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Aniekan Akpakpan
AKWA IBOM STATE UNIVERSITY , NIGERIA

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Article

Pulp and Paper from Agricultural Wastes: Plantain Pseudostem Wastes and Screw Pine Leaves

U.D. Akpabio *, A.E. Akpakpan

Department of Chemistry, University of Uyo, Uyo, Akwa Ibom State, Nigeria

* Author to whom correspondence should be addressed; E-Mail: ukanadakpabio@yahoo.com.

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Abstract: Two agricultural wastes, the aerial stem of *Musa paradisiaca* (plantain pseudostem) and the leaves of *Pandanus candelabrum* (screw pine) were characterized and pulped by soda and Kraft processes. The pulps were bleached with hydrogen peroxide and handsheet was formed with the British sheet former. The results showed that the plantain stem fibre has a length of 2.14 ± 0.18 mm, while that of the screw pine leaf fibre was 1.98 ± 0.12 mm, these are longer than that of *Gmelina arborea*, hardwood fibre (0.95 ± 0.05 mm), commonly used for paper making. The pulps from these agricultural wastes formed good and strong papers which can be converted into different forms for various applications.

Keywords: agricultural waste; plantain pseudostem; screw pine; pulp; paper.

1. Introduction

When the art of paper making was introduced in A.D. 105 by the Chinese [1], Ts'ai Lun, old fishing net made from cotton, rags, leaves and barks of trees were used as the fibrous raw materials for paper making [2,3]. Further investigations proved that other non-wood plant sources, such as straws from grains, bagasse from sugar cane, cotton linters, esparto grass and sisal leaves have fibres suitable for paper making [3]. Later on, as the technology improved wood was pulped successfully and today it is the main source of paper pulp in the world over. There are two types of wood pulp, the long fibre pulp from softwood trees and the short fibre pulp from hardwood trees. The softwood trees grow mostly in the temperate zones of the world whereas the hardwood trees dominate the tropical regions as in Nigeria. Therefore in Nigeria long fibre pulps are usually imported at exorbitant cost to blend with the locally manufactured short fibres in other to make good cultural papers e.g. printing, writing paper and newsprint etc.

Although some exotic wood such as *Pandanus candelabrum* is thriving well in Nigeria today they have not been planted in a large plantation for commercial exploitation for pulp and paper making [4]. Since long fibres are very crucial in making strong papers, it therefore becomes necessary to search for alternative sources of long fibre pulp, probably from cheap sources such as the agricultural wastes namely the aerial stem of *Musa paradisiaca* (plantain pseudostem) and the leaves of *Pindanus candelabrum.* Thousands of tones of these agricultural wastes are produced annually in Nigeria and allowed to rot away.

The paper pulp raw materials are usually of plant origin (the wood and the non-wood plants) and the properties of pulpwood plants have been studied extensively [1, 5], their major components are the cellulose and the hemicelluloses, which are carbohydrate in origin and the lignin; the non-carbohydrate substance which binds the cellullosic fibres together to form the coherent solid woody structure in plants. Others are the extractive components usually soluble in organic solvents and a small amount of inorganic component left as ash after burning. To produce pulp (the fibrous component) from plants, the lignin must be removed to free the fibres and the process of doing this is called ‘pulping’ [1]. It may be carried out mechanically, chemically or by the combination of both methods in the semi-chemical process. The chemical agents which are used in pulping should have mild action on the cellulosic fibres. The common pulping processes [5] are: (1) The soda process, using soda as the active chemical. (2) The Kraft/sulphate process, using a mixture of caustic soda and sodium sulphide. (3) The sulphite process, using either the sulphite or bisulphate ion as the delignification agent. (4) The organo pulping, using organic solvent as the pulping chemical. To completely separate the cellulosic fibres from other colouring components in the vegetable materials, the resultant pulp is bleached with suitable bleaching chemicals [1].

Paper making process consists of the following operation [6]: (i) Stock preparation, in which the fibres are disintegrated, beaten to the required process, cleaned and mixed with the chemical additives and diluted to the required consistency. (ii) Sheet formation, in which the stock prepared as above is deposited on a wire mesh to form a wet web. (iii) The pressing, which consolidates the fibres in the wet web and removes most of the excess water. (iv) Drying section, here the water in the wet sheet is gradually removed by drying on steam heated cylinders to the air moisture content. (v) Finishing, here the paper is calendared to smoothen the surfaces and cut into the required commercial size. The paper structure itself consists of interlocking cellulosic fibres held together by H-bonds while the additives are retained by sorptive forces or are chemically bonded to the cellulosic fibres.

Plantain (*Musa paradisiaca*) is a member of *Musaceac* family. The plant is one of the earliest cultivated crops, originating from the South East Asia [7]. Today they are found in many countries that have the tropical rainforest types of climate; they are found in West Africa, India, Jamaica, the Cameroon and some other African countries. The fruits are eaten when unripe and in ripe form and are very important in the international trade. In Nigeria, plantain which are grown together with banana (*Musa sapientum*) are found mostly in the Southern States namely; Edo, Oyo, Ondo, Cross River, Akwa Ibom, Abia, Imo, Rivers, Bayelsa and Delta States, where the fruits form the stable food for the people as well as an important article of trade with the northern states and other West African Countries. The plant grows for about six to seven months to reach maturity for fruiting, after which the aerial stem is felled, the fruit cut off and the stem is allowed to rot away. This is because the plant is propagated by the sucker, an underground stem which produces new shoots. Both the plantain and the banana pseudostems are fleshy and soft, they are actually the lower parts of the leaves folded together and structures with some intercellular openings are found within each fold; there is a large fleshy central core at the centre of the folds. The folds can easily be separated by hand. The core transports the nutrients from the roots to the upper part of the plant and finally terminates in fruit formation. The green pseudostem contains much water that fills up the intercellular openings. The pseudostem except the core is made up of cellulosic filaments which are bonded together into cellulosic films by lignin and hemicelluloses [8]. Through pulping process the fibres that make up the filaments are separated. Locally the filaments can be made into strands for making ropes and textile materials such as clothing. Characterization of plantain and banana pseodostem has been reported in our previous work [8].

The screw pine (*Pandanus candelabrum*) come from the family *Pandanales*, the genus pandanus, with 600 species, produces from the trunk and branches stilt-like aerial prop roots that support the plant and gives them a distinctive appearance [9]. The leaves are usually numerous, long, narrow parallel-veined, palm-like leaves slowly growing season margins; midribs are produced in tufts at the branch tips in three or four close twisted ranks around the stem, forming the screw-like helices of leaves that give the common name “screw pine” to these plants. The plant grows along sea coast and in marshy places and forests of the tropical and subtropical regions especially in Asia and Africa. Only the genus, *Pandanus* [7] is representative in Nigeria. The stem is fibrous with open structure and takes about 8-17 years to mature. Pulping of the stem and the leaves separates the cellulose fibres from the rest of the chemical components present in the plant.

In this study the aerial stem (pseudostem) waste from a matured plantain plant from which ripe fruits have been cut, and the leaves of the screw pines were characterized and then pulped with caustic soda solution and a mixture of caustic soda and sodium sulphide solution (kraft process); handsheets were made, the properties of the handsheets were determined and compared with the properties of paper made from Melina (*Gmelina arborea*) and *Pinus caribeae* pulps which are short fibres and long fibres, respectively [10].

2. Materials and Methods

2.1. Materials

The leaves of the screw pine were cut from the screw pine trees in Ekpri Nsukara while the plantain stem wastes were obtained from a garden in the Housing Estate, Ewet, all in Uyo Local Government Area of Akwa Ibom State, Nigeria. The chemical reagents used in the experiment were bought from the local stores in Uyo.

2.2. Characterization of the Raw Materials

2.2.1. The moisture content and ash content

The moisture content and the ash content of the samples were determined according to the TAPPI standard methods T 258 os 76 and T 211 os 80, respectively [11].

2.2.2. Determination of fibre dimension

The samples were defibered with 1:1 H_2O_2/CH_3COOH solution mixture and heated at 60 ^oC in an oven for 24 h. The fibre dimensions of the resultant beached fibres were determined microscopically by the TAPPI Standard [11] T 233 os 75.

2.2.3. Solubility in 1% NaOH

A dry sample of 2.0 g ground to powder was taken in a 250 cm^3 conical flask and 100 cm^3 of 1% NaOH solution was added. The mixture was placed in water bath maintained at 105 ^oC for 1 h after which the solution was filtered; the residue was washed, dried and reweighed. The solubility was then calculated in percentage based on over oven dried sample (T 212 os 76) [11].

2.2.4. Solubility in 2:1 benzene-ethanol mixture

The powder sample of 3.0 g was wrapped properly in a clean filter paper and inserted in a Soxhlet extractor. A solvent mixture of benzene and ethanol in the ratio of 2:1 was added into the flask. The extraction was carried out for 6 h and the solvent was recovered by distillation. The extract was dried in air to remove all the solvent and then dried in the oven and cool in the dessicator. The weight of the extract was determined and expressed in percentage of the oven dry sample (TAPPI, 204 os 74) [11].

2.2.5. Acid insoluble lignin

A 2.0 g of the extractive free sample in powder form was mixed with 15 mL of 72% H_2SO_4 and the beaker was placed in a water bath and kept at 2 ^oC for 10 min, with constant stirring. The mixture was transferred to a 500 mL beaker and rinsed with water until the solution reached 3% acid content.

The solution was boiled for 4 h maintaining constant volume by frequent addition of hot water.

The lignin settled down and was filtered using a filter paper in sintered filter funnel. It was then dried at 100 ^{o}C and weighed. It was reported in percentage of oven dry extractive frees sample (T 222 os 06) [11].

2.3. Pulping of the Samples

The plantain pseudostem waste was pulped by the soda process using 10% NaOH solution. The leaves of screw pine were pulped by the kraft process using pulping liquor containing 45 g of NaOH and 60 g of Na_2S per litre of water having 16% sulphidity. In each case a laboratory digester was used and the cooking was done at 100 ^{o}C and one atmospheric pressure for two hours. After pulping, the pulp was washed with tap water to pH 7, mild beating defibered the sample completely.

Further beating in a mortar, washing and bleaching with alkaline hydrogen peroxide solution and washing produced white pulp. The yield, the moisture content, and their paper quality were then determined in accordance with TAPPI standard methods [11].

2.4. Paper Making

Standard waterleaf handsheets of about 1.2 g were made from the pulp slurry at 1% consistency according to the British standard method [12]. Handsheets were made from the individual pulp slurry and also from blended pulps using British sheet former. The characteristics of the resultant sheets were determined and are shown in Tables 2 and 3.

3. Results and Discussion

3.1. Physical and Chemical Characteristics

Table 1 present some physical and chemical characteristics of the plantain pseudostem waste and the screw pine leaves. The plantain stem waste has an open structure and it readily absorbs water such that its moisture content is very high when green. Therefore, it becomes necessary to press out the excess water from plantain stem and to dry it in air before transporting it to the mill; the leaves of the screw pine should also be dried in air before pulping.

The stem and the leaves consist mostly of cellulose arranged in long flexible smooth filaments made up of fibres bonded longitudinally. The fibres have thin cell walls and wide lumen; both of them are of medium fibre length range, the screw pine leaf fibres are thinner than those of the plantain stem: this is reflected in their L/W ratio. Some components in the plantain stem waste and the screw pine leaves dissolved readily in 1% NaOH solution, therefore any pulping by alkaline process must be highly controlled in terms of temperature, pressure and time. Organic solubles were greater in screw pine leaves because it contains chlorophyll which assists in carbohydrate synthesis by the plant leaves. Their lignin contents are lower than those present in the wood plants. The ash content is higher in the plantain stem waste than in the screw pine leaves because the stem retains all the minerals absorbed by the roots. Generally these properties are within the range for non wood materials commonly used in making paper pulps [1].

Table 1. Some characteristics of *Musa paradisiaca* (plantain) and *Pandanus candelabrum* (screw pine) leaves

Characteristics	Plantains tem waste	Screw pine leaves
Air dried sample (%)	12.2 ± 0.05	15.7 ± 0.05
Fresh sample (%)	90.0 ± 0.05	80.0 ± 0.05
Ash content (%)	4.2 ± 0.05	1.4 ± 0.05
Acid insoluble lignin (%)	7.0 ± 0.02	18.0 ± 0.15
Solubility in 1% NaOH (%)	30.0 ± 0.52	21.5 ± 0.35
Organic soluble (2:1 benzene/ ethanol) (%)	2.6 ± 0.2	16.3 ± 0.02
Fibre length, L (mm)	2.14 ± 0.18	1.98 ± 0.02
Fibre with, W(mm)	0.018 ± 0.001	0.012 ± 0.001
L/W	118.8	165.0
Pulp yield %	35.0 ± 0.94	64.4 ± 023

Notes: *Gmelina arborea* has a fibre length of 0.95 ± 0.05 mm.

3.2. Handsheet Characteristics

Handsheets made from the pulps had good formation, and each had a grammage of about 66 gsm (Table 2). The strength properties (tear and tensile) were also high, comparing well with the handsheet formed from traditional long fibre pulp (*Pinus caribeae*). Paper made with only hardwood (*Gemlina arborea*) pulp had strength properties inferior to those made from plantain pseudostem waste, screw pine leaves and *Pinus caribea* hence this is the reason that melina pulp (*Gemlina arborea*) are blended with other pulps in order to made good and strong cultural papers. Paper qualities are also affected by the mechanical treatment of the pulp [13], and the pulping processes [14, 15].

Table 2. Handsheet characteristics: paper from plantain pseudostem, screw pine leaves, melina wood and pinus wood pulps

Characteristics	***Musa paradisiaca* (plantain pseudostem)**	***Pandanus candelabrum* (screw pine leaves)**	***Gmelina arborea* wood**	***Pinus caribeae* wood**
Grammage (air dried) (gsm)	66.1	66.3	66.2	66.5
Tear index (mNm^2/g)	5.8	5.7	1.0	5.3
Tensile index (Nm/g)	51.6	78.5	34.2	98.0
Stretch (%)	2.2	2.2	0.48	2.2
Sheet M. C (%)	10.8	10.8	10.6	10.2

Table 3 present characteristics of handsheets made from 80% Melina pulp (CAP) and 20% plantain (MAP), screw pine (PAC) or *Pinus caribeae* (PIC) pulps, respectively. Though the strength properties of the Melina pulp blends with plantain stem waste or screw pine leaf pulps were lower than those of the Melina/pine blend handsheets and those the local newsprint, the values were good enough for producing papers that can withstand the pressure during printing processes or during writing.

Table 3. Handsheet characteristics: paper from pulp blends

Characteristics	**GAP/MAP blend**	**GAP/PAC Blend**	**GAP/PIC blend**	**Local Newsprint**
Grammage (air dried) (gsm)	66.3	66.5	66.1	66.4
Tear index (mNm^2/g)	4.05	4.27	4.91	4.04
Tensile index (Nm/g)	20.25	22.30	29.74	26.05
Stretch (%)	1.21	1.02	2.33	1.94
Sheet M. C (%)	10.4	10.6	10.5	10.1

Notes: A blend of 80% *Gmelina arborea* pulp and 20% imported long fibre kraft pulp. GAP: *Gmelina arborea* pulp (locally produced short fibre pulp). MAP: *Musa paradisiaca* pulp (plantain pseudostem). PAC: *Pandanus candelabrum* pulp. PIC: *Pinus caribeae* pulp (imported long fibre pulp).

4. Conclusions

This study has shown that: (1) the fresh plantain pseudostem and the leaves of screw pine contain much moisture, hence there is a need to press out the excess water and dry them in air before transportation to the mill for pulping; (2) their lignin content is lower than the amount of lignin present in woods, hence pulping them chemically will be economical; as little pulping chemicals will be consumed and a less complicated pulping system may be used; (3) they have fibres of medium length range, longer than the fibres from hardwoods; (4) their pulps form good strong papers individually or in blends with short fibres from *Gmelina arborea* and their strength properties compare well with those of paper formed from traditional short fibre/long fibre pulp blends. In view above, thousands of tones of plantain pseudostem wastes and the leaves of screw pine allowed to rot away annually in our gardens and plantations should be utilized in the production of good cultural papers.

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