



## Production of Bioplastics from Agricultural Waste

Khadiga Mohammed Ahmed Badri<sup>1\*</sup>, Kamal Eldin ELtayeb Yassin<sup>1</sup>

<sup>1</sup>Department of Chemical Engineering, University of Khartoum, Sudan

\*Corresponding author (E-mail: [khadiga.jm93@gmail.com](mailto:khadiga.jm93@gmail.com))

### ARTICLE INFO

#### Keywords:

Bioplastics, Banana peel waste, Agricultural biomass, Batch reactor, Cellulose-based polymers, FTIR characterization

#### Article History:

Received on:

Accepted on

#### Article Type:

Research Article

DOI: 10.53332/uofkej2237

### ABSTRACT

The diminishing availability of petroleum resources, coupled with escalating environmental and waste management challenges, has intensified the global search for sustainable alternatives to conventional petroleum-derived plastics. In 2017, the Higher Council for Environment and Urban and Rural Promotion in Khartoum State, Sudan, issued a formal decree prohibiting the manufacture and circulation of lightweight plastic bags. Bioplastics have emerged as a critical innovation to mitigate these issues by utilizing renewable and degradable natural resources. This study investigates a controlled process for the synthesis of bioplastics from banana peel (*Musa sapientum*) waste using a specialized waterbath batch reactor system. While previous experimental attempts often yielded inconsistent structural outputs, this research refines the methodology through controlled concentration and the strategic application of chemical additives. The process involves a multi-stage chemical treatment: Hydrochloric Acid (HCl) is utilized to disrupt molecular bonding, followed by Sodium Hydroxide (NaOH) for pH neutralization. Sodium Bicarbonate (NaHCO<sub>3</sub>) is introduced to react with acidic components, facilitating carbon dioxide release which creates a characteristic porous grain and expanded texture. Plasticity, flexibility, and coherence are further optimized through the incorporation of Glycerol, Gum Arabic, and UPOX oil. Characterization via spectroscopy confirmed the retention of the cellulose structure, with distinctive peaks at 3379.05 cm<sup>-1</sup> and 2929.67 cm<sup>-1</sup> aligning with cellulose standards. Furthermore, thermal cracking of the produced polymer at 293 °C resulted in a significant 70% mass loss, yielding a liquid fraction identified as light naphtha-grade fuel. These findings demonstrate that utilizing a batch reactor not only improves the structural integrity of agro-waste bioplastics but also reveals their potential as a dual-purpose precursor for renewable energy applications, offering an interdisciplinary solution to environmental sustainability.

## 1. INTRODUCTION

Environmental pollution represents one of the most critical challenges facing modern society. Among its major contributors is the extensive use of petroleum-based plastics across packaging, construction, and consumer product industries [1]. Although plastics offer versatility and durability, their resistance to degradation has resulted in long-term accumulation in the environment, with decomposition periods extending up to several centuries and the potential release of toxic by-products during degradation [2]. Concurrently, growing awareness of fossil fuel depletion has

highlighted the unsustainability of continued reliance on petrochemical plastics [3]. These concerns underscore the urgent need to develop alternative materials that reduce environmental impact while conserving non-renewable resources.

In Sudan, Plastic bags and wrappers continue to litter both urban and rural environments, obstructing drainage systems, polluting water bodies, and harming animals and ecosystems. In 2017, the Higher Council for Environment and Urban and Rural Promotion in Khartoum State, Sudan, issued a formal decree prohibiting the manufacture and circulation of lightweight plastic bags. The implementation was structured as a phased transition, intended to lead to a

total cessation of use once industrial and commercial stakeholders had reconciled their operational status. However, a significant gap emerged: no viable, publicly endorsed alternatives were introduced at the time of the ban.

While the environmental and public health hazards of plastic are substantial, the abrupt prohibition of plastic manufacture and distribution carries profound economic implications. Without the integration of sustainable alternatives, factories and traders face unavoidable financial instability. It is within this critical tension between ecological necessity and economic viability that the impetus for researching alternative plastic production methods arises.

Bioplastics facilitate a circular economy by using renewable, bio-based feedstock (e.g., starch, cellulose) to create materials with a lower carbon footprint that are often compostable or compatible with existing recycling, reducing reliance on fossil resources. They support sustainability through organic recycling (composting) and by reducing waste in landfills, particularly for food-related packaging [4].

The utilization of agricultural waste as a raw material for bioplastic production has emerged as a promising strategy due to its abundance, low cost, and minimal competition with food resources [1]. Various agro-residues, including bagasse, corn cobs, chitin, potato peels, and banana peels, have demonstrated potential as biopolymer feedstocks [5]. Despite this potential, large-scale adoption remains limited by inefficient waste-management systems, insufficient data on waste generation, and relatively low production yields compared to food-based feedstocks [1]. Nevertheless, advancements in biotechnology and increased governmental support are expected to enhance the feasibility of agro-waste-derived bioplastics in the near future.

Banana peels were selected in this study as a representative starchy agricultural residue due to their high availability and rich polysaccharide content. Approximately 80% of banana biomass, including peels, stems, and leaves, are discarded without further utilization [6]. In Sudan's commercial banana industry, covering approximately 23,000 hectares, annual production has reached approximately 1,150,000 tons annually [7]. While this reflects significant agricultural growth, it also generates a massive volume of biomass waste. Given that peels alone constitute approximately 40% of the fruit's total weight [8], Sudan generates an estimated 46,000 tons of banana peel waste annually. This waste is mainly concentrated in the fertile regions of Kassala State (particularly the Gash Delta), the River Nile and Blue Nile States, and Gezira State, where markets such as Wad Medani serve as hubs for fruit pro-

cessing [9]. This substantial residue presents a critical environmental challenge.

Banana peels contain significant amounts of starch, cellulose, hemicellulose, lignin, and pectin, with cellulose content reported to be approximately 18.71% [6]. Cellulose is a linear polymer composed of  $\beta$ -(1 $\rightarrow$ 4)-linked D-glucose units, represented by the empirical formula  $(C_6H_{10}O_5)_n$ . Its structural uniformity, chemical stability, biodegradability, and non-toxicity make cellulose an attractive material for polymeric applications [10]. In addition, the presence of hydroxyl ( $-OH$ ) functional groups enhances intermolecular bonding and contributes to desirable material properties (Table 1).

**Table 1.** Compositions of a Banana Peel (Source Songklanakarin Journal of Science and Technology) [5]

| Items Content (g/100 g dry matter) |                 |
|------------------------------------|-----------------|
| <b>Protein</b>                     | 8.6 $\pm$ 0.1   |
| <b>Fat</b>                         | 13.1 $\pm$ 0.2  |
| <b>Starch</b>                      | 12.78 $\pm$ 0.9 |
| <b>Ash</b>                         | 15.25 $\pm$ 0.1 |
| <b>Total dietary fiber</b>         | 50.25 $\pm$ 0.2 |

The production of bioplastics from *Musa sapientum* (banana) peels has been widely explored due to the significant polysaccharide profile of the biomass, specifically its starch, cellulose, and pectin content. However, previous literature reveals that conventional synthesis methods—typically utilizing standard laboratory beakers and unregulated heating—often suffer from poor reproducibility and inconclusive mechanical outcomes. These limitations are largely attributed to insufficient process control and suboptimal additive formulations, often restricted to basic plasticizers such as glycerol.

To address these challenges, this study introduces a stainless-steel batch reactor system designed to enhance paste concentration and thermal homogeneity during synthesis. Unlike traditional methods, this approach optimizes the additive system through the strategic integration of Gum Arabic and U-POX oil to improve material flexibility and molecular coherence, facilitating “self-separation” of the polymer film.

The research further bridges the gap between material synthesis and energy recovery; advanced Fourier Transform Infrared (FTIR) spectroscopy is employed to verify the retention of the cellulose backbone, while thermal cracking protocols are utilized to evaluate the bioplastic's potential as a precursor for light naphtha fuel. By integrating these process modifications, this work aims to advance sustainable materials engineering and provide a scalable model for the value-added utilization of agricultural waste.

## 2 MATERIALS AND METHODS

In this study, banana peels were selected as a representative starchy agricultural residue suitable for conversion into bioplastics. All experimental work related to waste processing and bioplastic production was conducted in 2017 at the Unit Operations Laboratory, Department of Chemical Engineering, University of Khartoum. Fresh banana peels were collected from the university's cafeteria and used as the primary raw material. The chemical reagents and additives employed in this study included hydrochloric acid (HCl) "is utilized to disrupt molecular bonding", sodium hydroxide (NaOH) "for pH neutralization", sodium bicarbonate ( $\text{NaHCO}_3$ ) "is introduced to react with acidic components", acetic acid, propane-1,2,3-triol (glycerol), Gum Arabic, and Oil." for Plasticity, flexibility, and coherence are further optimized through the incorporation "

The experimental setup comprised standard laboratory equipment, including stainless steel knives, measuring cylinders (50 and 1000 mL), beakers (50 and 1000 mL), a digital mass balance (PGW 4502, ADAM, maximum capacity 4500 g with 0.01 g readability), Petri dishes, filter mesh, and filter paper. Additional equipment included a Bunsen burner (IKATHERM HCT model), a commercial blender (Waring model), a refractometer (Traditional Abbe KARL KOLB, German model), a stainless-steel batch reactor (Kuhlwasser Entering Reaktionskessel, German model), and a laboratory oven (Heraeus model).

### 2.1 Preparation of Banana Peels and Production of Biofilm from Banana Paste

In the present work, bioplastic production involved a series of preliminary preparation steps followed by the final formation of bioplastic films. More than ten experimental runs were performed to optimize the production process. During each experimental run, the processing strategy, as well as the type and quantity of chemical additives, was systematically varied in order to identify the conditions that yielded bioplastics with improved physical properties. The type and quantity of chemical reagents and additive materials were varied systematically through successive experimental trials until optimum bioplastic formation was achieved, as described below.

#### 2.1.1 Initial Approach

The preparation of banana paste was initially carried out following the procedure reported in previous studies, as shown below:[11].

1. Distilled water (800 mL) was placed in a beaker and heated on a Bunsen burner.

2. Banana peels were then added to the beaker, followed by the addition of 25 g of sodium bicarbonate,
3. 5 mL of 0.5 M hydrochloric acid (HCl), and sodium hydroxide (NaOH) prior to the boiling process.
4. The mixture was boiled for 30 minutes, after which the water was decanted.
5. The treated banana peels were subsequently placed on filter paper and allowed to dry for approximately 30 minutes.
6. After incubation, the peels were completely dried and mechanically ground using a mixer until a homogeneous paste was obtained.

Polymer production from the banana paste was also conducted according to the method described in previous studies as shown below: [12].

1. A mass of 25 g of banana paste was transferred into a 50 mL beaker,
2. and 5 mL of 0.5 N HCl was added with manual stirring. Subsequently,
3. 2 mL of glycerol was incorporated and mixed thoroughly.
4. Sodium hydroxide (0.5 N) was then added gradually to neutralize the pH of the mixture to approximately 7.
5. The resulting mixture was poured onto a glass Petri dish and placed in an oven at 130 °C until drying was completed.

To ensure uniform heat distribution, the partially dried paste was transferred onto aluminum foil and returned to the oven for further drying, yielding the final bioplastic product.as shown in Figure 1.



Figure 1. Final bioplastic product obtained using the initial approach. (Source: Authors' experiment)

#### 2.1.2 Final Approach

The initial procedure was further improved by introducing a stainless-steel batch reactor to enhance paste concentration and homogeneity, in addition to incorporating new additive materials. Multiple experimental samples were prepared with varying types and quantities of additives until optimal bioplastic properties were achieved.

### A. Method of Preparation of Banana Paste

1. Banana peels were initially cut into small pieces using stainless-steel knives and weighed.
2. A total mass of 869 g of banana peels was mixed thoroughly with 800 mL of distilled water until a homogeneous mixture was obtained, after which the total mass of the mixture was recorded. Subsequently,
3. 1604 g of the prepared mixture was transferred into a stainless-steel batch reactor.
4. The reactor consisted of a vessel equipped with an agitator and an integrated heating and cooling system, connected to an under-vacuum arrangement to ensure safe operation at relatively low temperatures and pressures. This configuration provided effective mixing of the contents and enhanced heat transfer between the reactor walls and the mixture. On other hand the mechanical agitation and vacuum system allowed for a more uniform polymer matrix compared to traditional methods
5. The concentration of the mixture was measured using a refractometer "Traditional Abbe model" prior to loading into the batch reactor and subsequently monitored during reactor operation.
6. Samples were withdrawn at regular time intervals using an injection syringe while maintaining the operating temperature at 60 °C until the desired concentration was achieved. The recorded concentration values are presented in Table 2.

**Table 2.** Concentration Rate of Banana Paste during Batch Reactor Operation.

| Time (h) | Concentration Rate | Temperature (°C)     |
|----------|--------------------|----------------------|
| Initial  | 2.5                | Room temperature @30 |
| 2.0      | 5.0                | 60                   |
| 2.5      | 6.0                | 60                   |

To facilitate particle size analysis, 1 L of distilled water was added to 100 g of the prepared paste. The resulting suspension was subjected to filtration using a series of mesh sieves arranged in descending order of mesh size. Each sieve allowed the passage of particles smaller than those retained by the preceding sieve. The particle size distribution obtained after filtration is summarized in Table 3.

### B. Method of Production of Polymer from Banana Paste

Polymer production was carried out by first preparing the required chemical reagents, followed by

their sequential addition to the banana paste, as follows:

**Table 3.** Mesh Size Distribution of Banana Paste Granules.

| Mesh size (μm) | Weight after filtration (g) |
|----------------|-----------------------------|
| 595            | 27.71                       |
| 420            | 10.38                       |
| 250            | 1.98                        |
| 180            | 0.89                        |
| 150            | 0.80                        |

1. A mass of 25 g of the prepared paste was placed into a 50 mL beaker, as shown in 0.
2. Hydrochloric acid (HCl) was added to the paste and mixed manually in order to disrupt intermolecular bonding within the starch structure. This step was followed by the gradual addition of sodium hydroxide (NaOH) to neutralize the pH of the mixture to approximately 7.
3. Subsequently, sodium bicarbonate ( $\text{NaHCO}_3$ ) was introduced to the mixture to react with residual acidic components, resulting in the release of carbon dioxide gas. The evolution of gas caused expansion of the paste and contributed to the formation of its characteristic texture and granular structure. Acetic acid was then added to the mixture to complete the chemical treatment process.
4. A mixture of additives, including (Gum Arabic, glycerol, and U-POX oil), was subsequently introduced to the treated paste to function as plasticizing and property-enhancing agents. Upon thorough manual stirring, self-separation of the mixture was observed, accompanied by the formation of a white phase, which is indicative of cellulose-based bioplastic formation., as shown Figure 3.

## 3. RESULTS AND DISCUSSION

### 3.1 Fourier Transform Infrared (FTIR) Spectroscopy Analysis

Fourier Transform Infrared (FTIR) spectroscopy was employed using an attenuated total reflectance Fourier transform infrared (ATR-FTIR) technique to investigate the chemical changes occurring in the samples before and after polymer formation. This analysis was conducted to identify the principal functional groups present in banana peels, banana paste, and the final bioplastic product. Cellulose, which is a linear polymer composed of  $\beta$ -glucose units, is character-

ized by prominent  $C-H$  stretching vibrations and hydrogen-bonded  $O-H$  functional groups.



Figure 2. Sample prepared banana paste.  
(Source: Authors' experiment)



Figure 3. Self-separation of the mixture and formation of bioplastics. (Source: Authors' experiment) separated bioplastic material was then transferred into a Petri dish and dried in an oven at 60 °C until a constant mass was achieved, as shown Figure 4.



Figure 4. Final bioplastic product obtained from banana peels. (Source: Authors' experiment)

The FTIR spectra of the dried paste (untreated bioplastic) exhibited characteristic absorption peaks at 3417.63 and 2927.74  $\text{cm}^{-1}$ , while the treated bioplastic samples showed corresponding peaks at 3379.05 and 2929.67  $\text{cm}^{-1}$ . In addition, the presence of an absorption band around 1060  $\text{cm}^{-1}$ , attributed to  $C-O$  and  $C-H$  stretching vibrations, further confirmed the cellulose structure. The spectra were recorded over a wavenumber range of 500–4000  $\text{cm}^{-1}$  using a Perkin-Elmer FTIR spectrophotometer (model FTIR-

8400s). All FTIR measurements were performed at the Central Laboratory, Center Campus, University of Khartoum.

The standard FTIR spectrum of cellulose is characterized by prominent absorption bands at 3354.0 and 2900.7  $\text{cm}^{-1}$  [10]. In the present study, similar peaks were observed at 3417.63 and 2927.74  $\text{cm}^{-1}$  for the dried banana paste (untreated bioplastic), and at 3379.05 and 2929.67  $\text{cm}^{-1}$  for the final bioplastic produced from banana peels (treated bioplastic). In addition, an absorption band appearing around 1060  $\text{cm}^{-1}$ , corresponding to  $C-O$  and  $C-H$  stretching vibrations, was detected in both samples. The increased intensity of these characteristic bands suggests an enhancement in the crystalline nature of the samples, as illustrated in the corresponding FTIR spectra. The presence of these dominant absorption bands with comparable relative intensities confirms the cellulose-based structure of the produced bioplastics, as shown, Figures 5 and 6.

### 3.2 Thermal Cracking Analysis

Thermal cracking analysis was conducted to further verify the polymeric nature of the produced bioplastic. Thermal degradation of thermoplastic polymers typically occurs when sufficient thermal energy is supplied to transform the material from a solid state to a molten phase [9]. In this study, thermal cracking experiments were performed at the Unit Operations Laboratory, Department of Chemical Engineering, University of Khartoum.



Figure 5. FTIR spectra of the dried banana paste (untreated sample). (Source: Authors' Result of experiment, 2017).

The experimental setup consisted of a semi-batch reactor equipped with an electric heater and connected to a condenser system designed to convert evolved vapors into liquid products. Temperature measurements were continuously monitored using thermocouples.

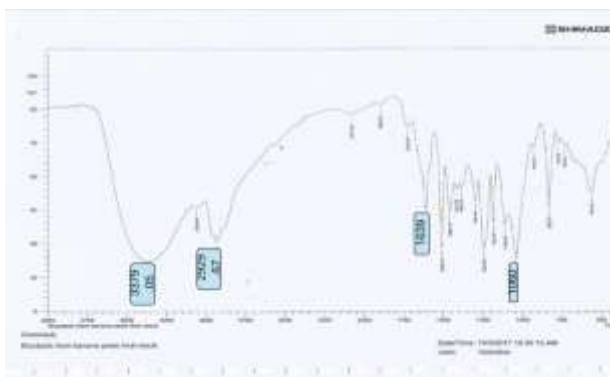


Figure 6 . FTIR spectra of the final bioplastic produced from banana peels. (Source: Authors' Result of experiment, 2017).

Prior to the experiment, the bioplastic samples were accurately weighed and placed inside the semi-batch reactor. The heating process was initiated gradually, leading to the evolution of vapors as the temperature increased. These vapors were condensed into liquid oil within the condenser, while a portion of the products existed as non-condensable gases and the remaining fraction formed solid ash, as shown in Figure 7. The entire thermal cracking process required approximately one hour, during which the polymer was fully transformed from the solid phase to a molten state at a temperature of 293 °C.

### 3.2.1 Results of GC Analysis

The results of gas chromatography (GC-FID) analysis using a flame ionization detector were consistent with the initial hypothesis. The upper liquid layer was confirmed to be a fuel fraction, with its chemical composition indicating classification as light naphtha (see Appendices). The dark coloration of this layer was attributed to process-related factors, likely associated with incomplete pyrolysis. In contrast, the lower liquid layer was identified as water.

These results are illustrated in Figure 8



Figure 7. Liquid oil obtained as the final product after thermal cracking. (Source: Authors' experiment, 2017).

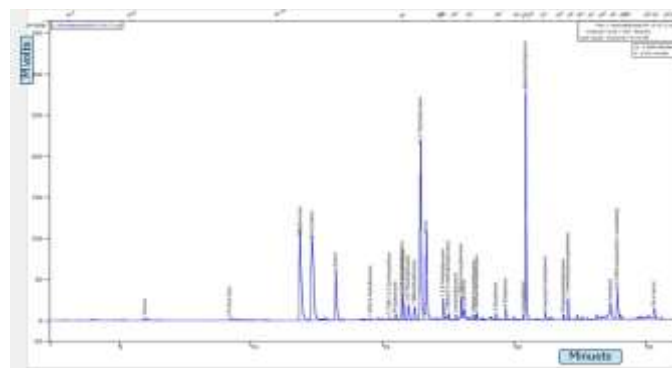


Figure 8. FID Chromatogram result. (Source: Authors' Result of experiment, 2017).

### 3.3. Comparison with recent results with literature and conventional plastics

This study focused primarily on material formation and chemical characterization. Mechanical testing, biodegradability assessment, and large-scale processing analysis were beyond the scope of the present work and should be addressed in future studies

The results indicate that increasing the glycerol content led to a noticeable improvement in the flexibility of the produced bioplastics. In addition, the incorporation of UPOX oil and Gum Arabic, particularly at higher ratios, further improved the material properties, resulting in enhanced cohesion and the occurrence of self-separation accompanied by the formation of a white phase. On other context, while the glycerin-based formulation produced a semi-solid and brittle material, the introduction of a mixture of Gum Arabic and UPOX Oil resulted in a

significantly more flexible and cohesive film, which exhibited spontaneous separation (self-peeling) from the evaporation dish.

The presence of hydrochloric acid (HCl) and sodium hydroxide (NaOH) at appropriate concentrations was found to be a critical factor influencing the strength of the bioplastic. Hydrochloric acid facilitates the hydrolysis of amylopectin, which is necessary to promote film formation through hydrogen bonding among glucose chains in starch. Excessive amylopectin content restricts film formation and leads to a reduction in starch recovery. Conversely, bioplastics composed predominantly of linear amylose tend to exhibit excessive hardness.

Sodium hydroxide was primarily used to neutralize the pH of the reaction medium. Acid hydrolysis modifies the physicochemical properties of starch without altering its granular structure. Accordingly, acetic acid (vinegar) was introduced to cleave the branched structure of amylopectin, promoting the for-

mation of linear amylose chains, which are more favorable for bioplastic film development.

### 3.4 Effect of Glycerol as a Plasticizer

Plasticizers, also referred to as dispersants, are additives that enhance the plasticity and flexibility of materials. Their most common applications are in polymer systems, particularly polyvinyl chloride (PVC), with glycerol and sorbitol being widely used examples. When incorporated into polymer matrices, plasticizers improve processing characteristics and impart flexibility to the final product. Similar effects are observed when plasticizers are used in materials such as concrete, clays, and related composites, including those containing U-POX oil and Gum Arabic.

Glycerol (glycerin) is a simple polyol (sugar alcohol) that is colorless, odorless, viscous, sweet-tasting, and nontoxic [5]. In starch-based bioplastics, glycerol acts by reducing intermolecular forces between polymer chains, thereby increasing chain mobility and improving flexibility. As a result, higher glycerol concentrations yield more flexible bioplastics, whereas lower glycerol contents produce harder materials. While glycerol serves as the primary plasticizer by intercalating between cellulose chains to reduce intermolecular forces [11], the integration of Gum Arabic in this study provides a secondary structural matrix that enhances molecular coherence and surface finish.

The liquid oil obtained after the thermal cracking process exhibited phase separation into two distinct layers. The upper layer was dark in color, characterized by low density and high viscosity, whereas the lower layer appeared yellow in color with comparatively higher density, as shown in Figure 7. This phase separation prompted further investigation into the nature of each layer. It was hypothesized that the upper dark layer corresponded to a fuel fraction, while the denser lower layer was likely composed primarily of water. To verify this assumption and determine the chemical composition of the liquid products, gas chromatography (GC) analysis was performed, as shown in Figure 8. The analyses were conducted at the Petroleum Laboratories for Research and Studies (PLRS).

It is essential for future research to investigate the impact of additive composition on thermal cracking outcomes. While these additives are necessary for mechanical properties, their effect on fuel yield requires quantitative analysis.

On the other hand, from the above results to compare that the FTIR results of the untreated dried banana paste and the treated final bioplastic show the functional groups expected for polysaccharide-rich materials (cellulose/starch). In the untreated paste, the broad O–H stretching band was observed at 3417.63

$\text{cm}^{-1}$  and the C–H stretching band at 2927.74  $\text{cm}^{-1}$ , while the treated bioplastic showed corresponding peaks at 3379.05  $\text{cm}^{-1}$  and 2929.67  $\text{cm}^{-1}$ . These values are close to the cellulose reference bands reported in the manuscript ( $\approx 3354.0 \text{ cm}^{-1}$  for O–H and 2900.7  $\text{cm}^{-1}$  for C–H), supporting the conclusion that the produced film retains a cellulose-consistent backbone. A band near  $\sim 1060 \text{ cm}^{-1}$  was also detected in both materials, consistent with C–O/C–H vibrations typical of polysaccharides. This FTIR pattern (broad O–H  $\sim 3300\text{--}3400 \text{ cm}^{-1}$ , C–H  $\sim 2900 \text{ cm}^{-1}$ , and strong C–O bands  $\sim 1000\text{--}1150 \text{ cm}^{-1}$ ) agrees with banana-peel/starch bioplastic FTIR spectra reported in the recent literature [13]. In other words, our FTIR results are comparable to Ref. [13] in terms of the key polysaccharide bands, indicating that the chemical backbone is consistent with previously reported banana-peel bioplastics.

A second comparison point is the processing strategy. In this work, a stainless-steel batch reactor was used to concentrate and homogenize the banana paste prior to film formation. The paste concentration increased from 2.5 (initial,  $\sim 30^\circ\text{C}$ ) to 5.0 after 2.0 h at  $60^\circ\text{C}$  and reached 6.0 after 2.5 h at  $60^\circ\text{C}$ . Recent studies commonly concentrate banana-peel slurry/gel using beaker heating and then cast films [13,14]. Compared with these approaches [13,14], our controlled concentration profile (2.5  $\rightarrow$  6.0 at  $60^\circ\text{C}$ ) provides a more controlled pre-casting step, which may improve reproducibility of paste viscosity and film formation even without adding new measurements.

The formulation behavior observed in this study is also consistent with established bioplastic formulation trends. The manuscript reports that increasing glycerol improves flexibility, whereas glycerol-only samples can remain semi-solid/brittle; in contrast, incorporating Gum Arabic and U-POX oil improved cohesion and enabled spontaneous separation (“self-peeling”) from the evaporation dish. This qualitative trend is consistent with recent reports that plasticizer ratio and multi-component formulation strongly affect film integrity and handling in banana-peel and agro-waste bioplastic films [14,15]. Therefore, our observed formulation effect (glycerol vs glycerol+ Gum Arabic +oil) is consistent with the direction of effects reported in Refs. [14,15], even though mechanical testing was not performed here.

Thermal conversion provides an additional point of comparison. The semi-batch cracking test showed complete transition from solid to molten at approximately  $293^\circ\text{C}$  over about one hour, with approximately 70% mass loss and a condensed liquid that separated into two layers. GC analysis identified the upper layer as a light-naphthagrade fuel fraction, while the lower layer was water. This behavior is con-

sistent with biomass thermal conversion literature showing that starch/cellulose-rich components can generate volatile organic products and condensable liquids during pyrolysis/cracking [16]. Thus, our cracking outcome (melting near 293 °C and condensable fuel fraction) is qualitatively consistent with the product formation mechanisms described in Ref. [16].

Finally, compared with conventional LDPE, the present material has the advantage of being produced from renewable agricultural residue (banana peels) and processed using low-temperature casting and drying. Because the film is polysaccharide-based, it is expected to be more biodegradable than LDPE; however, biodegradation rate was not measured in this study. However, LDPE typically exhibits superior water resistance and mechanical performance compared with starch/cellulose films, so it takes centuries to degrade. In this study, mechanical and barrier testing (tensile strength, elongation at break, water uptake, and water-vapor permeability) were not measured; therefore, direct performance equivalence to LDPE cannot be claimed and should be addressed in future work

### 3.4. Limitation and Future Work

Future research is recommended to explore the utilization of the produced material for:

1. **Quantitative Mechanical Characterization:** Future research should prioritize standardized ASTM testing to determine precise engineering values for Tensile Strength (MPa), Young's Modulus, and Elongation at Break. This data is essential for comparing the material's performance against conventional low-density polyethylene (LDPE).
2. **Long-Term Biodegradability and Soil Impact:** Given Sudan's specific soil pH and arid climate, longitudinal studies on the degradation rate of the bioplastic in local environments are necessary to ensure that its breakdown products do not negatively affect soil nitrogen levels or local microbiology.
3. **Biofuel generation** is through thermal cracking.
4. **Validation of Molded Non-Structural**

**Applications:** While non-structural items—such as door handles or interior trim—are hypothesized as viable applications, empirical validation is required. Research should utilize standardized injection molding or 3D printing techniques to test the durability and wear-resistance of banana-peel bioplastics in these specific forms [15].

1. The valorization of waste materials for the production of value-added products aligns with the

principles of green engineering and sustainable development. Such research efforts play a critical role in reducing environmental pollution while simultaneously promoting economic benefits. Continued experimental optimization and development are therefore essential to enhance the performance of ecofriendly materials and support sustainable waste management strategies.

2. **Simultaneous evaluation of mechanical properties and thermal degradation efficiency** across various formulations. The objective is to identify the optimal composition that achieves the best balance between material performance during its service life and efficient energy recovery at its end of life.

## CONCLUSIONS

This study contributes to the synthesis and characterization of natural polymeric materials derived from agricultural waste "Banana Peels". While the present findings demonstrate promising technical feasibility, further investigation is required to fully realize the economic and environmental potential of such materials. A series of experimental trials was conducted to achieve bioplastics with desirable properties, as summarized in Table 2. These trials involved systematic variation of additive type and concentration to obtain optimal material performance.

The experimental approach was initially based on previously reported methods and subsequently enhanced through procedural modifications, including the introduction of a batch reactor to increase paste concentration and the incorporation of additional plasticizing and property-enhancing agents. Based on the results obtained, the following conclusions can be drawn:

1. The use of a batch reactor significantly increased paste concentration and improved textural properties without altering the intrinsic structure of the banana peel material.
2. Glycerol acted as an effective plasticizer by facilitating molecular mobility between starch chains, thereby increasing flexibility. Higher glycerol contents resulted in more flexible bioplastics, whereas lower amounts produced comparatively harder materials.
3. Sodium bicarbonate ( $\text{NaHCO}_3$ ) reacted with acidic components in the paste to release carbon dioxide, leading to paste expansion and the formation of a characteristic porous texture.
4. Acetic acid (vinegar) contributed to the breakdown of branched starch structures into smaller, more manageable chains, thereby enhancing bioplastic formation.

5. The combined addition of U-POX oil and locally available additive like -Gum Arabic is a qualitative leap that further enhanced the quality and overall performance of the produced bioplastics.

The study confirms that biodegradable bioplastics can be successfully produced from banana peels using a batch reactor in combination with appropriate chemical additives. Thermal degradation of the bioplastic occurred at approximately 293 °C, indicating potential for further conversion processes.

### ACKNOWLEDGEMENTS

The authors wish to express their profound gratitude to the Department of Chemical Engineering, Faculty of Engineering at the University of Khartoum, for providing the laboratory facilities and technical environment necessary to conduct this research.

Special thanks are extended to the laboratory technicians and staff “Mr. Ibrahim” for his invaluable assistance in the operation of the batch reactor system and for their guidance during the chemical synthesis phases. We are also grateful to the Central Laboratory at the University of Khartoum for their support in performing the FTIR spectroscopy and Gas Chromatography (GC) analyses, which were fundamental to the characterization of the synthesized bioplastics and thermal cracking products. Finally, I would like to thank my colleagues (Eng. Hozafa, Eng. Ammar & Eng. Eman) and families (Mother & Spirit of my father) for their unwavering encouragement and support.

### STATEMENT ON THE USE OF AI TOOLS

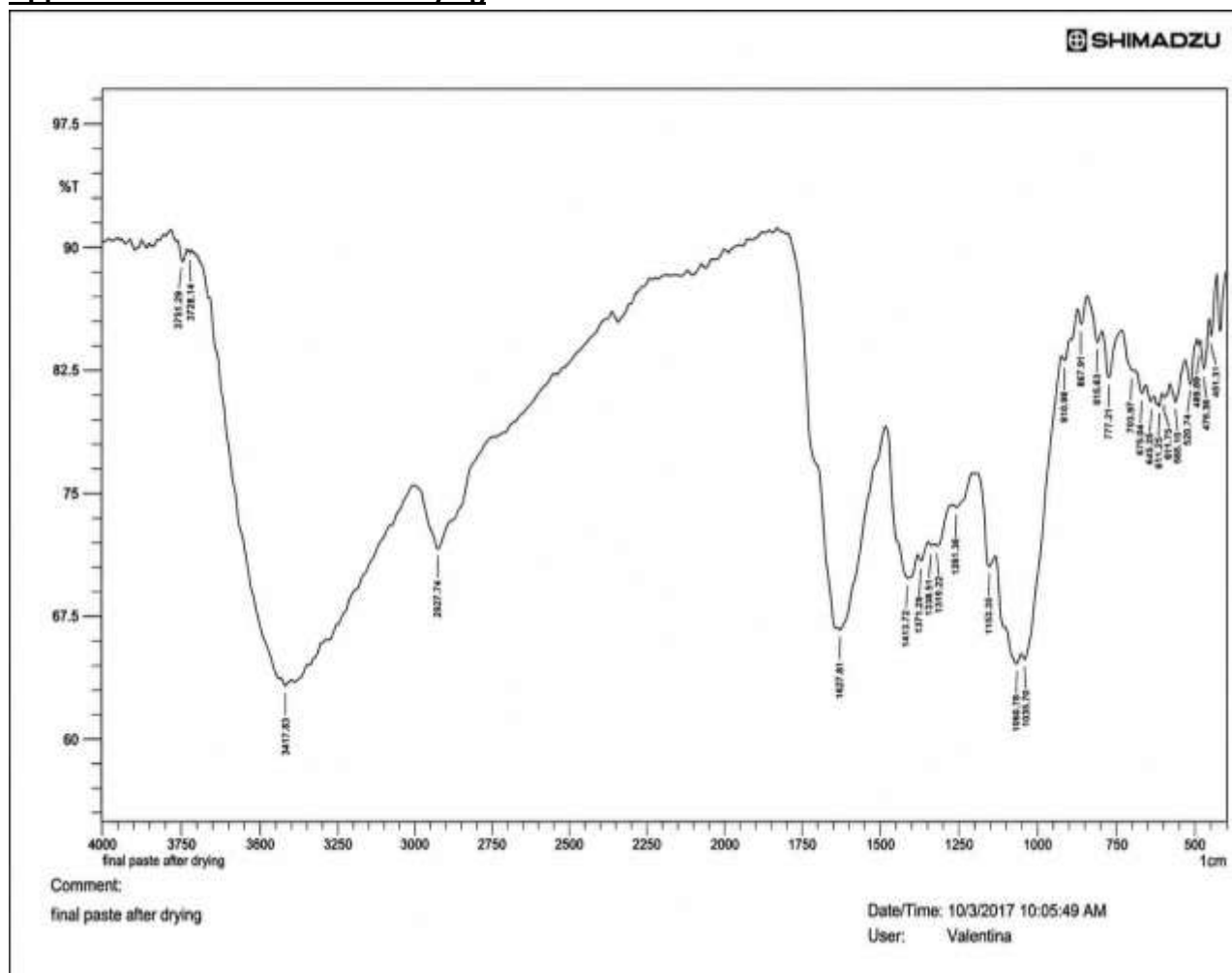
The author used ChatGPT (OpenAI) to assist with drafting and improving the clarity of this manuscript. All content was reviewed and edited, and the author assumes full responsibility for its accuracy and originality.

### REFERENCES

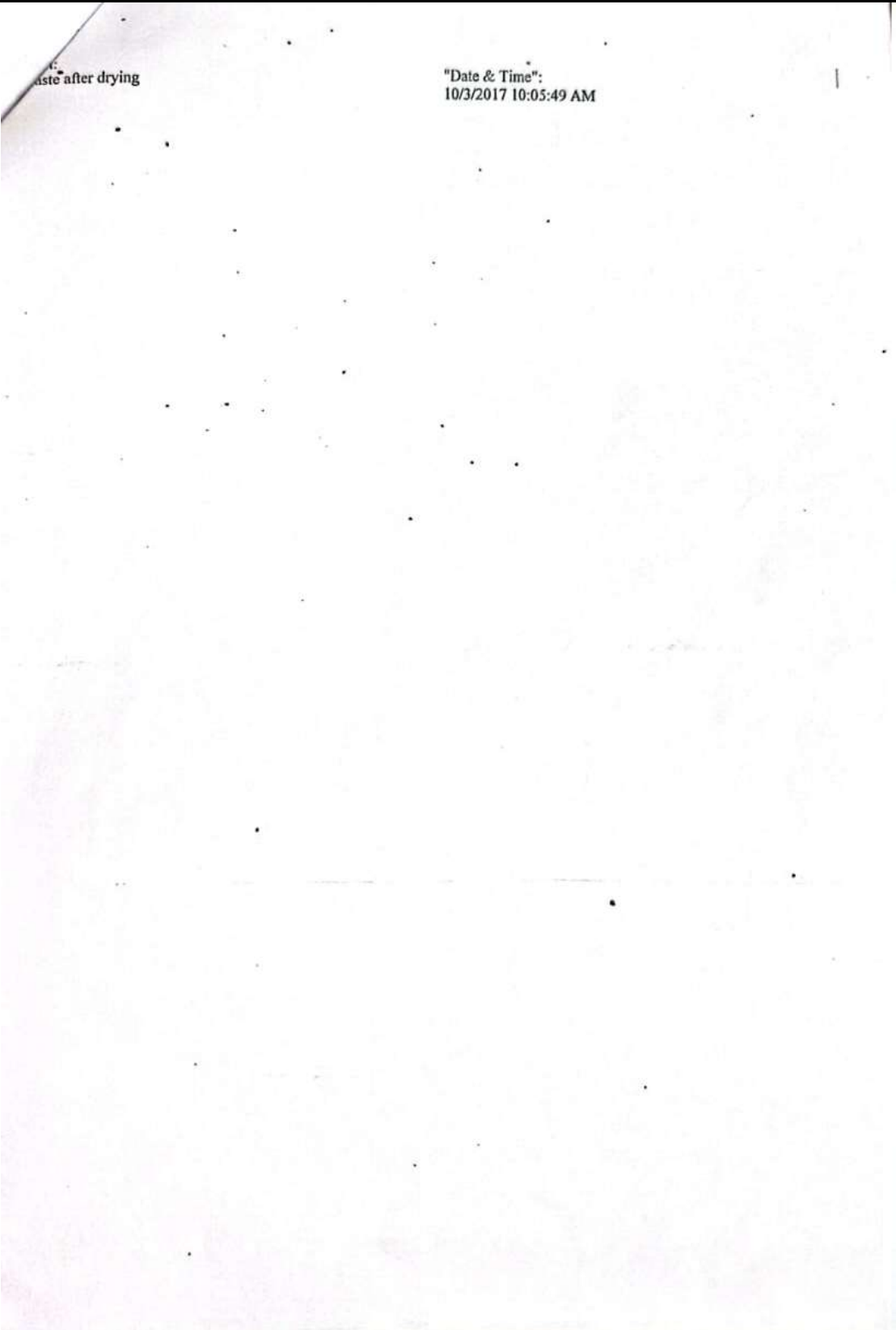
- [1]. [1] Rizwana Beevi, K., Sameera Fathima, A. R., Thahira Fathima, A. I., Thameemunisa, N., Noorjahan, C. M., & Deepika, T. Production and characterization of bioplastics from agricultural waste. *International Journal of Scientific & Technology Research*. 2020;9(1). ISSN: 2277-8616.
- [2]. [2] Chandarana, J., & Sai Chandra, P. L. V. N. Bioplastic production from biodegradable resources. *International Journal of Scientific Research & Engineering Trends*. 2021;7(1). ISSN (Online): 2395-566X
- [3]. [3] Chan, J. X., Wong, J. F., Hassan, A., & Zakaria, Z. Development of biodegradable plastics from agricultural waste. ResearchGate (online publication). 2020. Available at: <https://www.researchgate.net/publication/346032121>
- [4]. [4] R. Rosenboom, R. Langer, and G. Traverso, “Bioplastics for a circular economy,” *Nature Reviews Materials*, vol. 7, no. 2, pp. 117–137, Feb. 2022, doi: 10.1038/s41578-021-00407-8.
- [5]. [5] Wachirasiri, P., et al. The effects of banana peel preparations on the properties of banana peel dietary fiber concentrate. *Songklanakarin Journal of Science and Technology*. 2009;31(6):605–611..
- [6]. [6] Gaonkar, M. R., Palaskar, P., & Navandar, R. Applications of plasticizers in polymer processing. *International Journal of Advances in Science, Engineering and Technology*. 2018;6(1) (Special Issue 1). ISSN (Print): 2321-8991; ISSN (Online): 2321-9009. Available at: <http://iraj.in>
- [7]. [7] Osman, A. A., Daffalla, M. E. H., & Habeeb, B. I. Evaluating markets of banana for Sudan. *IJSET – International Journal of Innovative Science, Engineering & Technology*. 2015;2(5)
- [8]. [8] Alzate Acevedo, S., Díaz Carrillo, Á. J., Flórez-López, E., & Grande-Tovar, C. D. Recovery of banana waste-loss from production and processing: A contribution to a circular economy. *Molecules*. 2021;26(17):5282. <https://doi.org/10.3390/molecules26175282>
- [9]. [9] Elhassan, G. O. Competitiveness of banana production in Blue Nile State Sudan: A policy analysis matrix approach. *Algerian Scientific Journal Platform*. 2021.
- [10]. [10] Hariani, P. L., Riyanti, F., & Asmara, R. D. Extraction of cellulose from Kepok banana peel (*Musa paradisiaca* L.) for adsorption of Procion dye. *Molekul*. 2016;11(1):135–142..
- [11]. [11] Gaonkar, M. R., Palaskar, P., & Navandar, R. Production of bioplastic from banana peels. *International Journal of Advances in Science, Engineering and Technology*. 2018;6(1):101–105.
- [12]. [12] McKeen, L. W. (2021). *The Effect of Long-Term Thermal Exposure on Plastics and Elastomers* (2nd ed.). Oxford, UK: William Andrew/Elsevier.
- [13]. [13] Gnanendra Kiran, V., Kavi Varsha, A., Vijayalaksmi, M., Govindaraj, V., Anisha, M., Vigneshwari, N., Gokul, M., Nithila, E. E., Bebin, M., Arun Prasath, T., & Chezhiyan, P. Synthesis and characterization of banana peel starch-based bioplastic for intravenous tubes preparation. *Materials Today Communications*. 2022;33:104464. <https://doi.org/10.1016/j.mtcomm.2022.104464>

- [14]. [14] Sheikh, S., Amin, F., & Iqbal, Y. Sustainable synthesis and characterization of bioplastic films from whole banana peel: A comparative study on plasticizer–hydrolyzer ratios. *Chemical Papers*. 2025;79:6999–7009. <https://doi.org/10.1007/s11696-025-04241-y>
- [15]. [15] Castillo-Patiño, D. L., Rosas-Mejía, H. G., Albalade-Ramírez, A., Rivas-García, P., Carrillo-Castillo, A., & Morones-Ramírez, J. R. Transforming agro-industrial waste into bioplastic coating films. *ACS Omega*. 2024;9(42):42970–42989. <https://doi.org/10.1021/acsomega.4c05924>
- [16]. [16] Zong, P., Jiang, Y., Tian, Y., Li, J., Yuan, M., Ji, Y., Chen, M., Li, D., & Qiao, Y. Pyrolysis behavior and product distributions of biomass six group components: starch, cellulose, hemicellulose, lignin, protein and oil. *Energy Conversion and Management*. 2020;216:112777. <https://doi.org/10.1016/j.enconman.2020.112777>

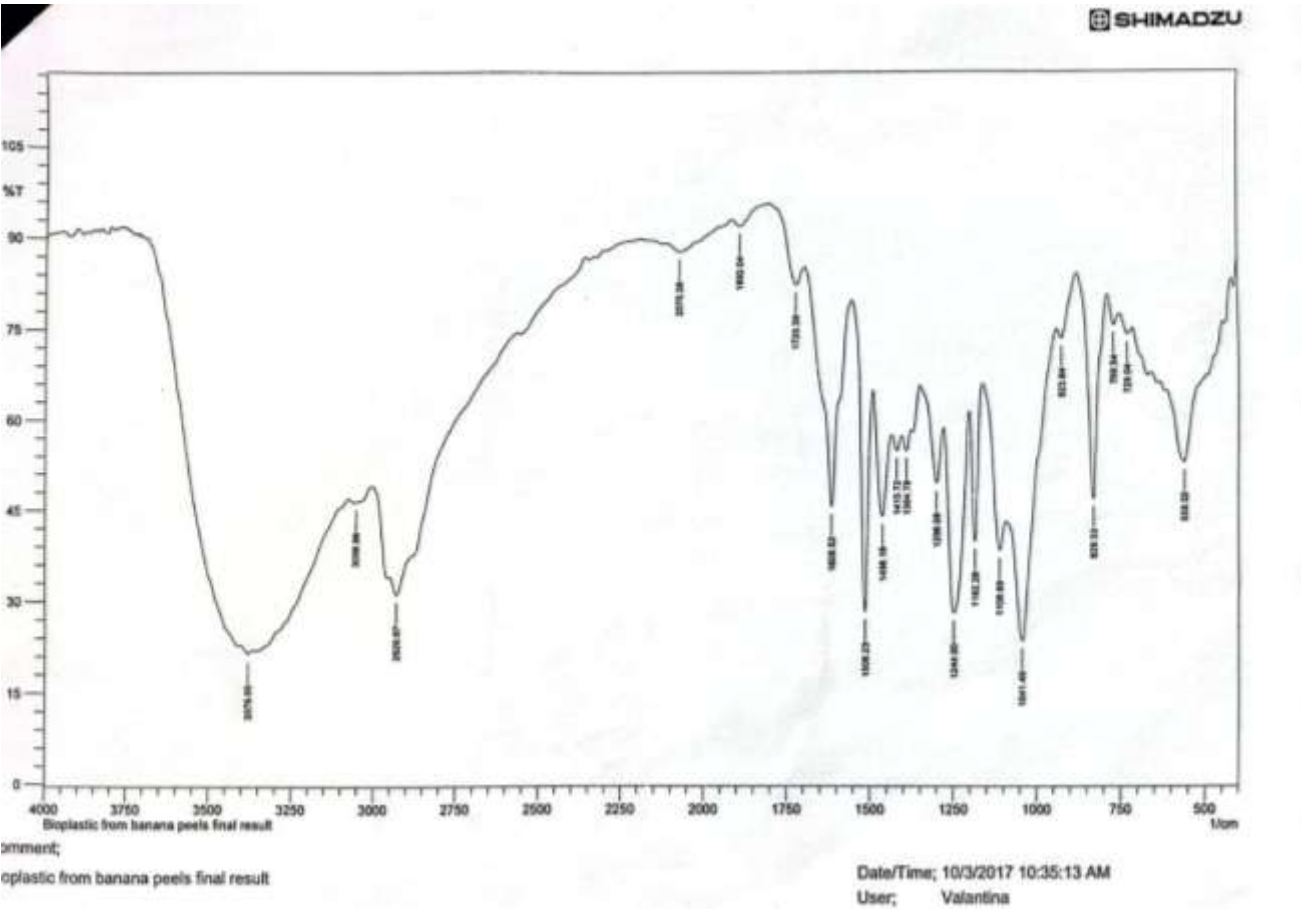
PP

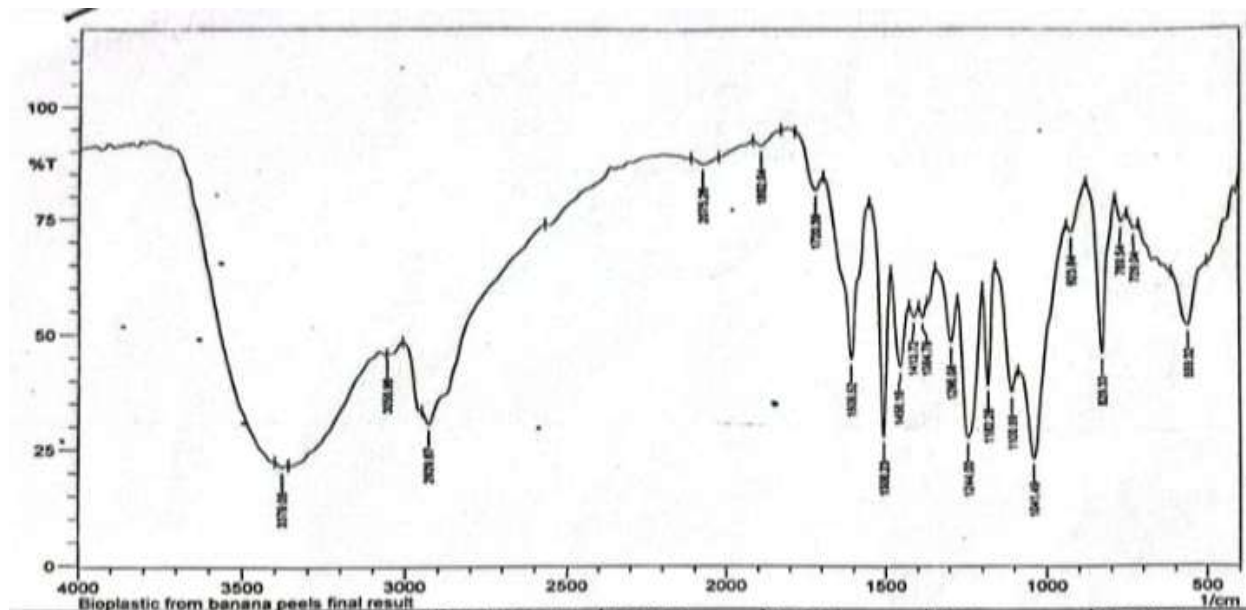
**Appendix A1: Final Paste after Drying**





**Appendix B1: Bioplastics from Banana Peels Final Result**



**Appendix B2: Bioplastics from Banana Peels Final Result Data**

| Bioplastic from banana peels final result |         |           |                 |          |          |         | 1/cm       |
|-------------------------------------------|---------|-----------|-----------------|----------|----------|---------|------------|
|                                           | Peak    | Intensity | Corr. Intensity | Base (H) | Base (L) | Area    | Corr. Area |
| 1                                         | 559.32  | 52.486    | 12.921          | 611.39   | 497.6    | 25.367  | 4.456      |
| 2                                         | 729.04  | 73.635    | 1.997           | 750.26   | 713.61   | 4.632   | 0.225      |
| 3                                         | 769.54  | 75.14     | 3.561           | 786.9    | 750.26   | 4.189   | 0.357      |
| 4                                         | 829.33  | 46.418    | 35.454          | 879.48   | 786.9    | 15.283  | 7.305      |
| 5                                         | 923.84  | 72.971    | 3.959           | 939.27   | 879.48   | 6.662   | 0.553      |
| 6                                         | 1041.49 | 23.205    | 29.639          | 1089.71  | 939.27   | 53.291  | 15.824     |
| 7                                         | 1108.99 | 37.917    | 11.063          | 1159.14  | 1089.71  | 21.435  | 2.203      |
| 8                                         | 1182.28 | 39.333    | 23.509          | 1199.64  | 1159.14  | 11.429  | 3.339      |
| 9                                         | 1244    | 27.72     | 31.495          | 1274.86  | 1199.64  | 30.441  | 13.45      |
| 10                                        | 1296.08 | 48.994    | 11.216          | 1346.22  | 1274.86  | 17.217  | 2.174      |
| 11                                        | 1384.79 | 54.332    | 2.953           | 1398.3   | 1371.29  | 6.645   | 0.312      |
| 12                                        | 1413.72 | 54.371    | 2.509           | 1429.15  | 1398.3   | 7.856   | 0.295      |
| 13                                        | 1456.16 | 43.42     | 17.169          | 1485.09  | 1429.15  | 16.211  | 4.046      |
| 14                                        | 1508.23 | 27.931    | 41.682          | 1552.59  | 1485.09  | 17.488  | 7.674      |
| 15                                        | 1608.52 | 45.098    | 36.494          | 1695.31  | 1552.59  | 25.321  | 13.132     |
| 16                                        | 1720.39 | 81.953    | 5.835           | 1784.03  | 1695.31  | 5.168   | 1.027      |
| 17                                        | 1892.04 | 91.607    | 1.852           | 1917.11  | 1828.39  | 2.646   | 0.33       |
| 18                                        | 2075.26 | 67.7      | 1.484           | 2111.91  | 2023.19  | 4.757   | 0.355      |
| 19                                        | 2929.67 | 30.821    | 5.222           | 2950.89  | 2570.93  | 102.456 | -11.344    |
| 20                                        | 3056.96 | 46.2      | 0.125           | 3058.89  | 3010.67  | 15.736  | 0.17       |
| 21                                        | 3379.05 | 21.343    | 0.961           | 3402.2   | 3359.77  | 27.96   | 0.333      |

Comment:  
Bioplastic from banana peels final result

"Date & Time":  
10/3/2017 10:35:13 AM

**Appendix C: Gas Chromatography (GC) raw reports**

Sample Type: Fuel from Banana peels  
 Sample Code: GC/1017/000665 Report number: 0021141  
 Sample ID: 0021141 Date/time report: 25/10/2017  
 Customer Name: Student  
 Customer Ref: \_\_\_\_\_  
 Date / Time Received: 22/10/2017

| Component Name                    | Method | Unit | Result    |
|-----------------------------------|--------|------|-----------|
| Toluene                           | CG-FID | Wt%  | 0.4453    |
| 3-Furfural hyde                   |        | Wt%  | 1.049     |
| Ethylbenzene                      |        | Wt%  | 12.37     |
| (m+p)-Xylene                      |        | Wt%  | 14.54     |
| o-Xylene                          |        | Wt%  | 5.884     |
| 1-Ethyl-4-methylbenzene           |        | Wt%  | 0.2563    |
| 7,7-DM-1,2,3-Cycloheptatriene     |        | Wt%  | 0.3971    |
| Propylbenzene                     |        | Wt%  | 0.5260    |
| 1-Ethyl-3-methylbenzene           |        | Wt%  | 2.200     |
| 1-Ethyl-2-methylbenzene           |        | Wt%  | 1.378     |
| 1,2,4-Trimethylbenzene            |        | Wt%  | 1.597     |
| 1-Methylethylbenzene              |        | Wt%  | 1.339     |
| 1,2,3-Trimethylbenzene            |        | Wt%  | 18.31     |
| phenol                            |        | Wt%  | 8.368     |
| 1,2,5-Trimethylbenzene            |        | Wt%  | 1.872     |
| 1-Methyl-2-(1-methylethyl)benzene |        | Wt%  | 0.6759    |
| 3-propenylbenzene                 |        | Wt%  | 0.4203    |
| 1-Methyl-4-propylbenzene          |        | Wt%  | 1.260     |
| butylbenzene                      |        | Wt%  | 1.049     |
| 1-Methyl-3-propylbenzene          |        | Wt%  | 2.5192017 |

- TEST (S) Has have been subcontracted, please refer to PLRS for details
- No part of this report can be reproduced except full in any form or by any electronic or mechanical including photocopying and recording without awritten permission of the issuing laboratory

Reported by: *Tawkeg*Sig.: *new*

(F-04-22)

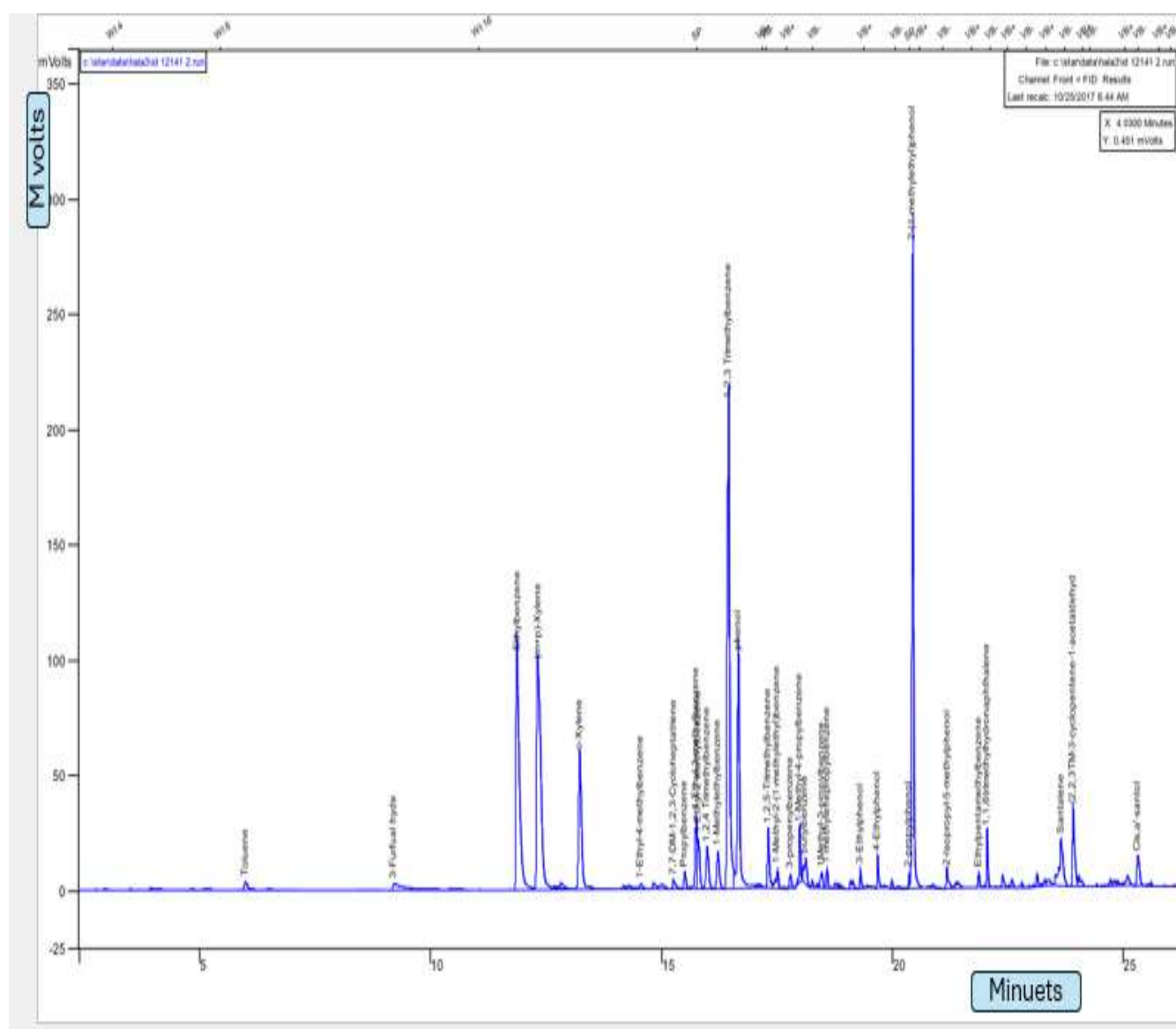
## TEST REPORT

| Component Name                        | Method | Unit | Result |
|---------------------------------------|--------|------|--------|
| 1-methylenepropylbenzene              | CG-FID | Wt%  | 0.4900 |
| 3-Ethylphenol                         |        | Wt%  | 0.4203 |
| 4-Ethylphenol                         |        | Wt%  | 0.6344 |
| 2-propylphenol                        |        | Wt%  | 0.2586 |
| 2-(1-methylethyl)phenol               |        | Wt%  | 15.13  |
| 2-Isopropyl-5-methylphenol            |        | Wt%  | 0.6518 |
| Ethylpentamethylbenzene               |        | Wt%  | 0.3908 |
| 1,1,6-trimethylhydronaphthalene       |        | Wt%  | 1.087  |
| Santalene                             |        | Wt%  | 2.687  |
| (2,2,3TM-3-cyclopentene-1-acetaldehyd |        | Wt%  | 2.605  |
| Cis,a'-santol                         |        | Wt%  | 1.217  |



|                                                                                                                                                                                                                                                                                                                                  |                                                         |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| <ul style="list-style-type: none"> <li>TEST (S) Has have been subcontracted ,please refer to PLRS for details</li> <li>No part of this report can be reproduced except full in any form or by any electronic or mechanical including photocopying and recording without awritten permission of the issuing laboratory</li> </ul> | Reported by: <i>Tan keq</i><br>Sig.: <i>[Signature]</i> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|

(F-04-22)



© 2026 Author(s). Published by the *University of Khartoum Engineering Journal (UoKEJ)*.

This article is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0).