Processing Waste: A Comprehensive Review. *Food Rev. Int.*
5. Reshmy R, Philip E, Vaisakh PH, et al (2021) Development of an eco-friendly biodegradable plastic from jack fruit peel cellulose with different plasticizers and *Boswellia serrata* as filler. *Sci Total Environ* 767:144285. <https://doi.org/10.1016/J.SCITOTENV.2020.144285>
6. Coppola G, Gaudio MT, Lopresto CG, et al (2021) Bioplastic from Renewable Biomass: A Facile Solution for a Greener Environment. *Earth Syst Environ* 5:231–251. <https://doi.org/10.1007/s41748-021-00208-7>
7. Chan JX, Wong JF, Hassan A, Zakaria Z (2021) Bioplastics from agricultural waste. *Biopolym Biocomposites from Agro-Waste Packag Appl* 141–169
8. Khorami M, Arti H, Ghasemi M, et al (2016) Biodegradable plastic production from fruit waste material and its sustainable use for green applications. *Int J Pharm Res Allied Sci* 5:
9. Anugrahwidya R, Armynah B, Tahir D (2021) Bioplastics Starch-Based with Additional Fiber and Nanoparticle: Characteristics and Biodegradation Performance: A Review. *J Polym Environ.* <https://doi.org/10.1007/s10924-021-02152-z>
10. Sintim HY, Bary AI, Hayes DG, et al (2020) In situ degradation of biodegradable plastic mulch films in compost and agricultural soils. *Sci Total Environ* 727:.. <https://doi.org/10.1016/j.scitotenv.2020.138668>
11. Zoungran Y, Lynda E, Dobi-Brice KK, et al (2020) Influence of natural factors on the biodegradation of simple and composite bioplastics based on cassava starch and corn starch. *J Environ Chem Eng* 8:.. <https://doi.org/10.1016/j.jece.2020.104396>