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PAPER FROM THE ROOTS, STEM AND LEAVES OF *Pandanus Candelabrum* (SCREW PINE)

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ABSTRACT

The yield of 79.8, 74.2 and 64.4 percent of chemi-mechanical pulps (CMP) were produced from the roots, the stem and the leaves of Pandanus candelabrum (screw pine) respectively, by impregnation in 15% kraft liquor for 3 hr at atmospheric pressure and a temperature of 95°C. $ACOH/H_2O_2$ mercerated samples produced fibres of average length of 2.13mm, 3.40mm and 1.98mm for the root, the stem and the leaves respectively. 66 GSM sheets formed from these pulps singly or in blend of 5 (leaves pulp): 2 (root pulp): 1 (stem pulp) ratio had good formation with their strength properties greater than those of the sheet formed from the CMP of Gmelina arborea, the local paper making hardwood; also sheets formed from blends of the mixed pulps and Gmelina arborea pulp produced well formed sheets with strength properties that compared well with papers made from Pinus caribaea (long fibre)/ Gmelina arborea (20/80) blended pulps and the locally manufactured newsprint.

INTRODUCTION

The plant, *Pandanus candelabrum* (PAC) belongs to the family Panadanaceae; it is a monocotyledonous plant containing three genera and about 700 species of shrubs and vines. The genus, *Pandanus* with 600 species produces from the trunk and branches stilt-like aerial prop roots that support the plants and give them distinctive appearance. The main roots usually

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decompose and disappear, leaving the plant entirely supported by the stout, slanting buttress roots. It has spirally strap-like leaves, up to 150cm long, armed with forward pointing thorns at the margin and midribs, 7.5cm broad at the base and tapering gradually to an acute apex; they are very thick and leathery. The plant can grow to a height of 9m and 45cm in girth with few branches. The stem is fibrous with open structure. The plant is cultivated by cuttings - a new small branch shoot is cut from the parent plant and planted in another location or they are grown by seeds. It takes 8 - 12 years to mature; they are found along coasts, marshy areas and grows all the year round of the tropical and sub-tropical regions of Asia and Africa. Only the genus, *Pandanus* is representative in Nigeria (l).

Some number of the species are grown as green house subjects, examples are *P. pygmaeus, P. veitclu* and *P. utilis; P. candelabrum* is especially favoured as an outdoor ornamental plant in warm regions throughout the world and may also be used as conservatory or house plant. The seeds of some species (*P. utilis* and *P. leram*) are edible. In Nigeria the leaves of *P. candelabrum* and *P. tectorius* are much used in making roofing thatchings, mats, hats, ropes, sails for small boats, baskets and bags. However, with the introduction of improved roofing materials (corrugated iron sheets, aluminium sheet, concrete - cement composites etc.) and due to the availability of better synthetic fibres and plastics for making mats, hats, ropes, sails, baskets and bags, the leaves of these plants are now allowed to decay away as they become dead and fall off from the plant; similarly the buttress roofs and the stems are burnt off during clearing of a piece of land for cultivation of food crops.

This work therefore aims at utilizing this plant as an alternative local source of paper making fibres by investigating the properties of the plant with respect to pulping and the suitability of the resultant pulps for paper making. The properties of the PAC pulps and the papers were compared to those made from the local long fibres source: *Pinus caribeae* (PIC), and the short fibre source: *Gmelina arborea* (GMA).

MATERIALS AND METHODS

MATERIALS:

The *P. candelabrum* plant was collected from a swampy area at Ekpri Nsukara, Offot in Uyo Local Government Area of Akwa Ibom State. Two trees were randomly selected and fell; the roots, stems and leaves were chipped and dried in air.

A matured *Pinus caribeae* (PIC) stem was obtained from Uyo. It was also chipped. *Gmelina arborea* stem was obtained from NNMC, Oku Iboku.

METHODS:

Pulping of these plants: the pulp and paper evaluation were carried out in accordance with the standard methods of the Technical Association of the pulp and paper Industries (TAPPI) (2).

Determination of the Physical Characteristics of Pandanus candelabrum

The Moisture Content The moisture content (MC) was determined for both the green plant samples and the air dried samples (Tappi Standard Test T 258 OS 76). One g of each sample; stem, root and leaves, was separately dried in and oven at 105°C ± 5°C for 24 hrs, cooled in a desiccator an weighed to a constant weight. The moisture content was then determined by the difference and expressed as a percentage over air dried sample.

The Basic Density

The basic density was determined by immersion of a disc - shaped green sample in water to obtain the green volume; the dry weight of the sample was obtained by drying the disc in an oven at 105 ± 5°C to a constant weight;

$$\text{Basic density} = \frac{\text{Oven dry weight of sample}}{\text{green volume of sample}}$$

(Tappi Standard T258 os76)

Determination of Percentage of the Bark (TAPPI Standard T7 os 74)

Percentage bark by volume:

$$\%\ \text{Volume of bark} = \frac{(G - H)}{G} \times 100$$

where G = area of cross section before barking
H = area of cross section after barking

Percentage bark by weight:

$$\%\ \text{of bark by weight} = \frac{(A - E)}{A} \times 100$$

where A = weight of sample disc before barking
E = weight of sample disc after barking.

Determination of Fibre Length

Two methods were used for the determination of the fibre length of samples:

The Microscopic Method

The chips of the samples: stem, root and leaves were separately mercerated in a 1 : 1 mixture of ethanoic acid hydrogen peroxide and placed in an oven at 60°C for 24 hr. The bleached fibres were washed and the fibre length determined microscopically.

Kajaani Fibre Analyser Method

The fibre length of the thermomechanical pulp produced at the Nigerian Newsprint Manufacturing Company (NNMC), Oku Iboku was determined with a kaajani Fibre Analyser (FS - 200) according to the Tappi Standard: T233 os 75.

Determination of Chemical Characteristics of the Plant Samples

The Ash Content: This was determined by igniting the air dried sample at 575 ± 25°C, cooling the ash in a desiccator and weighing of the ash to a constant weight according to TAPPI Standard T211 - os- 80.

Acid Insoluble Lignin: This was determined by treating extractive free sample powder with 72% H_2SO_4 solution according to TAPPI Standard T222 - os - 74.

Organic Solubles: Were determined by extracting the air dried sample with 2:1 benzene - ethanol mixture in a soxhlet apparatus according to TAPPI Standard: T204 - os - 76.

Solubility in Water: This was determined by digesting air dried well beaten stem, root and wood samples in cold water for 48 hr at room temperature. The sherry was filtered and the pulp washed with cold water. The residue was dried in air to constant weight and the difference in weight gave the cold water solubility. The solubility in hot water was similarly determined by digesting the well beaten pulp sample in hot water and then the mixture heated for three hr. The solubility was expressed in percentage of air dried samples.

Alkali Solubles: Solubility of the samples in 1% and 18% NaOH was determined according to TAPPI Standard T 212 - os- 76 while cold and hot water solubles were determined according to Tappi standard T 207 - os - 71.

Pentosan Content: Pentoses obtained by hydrolysis of each sample in 13% HCL solution was converted into furfural which was then determined by means of UV spectrophotometer after addition of a solution of orcinol - iron (iii) chloride mixture to the distillate. The absorbance was read at a wave length of 630nm.

Pulping

A modified kraft chemimechanical pulping method was adopted. 300g of BD chips of each sample were taken in a cylindrical steel vessel, warm kraft liquor (7.2g of Na_2S and 37.8g NaOH of sulphidity 16% and constituting 15% of the BD

chips) was then added. Cooking parameters are shown (Table III). The chips were soaked in the warm liquor for 3 hr and thereafter cooked for 3 hr at 95°C and one atmospheric pressure. The whole content was transferred to a press whereby the black liquor was separated from the chips. Defibering was carried out in a refiner. Washing and screening were carried out and the yield was determined.

Paper Making

Stock Preparation and Sheet Formation

Thirty (30)g BD pulp prepared above were disintegrated and beaten in a PFI Beater at 5000 revolutions in accordance with Tappi Standard: T 248 - pm - 74. The freeness was determined using Canadian Standard Freeness Tester. Further disintegration and dispersion in water to a 1% consistency were carried out in the appropriate equipment; handsheets, each about 1.2g, were formed from this stock using British Sheet Former and in accordance with the method of the Second Reports of the British Paper and Board Association of 1936 or Tappi Standards; T 205 - om - 81 and T227 - os - 74. The handsheets were made separately from the pulps from the leaves, roots and stem and their blends in the ratio of 5: 2 : 1 respectively which is the ratio of their relative abundance counted by Kajanni Fibre Analyser (FS - 200). Sheets were also made from blends of PAC and GMA pulps in the ratios of 50:50; 70:30, 80:20, and 100% GMA pulp. Other papers made were from the pulp blend: 80: 20 GMA and imported kraft pulps, 80: 20 GMA and PIC pulps and 100% PIC pulps. The sheets were stacked in the rings and were conditioned at 20°C, 65% R. H. before the grammage, the moisture content, the strength properties; tensile and tear and the stretch were determined.

RESULTS AND DISCUSSION

Physical characteristics of *Pandanus candelabrum* (PAC):
Tabal 1a shows the physical characteristics of the stem, the root and the leaves of *Pandanus candelabrum* plant.

The average moisture content (M. C.) was 77.2% on AD basis, the leaves having the greatest moisture content (M. C) of 80%. The M. C. after drying in air for 60 days (October - November) reduced the average M. C. to an average 20.9%, the leaves having the lowest of 15.7%. This suggests the need to fell the plants or cut their leaves off the plant and dry them before carrying them to the pulp mill for processing in order to serve the cost for transporting about 56.3% water.

The density of the green stem and the root were found to be 330 kg/m^3 on the average, this falls within the range of 300 to 600 kg/m^3 for most pulpwoods.

The average barks of the roots and the stem were 17.93% by volume, 17.4% and 19.36% by weigh. These volume being comparable to 15.2% and 18.9% by volume and weight basis for the pulpwood, *Pinus caribeae*. These values are low hence may be tolerated during pulping (3).

The average fibre length of unmutilated fibres (ACOH/H_2O_2 mercerated and viewed under microscope) was 2.50mm showing that PAC fibres belong to long fibre class hence should provide long fibre pulp for the paper industry. The length in increasing order was 1.98mm for the leaves, 2.13mm for the root and 3.40mm for the stem. However, the chemimechanical pulps had an average length of 1.95mm, with roots having 2.18mm, stem 1.96mm and leaves 1.73mm using Kajaani Frbre Analyzer (FS - 200) which is still high considering the mechanical treatment given to the pulps during defibering operations which usually reduce the length of the fibres by cutting action. The length to width ratio were also found to be 126.8, 166.7 and 168.4 for the root, stem and leave fibres respectively, indicating that the leaves fibres were the thinnest and most flexible and should be able to form strong interlocking bonds among the fibres to form strong papers. Microscopic observation showed PAC fibres as flexible and tubular in shape, pointed at both ends. They should require small beating energy for fibrillation in order to develop strength properties during paper making.

Chemical Characteristics of Pandanus candelabrum

Table 1b shows the chemical characteristics of the roots, stem and leaves of *PAC* as related to pulping operations.

The average ash content was 1.9% with leaves having the lowest amount of 1.4% while root and the stem had 2.1 and 2.2% respectively; the ash content of the pulp was lower and in the same order: leaf pulp (0.50%), root pulps (0.60%) and stem pulp (0.68%) showing that 68.4% of the ash was removed during impregnation in the pulping liquor.

The extractable matter in cold water was highest for the leaves (29.2%) and had an average of 27.7% while the root had the highest solubility in hot water (30.5%) and an average of 29.0%. There was no significant difference in the cold and hot water extractable materials (9.0% and 9.1% respectively) of the pulps because during impregnation most of the water solubles (about 69%) had been removed. They were mainly the gums, tannins, starches and colourings present in the plant samples.

The average extractable material with 1% NaOH was 29.9%, the stem having the highest value of 33.3%; the leaves had the highest solubles (40%) when the samples were treated with 18% NaOH, average being 38% for the three plant samples; the solubles were mostly the phenols and the resin acids. Pulp analysis indicated that 80 - 86% of the alkali solubles were removed during chemical treatment.

Also 2: 1 benzene - ethanol solution mixture extracted an average of 10.9% of the samples with leave sample having the highest value of 16.3%. Comparing this with the pulp extract (2.0%) with the same solvent system, it was observed that 81.7% solubles had been removed during impregnation. The lignin content found in the form of acid - insoluble lignin had an average value of 20.1% with stem having the highest value and leaves the lowest (16.3%); the residual pulp lignin content was 14.3% (root), 16.0 (stem) and 11.5% (leaves) showing that only 30.8% of the original lignin was removed from the samples during chemical treatment, hence much lignin still remained in the pulp.

These values were however higher than those obtained for *Raphia hookeri* - a non woody plant (4).

The pentosan content which measures the xylan (hemicalluloses) content in the sample was the same in the leaves as in the stem: 15.3% each and 13.5% for the roots all giving an average of 14.7%.

The Pulp Yield

The root samples had the highest pulp yield of 79.8% during kraft (NaOH + Na_2S) impregnation, others were 74.2% for the stem and 64.4% for the leaves (Table II). However, the low yield of the leaf pulp did not make the leaves unsuitable for pulp making because these are very often regenerated by natural growth and since the plant grows all the year round the leaves become the most abundant and easily available part of PAC which can be used for producing pulp for the paper industry.

Pulp Properties

The Fibres

The leaf pulp consisted of the shortest, thinnest and the most flexible fibres, and its fibres were the most abundant: 12, 325 (based on a pulp coarseness of 65 MG/M, prepared for Kajaani: FS - 200 Fibre Analyser): while the root with a count of 5,393 was the longest and the stem with 2,436 counts had an intermediate value, the average fibre length by microscopic determination was longer than that of the PIC fibre which is classified as long fibre; therefore the PAC pulp has long fibres and can serve as a substitute for the imported long fibre pulp for the paper industry.

The freeness of the beaten pulps indicated that leaf pulp with $162cm^3$ CSF (Canadian Standard Freeness) responded more readily to beating than the roots or stem pulp with 282 and $328cm^3$ SCF respectively (Table IV). Freeness measures the ability of the pulp to retain water on the paper wire during sheet formation, hence affects the rate of removal of water froms the forming unit of the paper machine. The extent of pulp beating also determines the strength properties of the paper made from

them. In this respect the leaf pulps develop strength properties when beaten much more readily than the root or the stem pulps.

Each pulp sample being unbleached had a darker brown colour than the PIC pulps or GMA pulps.

Paper Properties

About 66 GSM sheets made from the roots, the stem and the leaves pulps beaten to 5000 revolution had good formation.

Their strength properties are shown (Table IV). The tear index for the Root Fibres (RF) sheet was the highest (9.63 mNm^2g^{-1}) while those for the Stem Fibres (SF) sheet and the Leaf Fibre (LF) sheet were 7.46 and 6.50 mNm^2g^{-1} respectively. Thus the tear index for the LF paper was 35% lower than that of the Rf paper while its tensile strength index (67.3 Nmg^{-1}) was 76% higher than that of the RF paper (38.2 Nmg^{-1}). The strength properties are indications of the performance of paper in use. Factors that generally affect the strength properties of paper are the fibre length and the length factor (L/w)value, the cell wall thickness, the fibre flexibility, the residual lignin and the response to beating i.e. ease of fibrillation to form inter-fibre and inter fibrillar bonds to form the paper web. The stronger these bonds and the actual physical entanglement of the fibres, the better the strength properties of the paper (5). The results obtained in these experiments indicated that LF had the highest L/w ratio, the lowest residual lignin, they responded much more readily to beating than others and had the greatest tensile strength, therefore the pulp from the LF had the best bonding capability to make stronger paper than those of the RF and the SF.

When the pulps from the LF, the RF and the SF of PAC were blended in the ratio 5: 2: 1 based on the actual fibre counts, the tear index reduced to 4.1 mNm^2g^{-1} i.e 63.1% of the LF paper; it was 77.8% of that of 100% PIC pulp (long fibres) papers and 410% greater than the tear index of a sheet formed from GMA pulp alone, while it was 101% of that of the newsprint (NNMC). On the other hand the tensile index increased to 85.5 Nmg^{-1} under the same conditions i.e it increased 109% of the value for the LF paper; 87.2% of the 100% PIC paper (long fibres) and to 328.8% of the NNMC newsprint. 100% GMA paper had inferior strength properties to the PAC papers (Tables V and VI).

Further blending of this mixed LF, RF and SF of PAC pulps with GMA pulp, all CMP samples, resulted in the formation of sheets of good strength properties as shown (Table V and Fig 1). The strength properties increased with the percentage of the PAC (mixed) pulps; the strength properties developed by 50: 50 (PAC : GMA) blend were comparable to the values obtained for the locally manufactured newsprint by other possible paper formulations (Table 6 column (A) and (B).

These results showed that the pulps from the plant: *Pandanus candelabrum* could be used as suitable substitutes for the imported long fibre pulp usually blended with the locally produced short fibre for making cultural papers.

CONCLUSION

The study showed that the plant *Pandanus candelabrum* had an open structure (basic density 33g/mm³), and was therefore a non woody plant. Its average fibre length was 2.50mm which classified it as long fibre plant.

Chemimechanical kraft pulping gave reasonable pulp yield for the buttress roots, the stem and the leaves. Papers made from these pulps either singly or in blends had good formation and good strength properties; a blend of 5 :2:1 (LF: RF: SF) gave papers of very good strength properties and could be used in making cultural paper. When this mixed pulp was blended with Gmelina pulp (short fibre pulp locally used for paper making). 50: 50 blend produced papers whose strength properties compared well with the locally produced newsprint and other paper formulations.

More investigations are being carried out to produce chemical pulps and other paper formulations from PAC and on the development of the plant, *Pandanus candelabrum* on plantation system.

Table 1A. Physical Characteristics of Pandanus candelasrum Plant

	Root	Stem	Leaves
Moisture content (%) green sample	76.0	74.0	80.0
Air dried sample	31.0	16.0	15.7
Basic density (9/cm³)	0.35	0.31	
Bark content (%) by volume	21.76	13.09	
by weight	21.22	17.5	
Fibre Dimensions:			
Length (mm)	2.[illegible]13(2[illegible]8)	3.[illegible]40(1[illegible].96)	[illegible].99.[illegible] 73
width (mm)	0.0168	0.0204	0.0113
Length to width ratio	126.8	[illegible]	168.4
Wall thickness (mm)	0.0019	[illegible]	0.0012
Runkel ratio	0.296	0.538	0.256

* $ACOH.H_2O_2$ Mecerated Fibre

** Chemimechanical Pulp fibre

Table 1B. Chemical Characteristics of Pandanus candelabrum Plant

	Root	Stem	Leaves
Ash content (%)	2.1	2.2	1.4
Solubility (%):			
(a) Cold water	27.4	26.6	29.2
(b) Hot water	30.5	30.0	26.5
(c 1% NaOH	25.5	33.3	31.0
(d 18% NaOH	36.5	37.5	40.0
(e 2: 1 Benzene/Ethanol	8.6	7.7	16.3
Acid - insoluble lignin (%)	21.8	22.6	16.3
Pentosan content (%)	13.5	15.3	15.3

Table II. Cooking Parameters and Pulp Yield of Pandanus candelabrum at 15% Chemical Cook

	Root	Stem	Leaves
Cooking Time (Hrs)	3	3	3
Fresh liquor (g/dm³)			
NaOH	37.8	37.8	37.8
Na_2S	7.2	7.2	7.2
Spent liquor (g/dm³)			
NaOH	12.0	8.8	6.8
Na_2S	4.28	2.77	3.65
Sulphidity (%)	16.0	16.0	16.0
Weight of cooked chips (g)	260.8	412.0	243.8
Moisture content of chips (%)	8.2	46.0	20.8
Yield (%)	79.8	74.2	64.4
Residual lignin (%Ö)	14.3	16.0	13.1

Table III. Pulp Characteristics at 15% Chemical Cook

	Root	Stem	Leaves
Cooking Time (Hrs)	3	3	3
Ash content (%)	0.60	0.62	0.50
Solubility (%)			
(a) Cold wat	8.0	8.35	10.6
(b) Hot water	9.0	10.3	9.1
(c 1% NsOH	5.5	7.5	5.5
(d) 18% NaCh	10.1	10.1	10.0
(e) Benzene/Ethanol	1.8	1.6	2.6
Residual lignin	14.3	16.0	13.1

Table IV. Handsheet Results for Pandanus candelabrum at 15% Chemical Cook

	Root	Stem	Leaves
Cooking Time (Hrs)	3	3	-3
Beatings (Rev.)	5000	5000	5000
CSF Freeness (Cm³)	282	328	162
Grammage A/D (g/m²)	66.0	66.1	67.1
Grammage O/D (g/m²)	62.3	59.0	60.3
Tear (mN)	600	440	380
Tear index (mNm²/g)	9.63	7.46	6.30
Tensile strength (KN/m)	2.38	2.05	4.06
Tensile Index (nm/g)	38.2	34.75	67.3
Stretch (%)	1.3	2.0	2.1
Moisture content of sheet (%)	5.6	10.8	10.1

Table V. Sheet Properties of PAC/GMA Puly Blends**

Properties	*PAC/GMA BLEND				
	100/0	50/50	30/70	20/80	0/100
Freeness cm³ CSF	109	228	280	368	522
Grammage (AD) (gm⁻²)	66	65.5	55.4	65.7	64.5
Tear Index (mNm² g⁻¹)	4.1	5.1	4.03	3.01	1.0
Drainage Time (Sex)	10.15	5.53	4.69	4.45	4.28
Tensile Index (Nmg⁻¹)	85.5	25.4	15.20	13.3	6.02
Stretch %	2.22	1.72	1.2	1.0	0.48
M. C. %	10.4	10.2	10.3	13.5	10.6

+ : PAC Pulp = 5: 2: 1 (LF: RF: SF) Blend.

+ : Each pulp sample was beaten to 5000 revolution in PFI Beater.

Table VI Sheet Properties for Papers Used as Control

Properties	Paper Formulation			
	(a) GMA/IKP* 20/80	(b) GMA/PIC 80/20	LMN**	PIC 100%
Freeness (cm³CSF)	110	165	197	102
Grammage AID (gm^{-2})	66.0	64.8	66.3	65.5
Tear Index ($mNm^2 g^{-1}$)	5.12	4.91	4.04	5.27
Drainage Time (Sec)	9.25	9.86	8.12	12.5
Tensile Index Nmg^{-1}	13.39	29.74	26.0	98.10
Stretch (%)	2.11	2.33	1.97	3.53
M. C. (%)	10.2	10.6	9.5	10.3

IKP = Imported Kraft Pulp;
LMN = Locally Manufactured Newsprint by NNMC
NNMC = Nigerian Newsprint Manufacturing Company.

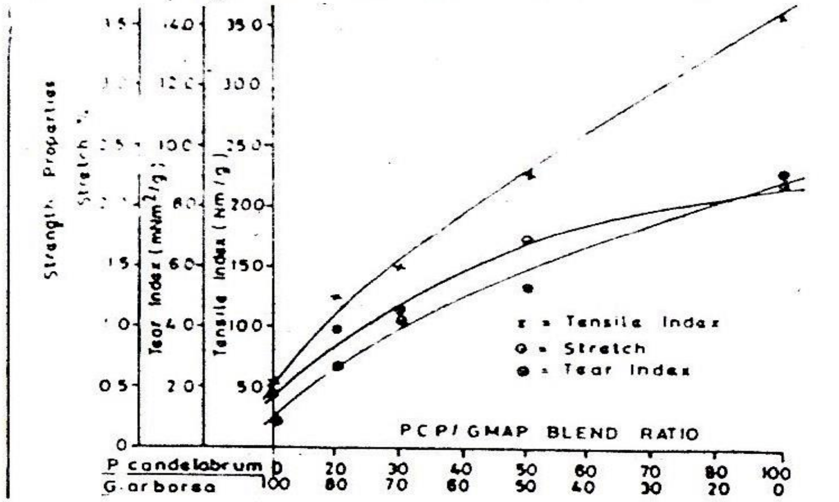

Fig. 1. Variation of handsheet properties of *P. candelabrum/Gmelina arborea* blend with ratio of blending.

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