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Development of pulp and paper using stem and fruit stem of *Musa Species*

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Abstract ─ Paper is a thin material mainly used for writing, printing, and packaging. The stem and fruit stem of two *Musa species*, *Musa Acuminata Balbisiana* (Banana stem) and *Musa Paradisiaca* (Plantain stem), were expanded. This research aimed to find other alternatives to reduce the use of wood fibers that are being converted into paper. The stem chips were charged into a digester with different percentages (5, 10, and 15%) of sodium hydroxide (NaOH) and were subjected to the impregnating temperature (60^{o}C) for 1 hour before heating to 100^{o}C for 3 hours. The stems were pounded finely with mortar and pestle and then bleached using 15% hydrogen peroxide. Calcium carbonate (10%) was added to both pulps obtained as filler, while 5% glue was added as a sizing agent. The mixture was agitated, pressurized, and air-dried, and mechanical tests were carried out. It was shown that the tearing resistance, tensile strength, and elongation tests obtained using 5% NaOH for banana, plantain and banana fruit stems were 0.84 mN, 17.82 N/m^2, and 4.90 mm; 1.35 mN, 14.95 N/m, and 2.17 mm; and 1.90 mN, 24.77 N/m^2, and 5.49 mm while the pulp yields were 36.7%, 35.5%, and 38.5%, respectively. The results obtained using 10% NaOH for banana, plantain, and banana fruit stems were 0.80 mN, 17.30 N/m^2, and 4.85 mm; 1.25 mN, 14.73 N/m^2, and 2.0 mm; 1.85 mN, 23.60 N/m^2, and 5.35 mm while the pulp yields were 35.80%, 34.12%, and 32.25% in that order. Moreover, using 15% of NaOH for banana, plantain, and banana fruit stems gave 0.70 mN, 6.89 N/m^2, and 1.86 mm; 0.79 mN, 8.70 N/m^2, and 2.90 mm; and 1.5 mN, 12.62 N/m^2, and 3.03 mm while the pulp yields were 33.8, 33.11, and 31.03%, respectively. This showed that banana fruit stems pulped at 5% NaOH gave better results than banana and plantain stems. In conclusion, the pulp is suitable for producing fiberboards and cartons.

Keywords: *Banana stem, plantain stem, pulp, pressurized, filler, tensile strength*

Subject Classification (2020):

1. Introduction

Man derives his livelihood directly from the natural endowment in which trees fall into this category with more economical and biotechnological values. Naturally, wood has diverse applications for humanity, such as paper production, which has increased tremendously over the past four decades. Other agricultural residues can also be used for pulp and paper production. The high demand for pulp and paper has dramatically reduced pulp wood with a decline in forest-based material. This has prompted many researchers to look for alternatives to pulp wood, such as waste of bagasse and rice straw for producing paper. It is observed that among the agro waste, much research has not been carried out using banana stems [1]. Paper is a slender material produced by pressing together moist fibers derived from cellulose pulp capable of writing or packaging. In developing

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countries like Nigeria, the availability of a steady supply of paper is an essential tool for promoting education and increasing literacy. The development triggers an increased demand for the local production of paper and paper products in food processing, export packaging, hygiene, and household items [2]. The research focused on producing paper from the Pulp obtained from banana stem waste, plantain stem waste, and banana fruit stem waste.

2. Preliminaries

2.1. Chemistry of Paper

The basic structure of pulp and paper sheets is a felted mat of cellulose fibers held together by hydrogen bonds. Cellulose is a polysaccharide with 600 to 1,500 repeated sugar units. It is the structural component of the primary cell wall of green plants and many forms of algae. Cellulose is the most common organic compound on Earth. About 33% of all plant matter is cellulose. Cellulose fibers have high tensile strength, will absorb the additives used to modify pulp into paper and board products, and are supple and chemically stable. The purpose of pulping is to separate cellulose fibers from the other components of the fiber source. In the case of wood, these include hemicelluloses (with 15 to 90 repeated sugar units), lignin (highly polymerized and complex, mainly phenyl propane units; they act as the "glue" that cements the fibers together), extractives (fats, waxes, alcohols, phenols, aromatic acids, essential oils, oleoresins, sterols, alkaloids and pigments), and minerals and other inorganic. The relative proportions of these components vary according to the fiber source, as shown in Table 1 [3].

Table 1. Chemical constituents of pulp and paper fiber sources

Woods / Carbohydrates	Softwood	Hardwood	Straw	Bamboo	Cotton
α-cellulose	38–46	38–49	28–42	26–43	80–85
Hemicelluloses	23–31	20–40	23–38	15–26	nd
Lignin	22–34	16–30	12–21	20–32	nd
Extractives	1-5	2-8	1-2	0.2-5	nd
Minerals	0.1-7	0.1-11	3-20	1-10	0.8-2

Sourced from Anya and Teschke [4]

2.2. Wood Pulp

Wood pulp is a dry fibrous material prepared by chemically or mechanically separating the fibers which make up wood. [5] revealed that pulping is the process by which the bonds within the wood structure are mechanically or chemically ruptured. Chemical pulps can be produced by either alkaline sulfate, Kraft, or acidic (sulfite) processes. The highest proportion of pulp is produced by the sulfate method, followed by mechanical (including semi-chemical, thermomechanical, and mechanical) and sulfite methods. Pulping processes differ in the yield and quality of the product, and for chemical methods, in the chemicals used and the proportion that can be recovered for reuse [6].

2.2.1. Mechanical Pulping

[7] revealed that mechanical pulps are produced by grinding wood against a stone or between metal plates, thereby separating the wood into individual fibers. Shearing breaks cellulose fibers and the resulting pulp is weaker than chemically separated pulps. The lignin connecting cellulose to hemicelluloses is not dissolved; it merely softens, allowing the fibers to be ground out of the wood matrix. The main difference between chemical and mechanical pulp is the yield ratio. Mechanical pulp uses 80 to 95% of the wood fiber, while chemical pulp

uses approximately 45 to 55%. The critical characteristic of mechanical pulp is that it is primarily used for producing paper products where quality is not a significant concern (e.g., newsprint). Mechanical pulping is additionally the only option for processing recovered paper for pulp production. Several mechanical pulping techniques exist [8].

Refiner mechanical pulping (RMP): Its key characteristics are the high yield and the fact that fibers are not too short. RMP can use chips as raw material, processed by two grooved discs. The fibers produced with this technique are lighter than usual; thus, the ratio of paper produced per wood use is increased compared to other pulping methods [9].

Chemi-thermomechanical pulping (CTMP): This technique is characterized by using chemicals in the refining process and the increased flexibility and brightness of the fiber produced. The main advantage of this pulp type, while also a significant drawback, is the relatively high energy demand. The main disadvantage of mechanical pulping is that it is an energy-intensive process and is the most effective energy consumer per product quantity compared to other pulping options. Some additional drawbacks are the relatively short fibers of pulp produced, the low ratio of impurities removal, and the paper products' low strength and brightness characteristics [9].

2.2.2. Chemical Pulping

Chemical pulps are produced by chemically dissolving the lignin between the wood fibers, enabling the fibers to separate relatively undamaged. Because most non-fibrous wood components are removed in these processes, yields are usually 40 to 55%. In chemical pulping, chips and chemicals in an aqueous solution are cooked together in a pressure vessel (digester), which can be operated on a batch or continuous basis. In batch cooking, the digester is filled with chips through a top opening, the digestion chemicals are added, and the contents are cooked at elevated temperature and pressure. Once the cooking is complete, the pressure is released, "blowing" the de-lignified pulp out of the digester and into a holding tank. The sequence is then repeated. In continuous digesting, pre-steamed chips are fed into the digester continuously. Chips and chemicals are mixed together in the impregnation zone at the top of the digester and then proceed through the upper, lower, and washing zones before being blown into the blow tank [10].

2.3. Sulphate Pulping

The sulfate or Kraft pulping process produces a stronger, darker pulp than other methods and requires chemical recovery to compete economically. The method evolved from soda pulping (which uses only sodium hydroxide for digestion). It began to gain prominence in the industry from the 1930s to 1950s with the development of chlorine dioxide bleaching and chemical recovery processes. Developing corrosion-proof metals, such as stainless steel, to handle the acidic and alkaline pulp mill environments also played a role [11]. The cooking liquor for the sulfate process is a solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). The NaOH dissolves some of the non-fibrous materials. Others decomposed upon being heated, forming acids as displayed in (2.1). These acids react with the base NaOH to form compounds soluble in water. The NaOH also reacts with the resins in the wood, forming water-soluble soaps. Thus, in one way or another, the non-fibrous materials are dissolved and separated from the cellulose fibers. As sodium hydroxide is consumed, the sodium sulfide reacts with water to produce more sodium hydroxide [12].

$$Na_2S + H_2O \rightarrow NaHS + NaOH \quad (2.1)$$

2.4. Bleaching the Pulp

[13] stated that bleaching is a multi-stage process that refines and brightens raw pulp. The objective is to dissolve (chemical pulps) or modify (mechanical pulps) the brown-colored lignin that was not removed during pulping while maintaining the integrity of the pulp fibers. A mill produces customized pulp by varying the bleaching agents' order, concentration and reaction time. Each bleaching stage is defined by its bleaching agent, pH (acidity), temperature, and duration. After each bleaching stage, the pulp may be washed with caustic to remove spent bleaching chemicals and dissolved lignin before progressing to the next stage. After the last stage, the pulp is pumped through screens and cleaners to remove contaminants such as dirt or plastic. It is then concentrated and conveyed to storage [14].

2.5. Stock Preparation and Paper Making

There are two types of stock preparation systems used. In one, the stock is treated first in a beater and then in a Jordan conical refiner. Continuous stock preparation, consisting of disk-type refining and conical refining, is employed in high-production mills. What happens to the cellulose fibers during stock preparation has an essential effect on the characteristics of paper produced. The beaters and the refiners roughen the individual fibers and fray their ends; this condition is desirable. When such fibers are used to create paper, the fibers interlock to make a strong paper. Secondly, the beating also breaks down the water-resistant outer walls of the fibers, thereby exposing the inner fibrils. This effect is called fibrillation. Once it takes place, the fibers take on water and swell. This effect is called hydration. The longer the refining process continues, the more the fibers are hydrated and the stronger the resulting paper becomes [10].

2.6. Fillers

Materials called fillers are added to the pulp during stock preparation. Printing papers may contain 15 -25% of fillers by weight. Other papers designed for strength and rugged use, such as bond and ledger, may have 2-6% fillers. The three materials most commonly used for fillers are clay, a naturally occurring Alumino-Silicate; Titanium Dioxide, TiO_2; and Calcium Carbonate, $CaCO_3$. The principal reason for adding fillers is to increase opacity, brightness, and smoothness and to reduce ink-strike through [10].

2.7. Drying of Pulp and Paper

Drying involves using air or heat to remove water from the paper sheet. In the earliest days of paper-making, this was done by hanging the paper sheets like laundry. In more modern times, various forms of heated drying mechanisms are used. On the paper machine, the most common is the steam-heated can dryer. These dryers can heat to temperatures above 93°C and are used in long sequences of more than 40 cans. The heat produced by these can quickly dry the paper to less than 6% moisture [15].

2.8. Finishing

The paper may undergo sizing to alter its physical properties for various applications. The paper, at this point, is uncoated. Coated paper has a thin layer of material such as calcium carbonate or China clay applied to one or both sides to create a surface more suitable for high-resolution halftone screens. Coated or uncoated papers may have their surfaces polished by calendaring [16]. This research aimed to produce paper from the pulp obtained from banana, plantain, and fruit stem wastes and to evaluate the mechanical properties of the paper produced.

3. Materials and Methods

Papermaking begins with the collection of raw materials. It continues through preparing the raw material, making pulp, screening out the sheets of paper, drying the paper, and finally finishing it.

3.1. Chemicals Used

Sodium Hydroxide (NaOH), Hydrogen peroxide (H_2O_2)

Calcium Carbonate ($CaCO_3$), Binder (Top Bond with compositions of polyvinyl formal, calcium carbonate and water)

3.2. Raw Materials Used

Banana stem waste

Plantain stem waste and

Banana fruit stem waste

3.3. Pulping Process

The raw materials, which are *Musa Species* (banana stem waste, plantain stem waste, banana fruit stem waste, banana peel, and plantain peel), were obtained from Yaba College of Technology staff quarters, where they were locally grown. The freshly-cut sample parts were cut into an average of 2.0 cm chips, pounded with mortar and pestle for about 10 minutes, and then squeezed to remove some juice.

3.3.1. Chemical Method

The freshly cut and pounded (685.76g) samples chips of average length of 2.0 cm were charged into the digester (1000 ml Beaker) with the required amount of chemical solution of liquor to goods ratio (LR) of 5:1. Different percentages (5%, 10% and 15%) of Sodium Hydroxide concentration were used as cooking liquor. The pulping consisted of two stages. In the first stage, the crushed sample stems were heated to the impregnating temperature 60^0C and maintained at this temperature for 1 hour (60 minutes) so that the cooking liquor could penetrate the sample before it was heated to a boiling point 100^0C and maintained at this temperature for 3 hours (180 minutes) for the digestion to be completed. At the end of the cooking (digestion), the pulp, which at this stage was dark brown and called black liquor, was washed several times with water. The resulting pulp was filtered, pressed, and passed (to neutralize any residual alkaline) once with hot water and several times with cold water. The pulp collected was defibrated and kept for further processing (bleaching or paper making).

3.3.2. Chemical/ Mechanical Method

A small sample quantity was collected and weighed in the chemical-mechanical method. The weighed sample was cut and chopped into about 2 mm and then pounded with mortar and pestle until it became a fine slurry (pulp). The sample was weighed in a beaker containing 5%, 10%, and 15% sodium hydroxide solution. The content was then boiled for an hour (60 minutes) and stirred occasionally. After 1 hour of boiling, the sample was removed from the alkaline solution and rinsed with water to remove the black liquor of the sodium lignite and the unused alkali. The washed sample was then pounded with mortar and pestle until it became slurry (pulp). The pounded sample (pulp) was then washed, filtered, defibrated, and kept for further processing (bleaching or paper making). The established standard used for this work was the TAPPI standard.

3.3.3. Bleaching Stage

The slurry (pulp) was bleached with hydrogen peroxide by boiling for 30 minutes to increase the brightness of the pulp. After this, the bleached pulp was washed in running water, and the pulp water slurry was adjusted to contain 5% fiber and 95% water. It was then left as stock for paper making.

3.4. Production of Handmade Papers

Procedure

Banana stem waste was cut and weighed (685.76g). The sample was cut into 10-20 mm chips, pounded with mortar and pestle for about 10 minutes, then squeezed to remove some juice from it and reweighed. The banana chips were charged into the digester (1 Litre Beaker) with a 5% concentration of Sodium Hydroxide at liquor to goods ratio (LR) of 5:1. The pulping consisted of two stages. In the first stage, the crushed sample stems were heated to the impregnating temperature 60^0C and maintained at this temperature for 1 hour (60 minutes) before it was heated to a boiling point 100^0C and kept at this temperature for 3 hours (180 minutes). At the end of the cooking (digestion), the pulp, which at this stage was dark brown, is called black liquor. The resulting pulp was filtered, pressed, washed several times in running water, and filtered. The sample was then bleached by boiling with hydrogen peroxide (15% w/v mass of pulp) for 30 minutes, filtered, and then the pH was taken.

5% of binder " Top Bond" and 10% $CaCO_3$ were added to the pulp. The mixture was appropriately attired with a stirrer to defibrate (separate) the fibers with other chemicals of different proportions, as shown in Table 2. The mixture (pulp) was then transferred to the paper-making mold screen. The paper produced was dried in the open air for 2-3 hours, hot pressed, and then calendered to smoothen the surface.

The pulp yield in stem and pulp yield in residue indicates the mass (weight) amount of material recovered after a specific process compared to the starting amount of material before the process. The recovery from pulping wood is commonly expressed as the percentage, by oven-dry weight, of pulp obtained from the original wood weight.

Table 2. The mixing proportion of Stems and Chemicals

Chemical/Parameters	NaOH (%)	H_2O_2 (%w/v)	$CaCO_3$ (%w/v)
Banana Stem	5 10 15	15	10
Plantain Stem	5 10 15	15	10
Banana Fruit Stem	5	15	10

3.5. Calculations Involved

Digestion Stage:

Weight of the Banana stem after chopping = 685.76g

Weight of Banana stem after pounding & squeezing = 208.38g

Liquor to goods ratio (LR) = 5:1

$\text{Total volume of bath} = \text{weight of goods} \times \text{ liquor ratio}$

= 208.38 x 5 = 1042 ml

Mass of sodium hydroxide (NaOH) = 5% × Weight of Sample

= $\frac{5}{100} x$ 208.38 = 10.42g

The volume of water for digestion = Total volume of bath =1042 ml

Impregnating Temperature = 60 ^{0}C

Impregnating Duration = 60 minutes

Cooking Temperature = 100 ^{0}C

Cooking Duration = 180 minutes

Mass of pulp obtained after digestion = 76.47g

pH of pulp = 11.05

Bleaching stage:

$\text{Volume of Hydrogen Peroxide } (H_2O_2) = 15\% \frac{w}{v} \text{ of weight of pulp} \times \text{ liquor ratio}$

=15/100 × 76.47 × 5 = 57.35 ml

$\text{Total Bath} = \text{Mass of pulp} \times \text{ L. R (goods to liquor ratio)}$

= 76.47 × 5 = 382 ml

$\text{Volume of Water for bleaching} = \text{Total bath} - \text{Volume of Hydrogen Peroxide}$

= 382ml – 57.35 ml = 324.65 ml

Duration of bleaching = 30 minutes

Mass of pulp obtained after bleaching = 68.80g

Paper Making Stage:

Mass of pulp for paper making = 9.16g

Mass of Calcium Carbonate (10%w/w $CaCO_3$) added = 10% of mass of pulp

= 10/100 × 9.16 = 0.916g

Mass of binder added = 5 % mass of pulp

= 5/100 × 9.16 = 0.458g

$\text{Volume of water added to bleach sample to form paper slurry} = 5 \times \text{Mass of pulp}$

= 5 × 9.16 = 46 ml

Condition of Drying = Normal Atmospheric Condition

Duration of Drying = 2 hours

3.6. Mechanical Properties

Mechanical tests such as tearing resistance, tensile strength, and elongation were carried out on the produced paper using an Instron Universal Testing Machine with Model Number 3369 and its tenacity. The test procedure started in load control until the sample was loaded with a force of 0.25kN. Then, the procedure was carried out entirely under displacement control through the vertical LVDT at a rate of 3μm/s.

4. Results and Discussions

4.1. The Production of Pulp and Paper

Figures 1-3 show the pulp and paper produced by different mixing proportions of raw materials. These were made from chemical/mechanical pulp of freshly harvested banana, plantain, and banana fruit stems pulped with 5, 10, and 15% of sodium hydroxide (NaOH), 10% of calcium carbonate (CaC03), 5% of binder, 15% of Hydrogen peroxide (H_2O_2), the required amount of chemical solution of liquor to goods ratio (LR) of 5:1 while the mass of pulp was 9.16g. Generally, the samples pulped with 5% sodium hydroxide (NaOH) showed lighter and smoother surfaces, while samples pulped with 15% NaOH were darker with rough surfaces. The brightness of the papers produced from plantain, banana, and banana fruit stems decreased steadily in that order [6].

(a) (b) (c)

Figure 1. Banana stems; (a) 5% of NaOH, (b) 10% of NaOH, and (c) 15% of NaOH

(a) (b) (c)

Figure 2. Plantain stems; (a) 5% of NaOH, (b) 10% of NaOH, and (c) 15% of NaOH

(a) (b) (c)

Figure 3. Banana fruit stems; (a) 5% of NaOH, (b) 10% of NaOH, and (c) 15% of NaOH

4.2. *Musa Species* Pulped with three different percentages of Caustic Soda (NaOH)

The delignification of the chopped raw materials (banana, plantain, and banana fruit stem wastes) was varied according to independent parameters. The independent variables obtained after the operation by mixing 5% of Sodium Hydroxide (NaOH) are displayed in Table 3, while 10% and 15% (NaOH) mixture proportions are shown in Tables 4 and 5, respectively. Each factor was studied with pulp yield, and different types of handmade paper were produced from the pulp. In Table 3, the quantity of pulp (yield) in residue for banana, plantain, and banana fruit stems was 36.70, 35.50, and 38.5%, respectively, while the quantity of pulp (yield) in the stem for banana, plantain, and banana fruit stems were 11.15, 11.22, and 14.19% in that order. Moreover, in Table 4, the quantity of pulp (yield) in residue for banana, plantain, and banana fruit stems was 35.80, 34.12, and 32.25, respectively, while the quantity of pulp (yield) in the stem were 10.86, 10.51, and 11.90% in that order. Table 5 displayed that the quantity of pulp (yield) in residue for banana, plantain, and banana fruit stems was 33.80, 33.11, and 31.20%, while the quantity of pulp (yield) in the stem was 10.32, 33.11, and 31.20 % in the same order [6].

Table 3. *Musa Species* Pulped with 5% charge Caustic Soda (NaOH)

Particulars	**Banana Stem**	**Plantain Stem**	**Banana Fruit stem**
Mass of Stem before Pounding (g)	685.76	708.96	427.09
Mass of Stem after pounding (g)	208.38	224.06	157.40
Quantity of residue in Stem for pulping (%)	30.39	31.60	36.8
Volume of Fluid obtained from Stem (ml)	472	481	264
Mass of Fluid obtained from Stem (g)	474.38	482.36	266.81
Quantity of Fluid in Stem (%)	69.20	68.04	62.47
Mass of Pulp obtained (g)	76.47	79.54	60.60
Mass Rejected (Undigested residue)(g)	4.79	5.26	3.81
Quantity of pulp (yield) in residue (%)	36.70	35.50	38.5
Quantity of pulp (yield) in stem (%)	11.15	11.22	14.19
Quantity rejected (Undigested) in residue (%)	2.30	2.35	2.42
Quantity rejected (Undigested) in Stem (%)	0.70	0.70	0.89
pH of Black Liquor	11.05	11.10	11.13

Table 4. *Musa Species* Pulped with 10% charge Caustic Soda (NaOH)

Particulars	Banana Stem	Plantain Stem	Banana Fruit stem
Mass of Stem before Pounding (g)	650.50	650.50	650.50
Mass of Stem after pounding (g)	197.25	200.35	240.00
Quantity of residue in Stem for pulping (%)	30.32	30.80	46.89
Volume of Fluid obtained from Stem (ml)	445	448	407
Mass of Fluid obtained from Stem (g)	449.15	449.40	409.20
Quantity of Fluid in Stem (%)	69.05	69.09	62.91
Mass of Pulp obtained (g)	70.62	68.36	77.40
Mass Rejected (Undigested residue)(g)	4.14	4.31	3.57
Quantity of pulp (yield) in residue (%)	35.80	34.12	32.25
Quantity of pulp (yield) in stem (%)	10.86	10.51	11.90
Quantity rejected (Undigested) in residue (%)	2.10	2.25	2.38
Quantity rejected (Undigested) in Stem (%)	0.64	0.66	0.88
pH of Black Liquor	12.90	12.92	12.95

Table 5. *Musa Species* Pulped with15% charge Caustic Soda (NaOH)

Particulars	Banana Stem	Plantain Stem	Banana Fruit Stem
Mass of Stem before Pounding (g)	650.50	650.50	650.50
Mass of Stem after pounding (g)	198.50	200.35	240.00
Quantity of residue in Stem for pulping (%)	30.51	30.80	36.92
Volume of Fluid obtained from Stem (ml)	447	448	406
Mass of Fluid obtained from Stem (g)	450.47	448.32	409.00
Quantity of Fluid in Stem (%)	69.25	68.92	62.82
Mass of Pulp obtained (g)	67.10	66.33	76.87
Mass Rejected (Undigested residue)(g)	3.57	4.12	5.48
Quantity of pulp (yield) in residue (%)	33.80	33.11	31.2
Quantity of pulp (yield) in stem (%)	10.32	33.11	31.2
Quantity rejected (Undigested) in residue (%)	1.80	2.06	2.28
Quantity rejected (Undigested) in Stem (%)	0.55	0.63	0.84
pH of Black Liquor	13.12	13.17	13.48

4.3. The Mechanical Properties of Produced Pulp and Paper

The mechanical test results from handmade paper produced from pulp from raw samples (banana, plantain, and banana fruit stem waste) pulped with 5, 10, and 15% NaOH are presented in Table 6. Three mechanical properties were examined using the procedure stipulated by the Technical Association of Pulp and Paper Industry (TAPPI), including tear resistance, tensile strength, and elongation tests. The results were then compared with test results from already-made commercial papers. It was discovered that banana fruit stem waste pulped with 5% NaOH gave the highest tearing resistance, tensile strength, and elongation test (1.90 mN, 24.77 N/m^2, and 5.49 mm) while banana stem waste pulped with 15% NaOH gave the lowest tearing resistance (0.5mN). It was noticed that the mechanical properties of the handmade paper decreased as the concentration of the NaOH increased [14].

The results of the tearing resistance, tensile strength and elongation test obtained using 5% NaOH for banana stem, plantain stem and banana fruit stems were 0.84 mN, 17.82 N/m^2, and 4.90 mm; 1.35 mN, 14.95 N/m, and 2.17 mm; and 1.90 mN, 24.77 N/m^2, and 5.49 mm; while the pulp yields were 36.7, 35.5, and 38.5%, respectively. The results obtained using 10 % NaOH for banana stem, plantain stem, and banana fruit stems were 0.80 mN, 17.30 N/m^2, and 4.85 mm; 1.25 mN, 14.73 N/m^2, and 2.0 mm; and 1.85 mN, 23.60 N/m^2, and 5.35 mm; while the pulp yields were 35.80%, 34.12%, and 32.25 % in that order. The results obtained using 15% NaOH for the banana stem, plantain stems, and banana fruit stems were 0.70 mN, 6.89 N/m^2, and 1.86 mm; 0.79 mN, 8.70 N/m^2, 2.90 mm; and 1.5 mN, 12.62 N/m2, and 3.03 mm while the pulp yields were 33.8, 33.11, and 31.03%, respectively. This showed that banana fruit stems pulped at 5% sodium hydroxide gave better results than banana or plantain stems. The study showed that the pulp is suitable for producing corrugated boards, fiberboards, and cartons [6].

The evaluation of the mechanical test on the handmade paper shows that the banana fruit stem pulped with 5% NaOH gave the highest tearing resistance, tensile strength, and elongation test. The banana stem pulped with 15% NaOH gave the lowest tearing resistance, while the Dried Plantain stem pulped with 10% and 15% NaOH gave the most insufficient tensile strength and elongation test. Comparing the pulp yield (which is a relative return of the pulp compared to the raw chips) obtained from all the raw materials (banana stem, plantain stem, and banana fruit stem) pulped with 5%, 10%, and 15% NaOH, it could be seen that banana fruit stem waste pulped with 5% NaOH gave the highest pulp yield (38.5%). The same banana fruit stem waste gave the lowest pulp yield (30.20%) when pulped with 15% NaOH. It was noticed that the pulp yield decreased as the percentages of the NaOH used increased [5].

The result of the mechanical test carried out on the paper produced from *Musa Species*, when compared with that obtained from commercial papers (Universal Extra white 80 grams bond, Newsprint, and File cover), shows that paper produced from banana fruit stem pulped with 5% NaOH gave a higher tearing resistance and elongation test. As a result, paper made from this *Musa Species* could be suitable for wrapping, packaging, and offset printing purposes [6].

Table 6. Mechanical properties of produced paper

Samples	Pulped up with Chemical	Elongation (mm)	Tearing Resistance (mN)	Tensile strength (N/m^2)
Banana stem	5% (NaOH), 10% ($CaCO_3$), 5% Binder,15% (H_2O_2)	0.84	17.82	4.90
Plantain stem		1.35	14.95	2.17
Banana fruit stem		1.90	24.77	5.49
Banana stem	10% (NaOH), 10%($CaCO_3$), 5%, Binder,15% (H_2O_2)	0.80	17.30	4.85
Plantain stem		1.25	14.73	2.00
Banana fruit stem		1.85	23.60	5.35
Banana stem	15%(NaOH), 15% ($CaCO_3$), 5% Binder,15% (H_2O_2)	0.50	8.90	2.21
Plantain stem		0.59	4.14	1.90
Banana fruit stem		0.67	13.84	3.89

The graphical representation of the pulp yield of samples is shown in Figure 2. Comparing the pulp yield (which is a relative return of the pulp compared to the raw chips) obtained from all the raw materials (banana stem, plantain stem, and banana fruit stem) pulped with 5, 10 and 15% of NaOH, it could be seen that banana fruit stem waste pulped with 5% NaOH gave the highest pulp yield (38.5%). The same banana fruit stem waste gave the lowest pulp yield (30.20%) when pulped with 15% NaOH. It could also be observed that the pulp yield decreases as the percentages of the NaOH used increase [14].

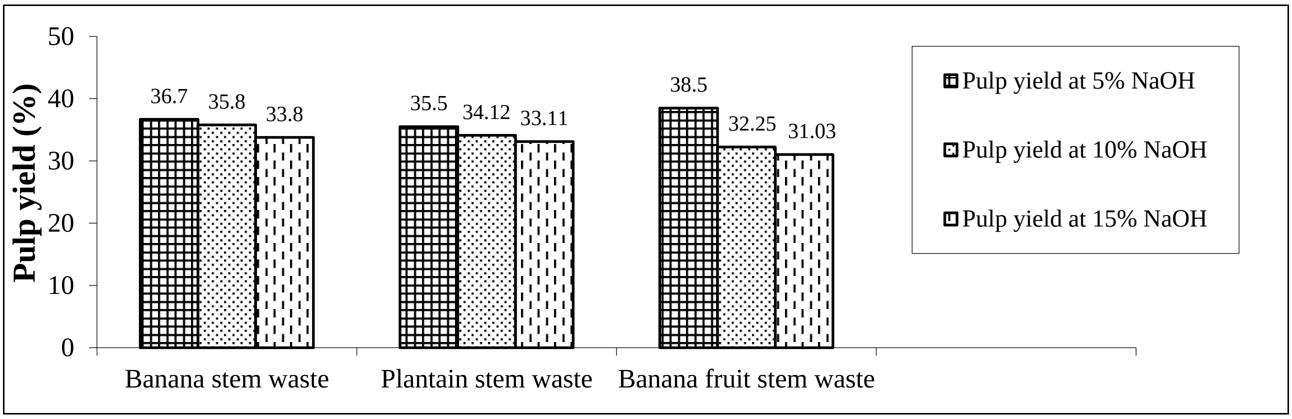

Figure 2. Graphical representation of pulp yield of banana, plantain, and banana fruit stem waste pulped with 5%, 10%, and 15% NaOH

5. Conclusion

The percentage pulp yield from banana stem waste, plantain stem waste, and banana fruit stem waste for pulp yield at 5 %, 10 %, and 15 % NaOH were 36.70, 35.80, and 33.80%; 35.50, 34.12, and 33.11%; and 38.50, 32.25, and 31.03%, respectively which are high enough for industrial pulp and paper making. This study has shown that pulp could be produced from *Musa species* and that the pulp is suitable for the production of corrugated boards, fiberboards, and cartons. It could also be ideal for printing and writing papers when mixed with long fiber pulp.

Author Contributions

All the authors equally contributed to this work. They all read and approved the final version of the paper.

Conflict of Interest

All the authors declare no conflict of interest.

References

[1] J. U. Odo, E. L. C. Nnabuife, A. B. Ukaegbu, *Production of paper from rice straw*, Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, The Nigerian Materials Congress, Awka Anambra State Nigeria, 2004, pp. 39–41.

[2] M. A. Omotoso, B. O. Ogunsile, *Fiber and chemical properties of some Nigerian grown Musa Species for pulp production*, Asian Journal of Materials Science, 2 (3) (2010) 160–167.

[3] O. E. Onuorah, *Preliminary investigation of the potential of six Nigerian grown hardwood species as sources of fiber for the pulp and paper industry*, Journal of Agricultural Technology (9) (2001) 17–24.

[4] K. Anya, K. Teschke. *Fiber Sources for pulp and paper. Encyclopaedia of Occupation and Safety. International Labour Organization Geneva* (2011), http://www.ilo.org/oshenc/part-x/paper-and-pulpindustry, Accessed 24 Apr 2013.

[5] H. Ibrahim, I. M. Bugaje, I. A Mohammed, *Utilization of bagasse as raw material for the production of pulp and paper in Nigeria*, International Journal of Engineering and Mathematical Intelligence, 2 (1-3) (2011) 26–33.

[6] B. U. Anyanwu, O. S. Olokode, P. O. Aiyedun, F. T. Owoeye, Y. T. Oyeleke. *Potentials of ukwa tree (sterculia setigera) as a source of raw material for pulp and paper making*, The Pacific Journal of Science and Technology 13 (1) (2012) 145–159.

[7] N. K. Agarwal, N. K. Khanna, S. K. Chechi, K. L. Patel, S. L. Pawar, R. G. Patil, *Evaluation of banana pseudostem based on fiber as pulp and paper making raw material*, Soil and Water Management Research Unit, Navsari Agricultural University Navsari IPPTA J. 23 (3) (2011) 119–125.

[8] J. Christopher, Handbook of Pulp and Paper Making, Academic Press, San Diego, 2007.

[9] E. Sjostrom, Wood Chemistry: Fundamental and Application, Academic Press, San Diego, 2003, pp. 12–62.

[10] M. Hartsuch, J. Paul, *Chemistry for the graphic arts*, Pennsylvania Graphic Arts Technical Foundation, (2003) 196–214.

[11] P. Froass, R. Arthur, J. Jiang, *Chemical structure of residual lignin from kraft pulp*. Journal of Wood Chemistry and Technology 16 (4) (2000) 347–365.

[12] H. Jeffery, S. Smith, B. Jason. Second critical solids black liquor scalling pulp and paper. Engineering School of Chemical Engineering Georgia Institute of Technology Georgi, 2007, pp. 34–60.

[13] G. Astrakianakis, J. Anderson. Bleaching. *Encyclopaedia of Occupation and Safety; International Labour Organization Geneva* (2011), http://www.ilo.org/oshenc/part-x/paper-and-pulpindustry, Accessed 24 Apr 2013.

[14] P. P. Singh. The Bleaching of Pulp, 3rd Edition, TAPPI Press, Atlanta, 2007, pp. 45–65.

[15] G. Chuck. Paper and Pulp Dictionary CPPN Electronics 23 Mary Vale Drive, Webster NewYork, 2011.

[16] M. A. Hubbe, Properties of Paper Department Wood and Paper Science. North Carolina State University, 2013.