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Production of Cellulose from Different Species of Banana (*Musa paradisiaca*) Mid-Rib Waste: A Sustainable Raw Material for Industrial Applications

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Abstract

Wood fibre has been the primary source of raw materials for the production of cellulose for pulp and paper, bio-energy development and other industrial applications, and this has not only encouraged deforestation but also led to high costs of cellulose. This study examined the potential of generating cellulose pulp from four different species of banana (*Musa paradisiaca)* mid-rib wastes commonly known in Nigeria as Ibo banana, Saro, Paranta, and Ogede omini via alkaline sulphite pulping process using 1:1 ratio of NaOH and $NaHSO_3$. The results gave the percentage yield of cellulose of 30 to 40 %, with the highest cellulose of 40 % being produced from *M. paradisiaca* (Paranta); the same amount of 35 % cellulose yield was obtained from *M. paradisiaca* (Ogede omini) and *M. paradisiaca* (Ibo banana) respectively, while the lowest cellulose was produced by *M. paradisiaca* (Saro). Holocellulose range of 80 to 71 % was recorded, while the alpha cellulose and hemicellulose were calculated, respectively. The FTIR characterization of the cellulose from each banana mid-rib species confirmed their chemical identity. The Fiber Length, Fiber Diameter, Lumen Width, Cell Wall Thickness, Runkel, Flexibility, Slenderness ratios and Coefficient of rigidity indicated that the mid-rib cellulose from each of the banana species have suitable long fibers and good tensile strength properties for industrial cellulose applications and morphological properties of the fibers shown by the (SEM) analysis also confirmed the alignment of the cellulose fibers, thus making the various banana mid-rib wastes a viable potential for cellulose production.

Keywords: Banana mid-rib, Cellulose production, *Musa paradisiaca*, Pulping process, Holocellulose

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Introduction

Wood cellulose has been a traditional source of raw materials for the paper industry, and increasing demand for pulp and paper products due to rapid technological advancement has further worsened the global environmental impact arising from deforestation. Currently, there has been a continuous effort to find viable and sustainable sources of cellulose fibers [1]. Furthermore, the emission of greenhouse gases from the combustion of fossil fuels has generated public concern and has shifted research focus to the use of agricultural wastes as alternative and sustainable feedstocks for biogeny development [2].

The generation of biomass wastes emanating from agricultural residues has continued to gain increasing attention recently, especially in developing countries where poor waste management practices are dominant, thereby raising environmental and health concerns. Across the globe, 140 Gt of agricultural wastes are produced every year, and about 517 million tons of these biomaterials are unutilized. Over 60 % of agricultural residues generated in the world have been evaluated to come from low-income countries like Nigeria. Again, Nigeria is one of the major producers of banana fruit crop [3].

Banana, as an abundant agricultural resource, is over-cultivated amongst the tropical nations of the world such as Nigeria. Banana fruit is believed to be the eighth most essential plant globally and one of the world's most crucial agricultural food and staple crops; from 135 countries, 148 million tons were produced. It has been evaluated as a necessary requirement for achieving food security, and it serves as a staple food for over 400 million people across the world [4]. The crop has many economic benefits, ranging from affordable sources of raw materials for industrial uses to finished products. On the other hand, these vast chains of industrial processes produce large volumes of waste amounting to 200 tons on a daily basis [5]. These abundant bio-resources can be potentially harnessed into various industrial applications such as organic fertilizers, biochemicals, animal feedstuff and bioenergy development [6, 7]. Several studies and investigations have been carried out on banana pseudo-stem, FAO [8].

The banana pseudo-stem has been used to generate cellulose pulp fibers for textiles, pulp and paper industries, and in the production of confectionery, liquid fertilizer, and vermin-compost [9-11]. Recently, the banana pseudo-stem has been employed as a potential alternative cheap feed raw material [12].

Furthermore, studies have shown that over 353,443 tons of banana peel, empty banana bunch, and rejected banana fruit generated annually can be effectively utilized in the production of animal feed and some other medicinal uses [13].

It has been reported that the use of banana wastes facilitates the rate of bioremediation of crude oil-polluted soil by enhancing soil aeration and increasing the water-holding capacity of the soil material [14]. Investigation into the use of banana peels as a low-cost adsorbent for the removal of heavy metals such as zinc (Zn), copper (Cu), and manganese (Mn) in synthetic water and its adsorption capacity has been conducted [15]. While the study on the development of an industrial adsorbent using banana peel activated carbon for the treatment of water contaminated with various heavy metals like Mn, Pb, Zn and Fe has also been documented [16]. However, the current study on the potential cellulose sources from different species of banana leaf mid-rib abundant in Nigeria is still under investigation.

Materials and Methods

The chemicals and reagents used in the sample characterization and analyses were of analytical grade obtained from Sigma Aldrich UK, while the 97 % grade sodium hydrogen sulphite ($NaHSO_3$) and sodium hydroxide (NaOH) used for the pulping investigation was manufactured by JHY CHEM, Tianjin Jiahengyuan Chemicals Co., Ltd.

Sample collection and preparation

The four different species of the banana mid-rib waste investigated were sourced from Mountain Top University farmland at Km 12, Lagos/Ibadan Expressway, Ogun State, Nigeria (Geographical location -6.7292° N, 3.4126° E). The banana mid-rib was carefully separated from its parent leaves and was cut into smaller suitable sizes of 0.05 m diameter in accordance with TAPPI T257 test method.

Pulping investigation

Each of the mid-rib species of 250 g mass were subjected to alkaline sulfite chemical pulping. The white liquor used in pulping was prepared by dissolving NaOH (25 g) and $NaHSO_3$ (25 g) in 500 mL of distilled water, and 250 g of each sample was weighed into a 1 L Erlenmeyer flask containing the white liquor. The flasks were carefully sealed with cotton wool and later placed inside a stainless vertical autoclave with model: YX-280A England (18 L), NO. E280AHK220355 and pressure 0.14 MPa- 0.165 MPa with working volt: AC220V 50 Hz 2.0 kw and G.W/N. W:16.5/15 kg. The reaction was done for 90 min at a temperature of 16 °C, and at the completion of the pulping process, the cellulose pulp was separated from the black liquor, washed with deionized water and then air-dried for 24 h to give a bright fluffy pulp [17].

Determination of extractive content

The extractive contents of the different samples were determined using Soxhlet extractor in accordance with standard Tappi T204 om-88 test method under a solvent mixture of ethanol and acetone in the ratio 1:2, using 4 g each of the air-dried biomass of sample size 0.25 to 0.5 cm diameter and were put into the extraction thimble and covered with cotton wool. Reflux was carried out for 6 h with a Soxhlet extraction apparatus, and the solvent obtained at the end of each extraction process was evaporated at reduced pressure, and the weight of the dried extractive content was obtained [18].

Determination of lignin content

The lignin contents for each of the biomass waste samples were determined on 1.00 g; each of the extractive-free corn stalk, corn cob, corn husk and corn leaf was placed in a 50 mL beaker containing 15 mL of 72 % H_2SO_4 at 25°C for 2 h after which the reaction medium was transferred into a 1000 mL Erlenmeyer flask. The acid was diluted by adding 575 mL of distilled water after which the contents of the flask was refluxed for 4 h, allowed to cool and filtered. The residue was washed free of acid, then oven-dried to constant weight at a temperature of 105°C [19].

Determination of holocellulose

The holocellulose determination was conducted by weighing 3 g each of the mid-rib sample oven-dried samples into a 250 mL flask with watch glass cover and 150 mL of distilled water, at interval of an hour 0.2 mL of cold glacial acetic acid, and one gram of $NaClO_2$ was added for five hours and the flask was placed into a water bath at 70-80 °C. The content of the flask was filtered off with Buchner funnel and washed free of ClO_2 with cold distilled water. The residue was then dried at 105 °C in an oven and cooled in a desiccator and weighed repeatedly to obtain a consistent weight [20].

Determination of alpha cellulose

The oven-dried sample of 3 g of the different banana mid-rib waste was weighed into a 250 mL Erlenmeyer flask containing 17.5 percent NaOH and 50 mL of distilled water, placed in a water bath at a temperature of 20 °C, and stirred for 30 min. The reaction medium was transferred into a Buchner funnel and filtered, and the residue was cleaned with 40 mL of 10 % acetic acid and 40 mL of 8.3 % NaOH, after which 1000 mL of hot tap water was employed for the removal of the acid from the residue. The residue was finally dried at 105 ºC in an oven at a constant weight [20].

Hemicellulose cellulose determination

The amount of non-sugar monomer present in the four different waste samples was determined by subtracting the alpha cellulose content from the holocellulose content.

Fiber morphological characterization

The morphological determination of the cellulose pulp produced each of banana mid-rib waste was carried out by macerating the samples in a solution of 1:1 HNO_3 and $KClO_3$ for 30 min and the macerated samples were measured using an optical digital microscope (Olympus CX23). 20 fibers of each sample were analyzed and the average reading was taken in accordance with ASTM D-1037-12 2020 and ASTM D-1413-61 2007 [21, 22].

Results and Discussion

The results obtained from the pulping investigation in Table 1 showed that *M. paradisiaca (*P) banana mid-rib specie gave the highest cellulose pulp yield of 40.10 %, equal amount of cellulose of 35.23 and 35.30 % was produced by *M. paradisiaca* (I) and *M. paradisiaca* (O) banana species respectively while M. paradisiaca (S) produced lowest pulp yield of 30.20 %. It was also observed that there was similarity in the amount of lignin and extractive contents of the four-banana mid-rib and these results correlate with the yield of pulp lignin and extractive contents of Nigerian sawdust wood species [17].

Table 1: The mean percentage yield of cellulose pulp, lignin, extractive and ash contents obtained from the different species of Banana Mid-Rib Waste

Different Species of Banana Mid-Rib Waste	Common Nigerian Names	Mean Pulp Yield (Cellulose) (%)	Lignin (%)	Extractive Content (%)	Mean Moisture Content (%)	Mean Ash Content (%)
M. *paradisiaca* (S)	Saro	30.20 ± 1.20	12.00±0.05	3.0 ± 0.45	10.01± 0.54	2.50 ± 0.05
M. paradisiaca (P)	Paranta	40.10 ± 1.05	13.80±0.02	4.0 ± 0.47	12.00± 0.62	2.65 ± 0.03
M. paradisiaca (I)	Ibo banana	35.25 ± 1.00	14.05±0.03	3.7 ± 0.50	10.23± 0.54	2.60 ± 0.04
M. paradisiaca (O)	Ogede omini	35.30 ± 1.05	13.50±0.03	3.5± 0.50	9.50± 0.60	2.70 ± 0.10

Table 2: The percentage alpha cellulose, hemi cellulose and holo cellulose of different species of banana mid-rib waste

Different Species of Banana Mid-Rib Waste	Common Nigerian Names	Alpha Cellulose (%)	Hemi Cellulose (%)	Holo Cellulose (%)
Musa *paradisiaca* (S)	Saro	28.01	43.00	71.01
Musa paradisiaca (P)	Paranta	30.00	50.00	80.00
Musa paradisiaca (I)	Ibo banana	30.00	49.00	79.00
Musa paradisiaca (O)	Ogede Omini	30.01	48.00	78.01

The alpha cellulose content (Table 2) of 30 % obtained from the mid-rib species implies that their utilization in pulp and paper products formation will impact favorably on tensile strength. The highest holocellulose content of 80 % was produced from *M. paradisiaca* (P), while 79 and 78 % were recorded from *M. paradisiaca* (I) and *M. paradisiaca* (O), with the lowest holocellulose content of 71 % from *M. paradisiaca* (S). These results correlate with those of wheat straw and oil palm trunk, making the banana mid-rib waste a suitable alternative source of cellulose fibers [23].

The measurement of 1 % NaOH solubility, cold water and hot water solubility tests carried out on the different mid-rib banana species (Table 3) showed the potential of biomaterials for the generation of cellulose pulp for pulp and paper, bioenergy development and other industrial applications.

Table 3: The analysis of 1 % NaOH, cold water and hot water solubility test

Different Species of f Banana Mid-Rib Waste	Common Nigerian Names	Mean 1 % NaOH Solubility	Mean % Cold Water Solubility	Mean % Hot Water Solubility
M. *paradisiaca* (S)	Saro	20.25 ± 1.02	12. ± 0.65	13.80 ± 1.02
M. paradisiaca (P)	Paranta	19.67± 1.03	10.66 ± 0.45	12.25 ± 1.03
M. paradisiaca (I)	Ibo banana	18.20 ± 1.05	11.85± 0.56	13.08 ± 1.04
M. paradisiaca (O)	Ogede Omini	17.84± 1.04	8.05 ± 0.55	10.25 ± 1.04

Table 4: The mean values from fiber characterization of different species of Banana Mid-Rib waste

Different Banana Mid- Rib Waste	Fiber Length (mm)	Fiber Diameter (µm)	Lumen Width (µm)	Cell Wall Thickness (µm)	Runkel Ratio (RR)	Flexibility Ratio (FR)	Slenderness Ratio (S %)	Coefficient of Rigidity (CoR%)
M. paradisiaca (S)	1.625	19.13	10.021	4.850	1000	24500	0.084	24000
M. paradisiaca (P)	2.864	21.510	12.641	5.216	1100	26000	0.1568	25000
M. paradisiaca (I)	2.425	20.210	11.524	4.932	1000	25033	0.098	24000
M. paradisiaca (O)	2.150	19.744	11.450	4.855	1000	2500	0.0956	24333

The mean values of the Fibre Length (FL), Fibre Diameter (FD), Lumen Width (LW) and Cell Wall Thickness (CWT), Runkel Ratio (RR), Flexibility Ratio (FR), Slenderness Ratio (S %) and Coefficient of Rigidity (CoR %) established from the morphological determination of the four banana mid-rib species are (Table 4) showed high fiber length of 2.86, 2.42, 2.15 and 1.63 mm from *M. paradisiaca* (P). *M. paradisiaca* (I), *M. paradisiaca* (O), and *M. paradisiaca* (S) respectively and these values compared favorably with the fiber lengths of 1.05–1.36 mm obtained from eighteen different Nigerian wood species. It was also observed that the fiber diameter range of 19.13 to 21.51 µm obtained from the four species of the banana mid-rib was higher than 15.22 µm (*M. excelsa*). The lumen widths of 12.52, 11.90, 10.62 and 10.05 µm from the corn wastes were better than the smallest 8.89 µm recorded for *M. excelsa* wood. The average cell wall thickness of 4.76 µm, obtained from this study, favours large-scale industrial utilization compared to that of 2.61 to 6.92 µm obtained from wood species [24]. Other parameters like Runkel, Flexibility, Slenderness ratios and coefficient of rigidity determined from the banana mid-rib waste showed that these biomaterials can positively influence important paper product quality such as the tensile strength, paper sheet formation, tear resistance, and breaking load strain [25].

The FTIR analysis of different corn biomass waste; corn stalk, corn leaf, corn husk and corn cob indicated in Figs 1-4 showed observable peaks at 3272.6, 2926.0 and 1736.9 cm^1 of hydroxyl, methoxyl, carbonyl functional group confirm the presence of cellulose. The presence of similar peaks on the spectra of cellulose samples from corn stalk and corn cob were observed at 3450-3428 cm^1 *paradisiaca* (I) and *paradisiaca* (O) are characteristic of the hydroxyl group stretching tendency in the cellulose molecule, while the peaks at wavenumbers of 2915 to 3000 cm^1 shown in *paradisiaca* (I) and *paradisiaca* (S cellulose spectral correspond to C-H bonds in cellulose. The inter- and intra-molecular hydrogen bond vibrations in cellulose were also dictated in the regions of 1686 - 980 cm^1 in the cellulose produced from the mid-rib waste [26].

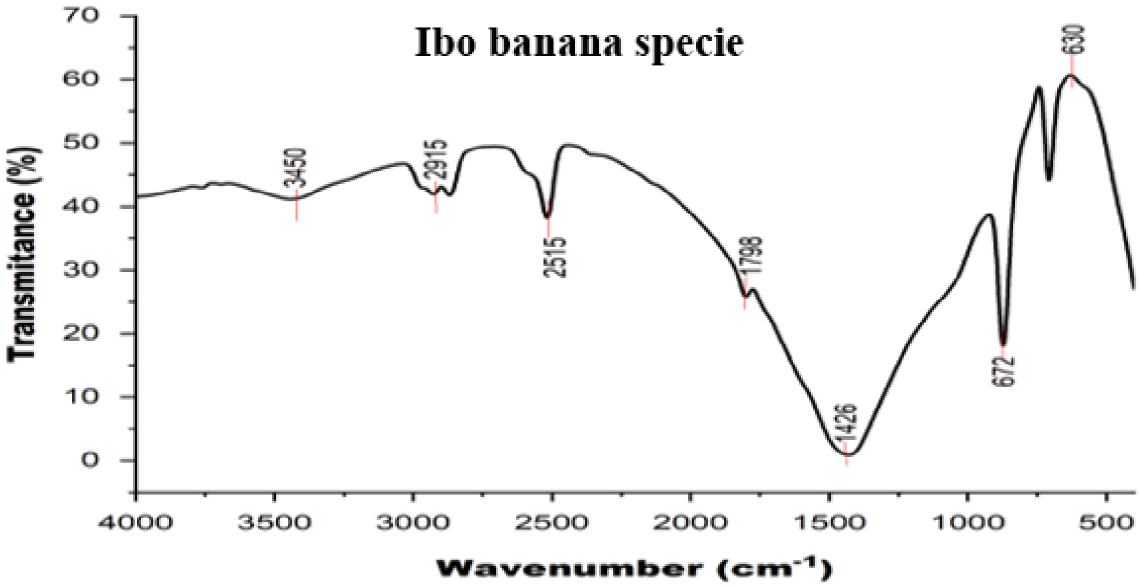

Figure 1: FTIR analysis of the cellulose from mid-rib *M. paradisiaca* (I)

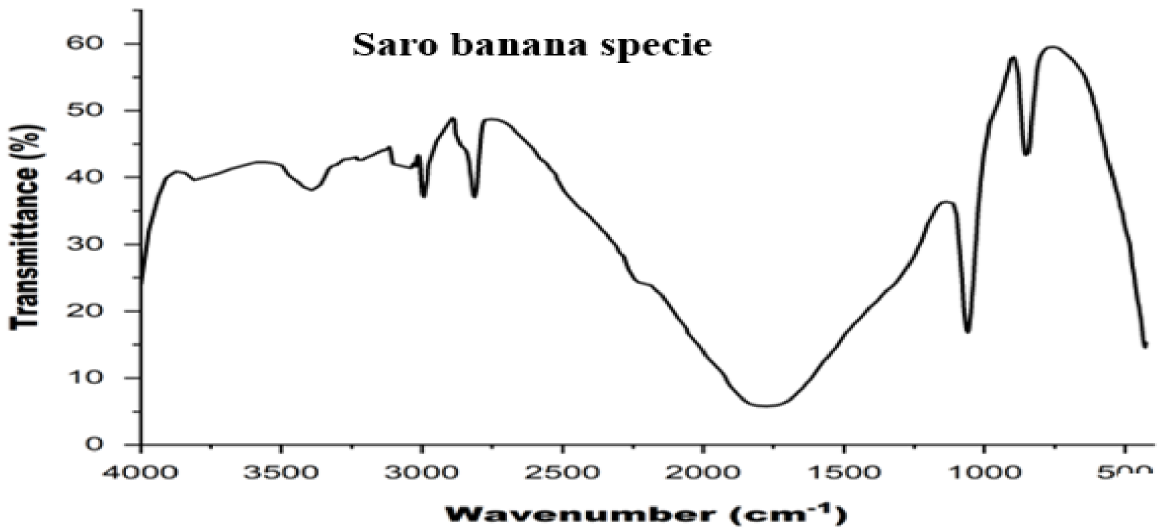

Figure 2: FTIR analysis of the cellulose from mid-rib *M. paradisiaca* (S)

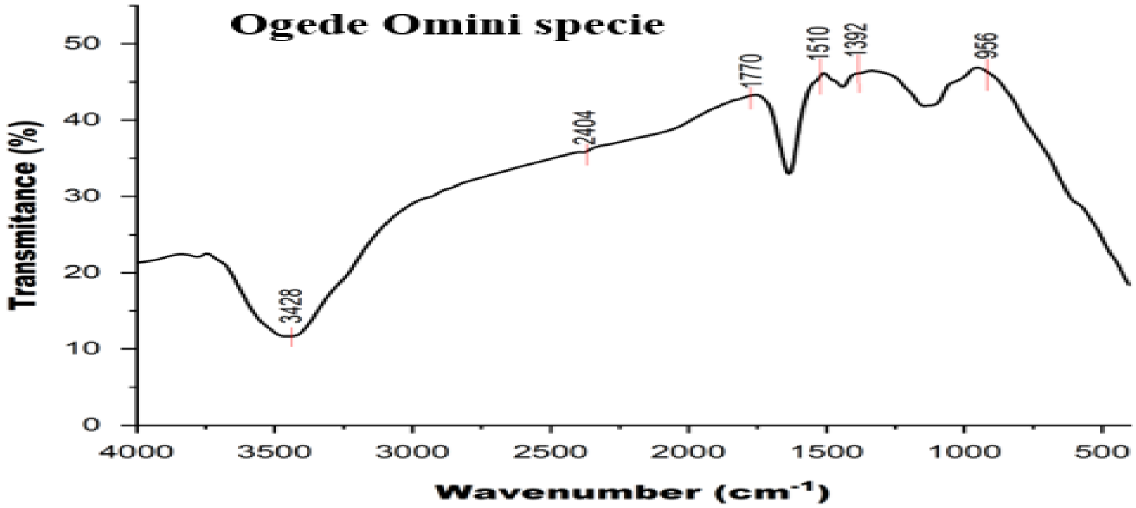

Figure 3: FTIR analysis of the cellulose from mid-rib *M. paradisiaca* (O)

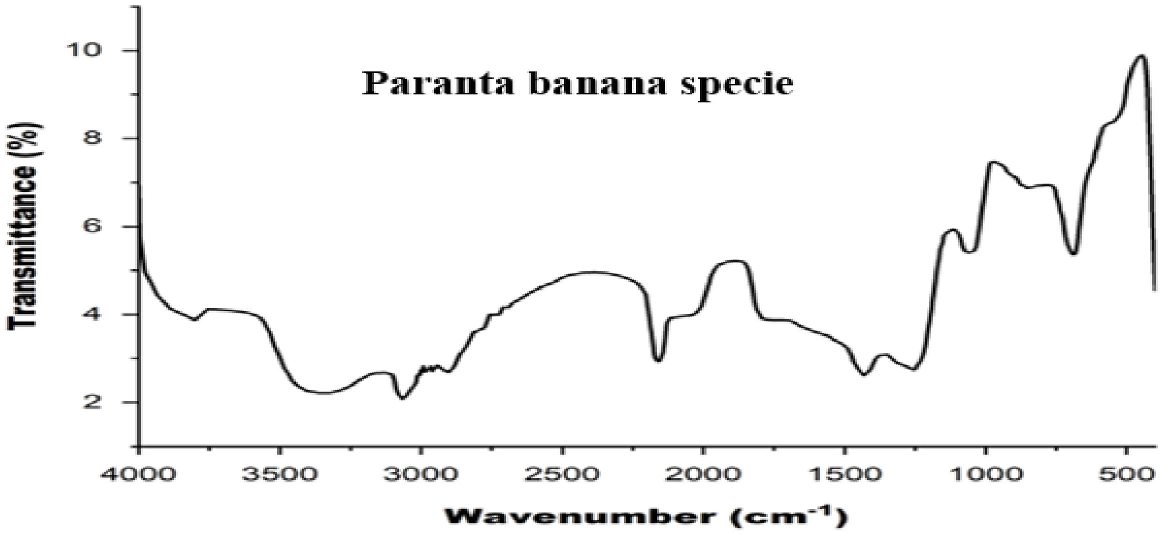

Figure 4: FTIR analysis of the cellulose from mid-rib *M. paradisiaca* (P)

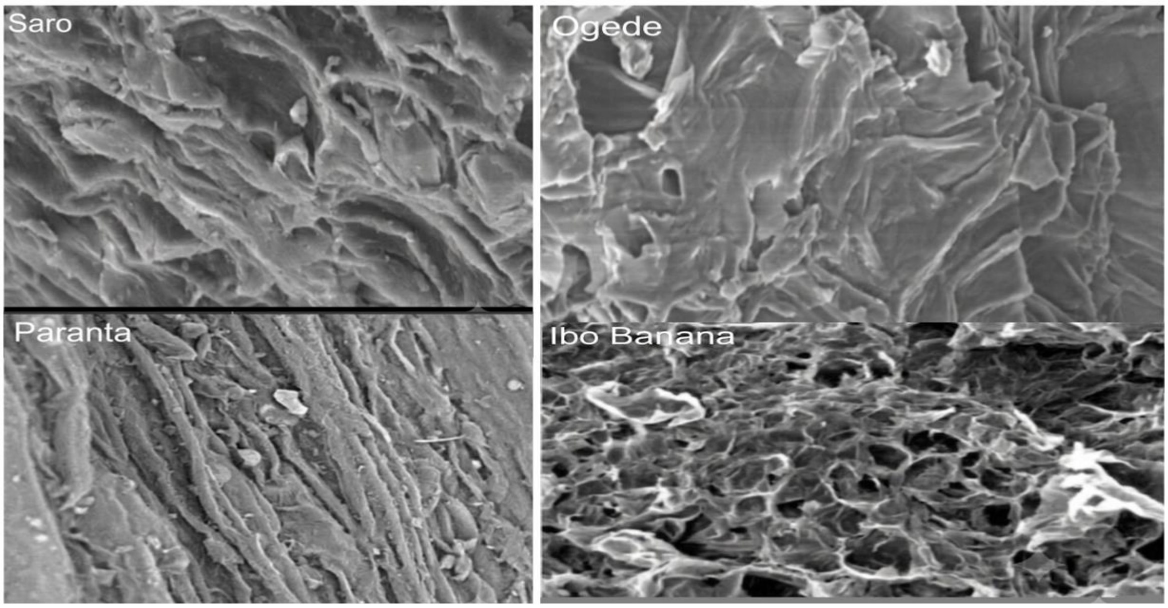

Figure 5: Surface morphology of the cellulose from the four different banana mid-rib wastes at 10,000 magnifications, Hv of 20 Kv, HFW of 130 um and pressure of 70 Pa

The surface morphological characterization of the four different mid-rib banana species using SEM (Fig. 5) showed suitable alignment of cellulose fibers and their conformity to pulp and paper development and various bioproduct applications.

Conclusion

This study has demonstrated the huge cellulose potential embedded in the four major species of banana mid-rib waste cultivated massively in Nigeria, making them a viable alternative bioresource for the production of cellulose polysaccharides for various industrial applications. The morphological and fiber characterization of the mid-rib cellulose compared favorably with that of wood cellulose. Hence, the utilization of banana mid-rib biomass waste for cellulose extraction will not only provide a sustainable and cheap bioresources for industrial application but will also reduce the environmental pollution from this waste.

Conflict of interest: The authors hereby declare that there is no conflict of interest in this research, nor was there any funding received to carry out this project.

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