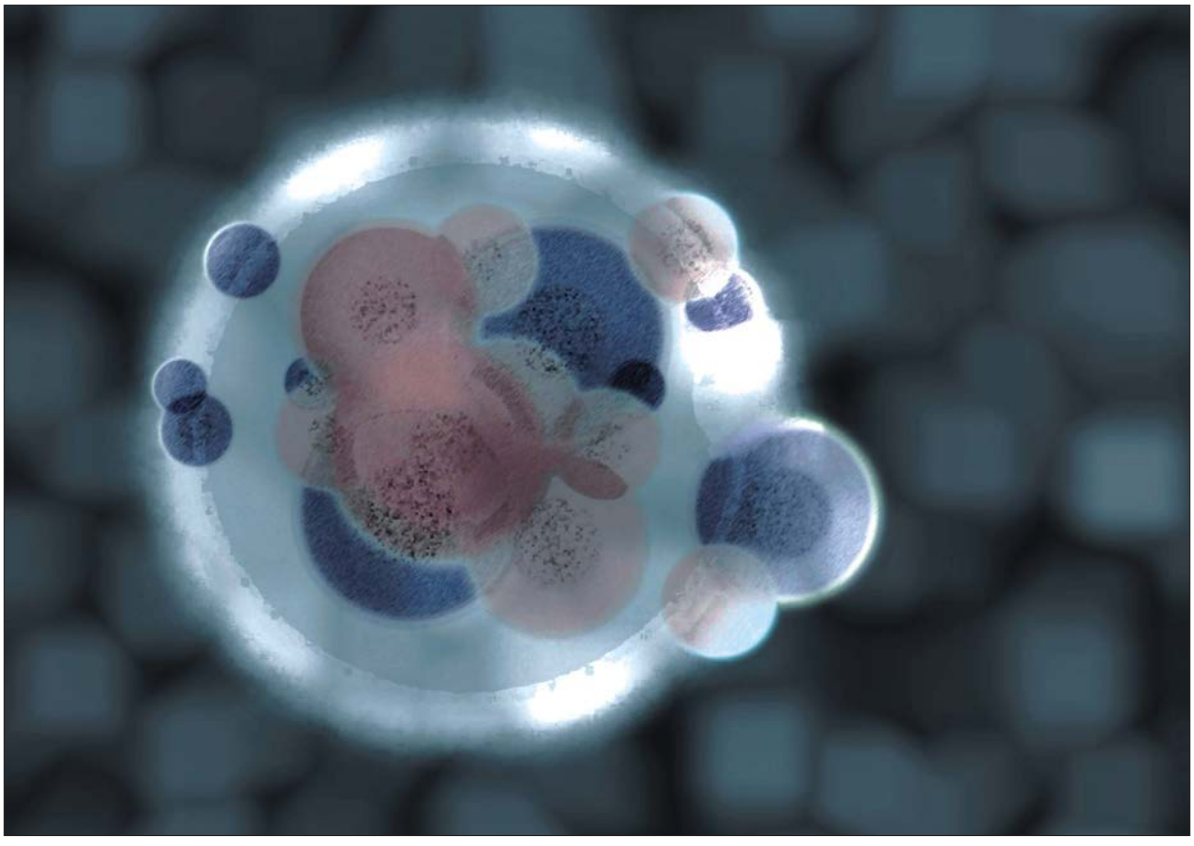

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Comparative Soda Pulps from the Mid-Rib, Pseudostem and Stalk of *Musa paradisiaca*

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Abstract: The fiber morphology, chemical properties and soda pulping of the mid-rib, pseudostem and stalk of Nigeria grown *Musa paradisiaca* were investigated as potential raw material for pulp and paper making. The lignin contents were desirably low and varied as follows: mid-rib, 12.4%, pseudostem, 7.4% and stalk, 11.2%. The cellulose contents were relatively tolerable ranging from 40.8 to 53.1%. The sampled parts were characterized with high values of ash and extractive contents. Their fiber lengths were relatively long ranging from 2.9 to 4.2 mm. At the best operating conditions, soda pulping of the sampled parts resulted in pulp yields of 49, 34.0 and 40.0% and residual lignin of 6.2, 4.1 and 2.1%, corresponding to the mid-rib, pseudostem and stalk, respectively. Prolonged cooking at a very low temperature resulted only in a small increase in the total yield over that obtained at a high temperature for the same degree of pulping for all the sampled parts.

Key words: *Musa paradisiaca*, fiber dimension, chemical composition, soda pulping

INTRODUCTION

The great value of the forest resources and the increasing demand for paper and paper board call for an overall plan for the utilization of these resources and for the development of plantation of species most suitable for the various sectors of forest industry. Wood has become a major source of fibrous materials for most paper industries all over the world. However, increasing cost of pulpwood and its scarcity in many countries have directed attention towards the use of non-woody plant fibers for the production of different grades of pulps (Guritno and Daswir, 1995). Research studies have been geared towards increasing the number of non-woody plants, majority of which have already found commercial use (Ray *et al*., 1990; Delmas and Gaset, 1991; Belayachi and Delmas, 1995). The utilization of non-wood fiber is an ethically sound way of promoting sustainable paper production especially in areas lacking forest and having abundance of annual fibre resources (Rousu *et al*., 2002).

The main fibrous raw materials available for pulp and paper making in tropical African counties like Nigeria are the short fibered hardwoods (RMRDC, 1996). Alternative to using hardwoods especially for specialty papers are the non-wood fibers from the herbaceous field crops. *Musa paradisiaca* plants are available in Nigeria and are characterised with long fiber and low lignin contents (Oluwadare, 1998). Although the suitability of *Musa paradisiaca* for pulp and paper production have been reported in the literature, research in the series focused only on the pseudostem (Sankia *et al*., 1997; Cordeiro *et al*., 2004; Kalpana *et al*., 2005). Other plant parts such as the mid-rib and stalk were given little or no attention. In the present study the chemical and physiological properties as well as the soda pulping characteristics of the mid-rib, pseudostem and stalk of *Musa paradisiaca* were investigated. This was to provide basic information on the prospects of using these sampled parts as raw material for pulp and paper production in Nigeria.

MATERIALS AND METHODS

Musa paradisiaca plants were collected at the Department of Agronomy of the University of Ibadan. The study was conducted between 2002 and 2004. The plants were sampled at three different levels, namely, pseudostems, stalks and mid-ribs. The sampled parts were cut into chips of about 2-4 cm, sun-dried and stored at room temperature in a polythene bag. The specific gravity was determined using representative samples from each plant part in accordance with the ASTM standard procedure designated D 2395-89 method.

The fiber dimension were taken at the Forest Resources Management Department while the chemical composition and soda pulping were carried out at the

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Chemistry Department of the University of Ibadan. Fiber dimension were measured by reducing some representative chips of the plant into splints of about 20-40 mm. The splints were placed in a mixture of equal volume (1:1) of glacial acetic acid and 50% hydrogen peroxide in a covered bottle. The macerated splints were disintegrated by shaking to release the fibers. The released fibers were mounted on slides and the fiber length (L), fiber diameter (D), lumen width (d) and cell wall thickness of about 30 fibers were measured under a Reichert visopan projector. The following morphological indices were determined from these measurements:

Relative fiber length = L/D
Flexibility coefficient (%) = (d/D) × 100
Where: L = Fiber length
D = Fiber diameter
d = Lumen width

The proportion of the chemical constituents that affects the characteristics of the plant were determined on ground samples of each plant part using standard methods. The ash content and solubilities of the samples in alcohol-benzene, water and one-percent caustic soda were determined by the ASTM standard methods. Kurschner-Hoffer method was used for the cellulose determination, while the TAPPI standard method was used for the lignin content.

The samples were digested in a 10 L electrically heated stainless steel digester design after the method of Grant (1961). The plant chips were charged into the digester with the required amount of chemical solution at liquor to solid (LS) of 7:1. The digester was heated to the operating temperatures (150 and 170°C), which was then maintained throughout the experiment for the different cooking times (30-150 min. At the end of each cooking scheme, the pulp was washed several times with water and dried at 102°C in the oven in order to determine the yield. The pulps were analyzed for Kappa number as described in TAPPI T236CM-85 1993. The Residual Klason Lignin (RKL) was estimated from the relationship:

RKL = Kappa number * 0.13 (TAPPI, 1993).

RESULTS

The results of the fiber characteristics and chemical composition of *Musa paradisiaca* are presented in Table 1 and 2. Figure 1 and 2 showed the effects of the

Table 1: Chemical composition of the mid-rib, pseudostem and stalk of *Musa paradisiaca* (% oven dry weight)

	Mid-rib	Pseudostem	Stalk
Ash	6.9	3.44	11.8
Extractives:			
Hot water	9.8	23.6	31.1
Cold water	6.4	18.0	26.9
1% NaOH	24.9	25.8	37.8
Alcohol	5.9	17.7	5.5
Alcohol-benzene (1:2)	8.2	12.8	2.3
Lignin,			
Klason	9.94	6.33	8.5
Soluble lignin	2.50	1.02	2.7
Cellulose,			
Kurschner-Hoffer	53.07	48.01	40.8

Table 2: Physical property, fiber characteristics and morphological indices of *Musa paradisiaca*

	Mid-rib	Pseudostem	Stalk
Specific gravity	0.31	0.29	0.4
Fiber dimensions			
Fiber length (mm)	4.0	4.2	2.9
Fiber diameter (μm)	31.7	31.3	37.5
Lumen width (μm)	13.2	19.4	20.6
Fiber wall thickness (μm)	9.3	6.0	8.5
Morphological indices			
Flexibility coefficient	42	62	55
Slenderness ratio	127	133	773

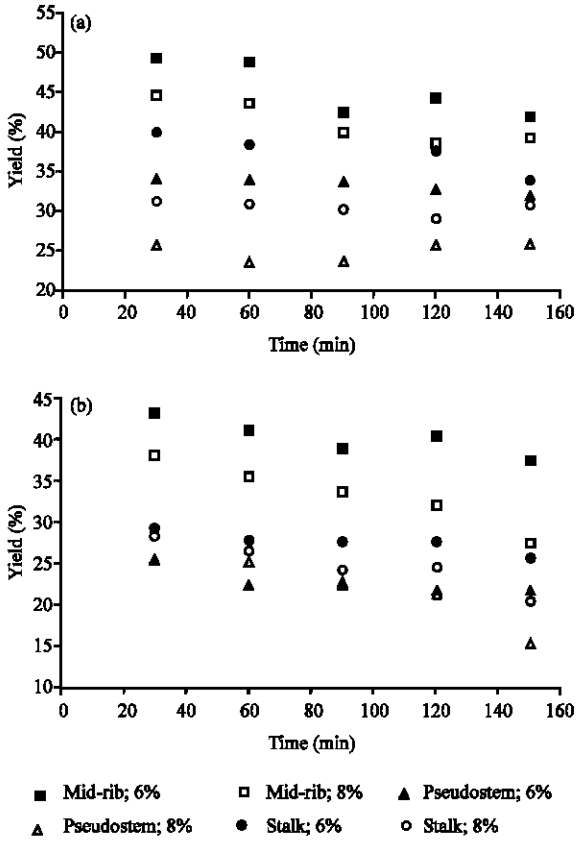

Fig. 1: Yield versus time plots of the soda pulping of *Musa paradisiaca* at (a) 150°C and (b) 170°C

Table 3: Combine effect of time and temperature on the pulp yields, residual lignin and carbohydrate contents of the *Musa paradisiaca*

Sampled parts	NaOH (%)	Cooking temperature	Time (min)	Pulp yields (%)	Residual lignin (%)	Carbohydrate (%)
Mid-rib	6	150	150	41.8	5.27	36.5
		170	30	42.9	3.20	39.8
	8	150	150	39.2	3.47	35.8
		170	30	38.0	1.57	36.5
Pseudostem	6	150	150	31.9	3.01	28.9
		170	30	25.4	2.59	22.8
	8	150	150	25.9	2.61	23.3
		170	30	25.3	3.37	21.9
Stalk	6	150	150	33.8	1.82	32.0
		170	30	29.2	1.37	27.8
	8	150	150	30.7	1.42	29.3
		170	30	28.3	1.74	26.6

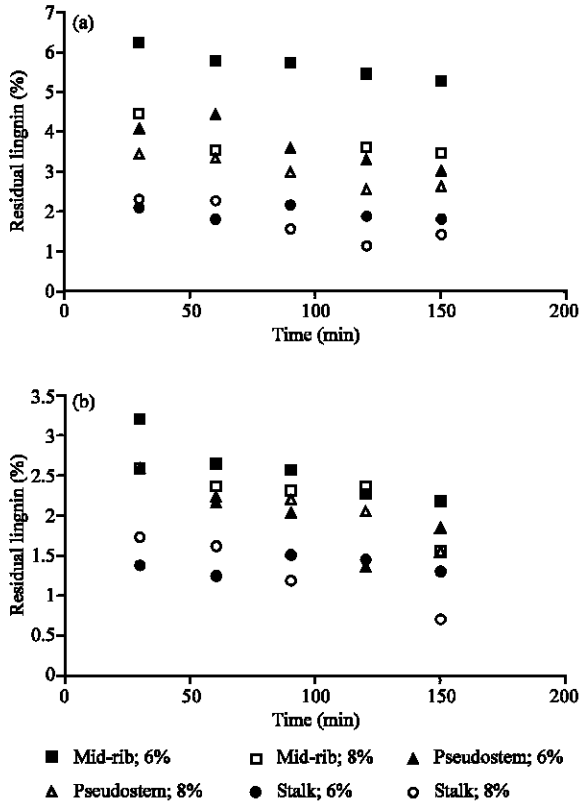

Fig. 2: Residual lignin versus time plots of the soda pulping of *Musa paradisaica* at (a) 150°C and (b) 170°C

process variables on the pulp yields and residual lignin contents, respectively. The combine effects of time and temperature on the pulp yields, residual lignin and carbohydrate contents of the *Musa paradisiaca* are summarized in Table 3 while the effects of anthraquinone addition on the pulp yields and residual lignin are illustrated in Fig. 3.

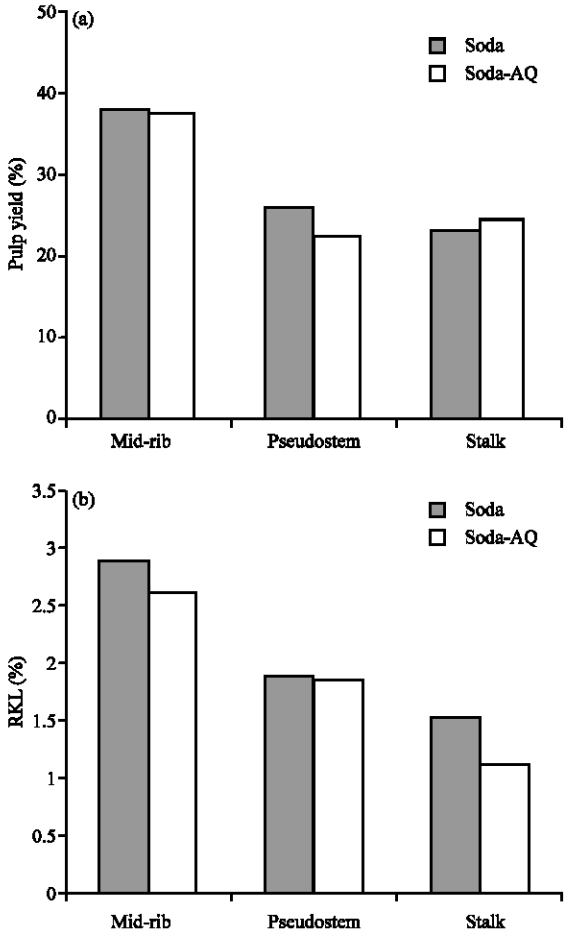

Fig. 3: Effect of Anthraquinone addition on: (a) pulp yield and (b) RKL of soda pulps

DISCUSSION

Fiber dimension: The specific gravity (Table 1) varied slightly according to the sampled parts with the stalk having the highest value (0.40 g cm^{-3}) while the pseudostems had the least (0.29 g cm^{-3}). The specific gravity falls within the low density value classification of 0.20-0.40 g cm^{-3} (Chittenden and Palmer, 1990). This implied easy penetration of cooking chemicals. However, large volume of materials would be needed for pulping because of the bulkiness of the plant. The sampled parts may be combined during pulping due to the close values of their specific gravity.

The average fiber lengths of all the sampled parts examined were relatively long, which means that strong papers would be produced from them (Taiz and Zeiger, 1991; Mc Dougall *et al*., 1993). It was observed that the stalk gave the highest fiber diameter and lumen width. Since fibers with large lumen and thin walls tend to

flatten to ribbons during pulping and paper making (Wood, 1981), papers made from the stalk is expected to exhibit good contact between fibers and consequently good strength characteristics.

Chemical characteristics: The values of the extractive contents were higher than usual for commercial pulpwood and tropical species but similar to those reported for some annual plants (Khristova and Karar, 1999; Law *et al*., 2001). The high values 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. High values of extractive contents are not desirable for pulping processes as they may impacts colour to the resulting pulp thus increasing the bleaching load. A detail analysis of the extracts may reveal its possible outlets in pharmaceuticals and other related applications. The ash content of the *Musa paradisiaca* was also high with the stalk having the highest (11.8%) while the pseudostem had the least (3.44%). Similar values were reported for banana crops in Egypt and South-Korea (Heikal and Ibrahim, 1977; Noronha *et al*., 1999). The ash contents may affect normal liquor consumption or give problems at waste liquor recovery. The lignin contents were generally low and desirable. It is an indication of easy delignification, short cooking cycle and low chemical consumption. The cellulose contents were indicators of average but tolerable pulp yields similar to 45.1-50% of acacia nilotica species (Khristova and Karar, 1999), 45.7-53.8% of kenaf (Khristova *et al*., 2002) and 49.20% of bagasse, (Belayachi and Delmas, 1997).

Pulp yields: As expected, there was a general decrease in the yield, which is caused by an increase in the cooking time at a constant temperature and alkali charge. The mid-rib gave the highest pulp yields in all the cooking conditions, followed by the pseudostem and then the stalk. The order was expected so because the mid-rib had the highest cellulose but least extractive content.

Two different phases were recognized with respect to the rate of dissolution of initial material as illustrated in the yield versus time plots shown in Fig. 1. The first phase called the easily soluble phase occurred predominantly in the first few minutes of the cooking (about 30 min). This was followed by the second phase, the less easily soluble phase, which proceeds at a slower rate (Iglesias *et al*., 1996). About half of the initial material dissolved in the rapid phase and this may not be unconnected with the high extractive contents of the sampled parts.

Delignification: There was a relative increase in delignification as the concentration of the cooking Liquors is increased. The stalk was the most delignified, followed by the pseudostem and the mid-rib. As shown in Fig. 2, two phases of lignin dissolution similar to Fig. 1 were obvious. The existence of such phases of delignification is a common behaviour with other pulping systems using different agents and methods (Labidi *et al*., 1993; Currelo *et al*., 1995) and seems to be related to the dissolution of lignin fractions of different structural origin in vegetable tissues. The initial phase of fast bulk delignification is regarded as caused by the rapid initial swelling of lignocellulosic residue in the cooking liquor and subsequent rapid hydrolysis of the polysaccharide exposed and corresponding solubilisation of the exposed lignin. In the latter stage, polysaccharide and lignin exposure is slow, thus the rate of delignificaion are much smaller even when the treatment duration are extended (Katzen *et al*., 1980).

Combined effect of time and temperature: Results of some pairs of pulps are presented in Table 3. One of each pair was cooked at low temperature (150°C) and the other at a higher temperature (170°C) but for a shorter time. It would be observed from Table 3 that the pulp yield and the residual lignin of some of the pairs are relatively close. Most of the cooks made at 150°C are associated with higher residual lignin and pulp yield while the reverse is the case with cook made at 170°C. The result showed that a decrease in the cooking temperature results in a higher amount of residual lignin and a longer cooking time to reach the transition point between the bulk and residual delignification. It also indicated that cooking for a long time at very low temperature results only in a small increase of the total yield over that obtained at a high temperature for a short time. The influence cooking temperature and time on the 'crude carbohydrate' content was also depicted in the able above. The term crude was used here because the values were estimated from the difference between the residual lignin and the pulp yield without any correction for ash and the extractives. The purpose of this section is to indicate the advantageous condition under which the carbohydrate would be protected especially if the ultimate aim is to selectively remove the lignin content from the pulp by an efficient bleaching process.

Under the two cooking schemes illustrated in Table 3, two conclusions were apparent. One where a low temperature preserves a higher percentage of carbohydrate at high alkali charge and the other

where a high temperature preserves a relatively high percentage of carbohydrate at the same alkali charge. The former is common with the pseudostem and the stalk pulps while the latter is more prominent with the mid-rib pulps. Whatever is the case, carbohydrate removal is greatly influenced by the cooking temperature.

Anthraquinone addition: The degree of delignification as expressed by the Residual klason Lignin (RKL) was lowered with anthraquinone dose of 0.1% in the oven dry sample. However, anthraquinone addition had a negative influence on the pulp yield of the mid-rib and the pseudostem. The reason for this is not yet clear. Although the effect of anthraquinone on the residual lignin was found less effective than with other plants (Khristova and Tissort, 1995), it still showed an appreciable beneficial effect. As a redox catalyst, anthraquinone stabilizes the carbohydrates by the oxidation of the reducing end groups and accelerates delignification by reducing lignin or some solubilized lignin fragments (Blain, 1993).

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