# Production of Sustainable Bioplastic Films from Banana Pseudostem Waste: Experimental Development and Preliminary Evaluation

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**Abstract**

The continually growing problem of non-biodegradable plastic waste generated from packaging is creating significant environmental issues that call for the development of eco-friendly substitutes based on renewable materials. Banana pseudostem is an ideal candidate as an available agricultural waste product containing large amounts of naturally occurring polymer-based materials. Utilizing banana pseudostem as the primary raw material for producing biodegradable bioplastics can be used to solve the problems associated with managing agricultural waste, while also reducing greenhouse gas emissions through decreased reliance on petroleum-based plastics. A laboratory scale bioplastic film fabrication method was developed to utilize banana pseudostem as a sustainable raw material source for developing biodegradable bioplastic films. After cleaning, drying, grinding, and treating the banana pseudostem to remove impurities (alkaline and hydrogen peroxide bleaching), it was then blended with agar (film forming) and glycerin (natural plasticizer). Following blending, the mixture was heated, casted onto a flat surface and allowed to dry at a controlled rate to create bioplastic films. The successful demonstration of the capability to generate continuous bioplastic films with a smooth surface and appropriate structural integrity (flexibility) confirmed the viability of utilizing banana pseudostem as a sustainable resource for generating biodegradable films. This study established a green technology path toward transforming agricultural waste into high-value bioplastic products. The results of this research will provide foundational knowledge for application in various areas such as sustainable packaging systems, single-use biodegradable products, and circular bio-economies, and will enable the use of artificial intelligence based methods for optimizing the processes involved in characterizing these new materials.

**Keywords:** Banana pseudostem, Biodegradable bioplastic, Sustainable packaging, Agro-waste valorization, Biopolymer films.

## 1. Introduction

The global presence of traditional petroleum-based plastics in packaging systems has transformed the way packages are made today with high quality mechanical properties at lower costs and simple processing capabilities. However, the inability for petroleum-based plastics to be biodegradable has contributed to some serious negative impacts on our environment by contributing to plastic waste that is being deposited into landfills, streams, lakes, and oceans. Furthermore, the increasing demand for packaging products as a result of the growing e-commerce industry has worsened these problems with an increase in usage of single-use packaging products. As such, developing biodegradable packaging products from natural (renewable) sources continues to be a significant area of research focus so that

the amount of pollutants in our environment can continue to decrease while utilizing natural resources sustainably [1], [2].

Biodegradable and renewable plastics made from natural polymers (bioplastics) are emerging as promising alternatives to traditional plastics because they can be both biodegradable and environmentally friendly. In addition, cellulose, starch, agar, chitosan, and other naturally occurring polymers have attracted considerable interest for packaging applications due to their film forming ability and potential for biodegradation [3]. Nonetheless, many commercially available bioplastics still utilize food-based feedstocks, which raises concerns about availability of food supplies and the cost of production. Thus, recent research has been directed toward use of agricultural residues as low-cost and sustainable raw materials for biodegradable polymer production [4].

In addition to other agricultural residues banana pseudostems are being produced on an industrial scale when bananas are harvested. As they are composed primarily of cellulose, hemicellulose and lignin, they present a valuable opportunity as a source of renewable biomass to be used as raw material to produce eco-friendly (biodegradable) products. Valuing this agricultural residue can minimize the pollution caused by agricultural waste and contribute to the development of a bio-based economy based on the reuse and recycling of products [5]. A number of studies have looked at the use of the banana pseudostem as a raw material to extract its cellulose and starch content; which could then be transformed into various types of composites and biodegradable films [6], [7]. The inclusion of glycerol as a natural plasticizer can improve film flexibility, whereas including agar in the formulation process can enhance film-formation properties. These types of materials represent an interesting alternative for developing packaging systems compatible with sustainable production models [8].

Recent investigations into optimizing biopolymer composition; to improve mechanical properties; and to increase biodegradation by adding natural fibers and additives are numerous. In comparison, few laboratories have demonstrated an entire laboratory-scale production of materials from banana pseudostem using relatively simple chemistry treatment and casting methods applicable to sustainable packaging. Additionally, few investigations have utilized a systematic experimental approach as part of developing a data-based optimization method and model for predicting new material designs in the future. Table 1 summarizes representative studies on banana pseudostem and related biodegradable bioplastic materials, highlighting their primary materials, processing methods, and major findings.

**Table 1. Summary of previous studies on banana pseudostem-based biodegradable materials**

| Raw Material | Processing Method | Major Findings | Research Gap | Ref. |
|---|---|---|---|---|
| Banana pseudostem fibers | Cellulose extraction | Improved reinforcement in composites | Limited film fabrication | [5] |
| Banana pseudostem cellulose | Biocomposite preparation | Enhanced mechanical properties | No complete fabrication workflow | [6] |
| Agricultural waste fibers | Biopolymer composites | Improved biodegradability | Limited packaging applications | [7] |

| | | | | |
|---|---|---|---|---|
| Starch–agar bioplastics | Solution casting | Good flexibility and film formation | Alternative agro-waste feedstocks not explored | [8] |
| Banana pseudostem | Chemical treatment + film casting | Laboratory-scale biodegradable bioplastic fabrication | Characterization and AI-based optimization planned | **Present Work** |

The objective of this research is to create an economical, bench scale method for creating biodegradable bio-plastic films from banana plant (pseudostem) agro-wastes. Agar and glycerin will be used as natural additives in developing the films. The research is primarily focused on processing and chemical treatments of the raw materials; preparing and testing samples of the created films; and evaluating the suitability of the developed films for further studies. The development described here could also provide an environmentally beneficial path for utilizing organic wastes, and establish a basis for subsequent detailed characterizations, optimizations and data-based designs of sustainable packaging materials.

## 2. Key Contributions

A lab-scale method to create biodegradable bioplastics made out of bioplastic films from banana pseudostem has been developed. Most prior research into banana-based materials have either looked at how to characterize them or how to strengthen their composite structure with other types of biopolymers. In contrast, this work provides a comprehensive lab-based approach to prepare feedstocks for use in bioplastic films including both chemical treatments and fabrication of bioplastic films using commonly found materials that are non-toxic such as agar and glycerol. The production of continuous bioplastic films confirm that it is possible to utilize banana pseudostems as a source of sustainable packaging feedstocks.

The primary contributions from this research can be identified with respect to the following points:

1. A straightforward and reproducible method for converting waste banana pseudostems into biodegradable bioplastic films was developed.
2. An example of how an integrated approach could be used to create an experiment that includes preparing biomass, treating (alkaline/peroxide), and fabricating a film through a solution casting process was demonstrated.
3. Experimental validation of the potential to develop films made from uniform, flexible bioplastics with banana pseudostem, agar, and glycerol as sustainable components was provided.
4. Agro-wastes were converted into a value-added, biodegradable product which is in line with the tenets of the circular bio-economy; therefore, it also promotes the utilization of biomass that has been previously unutilized.

The results of this research have established the base upon which a framework may be created for further quantifiable characterization, statistical analysis, and predictive models based on Python to further develop and refine formulations for bioplastics to meet needs for sustainable packaging products.

## 3. Method, Experiments and Results

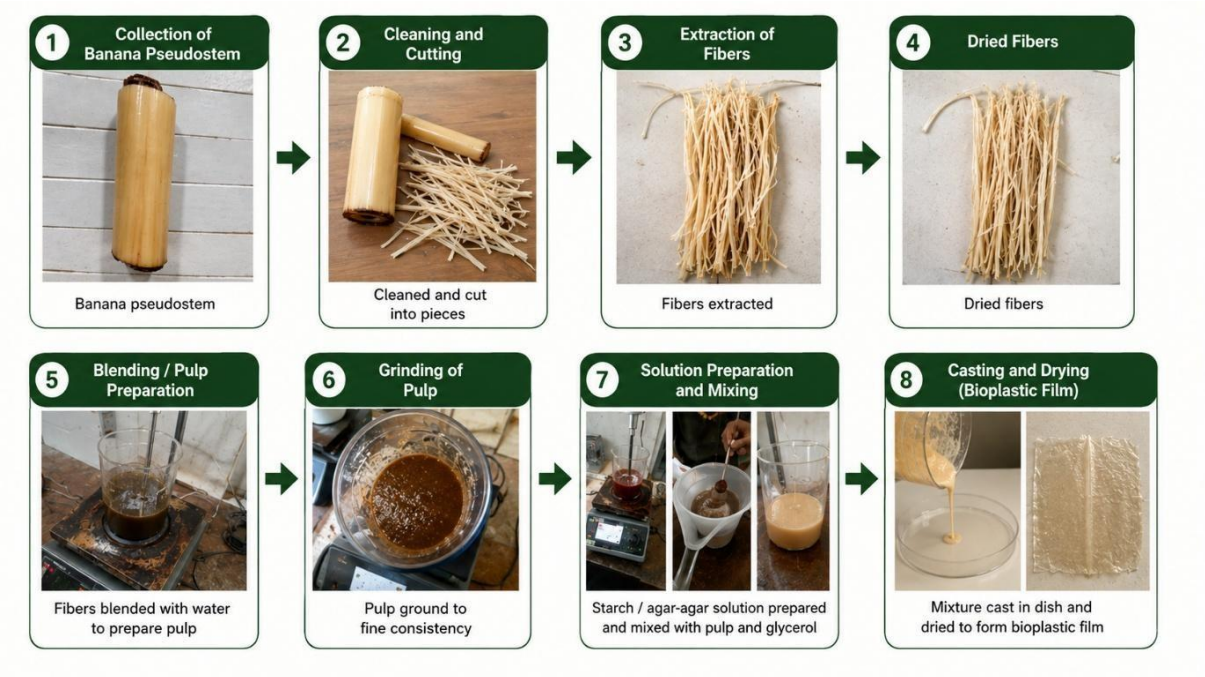
### 3.1 Materials

Banana pseudostem was chosen primarily as a raw material due to it being available locally, renewable, and containing very high levels of cellulose. The fresh banana pseudostems were obtained directly from the surrounding local agricultural areas during the time when fruits are harvested. Agar formed the basis of our use of the naturally occurring film forming polymers; glycerol was utilized in order to enhance flexibility of the produced films. For the purposes of enhancing the fiber quality through removal of lignin, hemicelluloses and colorants, sodium hydroxide (NaOH) and hydrogen peroxide ($H_2O_2$) were both applied during the chemical treatments and bleaching process. Distilled water was also utilized throughout this study.

### 3.2 Experimental Methodology

The general method used to complete this research is illustrated in FIGURE 1. Overall, it includes six main steps: (I) Collection of Banana Pseudostems; (II) Preparation of Feedstocks; (III) Chemical Treatment; (IV) Preparation of Composites; (V) Film Casting; and (VI) Bioplastics Film Production. This step-by-step, simplified laboratory scale conversion of Agri-Waste to Bio-Degradable Polymer Films represents an efficient pathway.

**Figure 1. Experimental workflow for fabrication of biodegradable bioplastic films from banana pseudostem.**




### 3.3 Preparation of Banana Pseudostem Feedstock

The fresh banana pseudostem was first rinsed with water to clean it of dirt and any other debris that may be clinging to it. It was then cut into very small pieces. The pieces were allowed to dry on their own so they would have less moisture. After drying, the material was ground in a laboratory mixer grinder. The resulting powder was then sifted through different mesh sizes to get the powder uniformly sized so it could be processed further. This is the starting material (the "precursor") from which the bioplastics will eventually be produced.

### 3.4 Chemical Treatment of Banana Pseudostem

Prepared banana pseudostem (pulp) powder underwent an alkaline treatment with diluted NaOH (sodium hydroxide) at about 60°C for 30 min. The alkaline treatment removed lignin, hemicellulose, waxes and all types of contaminants from the biomaterial. Following that the treated material was washed thoroughly in distilled water. The treated material was then bleached using hydrogen peroxide in a controlled temperature environment. Bleaching helped increase purity of fibers by eliminating pigment remnants as well as the remaining fragments of lignin. The treated material after filtration and washing was dried in a hot air oven, and it was stored for use in fabricating films.


**Figure 2** illustrates the major experimental stages involved in feedstock preparation and chemical treatment.

### 3.5 Fabrication of Bioplastic Films

An agar solution was prepared by mixing agar powder with distilled water. The agar solution then heated approximately 90-95 C with constant mixing. Then the treated banana stem powder was slowly mixed into the hot agar solution. Constant mixing continued to mix well. Finally glycerin was added as an all-natural plasticizer so that the composite film would be flexible.

The final liquid (now too thick) was then put in petri dishes for formation of thin films. The films were left to air-dry on lab benches until they dried completely. Once dry, the films were carefully removed from their molds.

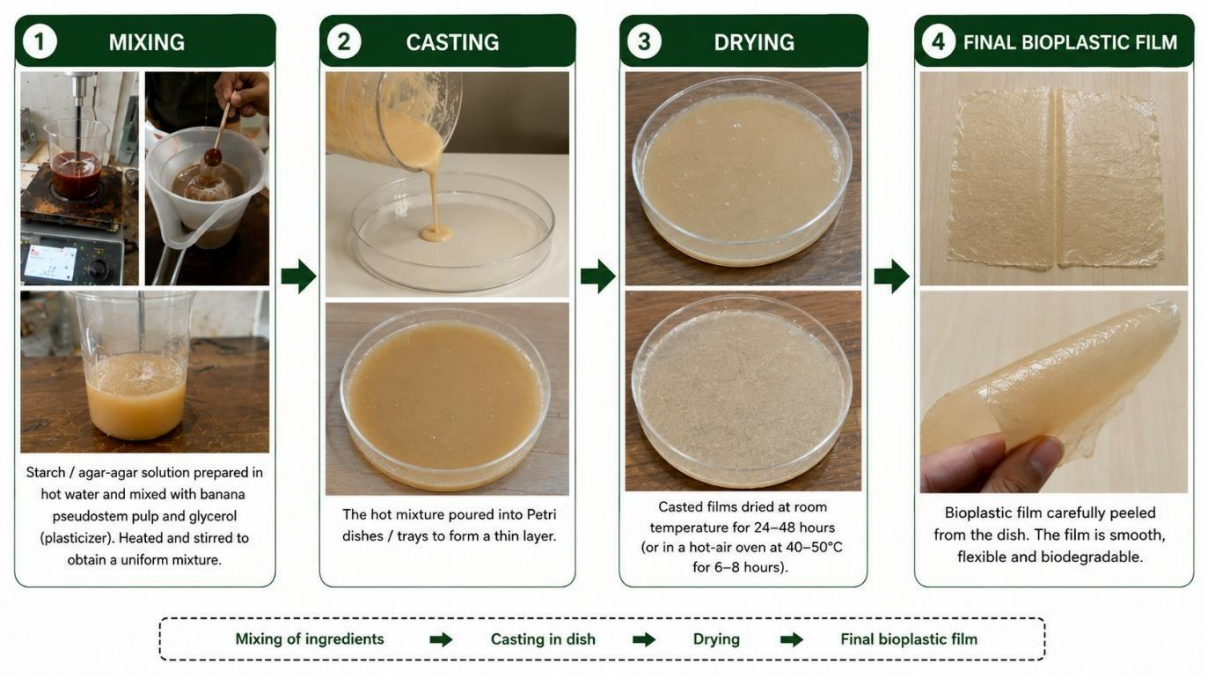



**Figure 3** presents the laboratory-scale fabrication process and the developed bioplastic films.

### 3.6 Preliminary Experimental Results

The production method for fabricating the bioplastics succeeded in producing continual bioplastic films made from banana pseudo stem. The visual observation showed that the film surface was generally smooth with good structural properties. Glycerol added to improve flexibility to the film; Agar helped create a uniform film through the process of solution casting. The films were easy to remove from the petri dish once dried, which indicates that the films have adequate physical structure and can be handled satisfactorily. While the details on the mechanical and physico-chemical evaluation of the fabricated films is still pending completion at this time, the successful creation of these uniform bioplastic films illustrates that it is technically feasible to utilize banana pseudo stems as a renewable resource to produce biodegradable packaging materials. The results of the initial observations collected throughout the experimental period are provided in Table 2.

**Table 2. Preliminary observations of fabricated bioplastic films**

| **Parameter** | **Observation** |
|---|---|
| Film formation | Successful |
| Surface appearance | Smooth and uniform |
| Structural integrity | Good |
| Flexibility | Moderate |
| Ease of film removal | Good |
| Visual defects | Not observed |

Beginning with the "proof of concept" for creating bioplastics sustainably from banana pseudostems, we have developed a series of artificially created films that are needed in order to carry out further characterization. We plan to test the mechanical properties of our film by determining its tensile strength; evaluate how much it absorbs water; determine how long it takes for the film to degrade after being placed into an environment where microorganisms can break down organic matter; use SEM to characterize the topography of the surfaces of these films; and statistically analyze factors related to the formulation of the materials we create to be able to optimize their physical characteristics.

**4. Discussion**

Beginning with this statement, "This research demonstrated the successful laboratory scale fabrication of biodegradable bioplastics, created from banana pseudostems as a single renewable feedstock." We have outlined our experimental process, which consists of preparing the feedstocks; chemically treating them to obtain pure cellulose and then creating the solution castings of the films. Our results indicate that we were able to successfully form a film from the banana pseudostem (which has high levels of cellulose) and therefore that there may be an alternative to petroleum based plastics for the sustainable manufacturing of bioplastics.

We found that alkaline treatments followed by hydrogen peroxide bleaching of the banana pseudostem increased the quality of our feedstocks by removing non-cellulosic compounds like lignin, hemicellulose, and other colorants. The bleach treatment lightened up the banana pseudostem so that we could create a more homogenous blend of polymers. Other researchers have used similar pretreatments of natural fibers prior to processing into bioplastics. In fact, they have reported that such pretreatments can increase the processibility and quality of both natural fiber based biopolymers by increasing the purity of cellulose and decreasing the number of contaminants that negatively impact film forming [5] [6].

Incorporation of agar as a film-forming matrix and glycerol as a plasticizer greatly aided us in fabricating our bioplastic film. The agar provided a continuous network of polymers whereas glycerol enhanced the flexibility by decreasing the molecular interaction within the polymer matrix. Observations showed that the fabricated film had a very smooth surface, was relatively flexible, and appeared to have good structural properties, with no visible cracks or breaks. Our observations are consistent with previously published works regarding agar- and starch-based biodegradable films, wherein researchers have noted that natural plasticizers can help to make films more flexible while still allowing films to maintain their integrity [7] [8].

While we demonstrate here only the concept of fabrication, we believe that this paper provides a reliable method for transforming banana pseudostem waste into biodegradable films. Studies concerning quantitative analysis (tensile strength, water uptake, degradation behavior, thermal stability, and surface morphology) are now being conducted. Data collected during those studies will allow us to perform statistical analyses on our results and develop python-based models to predictably modify our formulations and improve our bioplastic's properties.

Ultimately, our findings show that banana pseudostem can be converted into a biodegradable biopolymer and highlights its contributions to valorizing agro-wastes, promoting circular economy practices in bio-economy initiatives, and developing environmentally-friendly packaging materials.

## 5. Conclusions

The major conclusions of this study are summarized as follows:

1. **Problem Statement Addressed:**

   The research being conducted will address increasing environmental issues related to the use of traditional petroleum-based plastics in packaging through investigation into the potential for utilizing banana pseudostems (an inexpensive and highly available agricultural waste) as a substitute for petroleum-derived materials for producing biodegradable bioplastics.

2. **Method Used:**

   In this study a laboratory scale method of fabricating biodegradable bioplastic films from banana pseudostems has been developed that includes pretreatment of banana pseudostems using both alkaline solutions and hydrogen peroxide, then mixing with agar and glycerin after which solution casting is performed and the resulting film dried in a controlled environment.

3. **Key Findings:**

   - The banana pseudostem could be converted to an appropriate feedstock for bioplastics.
   - A method of producing continuously fabricated, flexible and structurally strong film type of bioplastics from banana pseudostems was successful in development.
   - Banana pseudostem waste can now be shown to be technically convertible to higher valued products such as biodegradable material through simple processes which are also environmentally benign.
   - The process described is beneficial to both waste recycling and will contribute to the development of new methods for developing sustainable packaging and other circular economy approaches within the bioeconomy.

4. **Limitations and Future Work:**

   The current research focuses primarily on developing biodegradable films at a lab scale. Biodegradability testing has been performed with positive results; however, detailed material property characterization (mechanical, thermal, barrier, etc.) along with testing for degradation rates are being completed. A future aspect of this project will be optimizing the formulation process using statistical methods as well as using Python based machine learning algorithms to develop predictive correlations between process variables and bioplastic properties to enable the design of high performance biodegradable packaging materials.

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