Biodegradable Plastic from Banana Peel Waste: A Sustainable Biomass Solution

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Abstract

Plastic waste is one of the biggest threats to our ecosystem, and its continued use may endanger the existence of human life on Earth if no viable alternative is found. Using paper as a substitute is not a suitable solution due to its limited applications compared to plastic. This situation urges the search for biodegradable alternatives derived from sustainable materials. This study aims to develop biodegradable plastic from banana peels, providing a sustainable and eco-friendly alternative to conventional plastic, while contributing to the circular economy and sustainable innovation. Waste banana peels were collected, cleaned, and dried. The peels were then blended into a paste and combined with natural additives such as gelatin (binding agent), glycerin (binding agent), and vinegar (pH adjustment). The mixture was processed under controlled heat to form biodegradable plastic. The resulting material was evaluated for strength, water resistance, and decomposition under controlled conditions. The produced biodegradable plastic showed signs of decomposition due to microbial activity, occurring significantly faster than in conventional plastics. This indicates the material's biodegradability and potential to improve soil quality as biomass. The approach represents a low-cost, eco-friendly solution that also adds value to organic waste, highlighting its potential role in sustainable material innovation.

Keywords

Bioplastic, Banana Peels, Pollution, Biodegradable Films, Decompose

1. Introduction

Banana (*Musa spp.*) is one of the most widely cultivated fruits in Bangladesh, contributing significantly to both rural livelihoods and the agricultural economy. According to the Food and Agriculture Organization (FAO), Bangladesh produced over 8.16 million metric tons of bananas [1]. Banana peels, which constitute approximately 30-40% of the fruit's total weight, are typically discarded as waste after consumption [2]. But it contains valuable bioactive compounds. Its composition varies depending on the variety and ripeness stage, but in general, banana peels are rich in: 50-60% carbohydrates, mostly cellulose, hemicellulose, lignin, and starch, which give things their structural stability, 6-9% of proteins, 3- 8%of lipids, dietary fiber 30-50%. The proximate composition of a banana peel is presented in Table 1**,** Banana peel content [3].

Table 1. Banana Peel Content

Item	**Proximate Composition**
Starch	50%-60%
Protein	8.6 %± 0.1
Fat	8.40(g/100g) ± 0.2
Starch	12.78% ± 0.9
Ash	15.25% ± 0.1
Total Dietary Fat	50.25 ± 0.2
Total Phenolic Content	7.4%

Improper disposal of banana peel waste not only leads to environmental concerns such as methane emissions and increased organic load in landfills but also represents a loss of valuable biomass. These peels are rich in natural biopolymers such as cellulose, lignin, and starch, which can serve as the polymer matrix for bioplastic production. It also includes secondary metabolites such as polyphenols, flavonoids, and alkaloids that have antioxidant and antibacterial qualities in addition to cellulose, lignin, and starch. Several studies have shown that banana peels have higher concentrations of phenolic compounds, antioxidant properties, and other bioactive than banana pulp [4].

Their starch content, which ranges from 15 to 18 percent, further increases their potential as a base material for bioplastics. These biological elements improve the tensile strength, water resistance, and biodegradability of bioplastics.

Natural biopolymers derived from renewable biomass sources, known as bioplastics, are increasingly recognized as sustainable alternatives to petroleum-based plastics. Bioplastics are biodegradable, non-toxic, energy-efficient, and capable of enhancing soil fertility after degradation. In contrast to conventional plastics, which can take 5-6 years to decompose in soil, bioplastics can break down within 4-5 months under suitable conditions. Global plastic pollution remains a critical issue, with an estimated 19-23 million tons of plastic waste leaking into aquatic ecosystems annually [5]. The urgent need to replace synthetic materials with bio-composite materials derived from renewable resources has driven research into plant fiber-based solutions.

In Bangladesh, plastic pollution is an issue, particularly in urban areas like Dhaka and Chittagong , where polythene bags and single-use plastics clog drainage systems, resulting in waterlogging and environmental harm. The government has previously banned plastic bags, but due to their high price and limited availability, there are still few good substitutes. Waste from banana peels, a year-round by-product, provides an inexpensive alternative that can reduce dependency on plastic while opening up new opportunities for rural businesses.

Banana peel-based bioplastics offer a promising, low-cost, and eco-friendly solution to this problem. In bioplastic production, glycerol is often used as a plasticizer to reduce brittleness and improve flexibility by decreasing hydrogen bonding between starch molecules. Vinegar is added to regulate pH and aid in breaking down peel fibers more efficiently, while gelatin serves as a biopolymer binder to enhance the material's structural integrity. The composition and unique properties of banana peels position them as a viable raw material for producing biodegradable plastics that are both mechanically robust and environmentally beneficial. One important advantage of bioplastics derived from banana peels is their ability to decompose rapidly in the environment. As they decompose, they return minerals like potassium and phosphorus to the soil, increasing soil fertility and supporting sustainable agriculture.

By transforming banana peel waste into value-added bioplastics, this approach not only addresses plastic pollution but also contributes to the circular economy and sustainable innovation in waste management, as opposed to polymers derived from petroleum that persist in the environment for many decades.

2. Materials and Methods

2.1 Collection of the Sample

Locally available bananas were collected from the markets in the Chittagongregion, the pulps were removed, and their peels were further used for plastic preparation. Figure 1 illustrates the type of banana and the peels used in this study.

(a) (b)

Figure 1. Banana and banana peel

The peel was removed and utilized as raw material for bioplastic development in this study.

2.2 Sample Preparation

The fresh banana peels were spread out on various trays for drying at room temperature for 4-5 minutes after being cleaned under running distilled water to remove dirt and other residues. After that, the peels were sliced into small pieces using a knife, and then boiled with distilled water for a few minutes and then dried at room temperature for 30 minutes. Figure 2, which illustrates the small pieces of banana peels sliced for boiling and blending purposes.

Figure 2. Illustration of banana peels

The peels were collected, cleaned with distilled water, chopped, and boiled for a few minutes, and then dried in a baking sheet for a few minutes.

2.3 Preparation of Banana Peel Slurry

Banana peels were blended with a small amount of water to form a smooth puree, which was subsequently strained to obtain a clear extract, removing any residual solid particles. Figure 3 shows the stepwise preparation of biodegradable plastic film from banana peels.

Figure 3. Stepwise preparation of biodegradable plastic film from banana peels

(a) Chopped banana peels were put in a blender (b) boiled, adding a small amount of water (c) mixture strained using a strainer along with the addition of gelatin, vinegar, and glycerin (d) mixture heated at a medium flame (e) The mixture was poured on a glass petri plate and dried.

2.4 Preparation of Banana Peel-Based Bioplastic Film

The banana peel extract was combined with gelatin powder in a mixing bowl at a ratio of 2 parts extract to 1-part gelatin. Specifically, 120 mL of banana peel extract was mixed with 60 g of gelatin powder until a uniform solution was obtained.

Following mixing, 15 mL of vinegar was added to aid in the breakdown of peel fibers, along with 22.5 mL of glycerin (optional) to improve flexibility. The mixture was transferred to a pot and heated over medium heat with continuous stirring to gelatinize the starch and ensure complete integration of the banana peel extract and additives.

Heating was continued until the mixture reached a glue-like consistency, ensuring it was smooth and free of lumps. The hot mixture was then poured onto molds or flat trays and evenly spread to form a thin layer. When molds were used, specific shapes could be obtained.

Drying was carried out in a hot-air oven at 50-60 °C or in a drying apparatus until the film was completely dry, typically requiring several hours. Alternatively, air-drying at room temperature was possible but required extended drying time. Once dried, the bioplastic films were carefully removed from the mold or tray, cut into the desired shapes, and trimmed to obtain smooth edges. The prepared films were stored in a cool, dry place until further use.

The Figure 4, Flowchart of Bioplastic Film Production from Banana Peel, below displays the steps for the production of biodegradable bioplastic using banana peel.

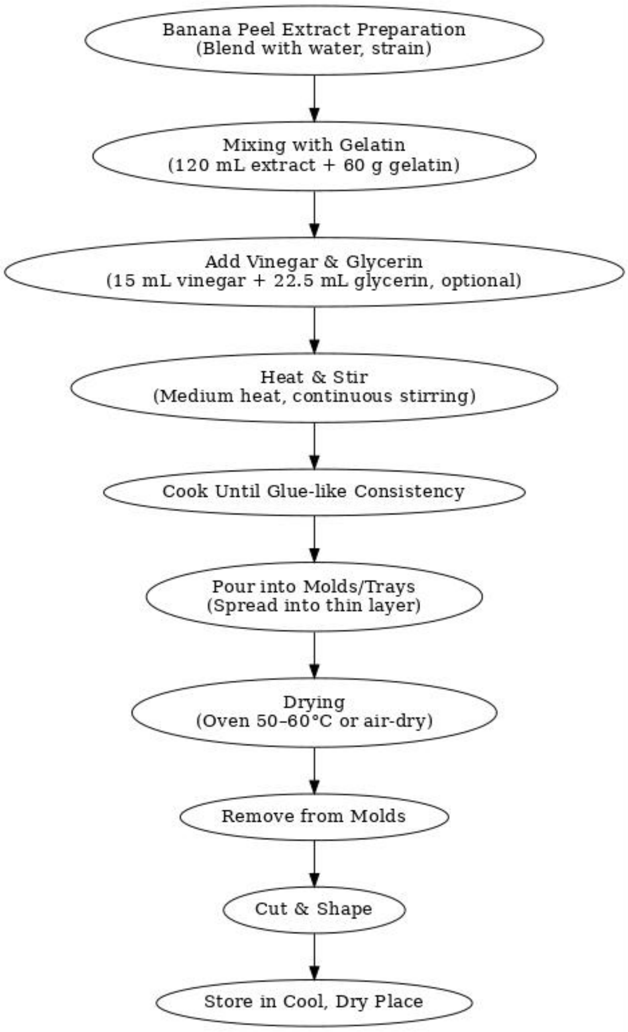

Figure 4. Flowchart of Bioplastic Film Production from Banana Peel

The process begins with the collection and cleaning of banana peels, followed by drying and blending into a fine puree. The puree is mixed with plasticizers such as glycerol, glycerin, and vinegar to form a homogenous solution. After heating and casting, the mixture is cooled and dried, resulting in biodegradable plastic films with eco-friendly applications.

2.5 Comparative Characterization of Banana Peel, Gelatin-Based, and Bio-ethylene-Derived Bioplastics

2.5.1 Tensile Strength

The ASTM standard machine was used to measure the tensile strength. In the addition of starch, the tensile strength improves, but in its absence, it is minimal.

2.5.2 Biodegradability Test

The synthesized bioplastic and other bioplastics were cut into small pieces and placed in three different marked pots containing soil at a depth of 5 cm from the surface [6]. To enhance bacterial enzymatic activity, a certain amount of water was sprayed onto the soil. These samples were stored in the beaker for approximately 18 days, during which time degradation of the bioplastic was observed every 5 days, and the findings were noted.

2.5.3 Transparency Test

A UV-Vis spectrophotometer set to 600 nm was used to measure light transmittance and visually inspect the films' clarity in order to assess the transparency of the banana peel bioplastic compared with the other bioplastics.

2.5.4 Flexibility Test

Flexibility was determined through manual bending and folding tests, as well as by applying tensile strength measurements using a Universal Testing Machine (UTM). Films were cut into strips (10 mm × 50 mm) and tested for elongation at break.

2.5.5 Water Resistance Test

Water resistance was tested by immersing bioplastic film samples in distilled water at room temperature for 24 hours and recording the degree of swelling and solubility.

2.5.6 Thermal Resistance Test

Thermal resistance was analyzed by heating gradually from 30°C to above, and observations were recorded.

Figure 5. A biodegradable film prepared using banana peel, which represents a golden-yellow color

It illustrates good flexibility and transparency.

3. Results and Discussion

Formation of biodegradable film: A biodegradable film with a golden color was successfully prepared from banana peels using starch and cellulose, which involved extraction, mixing with gelatin, vinegar, glycerin, and distilled water, with homogenization, and molding in a tray. Figure 5 shows the formation of a biodegradable film using banana peel, producing a flexible and durable film. The final product had a smooth texture and was moldable into various shapes before hardening [7].

Tensile Strength: The biodegradable film made from gelatin and banana peel extract exhibited a low to moderate tensile strength, indicating adequate mechanical resistance for light packaging applications. In comparison to gelatin-based bioplastic, as mentioned in Table 2, which shows low to moderate tensile strength as suggested by [8] and bio-ethylene-based bioplastic have shown higher tensile strength [9].

Table 2. Comparison of the developed bioplastic with other related commercial plastics, highlighting differences in physical and material properties

Feature	Banana Peel Bioplastic	Gelatin-based Bioplastic	Bio-ethylene-based Bioplastic
Source Material	Banana peel (agricultural waste)	Gelatin (animal collagen protein)	Bio-ethylene (from sugarcane/corn)
Type	Starch-based	Protein-based	Polymer-based (like polyethylene)
Biodegradability	Highly biodegradable	Highly biodegradable	Less biodegradable
Tensile Strength	Low to moderate	Low to moderate	High
Flexibility	Moderate	High	High
Transparency	Opaque or translucent	Transparent to slightly opaque	Clear and Transparent
Water Resistance	Poor	Poor to moderate	Good
Thermal Resistance	Low	Low	High
Cost of Production	Low	Moderate	High
Application	Disposable cutlery, packaging	Film wraps, capsules	Bottles, industrial packaging
Environmental impact	Very low	Low	Moderate

According to these comparisons, banana peel films still have an importance in environmentally friendly packaging, even though their tensile strength may be a little lower than that of some starch-based substitutes. This is especially so considering their reasonable price and potential for waste valorization.

Biodegradability: The prepared biodegradable film from banana peel demonstrated rapid degradation under controlled soil burial conditions, showing visible microbial activity and fragmentation within 2-3 weeks. This degradation rate is significantly faster than conventional gelatin-based plastics, which can persist in the environment for several years. As all the ingredients used are organic and biodegradable, and no harmful chemicals were used in the process, therefore, as mentioned in Table 2, the produced bioplastic film is highly degradable.

Similar results were reported by [10], who observed that banana peel starch-based films degraded within 120 days under composting conditions, confirming their suitability as an eco-friendly packaging material. In comparison, cassava starch-based bioplastics were reported to degrade completely in 90-100 days [8].

These findings confirm that banana peel bioplastic films are comparable to other starch-based biodegradable plastics, offering an environmentally sustainable and low-cost alternative with efficient degradability.

Transparency: The bioplastic films made from extract from banana peels showed a opaque or translucent level of transparency, as shown in Figure 5. The semi-transparent aspect of the films is a result of the structural elements of banana peel, particularly the starch and pectin. According to [11], light penetration and film clarity are significantly influenced by the starch and fiber content of banana peels.

Flexibility: The banana peel bioplastic film displayed moderate flexibility, which was significantly improved by the addition of glycerin as a plasticizer. Glycerin increases chain mobility and permits films to flex without breaking by decreasing intermolecular hydrogen bonds. [12] showed similar results with bioplastics based on starch and protein.

Water Resistance: The hydrophilic nature of the starch caused the films to show poor water absorption. On the other hand, adding vinegar and gelatin decreased solubility in water. [13] observed similar improvements in starch-gelatin-based films with plasticizer reinforcement.

Thermal Resistance: Banana peel-based film exhibited low stability under moderate heating but began to soften at higher temperatures due to starch gelatinization. The findings agree with the results reported by [8], who noted that starch films are generally limited in their usage in high-heat applications due to their tendency to thermally degrade at high temperatures.

4. Conclusion

This study shows that through the use of natural ingredients like vinegar, glycerin, and gelatin, banana peels—an agricultural waste that is widely available in Bangladesh—can be efficiently used to create biodegradable plastic films. The resultant film exhibited effective biodegradability in a few months under controlled conditions, along with desirable qualities including transparency, flexibility, water resistance, and thermal stability. Banana peel films demonstrated similar tensile strength and rates of breakdown when compared to other starch-based bioplastics, suggesting their promise as an affordable, environmentally responsible substitute for petroleum-based plastics. Additionally, developing them promotes a circular economy and waste valorization. All things considered, bioplastics made from banana peels are a sustainable development that has the potential to greatly lower plastic pollution and improve environmental preservation.

5. Future Aspects

To improve the mechanical and barrier qualities of bioplastics made from banana peels, future studies should concentrate on increasing production quantity and refining formulation parameters. Strength, flexibility, and water resistance may be further enhanced by adding natural fibers or nanomaterials. Life cycle assessment (LCA) studies are also required to examine the energy efficiency and environmental effect of large-scale production. The commercial potential could be increased by investigating uses in disposable dishes, agricultural sludge films, and food packaging. Lastly, in order to advance the use of banana peel bioplastics as a competitive substitute for petroleum-based plastics and satisfy global sustainability targets, cooperation between researchers, businesses, and lawmakers will be necessary.

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