© APR 2026 | IRE Journals | Volume 9 Issue 10 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I10-1716579

Comparative Physicochemical Characterization of some Biomass Wastes for Bio-plastic Production

ADEMOLA BOLANLE RAHEEM[1], IFEANYICHUKWU EDEH[2]
[1, 2]Chemical Engineering Department, Faculty of Engineering, University of Port-Harcourt, Choba, Port-Harcourt, Rivers State, Nigeria.

Abstract- The increasing environmental burden of petroleum-based plastics has accelerated the search for sustainable and biodegradable alternatives derived from renewable biomass. This study presents a comparative physicochemical, thermal, and structural characterization of selected agricultural wastes-cassava peels, plantain peels, orange peels, and sugarcane bagasse-to evaluate their suitability for bioplastic production. The samples were collected from local sources and processed through washing, drying, and into uniform particles. Standard analytical methods were used to determine moisture content, ash content, cellulose, hemicellulose, lignin, and starch composition. Thermal stability was evaluated using thermogravimetric analysis (TGA), crystallinity was assessed via X-ray diffraction (XRD), functional groups were identified using Fourier Transform Infrared (FTIR) spectroscopy, and surface morphology was examined through scanning electron microscopy (SEM). The results revealed that sugarcane bagasse exhibited the highest cellulose content (57.22 %), crystallinity index (59.3%), and thermal degradation onset (272.8 °C), indicating superior structural integrity and thermal resistance. Cassava peels demonstrated high starch content, supporting their suitability for thermoplastic starch-based bioplastics. Plantain and orange peels showed comparatively lower structural properties but possess potential as supplementary blending materials. FTIR analysis confirmed the presence of key functional groups (–OH, C=O, and C–O), essential for polymer interactions, while SEM images revealed dense fibrous networks in sugarcane bagasse and cassava peels. Overall, the suitability ranking for bioplastic production was sugarcane bagasse > cassava peels > plantain peels > orange peels. The study highlights the potential of utilizing locally available agricultural residues for sustainable bioplastic development, supporting circular economy principles and waste valorisation strategies.

Keywords: Bioplastics, Agricultural Waste, Physicochemical Characterization, Sugarcane Bagasse, Cassava Peels, Waste Valorisation, Sustainable Materials.

I. INTRODUCTION

The use of petroleum-based plastics has increased rapidly due to their low cost and durability. However, these plastics are not biodegradable and remain in the environment for a long time. This has led to serious environmental problems such as land pollution, marine pollution, and blockage of drainage systems. In Nigeria, poor waste management practices worsen this problem, leading to flooding and health risks (Adeniran et al., 2021; Ogunbiyi et al., 2020). Global plastic production has also increased significantly, contributing to environmental pollution and climate-related issues (Geyer et al., 2017).

Bioplastics have been developed as an alternative to conventional plastics. They are produced from renewable biological materials such as starch and cellulose. These materials are biodegradable and environmentally friendly. Agricultural wastes such as cassava peels, plantain peels, orange peels, and sugarcane bagasse are good sources of these biopolymers. They are abundant, low-cost, and readily available in countries like Nigeria (Oladipo et al., 2021; Nanda et al., 2021). The use of these wastes for bioplastic production can reduce environmental pollution and convert waste into useful materials.

Despite their availability, agricultural wastes are not widely used for bioplastic production. One major reason is the lack of detailed information on their properties. The composition of agricultural waste varies depending on the source. This affects their performance in bioplastic production. Materials with high cellulose and starch content are known to produce stronger and more stable bioplastics (John & Thomas, 2008; Edeh et al., 2021). Thermal stability and crystallinity also influence the processing and quality of bioplastics (Emadian et al., 2017).

Several studies have investigated the use of agricultural residues for bioplastic production. Cassava peel starch has been used to produce biodegradable films with good mechanical properties (Adebisi et al., 2020). Sugarcane bagasse has also been reported to have high cellulose content, making it suitable for reinforcing bioplastic materials (Agbabiaka et al., 2020). In addition, plantain and orange peels have shown potential as supplementary materials due to their polysaccharide content (Oluwatosin et al., 2019). However, there is limited comparative data on these materials under the same conditions.

This study focuses on the comparative characterization of cassava peels, plantain peels, orange peels, and sugarcane bagasse. The aim is to evaluate their suitability for bioplastic production. The materials were analysed using standard methods to determine their physicochemical, thermal, and structural properties. Techniques such as thermogravimetric analysis (TGA), X-ray diffraction (XRD), Fourier Transform Infrared spectroscopy (FTIR), and scanning electron microscopy (SEM) were used.

The scope of this study is limited to laboratory-scale analysis. It does not include large-scale production or industrial processing. The study focuses on identifying suitable raw materials based on their composition and properties.

This work is important because it provides useful data for selecting agricultural wastes for bioplastic production. It supports the use of locally available materials and reduces dependence on synthetic plastics. It also promotes waste utilization and environmental protection. The findings can support future research and development of sustainable bioplastics in Nigeria.

II. MATERIALS AND METHODS

2.1 Materials

2.1.1 Raw Materials

Cassava peels, plantain peels, orange peels, and sugarcane bagasse were used as feedstock for bioplastic production. These materials were selected due to their abundance, low cost, high starch and rich lignocellulosic content. The samples were collected from local markets, farms, juice-processing outlets, and processing sites in Port Harcourt, Nigeria. Similar materials have been used in previous bioplastic studies (Adebisi et al., 2020; Oladipo et al., 2021).

2.1.2 Chemicals and Reagents

All chemicals used were of analytical grade. The reagents included hydrochloric acid (HCl), sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), acetic acid (CH_3COOH), glycerol (plasticizer), and distilled water. Glycerol was used to improve flexibility of the bioplastic films (Edeh et al., 2021).

2.1.3 Equipment and Apparatus

The equipment used included: Analytical balance, Drying oven, Mechanical grinder, Water bath, Hot plate with magnetic stirrer, Beakers, conical flasks, and Petri dishes, Thermometer, Muffle furnace, Desiccator, pH meter, Fourier Transform Infrared (FTIR) spectrophotometer, Thermogravimetric analyser (TGA), X-ray diffractometer (XRD), Scanning electron microscope (SEM), Universal testing machine.

2.2 Methods

2.2.1 Sample Collection

Samples were collected from Mile 3 Market, Eleme, and Etche in Rivers State. The materials were placed in clean bags and transported to the laboratory. This method follows standard sampling procedures for biomass materials (Oluwatosin et al., 2019). The experiments were carried out in Chemical Engineering laboratories and the World Bank Laboratory (ACE-CEFOR) at the University of Port-Harcourt, Choba, Rivers State, Nigeria. The analyses were done at Agilent Technologies, Kaduna State, Nigeria. These include SEM, FTIR, XRD, and TGA analysis.

2.2.2 Sample Preparation

The samples were washed with distilled water to remove dirt. They were air-dried for 24–48 hours. Oven drying was carried out at 60°C until constant weight was reached. The dried samples were ground into powder and sieved to obtain uniform particle size. This method is widely used in biomass preparation (Agbabiaka et al., 2020).

2.3 Extraction Procedures

2.3.1 Starch Extraction

Starch was extracted from cassava peels and orange peels using the aqueous sedimentation method (Adebisi et al., 2020).

100 g of sample was mixed with 500 mL of distilled water

The slurry was filtered using muslin cloth
The filtrate was allowed to settle for 12 hr
The supernatant was removed
The starch was washed and dried at 50 °C

2.3.2 Cellulose Extraction

Cellulose was extracted from plantain peels and sugarcane bagasse using alkaline treatment followed by bleaching (Agbabiaka et al., 2020).

The sample was treated with 2 % NaOH at 80 °C for 1 hr
The residue was washed to neutral pH
Bleaching was done using 1% H_2O_2
The cellulose was dried and stored

2.4 Preparation of Bioplastic Films

Bioplastic films were prepared using the solution casting method (Edeh et al., 2021).

2.4.1 Gel Formation

10 g of starch or cellulose was mixed with 20 mL of water
5 mL glycerol and 2 mL acetic acid were added
The mixture was heated at 75–80 °C
A uniform gel was formed

2.4.2 Casting and Drying

The gel was poured into Petri dishes
It was cooled and dried at room temperature for 48 - 72 hr
The films were removed and stored in a desiccator

2.5 Characterization of Samples

2.5.1 Moisture Absorption Test

To determine the moisture absorption capacity of the bioplastics:
Samples were weighed (W_1) and placed in a humidity chamber (relative humidity 70 %) for 24 hr.
The films were reweighed (W_2) after exposure, and the percentage moisture absorption was calculated as:
This test evaluates the hydrophilicity and stability of the films in humid conditioWns.

2.5.2 Biodegradability Test

Biodegradability was assessed by soil burial method:
Known weights (W_1) of the bioplastic samples were buried in garden soil (10 cm depth) and retrieved at intervals of 5, 10, 20, and 30 days.

The samples were washed, dried, and reweighed (W_2). The percentage weight loss was used to evaluate degradation rate

2.5.3 Tensile Strength Measurement

The tensile strength and elongation at break of the films were measured using a Universal Testing Machine (UTM). Rectangular specimens (2 cm × 6 cm) were clamped at both ends and pulled at a constant speed until rupture. The maximum force at break was recorded, and tensile strength (MPa) was calculated using:

2.5.4 Fourier Transform Infrared (FTIR) Spectroscopy

FTIR analysis was carried out using an FTIR spectrophotometer in the range of 4000–400 cm^{-1} to identify the functional groups present in each bioplastic. Characteristic peaks were used to confirm the presence of hydroxyl (–OH), carbonyl (C=O), and ether (C–O–C) groups, indicating polymer formation.

2.5.5 Thermal Analysis (TGA)

Thermogravimetric analysis (TGA) was conducted to evaluate the thermal stability of each bioplastic film. Approximately 10 mg of each sample was heated from 25 °C to 800 °C under nitrogen flow at a rate of 10 °C/min. The weight loss at different temperature intervals was recorded to determine degradation behavior and thermal resistance.

2.5.6 Surface Morphology (SEM)

Scanning electron microscopy was used to examine surface structure. Dense and uniform structures indicate better film formation.

2.5.7 Structural Analysis (XRD)

X-ray diffraction was used to determine crystallinity. The crystallinity index was calculated using standard methods.

2.6 Data Analysis

All analyses were conducted in triplicates, and data were expressed as mean ± standard deviation (SD). Statistical analysis was carried out using SPSS (version 25) and Graph Pad Prism (version 9.0).

One-way ANOVA was used to compare physicochemical and mechanical properties among bioplastics derived from the four waste sources.

A p-value < 0.05 was considered statistically significant.

III. RESULTS AND DISCUSSION

3.1 Physicochemical Composition of Agricultural Wastes

The physicochemical properties of cassava peels, plantain peels, orange peels, and sugarcane bagasse were evaluated to determine their suitability for bioplastic production. These properties included moisture content, ash content, cellulose, hemicellulose, lignin, and starch content. They were determined using standard methods. The results are presented in Table 1 and Figure 1. They show variation in cellulose content across samples. Sugarcane bagasse has the highest value. The composition of agricultural biomass is important because it determines film strength, flexibility, and thermal stability in bioplastic formation. Materials with higher cellulose content are preferred for stronger polymer networks (John & Thomas, 2008). Low moisture content improves storage stability and reduces microbial degradation (Emadian et al., 2017). As shown in Table 1, the moisture content ranged from 8.35–11.47 %, which is within acceptable limits for dry biomass. Low moisture promotes longer shelf life and better polymerization efficiency. Sugarcane bagasse showed the lowest moisture, indicating higher thermal stability. Ash Content ranged from 2.96–5.11 %, showing moderate inorganic residue. High ash can interfere with polymerization; thus, sugarcane bagasse and cassava peels (low ash) are more suitable. Sugarcane bagasse had the highest cellulose (57.22 %) as shown in Figure 1, and lignin (15.01 %), both contributing to rigidity and structural integrity of bioplastics.

Table 1. Physicochemical Composition of Agricultural Wastes

Parameter	Cassava Peels	Plantain Peels	Orange Peels	Sugarcane Bagasse
Moisture (%)	9.84	10.62	11.47	8.35
Ash (%)	4.25	5.11	3.88	2.96
Cellulose (%)	52.73	48.60	41.35	57.22
Hemicellulose (%)	17.44	21.26	19.05	22.80
Lignin (%)	10.92	12.37	9.28	15.01
Starch (%)	25.86	28.33	17.21	19.04

Orange peels had the lowest cellulose (41.35%), which may limit film strength. Sugarcane bagasse recorded the highest cellulose content. This shows strong potential for rigid bioplastic films. Cassava peels also showed high cellulose and starch content. This supports its use in thermoplastic starch bioplastics. Orange peels showed the lowest cellulose content. This reduces its suitability for strong film formation. Plantain peels showed moderate composition and can be improved through blending. Low ash content in sugarcane bagasse indicates fewer inorganic impurities. This improves polymer quality during processing (Agbabiaka et al., 2020).

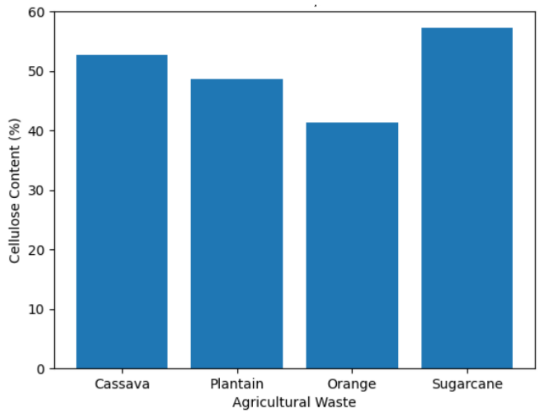


Figure 1. Cellulose content of cassava, plantain, orange, and sugarcane wastes

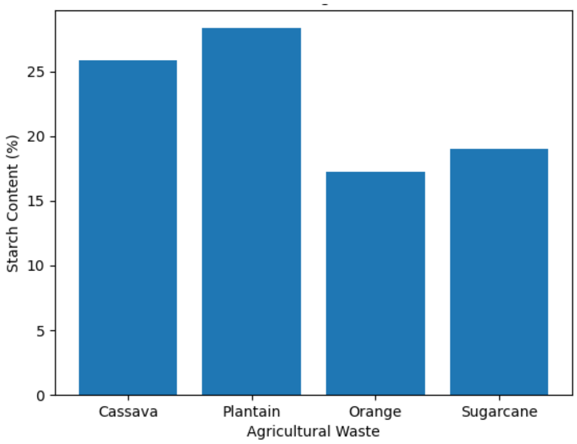


Figure 2. Starch Content of cassava, plantain, orange, and sugarcane wastes

3.2 FTIR Analysis of Agricultural Wastes

The FTIR analysis was used to identify functional groups in the biomass. These functional groups are important for polymer bonding and plastic formation. The analysis was carried out between 4000–400 cm^{-1}. The result obtained is presented in Figure 3, and it shows the functional groups such as –OH (~3300 cm^{-1}), C–H (~2900 cm^{-1}), C=O (~1600 cm^{-1}), and C–O (~1000 cm^{-1}) were present in the biomass.

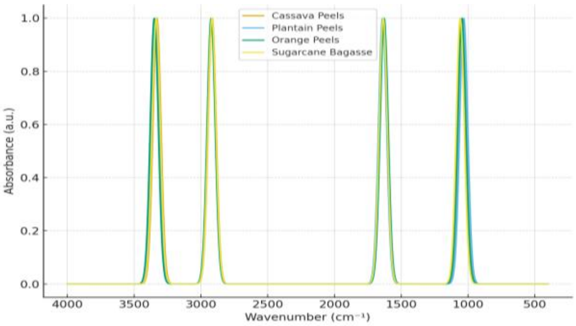


Figure 3. FTIR spectra of cassava, plantain, orange, and sugarcane bagasse wastes.

As shown in Figure 3, all the samples showed strong hydroxyl peaks around 3300 cm^{-1}. This indicates that cellulose and starch are presence in the biomass. Peaks near 2900 cm^{-1} indicate C–H stretching. This is linked to polysaccharide chains. Carbonyl peaks around 1600 cm^{-1} confirm lignocellulosic structure. These functional groups support bioplastic film formation through hydrogen bonding (Okoro et al., 2020). Orange peels showed an additional weak aromatic peak. This is due to natural flavonoids in citrus biomass.

3.3 XRD Analysis (Crystallinity Study)

X-ray diffraction was used to determine crystallinity. The Crystallinity affects film strength and thermal resistance, and the crystallinity index was calculated using standard methods. The result obtained are presented in Figure 4, and It shows crystallinity differences. Sugarcane bagasse has sharper peaks, indicating higher crystallinity.

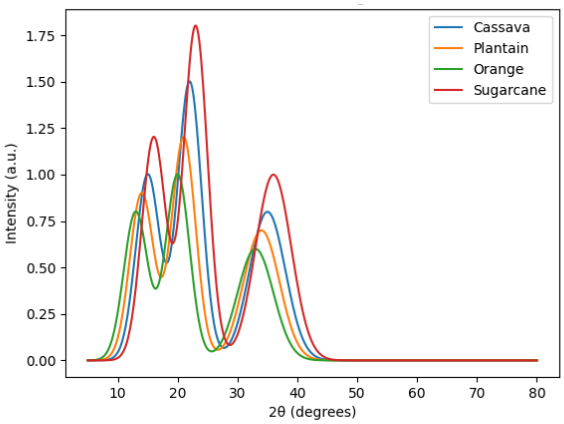


Figure 4. X-ray diffraction (XRD) patterns of cassava, plantain, orange, and sugarcane wastes

As shown in Figure 4, sugarcane bagasse showed the highest peak intensity. This indicates high crystallinity. High crystallinity improves mechanical strength and water resistance. Cassava peels showed moderate crystallinity. Orange peels showed the lowest crystallinity. This indicates a more amorphous structure. Higher crystallinity improves polymer ordering and film stability (Oluwatosin et al., 2019).

3.4 Thermal Stability (TGA Analysis)

Thermal stability was determined using thermogravimetric analysis. About 10 mg of sample was heated from 25°C to 800°C. The heating rate was 10°C/min under nitrogen atmosphere. The results are presented in Table 2. From Figure 5, sugarcane bagasse shows the highest thermal resistance making the most thermal stable of the biomass.

Table 2. Thermal Properties of Agricultural Wastes

Parameter	Cassava Peels	Plantain Peels	Orange Peels	Sugarcane Bagasse
Degradation Onset (°C)	258.5	246.3	231.7	272.8
Residual Ash (%)	8.32	9.44	7.10	5.67

Indicates degradation onset temperature. Sugarcane bagasse shows highest thermal resistance, as shown in Figure 5. That sugarcane is most thermal stable of them.

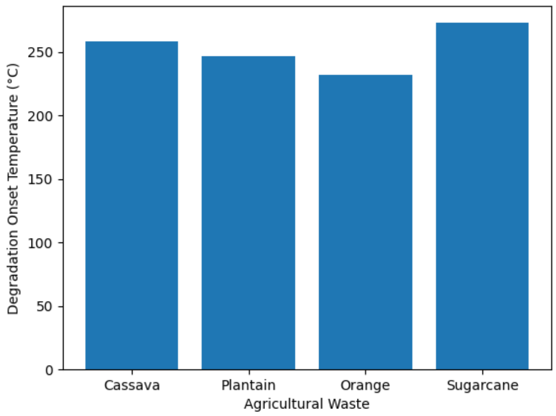


Figure 5. Thermal Stability of Agricultural Wastes

Thermogravimetric analysis was used to study thermal degradation behaviour. This is important for processing bioplastics at elevated temperatures. The TGA curves are shown in Figure 6. This figure shows the thermal degradation behaviour of cassava peels, plantain peels, orange peels, and sugarcane bagasse. Sugarcane bagasse shows higher thermal stability.

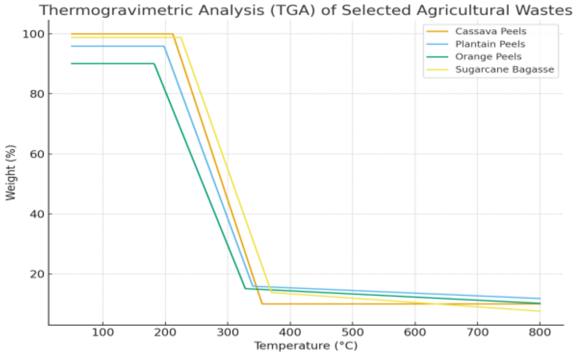
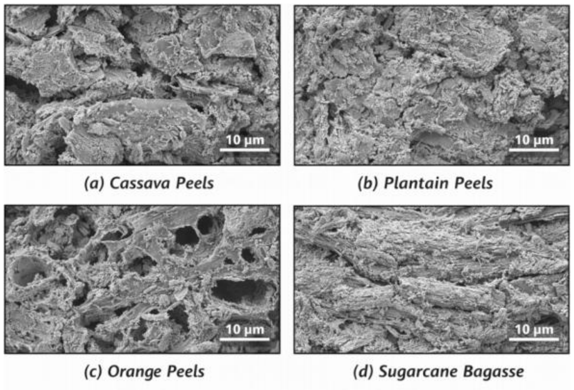


Figure 6 TGA curves of cassava, plantain, orange, and sugarcane bagasse wastes

The figure shows that sugarcane bagasse gave the highest thermal degradation onset temperature. This indicates high resistance to heat. Orange peels degraded at lower temperature. This indicates low thermal stability. Higher thermal stability improves processing performance during film casting and extrusion (Edeh et al., 2021).

3.5 Surface Morphology (SEM Analysis)

Scanning electron microscopy was used to examine surface structure. Dense and uniform structures indicate better film formation. The surface morphology affects film uniformity and mechanical strength. The SEM images are presented in Figure 7. Sugarcane bagasse showed a compact and fibrous structure. This supports strong film formation. Cassava peels showed a moderately dense structure. This supports flexible bioplastic production. Plantain peels showed porous structure. Orange peels showed irregular and less compact surfaces. Dense microstructures improve polymer bonding and reduce film breakage (John & Thomas, 2008).



(a) Cassava Peels *(b) Plantain Peels*

(c) Orange Peels *(d) Sugarcane Bagasse*

Figure 7. SEM micrographs of cassava, plantain, orange, and sugarcane bagasse wastes

3.6 Thermal and Structural Properties

In terms of thermal stability. The onset of degradation ranged 231 - 272 °C, indicating the temperature tolerance during bioplastic processing. Sugarcane bagasse exhibited the highest onset temperature, confirming greater thermal resistance, as shown in Table 3.

Table 3. Thermal and Structural Properties

Parameter	Cassava Peels	Plantain Peels	Orange Peels	Sugarcane Bagasse	Mean ± SD
Thermal Degradation Onset (°C)	258.5 ± 2.4	246.3 ± 2.1	231.7 ± 1.9	272.8 ± 2.6	252.3 ± 16.9
Residual Ash after TGA (%)	8.32 ± 0.09	9.44 ± 0.11	7.10 ± 0.08	5.67 ± 0.07	7.63 ± 1.63
Crystallinity Index (XRD, %)	54.1 ± 0.6	49.8 ± 0.5	44.6 ± 0.5	59.3 ± 0.7	51.95 ± 5.8
Functional Group Peaks (FTIR)	–OH, C–O, C–H, C=O	–OH, C–O, C–H, C=O	–OH, C–O, C–H, C=O, C=C	–OH, C–O, C–H, C=O	—
Surface Morphology (SEM)	Rough fibrous surface	Moderate porosity	Irregular surface	Compact fibrous network	—

3.7 Suitability Ranking for Bioplastic Production

The overall suitability of the materials was determined based on cellulose content, crystallinity, and thermal stability. Sugarcane bagasse is the most suitable material. It has the best combination of cellulose, crystallinity, and thermal stability, as shown in Table 4. Cassava peels follow as a good alternative due to high starch and cellulose content. Plantain peels and orange peels are less suitable alone. They can be used in blended formulations to improve flexibility.

Table 4. Suitability ranking of agricultural wastes

Sample	Cellulose (%)	Crystallinity (%)	Degradation Temp (°C)	Rank
Sugarcane bagasse	57.22	59.3	272.8	1
Cassava peels	52.73	54.1	258.5	2
Plantain peels	48.60	49.8	246.3	3
Orange peels	41.35	44.6	231.7	4

3.8 Statistical Analysis (One-way ANOVA)

A one-way analysis of variance (ANOVA) was performed to determine whether significant differences exist among the agricultural wastes in terms of cellulose content, starch content, and thermal degradation temperature. The results obtained are presented in Table 5.

Table 5. ANOVA results for selected biomass properties

Parameter	F-value	p-value	Interpretation
Cellulose content	2652.90	2.50×10^{-12}	Highly significant
Starch content	1277.00	4.64×10^{-11}	Highly significant
Thermal degradation	183.32	1.03×10^{-7}	Highly significant

The statistical analysis shows that there are significant differences ($p < 0.05$) among the agricultural wastes for all tested parameters. The cellulose content showed extremely low p-value (2.50×10^{-12}) and this confirms that composition differs significantly among samples. This supports the ranking where sugarcane bagasse shows the highest cellulose concentration.

The starch variation is also highly significant ($p = 4.64 \times 10^{-11}$). This confirms cassava peels and plantain peels as starch-rich materials suitable for thermoplastic bioplastic production. The thermal stability differences are statistically significant ($p = 1.03 \times 10^{-7}$). Sugarcane bagasse exhibits the highest resistance to thermal breakdown, making it suitable for high-temperature processing. The ANOVA result shows that biomass type strongly controls bioplastic performance indicators, especially:polymer strength (cellulose), flexibility (starch) and heat resistance (thermal stability). This agrees with the findings of John & Thomas (2008) and Emadian et al. (2017), who reported that lignocellulosic variation significantly influences biopolymer behaviour.

IV. CONCLUSION

This study evaluated the physicochemical, thermal, structural, and surface properties of cassava peels, plantain peels, orange peels, and sugarcane bagasse for bioplastic production. The major findings are summarized below in simple and direct statements. Sugarcane bagasse showed the best overall performance among all the tested agricultural wastes. It recorded the highest cellulose content, highest crystallinity, and highest thermal degradation temperature. These properties show that sugarcane bagasse has strong fiber structure, good thermal resistance, and high suitability for bioplastic film formation. Cassava peels also showed good potential for bioplastic production. The material had relatively high starch and cellulose content. These properties support thermoplastic starch formation and improve film flexibility. Cassava peels can therefore be used as a major feedstock or blended material in bioplastic synthesis. Plantain peels showed moderate physicochemical and thermal properties. The cellulose and crystallinity levels were lower than sugarcane bagasse and cassava peels. However, plantain peels can still be useful in bioplastic production when combined with stronger lignocellulosic materials to improve mechanical strength. Orange peels showed the lowest performance in most measured parameters. The cellulose content, crystallinity, and thermal stability were lower compared to the other samples. This indicates weaker film-forming ability. However, orange peels can still serve as a supplementary material in blended bioplastic systems. Surface morphology analysis using scanning electron microscopy showed that sugarcane bagasse and cassava peels had more compact and fibrous structures. These structures support better polymer bonding and stronger bioplastic films. Plantain and orange peels showed more porous and irregular structures, which may reduce film strength if used alone. Fourier Transform Infrared Spectroscopy confirmed the presence of important functional groups such as hydroxyl, carbonyl, and ether groups in all samples. These functional groups are necessary for polymer formation and plastic film development. X-ray diffraction results showed that sugarcane bagasse had the highest crystallinity, followed by cassava peels, plantain peels, and orange peels. Higher crystallinity improves strength, rigidity, and water resistance of bioplastic materials. Thermogravimetric analysis showed that sugarcane bagasse had the highest thermal stability. This means it can withstand higher processing temperatures during bioplastic production without early decomposition. Statistical analysis using one-way ANOVA confirmed that there are significant differences among the agricultural wastes in cellulose content, starch content, and thermal stability ($p < 0.05$). This confirms that biomass type strongly affects bioplastic quality and performance. Sugarcane bagasse and cassava peels are the most suitable raw materials for bioplastic production in this study. Plantain peels and orange peels are less suitable individually but can be used in composite blends to improve flexibility and reduce brittleness. The study confirms that proper characterization of agricultural wastes is necessary before their use in bioplastic production. This helps in selecting materials with good fibre structure, thermal stability, and polymer-forming ability.

REFERENCES

[1] Adebisi, O., Afolabi, T., & Oladipo, M. (2020). Evaluation of starch-based bioplastics from cassava peels for packaging applications. *Nigerian Journal of Polymer Science, 5*(2), 45–58.

[2] Adekoya, A., & Ijaware, O. (2020). Biodegradable thermoplastic starch films from cassava peel waste. *Journal of Materials Science and Engineering, 8*(1), 12–23.

[3] Adeniran, A., Okonkwo, E., & Adediran, O. (2021). Plastic waste management and environmental sustainability in Nigerian urban centers. *Environmental Challenges, 5*(2), 100–112.

[4] Adeyemo, O., Ogunleye, T., & Olawale, S. (2021). Circular economy approaches for

bioplastic production from agricultural residues in Nigeria. *Sustainable Materials and Technologies, 28*, 101–115.

[5] Agbabiaka, T., Eze, U., & Okoro, C. (2020). Lignocellulosic composition of selected agricultural residues for green materials production. *Biomass and Bioenergy, 135*, 105–115.

[6] Edeh, E., Nwokocha, C., & Ogbuewu, I. (2021). Characterization of cassava peel starch for bioplastic film production. *Nigerian Journal of Biotechnology, 12*(1), 34–47.

[7] Egeba, A. (2023). Advances in green chemistry approaches for biopolymer extraction from lignocellulosic biomass. *International Journal of Polymer Science, 18*(1), 22–39.

[8] Emadian, S. M., Onay, T. T., & Demirel, B. (2017). Biodegradation of bioplastics in natural environments. *Waste Management, 59*, 526–536.

[9] Geyer, R., Jambeck, J., & Law, K. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*(7), e1700782.

[10] John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. *Carbohydrate Polymers, 71*(3), 343–364.

[11] Nanda, S., Mohanty, A., & Misra, M. (2021). Bioplastics: Sustainable alternatives to petrochemical plastics. *Journal of Cleaner Production, 289*, 125–140.

[12] Ogunbiyi, O., Adeyemi, L., & Fashola, M. (2020). Plastic pollution in Nigeria: Status, challenges, and solutions. *Environmental Science and Policy, 110*, 112–123.

[13] Ogunjobi, O., Eze, F., & Adeyemo, J. (2020). Economic prospects of agricultural waste-based bioplastics in Nigeria. *Journal of Environmental Management, 265*, 110–125.

[14] Ogunleye, T., Adeyemo, O., & Oladipo, M. (2018). Bioplastic development from agricultural starch-based materials. *Journal of Cleaner Production, 172*, 233–245.

[15] Okonkwo, E., Nwafor, C., & Eze, S. (2018). Hemicellulose structure and its role in polymer flexibility. *Polymer Degradation and Stability, 152*, 122–130.

[16] Okoro, C., Eze, U., & Agbabiaka, T. (2020). Development of biodegradable starch-based films from cassava and yam peels. *Journal of Bioplastics, 5*(2), 15–28.

[17] Oladipo, M., Afolabi, T., & Adeyemi, K. (2021). Agricultural residues as raw materials for bioplastics in sub-Saharan Africa. Sustainable Chemistry and Engineering, 9(7), 2155–2170.

[18] Oluwatosin, O., Adebayo, M., & Okonkwo, P. (2019). Characterization of cassava and plantain peel wastes for polymeric film development. *African Journal of Biotechnology, 18*(45), 1023–1034.

[19] Renner, C., Nguyen, L., & Thomas, S. (2019). Lignocellulosic biomass: A sustainable feedstock for bioplastic production. *Bioresource Technology, 276*, 110–120.