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Utilization of Fruit peels for Bioplastic Production: A Waste to Wealth Approach

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Abstract

This study explores the potential of fruit waste specifically lemon and pineapple peels as renewable raw materials for bio plastic synthesis. These peels are rich in natural polymers such as cellulose, starch, and pectin, which are essential for forming biodegradable films with desirable mechanical properties. The present study involved carbohydrate analysis and the production of bioplastics through acid-base hydrolysis, followed by plasticizer incorporation, and enhancement with essential oil. Characterization of the bio plastics was conducted using FTIR and XRD to confirm the presence of functional groups and crystalline structures, while physical tests including swelling, solubility, and biodegradability test which assessed their performance. The produced films demonstrated good tensile strength, semi-transparency, stability in various solvents, and rapid degradation under soil burial within weeks, indicating environmental compatibility.

IndexTerms - Fruit Peels, Bioplastic, FTIR, XRD

I. Introduction

In recent years, the rapid increase in global population and industrial activities has resulted in the excessive production and consumption of plastics. These synthetic polymers have become an inseparable part of daily human life due to their low cost, strength, and durability. From packaging materials and household items to medical devices and electronics, plastics dominate almost every sector of modern society. However, their convenience has come at a high environmental cost. Conventional plastics are non-biodegradable and persist in the environment for hundreds of years, accumulating in landfills, waterways, and oceans. Their resistance to microbial degradation causes serious ecological challenges, threatening soil fertility, aquatic life, and even human health. As a result, the issue of plastic pollution has emerged as one of the most pressing environmental concerns of the 21st century. Many terrestrial animals and aquatic forms ingest plastic pieces, mistaking them for their food, which leads to suffocation, diseases, or even death. Micro plastics have also been detected in drinking water and also food, posing a potential risk to human health maintenance. Thus, the need for sustainable, eco-friendly, and biodegradable alternatives to traditional or conventional plastics has become an urgent global need.

The modern dependence on petroleum-based plastics has intensified the depletion of fossil fuel reservoirs. As most synthetic plastics are derived from petrochemical sources, their continuous production and usage contributes significantly to greenhouse gas emissions as well as climate change [1]. The improper disposal of these plastic wastes leads to land and water pollution, affecting biodiversity by changing food chains. The replacement of synthetic plastics with bioplastics produced from renewable and large agricultural or industrial waste is a most important research area [2, 3, 4]. Transforming agro- industrial waste into bio plastics, with many potential applications, provides an important route for producing biodegradable usable materials which support eco-friendly practices [5, 6]. In response to this crisis, researchers have increasingly turned their attention toward the development of bio plastics, which are polymers derived from renewable biological sources such as plants, microorganisms, or agricultural residues. Unlike conventional plastics, bioplastics can be designed to degrade naturally under environmental conditions, reducing long-term waste accumulation. These materials not only help in minimizing pollution but also reduce the dependence on petroleum-based resources. Bioplastics have shown promising alternative in various fields such as packaging, agriculture, biomedical devices, and food preservation. Their versatility, combined with environmental safety, has made them a potential replacement for non-biodegradable plastics in several industries.

A significant focus in recent research has been on producing bioplastics from waste biomass, especially from fruit and vegetable residues. Agricultural and food processing industries generate enormous quantities of organic waste each year, much of which is underutilized. These wastes often contain starch, cellulose, and pectin—natural polymers that serve as excellent raw materials for bioplastic production [7]. Utilizing fruit waste not only adds value to agricultural by-products but also helps manage waste more sustainably. Examples of such sources include orange, mango, banana, sapodilla and pomegranate [8].The conversion of such waste into useful bioplastic material is an eco-friendly and cost-effective approach that supports the principles of economy [9].

II RESEARCH METHODOLOGY

2.1 Preparation of Chemicals and Reagents:

All the chemicals and reagents used were of analytical reagent (AR) grade, and Millipore water was used for performing all experimental work.

2.2 Collection of samples

Fresh and nutritious pineapple (*Ananas comosus) and* Lemon (*Citrus limon*) peels were collected from Juice Center at local market of Tumkur district , Karnataka and used as samples. Fresh peels were carefully cleaned three times with distilled water to get rid of any contaminants as shown in Fig.1. Chemicals like HCl, NaOH, glycerol, KMS, and essential oils like lime and clove oils were employed.

Fig.1. (a) Pineapple peel (b) Lemon peel

2.3 Determination of carbohydrates in fruit peel

Preparation of the Extract: 10g boiled peels were dissolved in 10ml of distilled water. Crushed, filtered and filtrate was collected.

Production of Bioplastic film: Two primary phases, preparing the peels for use as a base material, and turning the peels into bio plastic film.Three samples were made: 100 g of Lemon peel, 100 g of Pineapple peel, and 70 g and 30 g of Lemon and Pineapple peel as shown in Fig.2.

Fig.2. (a) Preparation of Pineapple peel paste (b) Lemon peel paste (c) Pineapple composite lemon peel mixture

25 g of each peel paste obtained earlier was taken in a clean beaker. To this, 3 mL of hydrochloric acid (HCl) was added and the mixture was stirred thoroughly using a glass rod. Then, 1mL of glycerol, serving as a plasticizer, was added and the mixture was stirred continuously for 5 minutes to ensure uniform blending. After allowing the hydrolysis reaction to proceed for the desired residence time, 3 mL of 0.5 N sodium hydroxide (NaOH) was added gradually to neutralize the acidic mixture, maintaining the proportion with respect to the amount of HCl used. Following neutralization, 2% clove essential oil was incorporated into the mixture and stirred well to obtain a homogeneous solution as seen in Fig.(3 ,4) The prepared mixture was then evenly spread into three separate Petri plates to form thin film layers. These plates were placed in a hot air oven and dried at 130°C for 3 hours to facilitate the formation of biopolymer films. Once dried, the films were carefully scraped off from the Petri plate surfaces and allowed to cool at room temperature before further use or characterization [7].

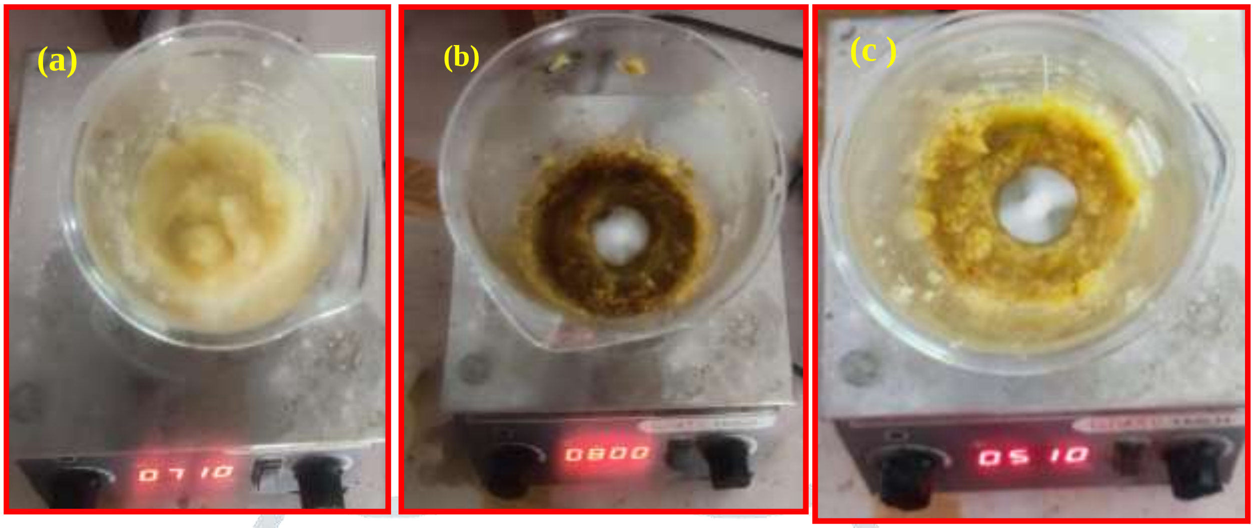


Fig.3 (a, b, c) Synthesis of lemon, pineapple and Lemon composite Pineapple paste

Fig.4 (a, b, c) Prepared of lemon, pineapple and Lemon composite Pineapple paste

III Characterization of Bioplastic:

3.1 Swelling test

A pre-weighed sample was prepared and placed in a test tube. The experiment was conducted on a medium that contained different solvents, including methanol, water, and chloroform, and the samples were left in the medium for roughly two hours. The results were then recorded appropriately [7].

3.2 Solubility test

Bio plastic, after being sliced into tiny pieces, each sample was put into a test tube with various solvents like water, sulfuric acid, and ethanol

3.3 Biodegradability test

5cm below the soil's surface, a pre-weighed piece of prepared bio plastic was buried.
To enhance the bacterial enzymatic activities, a small amount of water was sprayed on the soil [10]

3.4 X-ray Diffraction

X-ray diffraction patterns are obtained from the Rigaku smartLab X-ray diffractometer with Cu-Kα radiation (λ = 1.54 Å).

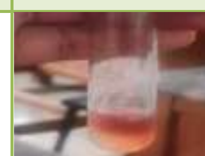
3.5 Fourier Transform Infrared Spectroscopy

Infrared spectroscopic studies were analyzed using a Bruker alpha II FTIR spectrometer.

IV RESULT AND DISCUSSION

4.1 Determination of Carbohydrate in Fruit peel

Table 1- Determination of carbohydrate content in Fruit peel

Sl. No	Test	Sample	Observation	Inference	Appearance
1.	**Molisch test**	Lemon	A deep violet color at the junction of two liquids is observed	Carbohydrate is present	
2.	**Benedict test**	Lemon	Green precipitate is observed	Presence of reducing sugar	
3	**Molisch test**	Pineapple	A deep violet color at the junction of two liquids is observed	Carbohydrate is present	
4	**Benedict test**	Pineapple	Green precipitate is observed	Presence of reducing sugar	

4.2 Production of Bioplastic

Fig.5. (a,b,c) Formation of bioplastic from lemon, pineapple and composites of lemon and pineapple

The generated bio plastic that was dispersed among the petri plates is clearly illustrated in Fig.5 The following traits apply to the bio plastics that are produced:

Colour: The colour of bio plastic differs depending upon the samples. Mixed fruit peels were used in this experiment. As a result, the bio plastic that was created had a Brownish-hue.

Texture: Touching the surface of the bio plastic film will reveal its texture. The top surface was rough, while the bottom has a smooth texture.

Transparency: While most bio plastics are transparent, some are only partially so. The bio plastic film created in this present study using a variety of fruit peels was semi-transparent.

Odor: The bio plastic had a smell similar to fermented fruit juices, but there was a pungency because of the various chemicals used.

The effectiveness of fruit peel-based bio plastics hinges on raw material composition and the process innovation exercised during synthesis. Banana peels exhibit superior starch content, enabling robust film formation and mechanical properties, while orange and other peels contribute minerals and fiber for strength and functional diversity. Mixed-peel approaches help balance the strengths and limitations of individual fruit sources, as reflected in comparative elongation, moldability, and water absorption test as seen Fig.5 [11,12,13].

In the present study these procedures were employed. Pretreatment with sodium metabisulfite for preservation and antioxidation. Boiling, drying, and grinding to facilitate polysaccharide extraction. Acid/base hydrolysis coupled with plasticizer and antioxidant inclusion for film stability and flexibility. Parameters such as the concentration of HCl, NaOH, and glycerol, boiling time, and drying temperature directly affect the film's textural, chemical, and physical properties, requiring careful standardization for reproducibility and product optimization [13,14,15].

Characterization tests for bio plastics focus on analyzing their physical, mechanical, chemical, and biodegradability properties to understand their performance and environmental impact. These tests help determine factors like film texture, transparency, chemical composition, tensile strength, and degradation rates, which are essential to evaluate the suitability of fruit peel-based bio plastics for practical applications such as packaging. Data from qualitative carbohydrate assays (Molisch, Benedict) confirm that fruit peels—especially bananas—deliver the critical polysaccharide load essential for starch-based film formation. The manifestation of reducing sugars and favorable starch/pectin ratios corroborate previous findings and underpin the rationale for utilizing peels as bio plastic feedstock [11,12,7].

a. Swelling Test

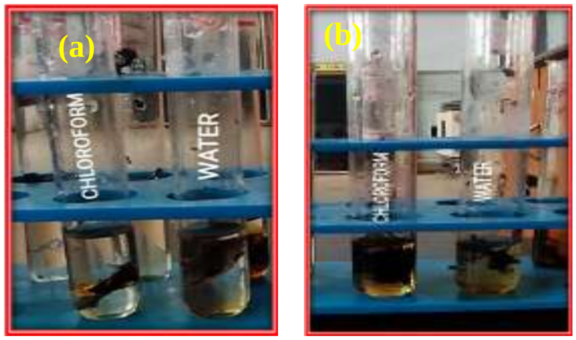


Fig. 6. Swelling test for lemon and pineapple Bioplastic

Swelling studies are typically carried out to determine whether the prepared material maintains the characteristics that existed when it was formed during the preparations. To check for pro tuberance and other morphological changes. A slight increase in sample weight was detected when immersed in water as shown in Fig.6.

b. Solubility Test

Table 2- Solubility test for prepared Bio plastic

Sample	Solvent	Insoluble	Partially soluble	Soluble
Lemon	Water	Yes	-	-
	H_2SO_4	-	Yes	-
	Ethanol	Yes	-	-
Pineapple peel	Water	Yes	-	-
	H_2SO_4	-	Yes	-
	Ethanol	Yes	-	-
Lemon-Pineapple peel mixture	Water	Yes	-	-
	H_2SO_4	-	Yes	-
	Ethanol	Yes	-	-

When compared to conventional methods, none of the samples were entirely soluble in the various media utilized. This indicates that the bio plastic materials made are stable and is undoubtedly what is intended for the production of bioplastics.The primary characteristic used to determine whether or not a synthetic bio plastic material is sustainable is its solubility. The bio plastic material can be regarded as an excellent material with stability as a characteristic feature if it has low or zero engorgement. According to numerous previous research, the resulting bio plastic proved insoluble in various solvents and is suitable for commercial usage as shown in Fig.7. Bioplastic films generally remained insoluble or only partially soluble in water, acetone, and other tested solvents ensuring product stability for packaging, carry bag, and service ware applications[10,7]. In the present study lemon, pineapple and composite samples were insoluble in water and ethanol and partially soluble in $H_2SO_4$and all were soluble in H_2SO_4

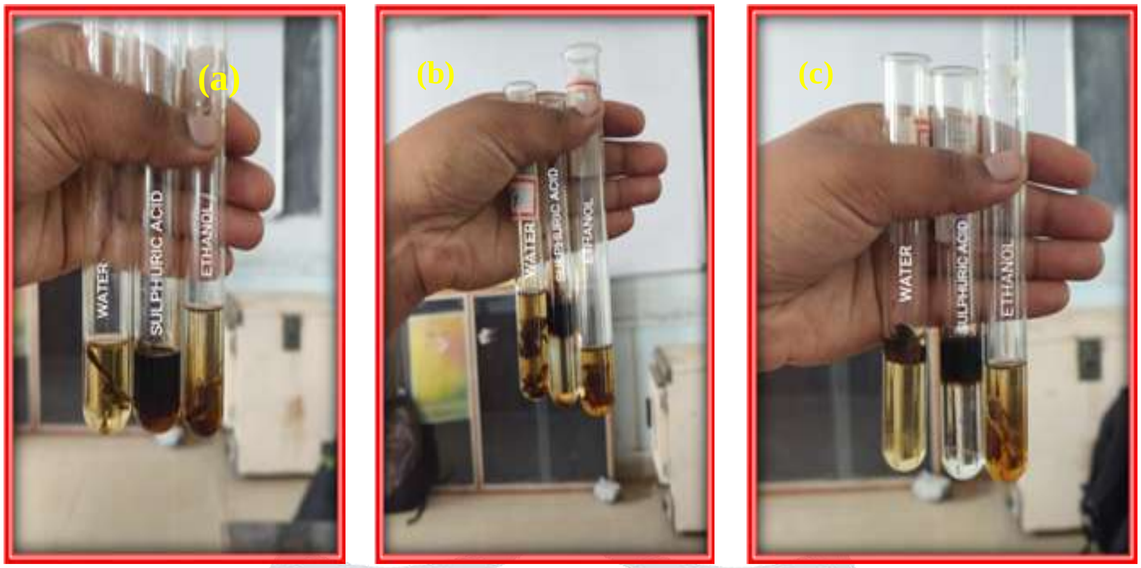


Fig.7. Solubility test for prepared Bioplastic

Continuous plastic pollution and the environmental persistence of petroleum-derived plastics make bio plastics from renewable resources an urgent priority for sustainable development. Fruit peels such as banana, orange, dragon fruit, musk melon bring together low cost, abundant availability, and desirable biopolymer content (starch, cellulose, pectin, protein, fiber), making them a compelling substrate for bio plastic production. The current research trajectory capitalizes on valorizing agricultural waste while addressing ecological and public health imperatives [12, 13]. The core utility of bio plastics lies in their ability to compete with conventional plastics in mechanical robustness, moldability, and durability.Experiments demonstrated films could be molded into varied shapes (cups, trays, plant pots), paralleling industrial plastic form factors [7]. Mixed peel films achieved elongation percentages over 20%, outperforming single-peel films [10]. Over the course of 15 days, a significant 60.00% weight reduction was noted in garden soil, indicating that the bioplastic is biodegradable due to soil microbial enzymes. This is a positive factor for the long-term environmental footprint and positions it as a potential environmentally friendly replacement for conventional plastics.

4.3 X-ray Diffraction

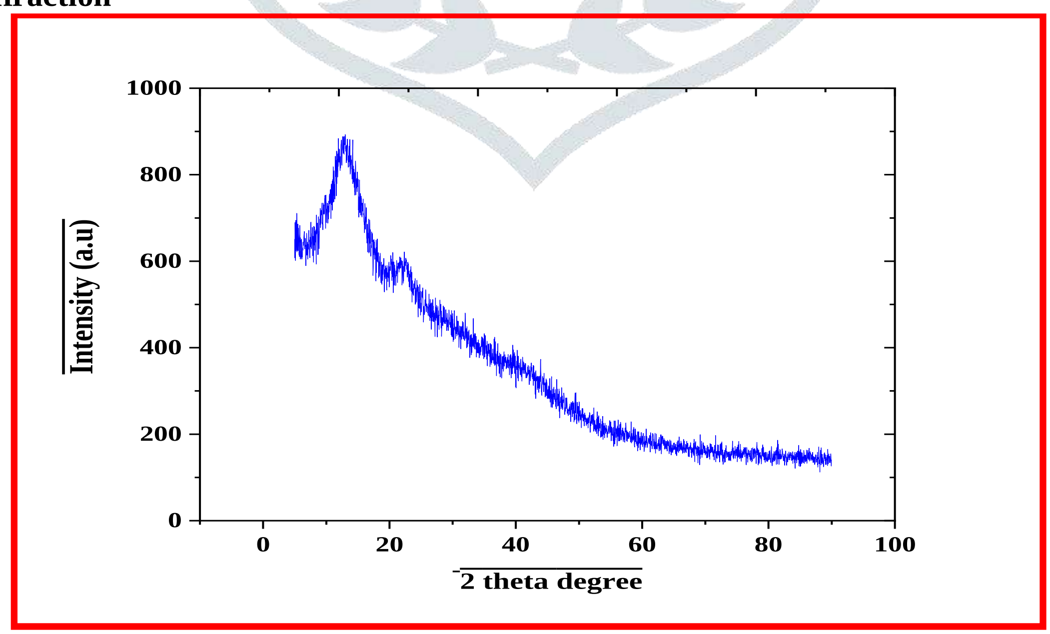


Fig 8. X-ray diffraction for prepared Bioplastic

X-ray diffraction (XRD) spectrum, which is used to study the crystalline structure of materials. The x-axis represents the diffraction angle 2θ (degrees), while the y-axis represents the intensity (a.u.) of the diffracted X-rays. The peaks observed in the pattern correspond to constructive interference from the crystal planes, In this spectrum, distinct diffraction peaks are present at different 2θ values, each representing a particular set of crystallographic planes. For example, strong peaks typically appear around 2θ = 28°–38°, 44°–48°, and 64°–78° for cubic materials. As shown in Fig.8. The sharpness and intensity of the peaks indicate the crystalline nature of the sample. Chemical modifications such as carboxymethylation and esterification of starch/polymer enhance mechanical strength, reduce water solubility, and improve shelf stability—addressing limitations of native fruit starches.

4.4 Fourier Transform Infrared Spectroscopy (FTIR)

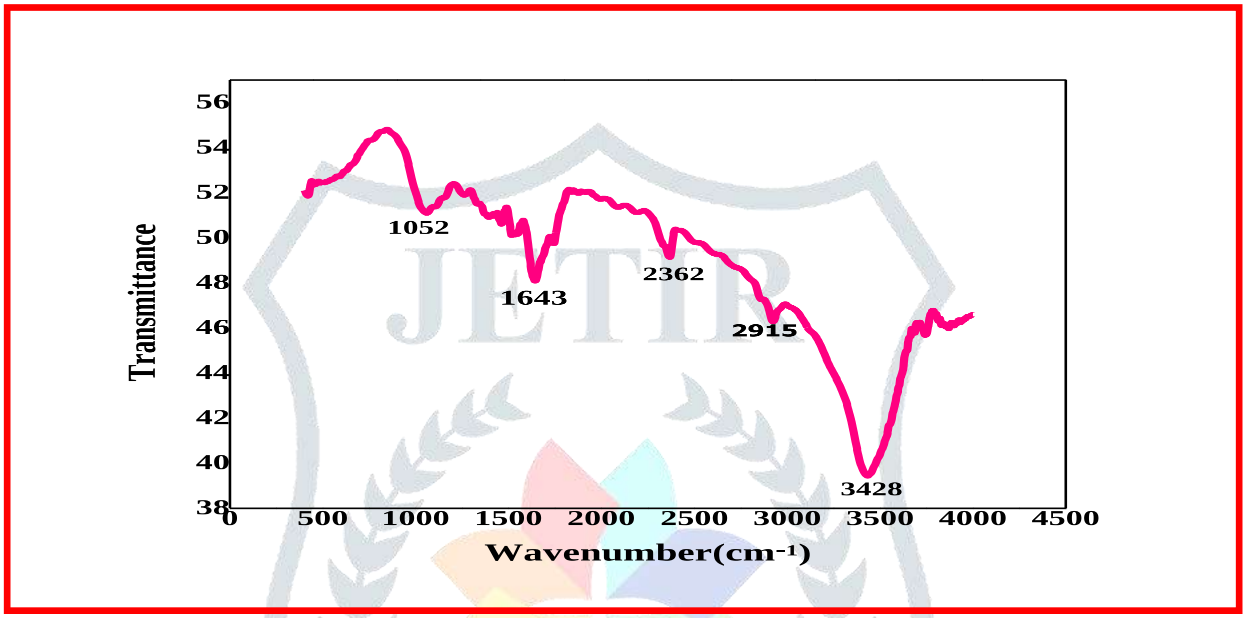


Fig. 9. FTIR for prepared Bioplastic

The Fourier Transform Infrared (FTIR) spectrum analyzes the absorption of infrared light at particular wavenumbers (cm^{-1}) to provide information about the functional groups that are present in a material. The transmittance (%) is shown by the y-axis in this spectrum, while the wavenumber (400–4500 cm^{-1}) is represented by the x-axis. Peaks at various locations correlate to particular chemical bond vibrational modes, which aid in determining the sample's molecular structure.

The stretching vibrations of -OH groups, which are generally connected to adsorbed water, hydroxyl functional groups, or hydrogen bonding interactions, are responsible for the broad and strong absorption peak seen at approximately 3428 cm^{-1}[17]. This characteristic is shared by biopolymers that are mediated by plant extracts and produced in aqueous environments. The presence of aliphatic -CH_2 groups is confirmed by the peak near 2920 cm^{-1}, which corresponds to asymmetric C-H stretching vibrations as shown in Fig.9 the peak at 1052 cm^{-1} is frequently attributed to the C–O stretching vibrations of polysaccharides, ethers, or alcohols, indicating that carbohydrate residues are involved in stabilizing and capping the substance.Particularly important in bio-functionalized composites, these functional groups show that organic molecules are important for binding or stabilizing the sample being studied [18]. Bioplastic sample did not show any peak in between of 2362 and 2910 cm−1 in the FTIR graph which proves the absence of cyanide groups suggesting, there are no toxic compounds in the sample [19,20].

V CONCLUSION

This study reveals that fruit waste especially, lemon and pineapple peels can be effectively used as renewable raw materials for the manufacture of bioplastics. Important natural polymers found in these peels, including cellulose, starch, and pectin, are essential for creating biodegradable films with the right mechanical and structural qualities. While XRD revealed semi-crystalline patterns that contribute to film strength and stability, FTIR analysis proved the presence of important functional groups linked with biopolymer structures. The produced films had good tensile strength, moderate flexibility, and semi-transparency Crucially, soil burial experiments revealed that the bioplastics broke down considerably in a matter of weeks, demonstrating their suitability for the environment and capacity to reduce plastic pollution. These films can be sustainable substitutes for traditional plastics, providing both ecological and financial advantages, as evidenced by their quick rate of biodegradation. Overall, the study demonstrates that discarded lemon and pineapple peels can be effectively converted into useful bioplastics with encouraging properties. In addition to promoting circular economy principles, using such agro-waste offers an eco-friendly method of handling fruit waste and aids in the continuous quest for biodegradable materials that can take the place of petroleum-based plastics.

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