

Research Paper

Biodegradable Plastic from Different Fruit and Vegetable Peels

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ABSTRACT

Traditional plastics' pervasive environmental challenges have underscored the urgent need for sustainable alternatives. Biodegradable plastics offer a promising solution to mitigate pollution and ecological damage. This study explores the feasibility of utilizing fruit peels as a renewable source for producing biodegradable plastic. Fruit and vegetable peels, including oranges, bananas, and potatoes, were collected from household resources and local juice bars. These peels were pretreated and ground into a fine powder. Further optimization of the ingredients was conducted. Orange peel powder in combination with arrowroot starch showed potential for bioplastic production. Bioplastics showed a tensile strength of $4.16 \times 10^{-9} \text{ N/m}^2$ (the conventional plastic exhibits a lower value of $2.5 \times 10^{-10} \text{ N/m}^2$). Rapid degradation of bioplastics made during this study under 35 days in soil and water, coupled with a lower carbon footprint of 2.2 g/ml, further justifies its eco-friendly and sustainable nature. Utilization of peels in the preparation of bioplastic minimizes waste, ultimately reducing plastic pollution and providing an eco-friendly solution to mitigating the impact of conventional plastic on our ecosystem.

KEYWORDS: Bioplastic; Biodegradable; Eco-friendly; Orange peel powder.

INTRODUCTION

Plastic, a type of polymeric material, can typically be molded or shaped through the application of heat and pressure. This property of plastic, in combination with other distinctive properties such as low density, low electrical conductivity, transparency, and toughness, allows it to be made into a great variety of products. These include tough and lightweight beverage bottles made of polyethylene terephthalate (PET), flexible garden hoses from polyvinyl chloride (PVC), insulating food containers from foamed polystyrene, and shatterproof windows made up of polymethyl methacrylate [1]. Plastics are a large family of polymers derived from fossil resources.

The industrial-scale production of plastic started in the 1950s with a 1.5 MMT capacity and rose to 390.7 MMT in 2021 and is expected to double in the next 20 years [2-4]. Plastic materials have become an integral part of the modern lifestyle, and their use has increased significantly in the past three

decades. The plastic materials produced from petroleum are considered non-degradable. Plastic materials are durable and strong. These materials cannot be degraded under normal conditions.

The primary methods of creating plastics are polymerization and polycondensation, both require catalysts. In polymerization molecules such as propylene and ethylene are affiliated to create extensive polymer chains. In polycondensation, monomers form ester linkages between the hydroxyl (OH) groups of the alcohol and carboxyl (COOH) groups of the acid creating long chains of polymers.

The complexity of plastics as materials, with thousands of combinations of polymer types and chemical additives, muddles our understanding of how these materials behave and degrade. Plastics can escape into the environment during their usage or once they've reached the end of their lifecycle. However, pinpointing the exact locations and quantifying these losses remains challenging. Factors such as plastic characteristics, source

location, environmental conditions, and changes in seasons have a significant influence on plastic inputs and transport [5].

Currently, plastic pollution is a global problem due to its toxicity. Research has shifted to the production of bio-based plastic to avoid ingestion of microplastics and harmful chemicals.

Monomers, derived from biomass compounds such as plant sugars, are either synthesized or extracted, then polymerized to produce either direct substitutes for existing plastics like polyethylene (PE) or innovative polymers like polyhydroxyalkanoates (PHAs). The uprooting of Biomass can also yield non-synthetic polymers like starch, natural rubber, and proteins. Despite frequent use the term 'bioplastic' remains misunderstood due to its ambiguous definition. Bioplastics are plastics made from renewable resources ('bio-based'), biodegradable, or manufactured through biological processes or a combination of these factors. Additionally, some biodegradable plastics derived from fossil fuels are also considered bioplastics [6-7].

Biomass, a rapidly replenishing resource, is commonly categorized into first-generation and second-generation feedstocks. The former chiefly consists of easily fermentable sugars derived from edible polysaccharide sources like corn and sugarcane, as well as edible vegetable oils. Some studies suggest the sustainable co-production of biomass for food, fuel, and consequently, for bio-based materials. At present, only 0.02% of global agricultural land is allocated to produce precursors for bioplastics. It is estimated that 70% of plastic produced is discarded without recycling. However, replacing fossil resources entirely with biomass for plastics is uncertain, emphasizing the need for decreased consumption and improved recycling. Transitioning all 170 million tons of global packaging plastics produced each year to bioplastics is estimated to necessitate

54% of current corn production and 60% more than Europe's annual freshwater withdrawal [8-9].

Among the list, fossil-based biodegradable polymers, bio-based biodegradable polymers, and bio-based non-degradable polymers can be considered as bioplastics [10]. For plastic to be categorized as bioplastic, the raw material should be biodegradable, biocompatible, or made from renewable sources. Bioplastics are generally synthesized from biological sources like plants, animals, and microorganisms.

Bioplastics play a substantial role in the bio-economy as they can mitigate environmental impacts by substituting traditional plastics. Nevertheless, the industrial-scale manufacturing of these bioplastics encounters many challenges, notably the higher production expenses. Research has suggested the scope of utilizing cheaper and renewable substrates (organic waste streams) as feedstock can reduce around 50 % of the total cost of production [11-12].

Plants like corn, sugarcane, tapioca, potatoes, rice, soy, wheat, vegetable oil, wood chips, and sawdust are used to make bioplastics. This also includes byproducts from recycled food production, such as rice, sugarcane, or barley straw.

Bioplastics derived from agricultural waste offer a promising avenue in sustainable material production. By utilizing leftover agricultural residues, such as stalks, husks, and other organic byproducts, these bioplastics mitigate waste while offering a renewable alternative to traditional plastics. The process involves converting these agricultural remnants into raw materials for bioplastic production, reducing environmental impact and dependence on fossil fuels. However, challenges like scalability, cost-effectiveness, and technology refinement still need addressing for wider adoption and effectiveness in curbing plastic pollution.

Plasticizers are adjuvants that are added to plastics to improve their quality. Chemical plasticizers are low-molecular-weight compounds with polar groups that can form temporary bonds with polymer chains. DEHP is a type of phthalate ester that has been majorly used as a chemical plasticizer in the production of polyvinyl chloride (PVC) to impart flexibility and durability to the material but it has raised concerns due to its potential toxicity. It persists in the environment causing pollution that harms health. Organic plasticizers are additives obtained from natural sources, such as vegetable oils, starches, or other renewable materials. They interact with the biopolymer chains, reducing intermolecular forces, and increasing chain mobility, resulting in a softened and flexible polymeric matrix. This allows better molding and shaping of bioplastics, while also contributing to their overall eco-friendly profile. Commonly used organic plasticizers are glycerol and sorbitol. Glycerol is a bio-based polyol that interacts with biopolymers, such as starch or cellulose enhancing their flexibility and processability. Glycerol inserts between polymer chains, acting as a lubricant and allowing them to slide past each other easily, thus strengthening the material's overall flexibility and reducing its brittleness. This plasticizing effect ultimately improves the bioplastic's mechanical properties, making it more suitable for various applications [13-15].

Agro peels such as (Orange, Banana, and Potato Peels) are easily available in significant quantities in the local market. These peels are rich in cellulose and fibrin which enhance the mechanical strength and flexibility of the bioplastic. They act as essential precursors in the development of natural plasticizers. Orange peels contain high concentrations of flavonoids and phenolic acid, surpassing even the levels found in the edible portion. This implies that numerous compounds will remain within the

peels. Certainly, some bioplastics are derived from orange peels; orange peels contain d-limonene which can be used as a building block of bioplastic production and can itself be a substrate of bioplastic [16].

Pectin is a naturally organic polymer found in peels that can be processed and combined with other biodegradable ingredients to create a bioplastic. In several applications, this eco-friendly material may be used as a substitute for conventional plastics derived from petroleum.

Bioplastics reduce reliance on fossil fuels and address the issue of organic waste disposal. The resultant bioplastic may biodegrade, providing a long-term solution to the issue of plastic pollution. This creative method demonstrates how agricultural by-products can be used to make environmentally friendly materials that adhere to the circular economy's tenets. This study yields two primary advantages applicable in practical experiments and as a beginning venture for further research trials. Its practical value lies in utilizing the refined process parameters attained in this study to enhance the quality of bioplastic derived from agro peels, thus establishing the foundation for scaling up the production of agro-based bioplastics. The secondary benefit involves exploiting this research as an underlying resource for subsequent studies, specifically those aimed at enhancing bioplastic quality and exploring wider opportunities in waste-based bioplastic production [17-18].

Considering this, the present study aimed to synthesize, optimize, and characterize agro-based bioplastic as a substitute for conventional plastic.

MATERIALS AND METHODS

The raw materials required for the construction of the slow sand filter included two container taps and pipes, which were

made from plastic and were purchased from the local market.

Agro-peels (orange, potato, and banana) were collected from households and various juice corners around Karachi, Pakistan. The peels were cut in pieces and oven-dried (for 20 mins). Dried peels were then crushed into a fine powder. The bioplastic film was prepared by adding 10g of crushed peels, 8g of sodium alginate, glycerin, coconut oil, and 500ml of water in a beaker. This mixture was refrigerated to eliminate air bubbles, following that, cotton (1.5g) was added to the mixture and was then poured into a mold. Calcium chloride was sprayed at the top and bottom of the bioplastic film, cast in the mold, and air dried for 3 to 7 days. After the given duration, the bioplastic sheet was gently removed from the mold [19].

In subsequent steps, arrowroot starch/flaxseed/agar was also added as plasticizer [20].

Optimizing bioplastic characteristics involves varying component ratios, altering processing parameters, adding reinforcements or additives, and investigating new materials. Optimization of bioplastics is necessary for enhancing their mechanical, functional, and environmental performance.

Characterization of bioplastics involves the scientific assessment of their physical, chemical, and mechanical properties to understand their behavior and suitability for specific applications. Several tests were conducted for the characterization of bioplastic to ensure its functionality and sustainability.

The mechanical properties of bioplastic are important and they were described in terms of tensile strength (TS) and elongation break (EB). The TS and EB values were investigated on the TINIUS Olsen H5KS machine.

The laboratory environment maintained a relative humidity (RH) of 25% and a temperature of 24.5 degrees Celsius. The specific test parameters, encompassing the test samples' thickness, width, and length, were inserted into the H5KS tester with a gauge length of 50mm and crosshead of 100 mm/min. pre-prepared samples of bioplastic were cut into dumbbell-shaped strips measuring 10 cm in length and 0.5 cm in width

The sensor records the force (MPa) required to strengthen or pull material and it is measured using a load cell or sensor integrated into the testing machine (H5KS).

The elongation of the bioplastic sample was measured using an extensometer or recording the change in position of the grips holding the sample. The speed is often set at a constant rate specified by testing standards (ISO or ASTM) the rate of stringing or pulling is measured in millimeters per minute or inches per minute. The following formulas were used in the calculation of tensile strength:

Cross-sectional area= width × mean thickness

Tensile Strength= Force/cross-sectional area

Elongation break (change in length/initial length)*100

To assess the biodegradability of bioplastic derived from agro-waste in soil, a soil burial method was conducted, and the natural degradation period of the bioplastic sheet was determined. The bioplastic sample was cut into 3 by 3 inches and the initial weight of the bioplastic was measured and buried 6cm deep in the soil.

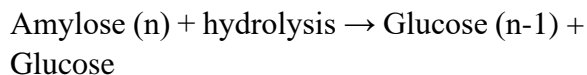
The morphological structure and change in weight of the bioplastic sample were determined after every 5 days for 20 days. The rate of degradation is calculated based on observed changes and the time taken for significant degradation. The final mass of the bioplastic post-degradation was measured

and the biodegradability was assessed falling below formula.

W_i and W_f are the initial and final weights of a bioplastic sample respectively [21].

$$\% \text{ Degradation} = \frac{W_i - W_f}{W_i} \times 100\%$$

The water-soaking process of bioplastics involves exposing the biofilm to water, which causes it to gradually degrade with time in the process of hydrolysis. In the case of bioplastic, hydrolysis breaks amylose bonds in the polymer. The general hydrolysis reaction for amylose in bioplastic is as follows:



Microorganisms such as bacteria and fungi play an important role in the degradation of bioplastic processes; they produce enzymes that facilitate the hydrolysis of samples resulting in small glucose fragments that are further metabolized by microorganisms. Ultimately the bioplastic is broken down into simpler components such as water, carbon dioxide, and biomass. This process is referred to as mineralization where bioplastic components integrate into the natural environment without causing long-term pollution. Bioplastic degradation depends on factors such as the composition and strength of the bioplastic while maintaining the surrounding temperature.

To determine the extent of degradation of prepared bioplastic in water, a preweighed (9.6 g) bioplastic sample was taken and soaked in 300 ml of water at room temperature. Then changes in terms of morphological structure and weight of bioplastic were observed periodically after every 5 days till 35 days. The degradation rate of bioplastic was calculated by the following formula [21].

$$\% \text{ Degradation} = \frac{W_i - W_f}{W_i} \times 100\%$$

Where,

W_i = initial weight of bioplastic before soaking water

W_f = final weight of bioplastic after soaking water

The carbon emission test of bioplastics involves evaluating the amount of carbon released during the decomposition or degradation of bioplastic materials. This test assesses the environmental impact of bioplastics by measuring the carbon dioxide (CO_2) emissions produced during their breakdown. The amount of carbon emitted by prepared bioplastic samples was determined by adopting the method [21].

The bioplastic samples were combined with soil and potassium hydroxide in a closed jar, simulating conditions under which the material could decompose and release carbon dioxide as a byproduct. Potassium hydroxide serves as an absorbent capturing the carbon dioxide released during bioplastic degradation allowing the quantification of the carbon emission from the bioplastic sample.

In the experiment, 50g of soil was sieved, then 25g of prepared soil sample was placed into a glass jar with pH levels maintained between 6 and 8. Additionally, 1g of bioplastic sample and 20 ml of 0.5N KOH were added to the jar. The jar was sealed tightly and kept at room temperature in a dark cabinet. The KOH solution from the jar was collected and then titrated with 0.5N hydrochloric acid once a week for 5 consecutive weeks and the results were recorded.

A similar methodology was adopted to estimate the amount of carbon released from conventional plastics by employing the following formula:

$$\text{Amount of } \text{CO}_2 \text{ evolved} = 0.5 \text{ N of HCl solution} \times \text{volume of HCl titrated} \times 44 \text{ g/mol of } \text{CO}_2.$$

The solubility tests help evaluate the chemical resistance, stability, and compatibility of bioplastics with various solvents under different temperature conditions, providing crucial insights for material selection in specific applications or environments. The bioplastic sheet was cut into small pieces of 0.2g, these samples were put into a test tube containing 6ml of solvents (ethanol, methanol, petroleum, acetic acid, chloroform, Acetone, sulphuric acid, and ammonia). The solubility of the sample was observed at both room temperature and elevated temperatures (50°C). The observed changes in the bioplastic's properties after exposure to different solvents are recorded and analyzed to determine the material's chemical resistance or susceptibility to these solvents [21].

The oil permeability test assesses how different conditions, such as room temperature and elevated temperature, affect the bioplastic's resistance to oil penetration.

Bioplastic samples were weighted, and each sample was submerged in different types of oil (olive oil, mustard oil, and coconut oil) in a conical flask. The oils covered the entire surface area of the sample, the flasks were sealed to prevent evaporation of the oil and placed at room temperature and elevated temperature (50c) for an hour. The observations of this test were based on the change in weight of the sample and calculating its absorption rate by subtracting the initial weight from the final weight of both room temperature and elevated temperature [21].

RESULTS AND DISCUSSION

Results showed varying strength of bioplastics which could be influenced by factors such as polymer blend or processing techniques. Four samples of bioplastics (QAK-17, QAK-18, QAK-19, and QAK-20) were tested for tensile strength. The average thickness of the bioplastics was found to be more than 2.4mm (2400 microns). The

differences in the properties of bioplastics can be attributed to various factors related to their composition, and molecular structure.

Table 1: Tensile Strength of Bioplastics (QAK-20)

Mechanical Properties	Bioplastic QAK-17	Bioplastic QAK-18	Bioplastic QAK-19	Bioplastic QAK-20	Polyethylene
Average Thickness(mm)	2.73	2.63	2.43	2.53	0.45
Cross-sectional area (m ²)	27.3	26.3	24.3	25.3	4.5
Break force (N)	0.166	0.266	1.166	2.666	0.55
Tensile Strength(N/m ²)	2.22x10 ⁻¹⁰	3.845x10 ⁻¹⁰	1.97x10 ⁻⁹	4.16x10 ⁻⁹	2.5x10 ⁻¹⁰
Break Elongation (%)	0	0	26	40	77

Bioplastic QAK-17 has the highest cross-section area than others, this difference in the area can affect the overall force required to break the material. Generally, as the thickness decreases, the cross-sectional area also tends to decrease. QAK-19 has the least thickness and cross-sectional area, followed by QAK-20, QAK-18, and QAK-17 in descending order for both parameters. The cross-section of bioplastics comes from the thickness of the sample multiplied by the width of the sample. The breaking force of the sample QAK-20 was 2.666 N, which is the highest, followed by QAK-19 (1.166 N), QAK-18 (0.266), and QAK-17 (0.166 N). The Bioplastic Sample of QAK-20 exhibits the highest tensile strength, respectively succeeded by QAK-19, QAK-18, and QAK-17. This trend correlates inversely with break force, as QAK-20, with the highest tensile strength, also has the highest break force. The samples of both QAK-19 and QAK-20 have

significant breaking elongation (26% and 40% respectively), indicating higher flexibility compared to QAK-17 and QAK-18, which show no elongation before breaking due to the mechanical structure and composition of these two samples (Table 1).

The coherence between a material's dimensional (thickness/cross-sectional area) and its mechanical characteristics, such as break force and tensile strength, is not consistently predictable or linear. Additional other factors beyond size, encompassing material composition and internal structural aspects, significantly influence the manifestation of these properties. Higher dimensions do not consistently result in higher break force or tensile strength. QAK-20 has comparatively high break force, tensile strength, and break elongation despite not having the largest dimensions, indicating a more robust and flexible nature compared to the other bioplastics in this dataset.

Bioplastic QAK-20 presents greater strength and tensile characteristics, high break force, and tensile strength per unit area compared to Polyethylene. QAK-20's thickness of 2.53 mm yields a larger cross-sectional area of 25.3 m², contributing to its greater resistance to force before breaking. Conversely, Polyethylene, with its thinner profile of 0.45 mm and smaller cross-sectional area of 4.5 m², displays notable flexibility, evidenced by its significantly higher break elongation of 77% compared to QAK-20's 40%. This indicates that while QAK-20 outshines in strength, Polyethylene displays superior stretchability and deformation capabilities before reaching its breaking point. The choice between these materials would depend on specific application needs, favoring QAK-20 for strength-centric applications and Polyethylene for scenarios where flexibility and elongation play crucial roles.

The outcomes of the soil burial test highlight the material's eco-friendliness and

degradation profile in the soil environment. Bioplastic samples (QAK-20) took 20 days to degrade in the soil conditions. The bioplastic was analyzed and weighed after every 5 days to check its degradation.

The degradation rate provided a quantitative measure of the material's breakdown. The gradual decrease in weight and stability of the bioplastic as depicted in Table 2, suggests a high degradation rate over time highlighting the material's susceptibility to the environmental factors in soil.

The bioplastic QAK-20 showed a notable reduction in weight over some time; it indicates the significant degradation of bioplastic. Appearance changes, from cracks to fragmentation and ultimately crumbles, are supported by the weight reduction, showcasing the physical breakdown of the material. The degradation rate progressively increased, reaching 100% at day 20, suggesting complete degradation and disappearance of the bioplastic. These findings suggest that bioplastic QAK-20 is highly degradable in the soil environment, undergoing a rapid breakdown and complete disappearance within the 20-day test period.

Complete degradation of bioplastics in water minimizes the risk of ingestion by aquatic organisms, reducing potential harm to marine life caused by plastic ingestion.

The degradation of bioplastics was observed over 35 days, with measurement of weight taken at various time intervals. The degradation rate increases gradually over time, with a regular reduction in weight. The bioplastic undergoes a significant degradation of 56.2% by day 25 and a complete degradation of 100% by day 35. The decreasing weight and increasing degradation rate indicate a progressive loss of bioplastic integrity. The material is highly susceptible to degradation, and its complete breakdown by day 35 suggests a rapid and substantial weakening.

Table 2: Biodegradability via Soil Burial (QAK-20)

Parameter	Initial weight	5 days	10 days	15 days	20 days
Weight(g)	9.6	6.7	4.4	1	0
Appearance	Intact	cracks	Fragments	Crumbles	Nothing visible
Degradation Rate (%)	0	29	54	89	100

Immersion of bioplastic samples over some time in water for testing the degradation of the material while placed in room temperature helps the production of alternative degradable bioplastic having eco-friendly properties. The ability of the bioplastic to degrade fully in water over a relatively short period reduces the risk of waterborne pollution. It prevents the accumulation of plastic waste in aquatic environments, benefiting marine ecosystems and wildlife. Understanding the degradation kinetics is crucial for assessing the material's suitability for specific applications, and this data indicates that the material may not be suitable for long-term use in scenarios where durability is essential (Table 3).

Table 3: Biodegradation of Bioplastic in Water.

Parameter	Initial weight	5 days	10 days	15 days	20 days	25 days	30 days	35 days
Weight(g)	9.6	8	7.5	6.7	5.9	4.2	2.7	0
Appearance	Intact	cracks	Fragments	Crumbles	Crumbles	Pieces	Pieces	Nothing visible
Degradation Rate (%)	0	16.6	21.8	30	38.5	56.2	71.8	100

Potassium hydroxide's role in the test is crucial for quantifying the carbon emissions associated with the breakdown of the bioplastic. It helps researchers understand the environmental impact of the bioplastic's degradation process by capturing and allowing the measurement of the carbon dioxide released, providing insights into its decomposition rate and environmental implications.

The difference between the carbon emission of bioplastic and conventional plastic was recorded. The measurements include initial and final hydrochloric acid consumption, as well as the corresponding CO₂ emissions. The difference between initial and final HCl represents the amount consumed during titration. The amount of CO₂ released during the degradation of both samples is trapped by using 0.5N HCl solution, the consumed HCl increases with time, representing progressive degradation while CO₂ emissions also increase over time. The rate of CO₂ emitted in bioplastic appears to decrease after 21 days while the CO₂ emitted from conventional plastics increases due to its non-degradable properties. Bioplastic shows a more favorable environmental profile compared to conventional plastic in terms of both HCl consumption and CO₂ emissions. The lower CO₂ emissions from bioplastics suggest that it's a more environmentally friendly alternative. This test indicates that bioplastic may degrade faster and produce organic CO₂ in the environment but decreases after a certain time showing the organic properties of this sample.

This data suggests that bioplastics have lower carbon emission rate during stimulated degradation compared to traditional plastics. This aligns with the general understanding that bioplastics tend to be more biodegradable and environmentally friendly compared to conventional plastics. However, this difference indicates that bioplastics have a significantly lower carbon footprint during its degradation process. This finding underscores the environmental advantages of bioplastic over conventional plastic, as it emits less CO₂, a major greenhouse gas contributing to climate change.

The data provided in Table 4 shows the conducted experiment involving the immersion of bioplastic samples in various types of oils for 1 hour to determine the permeability of QAK-20 in oil. Among the oils, olive oil shows the highest absorption by the bioplastic sample, followed by canola oil and then mustard oil. Notably, in the case of mustard oil at elevated temperature, there's no change in weight, suggesting no absorption by the bioplastic sample in that condition. The bioplastic samples show different absorption capacities for different oils. The absorption is likely influenced by the composition of the bioplastic and the specific interactions between the polymer matrix and the components of each oil. The data advocates that canola oil and mustard oil have similar absorption rates at elevated temperatures, however, olive oil behaves differently, potentially resulting in no observed absorption or weight gain. Excessive absorption will affect the structural integrity of the bioplastic causing changes in mechanical properties, due to which it will become soft and prone to deformation and it might be undesirable in certain applications. If the absorbed oil negatively affects the environment after disposal, concerns about environmental pollution will rise and it might affect the bioplastic recycling process. This experiment shows the absorption percentage of

bioplastic, concluding that under certain temperature conditions, QAK-20 bioplastic is non-permeable in oil or may absorb it in less quantity.

Table 4: Oil Permeability (QAK-20)

Variables	Room temperature			Elevated temperature (50°C)		
	Canola oil	Mustard oil	Olive oil	Canola oil	Mustard oil	Olive oil
Oils (ml)						
Initial weight (g)	1.2	1.2	1.2	1.0	1.06	1.0
Final weight (24hrs)	1.12	1.11	1.38	1.06	1.06	1.0
Absorption	0.08	0.07	0.18	0.06	00	00

CONCLUSION

In conclusion, the bioplastics from agro peels offer a promising and sustainable solution to the environmental concerns linked with traditional petroleum-based plastics. This approach of turning waste into valuable materials such as bioplastics embodies the principles of a circular economy reducing the burden on landfills and substantially lowering carbon footprints associated with plastic production. It mitigates the reliance on fossil fuel resources and promotes a closed-loop system. The utilization of agricultural waste, which is often discarded or left to decompose, demonstrates resource efficiency adds value to agricultural by-products, and reduces the environmental impact of disposal striving towards a more sustainable future and circular economy.

This research underwent a thorough exploration and testing of various fruit and vegetable peels, polymerizing agents, and optimum methodologies for an achievable and promising outcome. The use of arrowroot starch, which is a renewable source, provided the required strength and durability to the bioplastic film. Its utilization aligns with the increasing global emphasis on sustainable practices contributing to reduced

dependence on non-renewable resources. Arrowroot starch has enhanced the material's properties and demonstrated its potential as an effective polymerizing agent for the synthesis of bio-based plastic. The implementation of arrowroot-based plastic can provide a notable step towards a greener landscape.

Continued research and advancement in this field are vital to improve production processes, enhance material properties, and scale up the adoption of agro peel-based bioplastics. By fostering the concept of "waste to wealth." and embracing these eco-friendly alternatives, we can contribute to a healthier planet and build a more sustainable and resilient material landscape for the future. Despite potential higher costs, the environmental benefits make agro-peel-based bioplastics a compelling choice, leading toward a greener future.

While the synthesis of bioplastics from agro peels is promising, ongoing research is necessary to optimize production processes, improve material properties, and address any challenges associated with scalability and cost-effectiveness. The success of bioplastics derived from agro peels also depends on consumer acceptance and awareness. Education and marketing efforts can play a key role in promoting the use of these sustainable alternatives.

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