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Fibre and Chemical Properties of Some Nigerian Grown *Musa* Species for Pulp Production*

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Abstract: The physical, fibre and chemical properties of four *Musa* species, namely, *Musa cavendish, Musa paradisiaca, Musa nana* and *Musa sapientum* widely cultivated in south-western Nigeria were investigated for their pulp and paper potentials. The species were sampled at three different levels mainly the mid-ribs, the pseudostem and the stalk. All the *Musa* species had low specific gravities with values ranging from 0.22 to 0.43. The fibre lengths were within medium to long fibre class and varied significantly across species and plant parts from an average of 1.92 to 4.17 mm. The stalks gave the highest fibre diameter (28.11-37.5 μm) and lumen width (13.4-22.4 μm). Fibre slenderness on the other hand was slightly higher in the pseudostems (99-160) than the mid-ribs (91-125) and the stalks (80-119). The chemical analysis revealed that cellulose contents were moderately high and tolerable. The relatively low lignin contents (7.35-16.58%) was an indication of short cooking cycles, easy delignification and low to moderate chemical consumptions. The plants were rather high in their contents of ash and extractives.

Key words: Chemical compositions, fibre dimensions, lignin, pulp, paper

INTRODUCTION

Wood has become one of the major basic raw materials for the production of pulp, paper and fibre based products since the beginning of the 19th century. However, the ever increasing demand for wood as construction materials, furniture, fuels, charcoal, etc on one hand and the problem of deforestation and scarcity of wood in many countries, has directed attention to the use of non wood materials (Manfred, 1993; Oggiano *et al*., 1997; Hammett *et al*., 2001; Ververis *et al*., 2004; Jime´nez *et al*., 2005; D´ıaz *et al*., 2007). *Musa* species (plantain and banana) are important food crops in the humid forest and mid-altitude agro ecologies of sub-Saharan Africa. They provide more than 25% of the carbohydrate for 70 million people (Samson, 1991). The plant residues after the fruit had been harvested are left to decay and rot thereby constituting pollution and waste disposal problems. This ligno-cellulosic agricultural wastes could be utilized in the paper industry. The use of *Musa* for making pulp and paper had been reported in the literature (Gouzalex-Flores and Vazquez-Garcia, 1975; Sankia *et al*., 1997; Cordeiro *et al*., 2004; Kalpana *et al*., 2005). Paper sheets formed from the pulp showed high strength properties good for writing and printing paper. A comparative study of banana pseudo-stalk with cane trash, tobacco stalks bagasse and kenaf revealed that the petiole of the banana plant had the largest fibres and stimulated the greatest industrial interest (Gouzalex and Vazquez, 1975). It had been concluded that banana plants would be good source of raw material for cottage industry and a supplementary source for the pulp and paper industry (Sankia *et al*., 1997). The species exhibit medium to long fibre lengths. *Musa textiles nee* was reported to have high quality fibres and paper sheets with acceptable strength-related properties (breaking length, stretch and tear index), good yields and potential savings in capital equipment costs (Jime´nez *et al*., 2005).

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The papermaking characteristic of any given pulp is a function of the chemical and fibre properties of the plant. Analysis of the chemical component and fibre morphology of various plants are useful in selecting the right fibre materials for pulp and paper making. The specific physical and chemical characteristic is also important in the technical aspects of pulping which has a direct correlation with the economic, environmental and ethical contexts of the paper industry (Rousu *et al*., 2002). Since these properties vary greatly with species and their ecological environments, the need to investigate the pulp and paper potentials of *Musa* species grown in Nigeria becomes highly necessary. The present study was aimed at evaluating the fibre characteristics and chemical properties of four Nigerian grown *Musa* species for their suitability in the pulp and paper industry.

MATERIALS AND METHODS

Four *Musa* species, namely, *Musa cavendish, Musa paradisiaca, Musa nana* and *Musa sapientum* widely distributed and cultivated in south-western part of Nigeria, were obtained from the Department of Agronomy of the University of Ibadan. The study was conducted in 2004. The plants were sampled at three different regions: the pseudostems, the stalks and the mid-ribs. The specific gravity was determined using representative samples from each plant part in accordance with the ASTM standard procedure designated D 2395-89 method B. Fibre dimensions were determined by macerating each plant part in a mixture of equal volume of glacial acetic acid and 50% hydrogen peroxide. The macerated samples were prepared on a slide and the fibre length (L), fibre diameter (D), lumen width (d) and cell Wall Thickness (CWT) of about 60 samples each were measured under a Reichert visopan projector. The following morphological indices were determined from these measurements:

$$\text{Slenderness ratio} = L/D$$
$$\text{Flexibility coefficient (\%)} = (d/D)\times 100$$
$$\text{Fibre width}/(2\times\text{cell wall thickness}) = D/2CWT$$

The proportion of the chemical constituents that affect the characteristics of the plant was determined on a ground sample of each plant part. The ash contents, alcohol-benzene extractive, water and 1% soda solubilities of the samples were determined by the ASTM standard methods. The Kurschner-Hoffer cellulose method was used for the cellulose while the standard method of TAPPI (1998) (acid-insoluble lignin in wood and pulp-T22 om-98, 169) was used for the lignin content.

RESULTS AND DISCUSSION

Specific Gravity

The specific gravity varied slightly according to the sampled parts with the stalks recording the highest value while the pseudostems had the least (Table 1). The specific gravities fell within the low-density value classification of 0.20 to 0.40 of Chittenden and Palmer (1990). The implication is that low concentration of cooking liquor and low liquor to plant ratio would be required to achieve good delignification. The problem associated with wearing or tearing of chipper knives owing to excessive chipping may not be encountered with the *Musa* species. However, large volume of materials may be needed for pulping because of the bulkiness of the species. The sampled parts may be combined during pulping due to the relatively close values of the specific gravities.

Fibre Characteristics

The photomicrographs of the fibres are shown in Fig. 1a-f, 2a-f. Generally, the fibres appeared smooth and straight but exhibited slight variations in cell dimensions across and within species. Each

Table 1: Specific gravity and fibre characteristics of the *Musa* species

Musa species	Sampling position	Specific gravity	Average fibre length (mm)	Fibre diameter (μm)	Lumen width (μm)	Cell-wall thickness (μm)
M. paradisiaca	Mid-rib	0.31	4.02	31.7	13.2	9.24
	Pseudostem	0.29	4.17	31.5	19.4	6.05
	Stalk	0.40	2.83	37.5	20.6	8.45
M. cavendish	Mid-rib	0.33	2.65	21.6	10.0	5.81
	Pseudostem	0.29	3.81	23.9	9.8	7.03
	Stalk	0.40	3.30	28.1	13.5	7.26
M. nana	Mid-rib	0.24	2.12	22.7	12.1	5.27
	Pseudostem	0.22	2.67	19.9	11.2	4.32
	Stalk	0.43	3.52	31.7	22.3	4.70
M. sapientum	Mid-rib	0.30	2.04	22.4	8.9	6.76
	Pseudostem	0.26	1.92	19.5	7.9	5.85
	Stalk	0.41	2.87	35.9	21.0	7.42

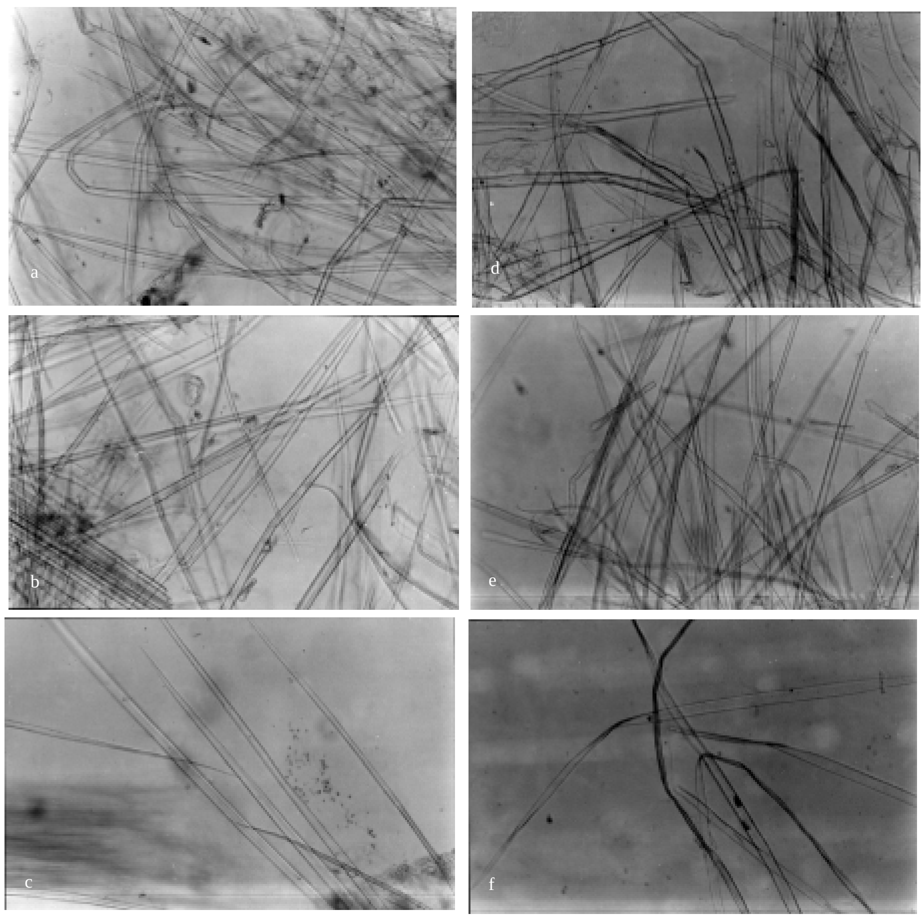

Fig. 1: Photomicrograph picture of fibers from the mid-rib, pseudostem and stalk of (a-c) *Musa paradisiaca* and (d-f) *Musa cavendish*, respectively (x100)

cell type can play different role in a fibrous network (Law *et al*., 2001). The results of the fibre dimensions are presented in Table 1. All the *Musa* species examined can be classified as long-fibre plants except for the pseudostem of *Musa sapientum*, which had a fibre length of 1.92 mm. This indicated that papers of high strength would be produced from these plants since a strong relationship

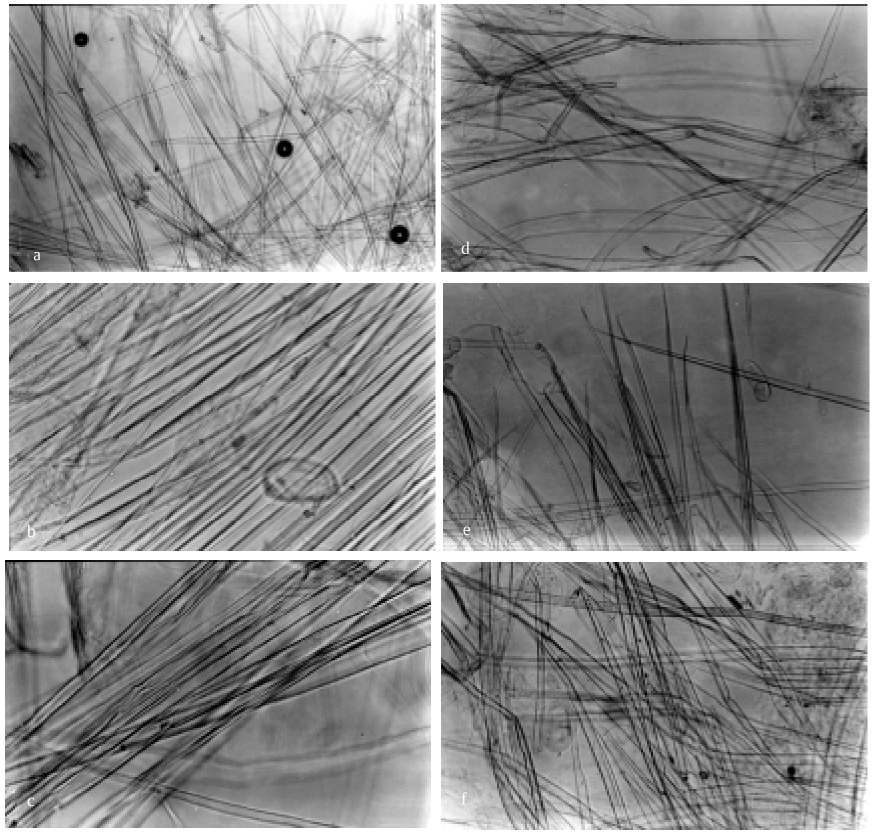

Fig. 2: Photomicrograph picture of fibers from the mid-rib, pseudostem, and stalk of (a-c) *Musa nana* and (d-f) *Musa sapientum*, respectively (x100)

exists between the strength properties of pulp and the fibre length constituting the pulp (Horn, 1978; Seth and Page, 1988; Horn and Setterholm, 1990; Ververis *et al*., 2004). Thus on the basis of fibre length, the plants are comparable with softwoods. It was noticed that the longest fibre was found in the pseudostem of *M. paradisiaca* and *M. cavendish* and the stalk of *M. nana* and *M. sapientum*. In all the species the mid-rib had the shortest fibre.

The values of the fibre diameter and lumen width for all the species range from 19.9 to 37.5 μm and 7.9 to 22.3 μm, respectively (Table 1). It was observed that the stalks gave the highest fibre diameter and lumen width than the mid-ribs and the pseudostems for all the species. Consequently paper made from the stalk would be expected to exhibit good contact between fibres.

Morphological Indices

The *Musa* species gave very good fibre derived values as presented in Table 2. The relative fibre lengths, that is, the ratio of fibre length to fibre diameter were a little higher in the pseudostem (99-160), than in the mid-ribs (91-127) and the stalks (111-119), respectively. Since pulp resistance to tear increases with increasing fibre slenderness, papers made from the pseudostems are expected to have increased tear strength suitable for wrapping and packaging purposes (Sankia *et al*., 1997) than the mid-ribs and the stalks. The flexibility coefficients were generally on the average and are indicative of acceptable burst and tensile strength (Ogbonnaya *et al*., 1997). *Musa nana* would give the highest

Table 2: Morphological indices of the *Musa* species

Musa species	Sampling position	Flexibility coefficient	Slenderness ratio	Fibre width/ (2x cell wall thickness)
M. paradisiaca	Mid-rib	42	127	1.71
	Pseudostem	62	133	2.63
	Stalk	55	77	2.22
M. cavendish	Mid-rib	46	125	1.80
	Pseudostem	41	160	1.70
	Stalk	48	119	1.91
M. nana	Mid-rib	54	95	2.15
	Pseudostem	59	138	2.45
	Stalk	70	111	3.37
M. sapientum	Mid-rib	40	91	1.66
	Pseudostem	40	99	1.67
	Stalk	59	80	2.40

Table 3: Extractive contents of the *Musa* species with data from other annual plants (% o.d. weight)

Raw material	Plant part	Alcohol	Alcohol-benzene	Cold water	Hot water	1% NaOH
Musa paradisiaca	Mid-rib	5.90	8.19	6.39	9.81	24.88
	Pseudostem	17.70	12.80	18.04	23.57	25.81
	Stalk	5.53	2.33	26.85	31.09	37.78
Musa nana	Mid-rib	7.75	9.41	9.29	14.33	31.54
	Pseudostem	5.99	8.95	14.22	17.76	46.75
	Stalk	13.25	10.81	28.75	36.70	36.91
Musa sapientum	Mid-rib	7.40	5.44	6.60	9.46	24.53
	Pseudostem	15.00	13.90	11.01	17.37	40.02
	Stalk	6.30	4.26	25.65	32.71	22.97
Musa cavendish	Mid-rib	8.26	4.00	9.57	13.35	27.76
	Pseudostem	15.66	10.78	16.59	20.90	24.97
	Stalk	8.11	5.56	13.55	16.11	42.29
Sweet sorghum	Depithed	n/a	11.40	n/a	25.30	52.10
	Extracted	n/a	24.00	n/a	43.80	63.10
Switch grass	Leaf	n/a	4.18	18.89	20.10	48.54
	Stem	n/a	1.69	10.88	12.44	27.94
Sunflower	Whole	n/a	4.50	n/a	22.00	44.90
	Depithed	n/a	7.90	n/a	15.30	30.10
Rice Straw	Whole	n/a	0.56	n/a	7.30	57.70

tensile strength with a flexibility coefficient of 70. The ratio of the fibre diameter to twice the cell wall thickness is significant in the overall properties of fibre. These values were high and similar to those of raphia stem and petiole (Odeyemi, 1984). The high values implied that the fibres were very slender with thin walls in comparison with their fibre width.

Chemical Characteristics of the Musa Species

Extractives

The extractive contents of the plant were higher than usual for commercial pulpwood and tropical species but similar to those reported for some annual plants (Table 3) such as sweet sorghum (Belayachi and Delmas, 1995), switch grass (Kristova *et al*., 1998), sunflower (Law *et al*., 2001) and rice straw (Rodriguez *et al*., 2008). The high values of extractives may be attributed to easy access and degradation of cell wall materials by weak alkali and high percentage of phenolic and soluble polysaccharides, gums and colouring matter. The high extractives may results in lower pulp yield and probably high Biochemical Oxygen Demand (BOD) load compare with woody materials. The high content of 1% caustic soda soluble of the *Musa* species may probably affect the pulp yields and also the chemical consumption. Pulp industry requires that the content of 1% caustic soda soluble should be low since this is indicative of low molecular weight materials and the content of rot in wood (Khristova, 1998).

Table 4: Chemical composition of the *Musa* species (% o.d. weight)

Musa species	Sampling position	Ash (%)	Klason lignin (%)	Acid -soluble lignin (%)	Cellulose (%)	Cellulose/ lignin ratio
M. paradisiacal	Mid-rib	6.87	9.94	2.50	53.07	5.3
	Pseudostem	3.44	6.33	1.02	48.01	7.4
	Stalk	11.80	8.47	2.70	40.77	4.8
M. cavendish	Mid-rib	12.99	8.17	2.55	44.92	5.5
	Pseudostem	12.74	6.92	2.96	51.16	7.4
	Stalk	25.03	4.75	2.78	41.50	8.7
M. nana	Mid-rib	5.21	14.38	2.20	48.99	3.4
	Pseudostem	3.10	8.35	2.54	50.55	6.1
	Stalk	18.61	5.81	1.64	45.25	7.8
M. sapientum	Mid-rib	5.98	11.36	2.16	49.49	4.4
	Pseudostem	2.67	9.19	1.15	44.28	4.8
	Stalk	10.72	7.99	1.45	47.76	6.0

Ash

The ash contents were generally high but within the range reported for most non woods. For instance a value of 13.5% was reported for wheat straw (Demibas, 1998) and 9.2% was reported for rice straw (Rodrígueza *et al*., 2008). The stalk contained the highest ash content. High ash contents are undesirable for pulping as they affect normal alkaline consumption and give problems at waste liquor recovery.

Lignin

The lignin contents of the *Musa* species (7.35-16.58%) were normal and within the range reported for most annual plants (Table 4). The lignin content of some annual plants ranges between 3 to 24% (Hurter, 1988). A value of 10.37% was reported for *Musa textiles nee* (Jime´nez *et al*., 2005). The low lignin content was an indication of easy delignification, short cooking cycle and low chemical consumption. Thus in practice, these materials would require mild conditions of pulping such as low temperature and cooking time. The cost of production and energy requirements would also be low.

Cellulose

The Kurschner Hoffer cellulose contents (40.8 to 53.1%) were indications of average and tolerable yields with acceptable level of pulp mechanical strength (Madakadze *et al*., 1999). The values were comparable to those of sunflower stalks (40.2-41.40%), kenaf, (45.7-53.8%) and *Acacia nilotica* species (45.1-50%) (Khristova *et al*., 1998; 2002, Khristova and Karar, 1999). The cellulose with the low lignin contents were indicators of tolerable yields and low chemical consumption, respectively. This was further confirmed by the cellulose/lignin ratio which was greater than two.

CONCLUSION

Nigerian grown *Musa* species examined are potential sources of long fibre pulp. The plant was characterized with low specific gravity values. The average fibre lengths were within medium to long fibre class and the morphological indices compared favourable well with typical dimensions of pulp wood materials. The chemical analysis of the plant revealed satisfactory level of cellulose contents. The relatively low lignin contents indicated short pulping cycles, easy delignification and low to moderate chemical and energy consumptions. The reactions of these species under major chemical pulping processes need to be investigated.

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