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Physical, Chemical and Anatomical Features of Some Promising Hardwoods for Fiber Production

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Abstract- Wood samples from each of *Leucaena leucocephala*, *Moringa peregrine*, *Ceiba pentandra* and *Calotropis procera* were macerated using Franklin method to evaluate their suitability as sources of cellulosic fibers (CFs). Chemical and anatomical characterizations of wood as well as its specific gravity (SG) were determinrd. The lignocellulosic resources (LRs) examined differed significantly in relation to all the properties studied. *L. leucocephala* wood is the best fibrous crop among the species studied due to it had the highest SG, holocelluloses content (HC) and fiber yield (FY) as well as the lowest lignin content (LC) and ash content (AC). *M. perigrina* had the highest LC, the shortest and the widest fibers. *C. pentandra* had the lowest total extractives content (TEC) and the longest fibers. Although *C. procera* possessed the lowest HC and FY and the highest TEC and AC, its utilization as a cellulosic precursor is not closed due to it has the lowest LC. The macerated fibers produced from the four species had low aspect ratio. Vessels of the four LRs are characterized by scalariform pitting system and *L. leucocephala* vessel has simple perforated plates.

Keywords- *Hardwood, Prosenchyma Cells, Maceration, Chemical Analysis of Wood, SEM*

I. INTRODUCTION

Wood is the most important precursor for the pulp and paper industry. The global wood fibers are the original source of over 98% of the fibrous constituent of paper in the world. Pulp is a product that is derived from wood and other cellulosic plant materials by mechanical or chemical treatment. The continued growth and economic considerations of the pulp and paper industry depends on availability of wood with propitiate quality and cost [1].

Cellulosic fibers (CFs) macerated from lignocellulosic natural resources have been attracting much attention due to their biodegradability, availability, eco-friendliness and ease handling and manufacturing [2]. *Leucaena leucocephala* is a multi-purposes tree that can be adapted to various environments. It has gained a great attention for its utilization commercially as a precursor for pulp and paper as well as packaging industries [3].

Moringa peregrina is widely grown in Saudi Arabia as a native tree as well as Iran and India. It has a wide range of utilization in agriculture as animal fodder, and human nutrition and health as a medicinal plant [4] as well as industry such as fixed oil extraction from seeds. Saudi Arabia is one of the main habitats of *M. peregrina* in the Middle East [5]. The *Moringa* is a fast-growing evergreen or deciduous multipurpose tree species comprised of 13 species**.** Due to its numerous economic importance, easy propagation and sustainability, the plant is suitable for cultivation in Saudi Arabia. The plant is highly tolerant to drought and is widely cultivated in arid and semiarid regions [6]. It was indicated by Hindi [7] that M. peregrina can be used to as a cellulosic resource to fill the gap between fiber production and demand.

Ceiba pentandra known as kapok or silk-cotton tree is ranked among the largest tropical trees in America and Africa. Importance of its wood has increased commercially due to its suitability for light constructions and plywood, easy for processing. Its wood is diffuse-porous, light brown, soft, straight-grained, and light in weight. Its specific gravity was ranged from 0.09 to 0.3 [8]. In Jeddah, at the campus of King Abdullaziz University, it gave good growth and pods yield when cultivated depending on treated sewage water as an ornamental tree.

Calotropis procera (Family: Asclepiadaceae) is a desert plant known as calotrope, usher or milkweed and is adapted to a wide range of different environments. Its wood is termite-proof and can be used for roofing, building huts and as a cellulosic fibers precursor. Chemical constituents of the calotrope wood showed high contents of ash (5.4%), lignin (18.5%) and low contents of total extractives (11.9% and holocelluloses (61.2%). Accordingly, the quality of its fibers is lower than some of other conventional fibers such as cotton and kapok. This is due to its high content of ash that negatively impacted the chemical recovery process and, therefore, could constitute a serious drawback [9].

The presence of permeable structure in the cellulosic resources was very important for the chemical reagents penetration required for the various chemical industries. The mean value of pore diameter for the crude cellulosic resources were estimated to be 4.01 µm for macerated woody fibers of *Leucaena leucocephala* [10].

The objectives of this study were therefore as follows:

- Determination of the specific gravity as well as chemical and anatomical properties of wood among the four lignocellulosic resources.
- Comparisons of the different wood properties between the species studied.

II. EXPERIMENTAL

A. *Raw material*

Four lignocellulosic resources, namely *Leucaena leucocephala* (Lam) de wit (Figure 1), *Moringa peregrine* Forssk. ex. Fiori (Figure 2), *Ceiba pentandra* (L.) Gaertn. (Figure 3) and *Calotropis procera* (Ait). Ait. (Figure 4) were used as sources of cellulosic fibers (CFs). The selected species are adapted to the arid and semi-arid conditions in the Western region of Saudi Arabia and are suitable for afforestation programs as multipurpose species. In addition, these species have different physical, chemical and anatomical characteristics and are expected to give good qualities for fibers production.

Species selection and samples processing were done during May-June 2018 based on the trees and shrubs grown in the Agricultural Research Station, King Abdulaziz University (KAU), Hada Al-Sham (about 120 km Southeast Jeddah and at a latitude of 21° 46'.839N and a longitude of 39° 39'.911E and above the sea level by 206 m), except for kapok trees that were selected from the KAU-campus at Jeddah Governorate. The chosen sites have a sandy soil. Reference samples were identified through flora of KSA [11]. The age of the chosen species were about 12 years-old except for milkweed that was about 3 years-old. The diameter of branches outside bark of the selected species ranged from 15-45 cm. Four healthy trees/shrubs were chosen from each species. Accordingly, 16 plants were selected to represent the four species specified for this study. From each of the selected species, two healthy primary branches were taken randomly to represent its tree/shrub.

B. *Samples Isolation*

For each of the selected trees/shrubs, the selected branches were cut at height of 10 cm above its base level at which the main stem is branched. The height between the branch base and ground level was about 40 cm for *Leucaena sp*. and *Calotropis sp*., and ranged between 140-170 cm for *Moringa sp*. and *Ceiba sp*. From each cut branch, one disc of about 20 cm along the grain was cut beginning from its base. The removed disc was sawn into a diametric strip in dimensions of 10 cm radially and tangentially and 20 cm longitudinally. The resulted strip was split toward its center into two diametric strips (4× 4× 20 cm^3 each) excluding the pith. The obtained strips were longitudinally sawn into sticks (1× 1× 20 cm^3 each), air dried, oven-dried at 100^0 C for 24 h and stored until used for determinations of wood properties and production of CF's (Figure 5).

1) *Sample Preparation for Characterization*

About 100 g of air-dried wood from each of the four trees/shrubs selected from each species were converted into meal by a suitable grinder. Then, wood meal was screened using different sieves depending on the standard methods for wood properties determinations as explained at each test.

Samples of about one gram each were taken randomly from the screened wood meal and used to determine the wood properties as follows:

- Three samples from each tree were used for the determination of ash content (3 g/per tree).
- Three samples for the determination of total extractives content (3 g/tree). Then, after extraction, each of them was used to determine the lignin content.
- Three samples for the determination of holocelluloses content (3 g/tree).

For specific gravity (SG) of wood, five cubic samples (1×1×1 cm^3) from each tree were used.

2) *Sample Preparation for Fiber Maceration Process*

About fifty grams of wood chips from each of the four species was delignified separately by applying Franklin method. The digestion agent was a mixture of hydrogen peroxide (35%) and glacial acetic acid in a ratio of 1: 1. The mixture was kept, with a compacted cotton stopper, in an oven at 60 °C for 24 h or until clear fiber-separation that featured by the white aspect [12]. The macerated fibers were removed, washed, air-dried and characterized.

C. *Results and Discussion*

Results of the specific gravity (SG) and chemical characterization, namely total extractives content (TEC), lignin content (LC), holocelluloses content (HC), and ash content (AC) of wood for the four species are listed in Table 1.

In addition, Fiber length (FL), fiber width (FW), aspect ratio (AS) and fiber yield (FW) are presented in Figures 11-14, respectively. It was indicated from the statistical analyses the four materials tested were significantly different among the properties determined.

TABLE I. MEAN VALUES* OF FIBER LENGTH (FL), SPECIFIC GRAVITY (SG), TOTAL EXTRACTIVES (TEC), LIGNIN (LC), HOLOCELLULOSE (HC) AND ASH (AC) CONTENTS OF SOME SAUDI LIGNOCELLULOSIC NATURAL RESOURCES.

Lignocellulosic material	SG	TEC%	LC%	HC%	AC%
Leucaena leucocephala wood	0.597 a	9.74 e	18.86 e	70.82 b	1.22 ef
Moringa perigrina wood	0.430 bc	8.52 f	28.26 c	59.64 d	2.73 d
Ceiba pentandra wood	0.392 cd	5.49 f	24.17d	69.69 b	0.646 f
Calotropis procera wood	0.405bc	11.9 de	18.5 e	64.2 c	5.4 c

*Means within the same colmn followed by the same letter are not significantly different according to LSD at P ≤ 0.05.

III. SPECIFIC GRAVITY (SG) OF WOOD

The SG of wood was affected significantly by species. The mean values of the SG increased from 0.392 for *Ceiba pentandra* to 0.597 for *Leucaena leucocephala*. Woods with higher SG values have more cell wall materials that can be used industrially comparing to those with lower SG. In addition, lower SG is inversely correlated with wood permeability. Porous materials permit to pulping reagents to penetrate more easily into cell walls of lignocellulosic tissues. However, the quality of a final fibrous product and the cost of production specify the required SG value of a certain wood precursor [8].

However, the woody materials studied had low specific gravity and subsequently had high permeability. Accordingly, they can be forced towards such industries such as particleboards or pulp manufactures [7].

A. Chemical Constituents of Wood

1) Total Extractives Content (TEC) of Wood

The lignocellulosic resources examined differed significantly due to their of TEC. As shown in Table 1. *Calotropis procera* wood had the highest TEC value (11.9 %) followed by *Leucaena leucocephala* (9.74 %), and *Moringa perigrina* (8.52 %). On the other hand, *Ceiba pentandra* wood possessed the lowest TEC value (Table 1). The highest TEC content for *Calotropis procera* wood may be attributed to its open anatomical structure that easily accessible for the chemicals [20]. Industrially, accumulation of high amounts of extractives into a lignocellulosic tissue is un-preferred due to their interference with the chemical reagents used for delignification and separation of the fibers [7,18]. In addition, there is another defect for materials possessing high TEC as reported by *Lopez et al*. [21] in which pulp yield is negatively correlated with ethanol-benzene and water soluble fractions present in wood. Accordingly, species with lower TEC are expected to yield more fibers than those with higher TEC. For the species studied other than *Ceiba pentandra*, one of three options may be selected: a) organic solvent-extracted before maceration, b) changing the maceration reagents after a suitable treatment period, and c) increasing strength of the reagents used for the chemical process [7,18].

2) Lignin Content (LC)

Statistical analysis revealed a significant difference between the four species in relation to the LC. It can be seen from Table 1 that *Moringa perigrina* had the highest LC (28.26 %), approaching to that for softwoods as well as to typical contents presented in annual plants, non-woods and hardwoods, while quite higher than the other resources studied. On the other hand, *Leucaena leucocephala* and *Calotropis procera* woods contained the lowest LC (18.86 % and 18.5 %, respectively) which is below that for hardwoods. It is worth mentioning that low LC in lignocellulosic material reduces pulping time and amounts of chemical reagents compared to those resources with high LCs [21,22]. In addition, higher LCs are expected to consume more chemical reagents upon the pulp industry [20]. The results are in agreement with Lopez *et al*. [21], Megahed *et al*. [23], Hindi [7,12,18].

3) Holocellulose Content (HC) of Wood

The HC results showed that the natural resources studied were significantly different. *Leucaena leucocephala* and *Ceiba pentandra* had higher HC values (70.82 % and 69.69 %, respectively). This shows their importance as fibrous crops for many applications such as cellulose derivatives, fiber-reinforced composite materials, and papermaking [9]. On the other hand, although *Calotropis procera* possessed the lowest HC value (64.2 %) as shown in Table 1, its utilization as a cellulosic precursor is not closed.

4) Ash Content (AC) of Wood

The lignocellulosic resources examined were significantly different in their AC. It is clear from Table 1 that *Ceiba pentandra* and *Leucaena leucocephala* contained lower ash (0.646 and 1.22 %, respectively) than the other resources. It is worth to mention that lignocellulosic materials with high AC such as *Calotropis procera* (5.4 %) will negatively impact the chemical recovery process after fiber maceration and consequently may constitute a serious drawback [9]. However, the results were in agreement with those arising from other literatures [7,18,21,22,24,25,26].

The wood species examined have more suitable properties for fiber products than the *Calotropis procera*. Furthermore, *Ceiba pentandra* and *Leucaena leucocephala* are the best resources due to their high contents of HC, and their lower TEC, LC and AC comparing with the other resources examined. Irrespective of their higher contents of LC and AC as well as relatively lower HC, wood of *Calotropis procera* could become important sources for fibers, chemicals and other industrial products.

B. Anatomical Features

1) Optical Microscopy

The morphogical aspects of the cellulosic fibers macerated from the four lignocellulosic resources are presented in Figure 1. The statistical analyses indicated that the four lingocellulosic materials examined were significantly different among the dimensional properties (fiber length, width and aspect ratio) of the species studied. Theses difference may be attributed to the genetic difference between these species [27].

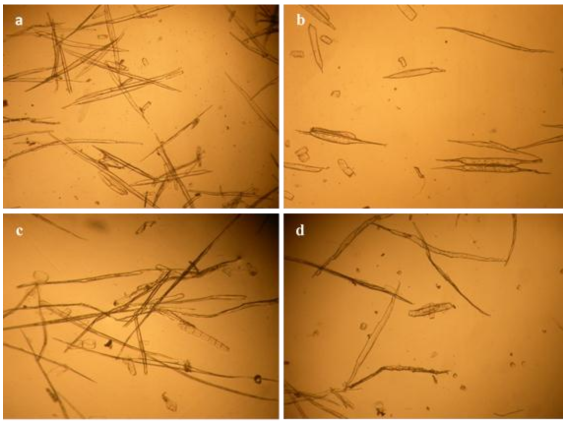

Figure 1. Optical images of macerated fibers from the species studied: a) *Leucaena leucocephala*, b) *Moringa perigrina*, c) *Ceiba pentandra*, and d) *Calotropis procera*.

a) Fiber Length (FL)

A statistical difference was found between the species studied in relation to their FL. It is obvious from Figure 2 that *Ceiba pentandra* fibers had the highest FL value (1.188 mm), while the FL of *Moringa perigrina* was the lowest (0.57 mm).

Since pulp strength is greatly affected by fiber length [28], paper manufactured from *Ceiba pentandra* (Figure 2) is expected to give higher paper quality than the others with shorter fibers, especially when blended with other softwood fibers in papermaking purposes [18]. The FL results agree with the previously published by other researches using other wood species such as Kherallah and Aly [29], Megahed *et al.* [23], Diaz *et al.* [22], Hindi [7,18,30].

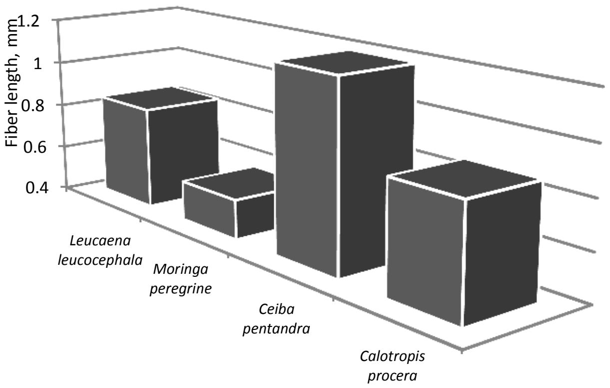

Figure 2. Length of the fibers macerated from the four lignocellulosic resources**.**

b) Fiber Width (FW)

The macerated fibers obtained from the four species were statistically different due to their FW. Regarding Figure 3, *Moringa perigrina* and *Calotropis procera* had the highest FW values (203.63 and 203.93 μm, respectively). On the other hand, *Leucaena leucocephala* had the lowest FW value (173.32 μm).

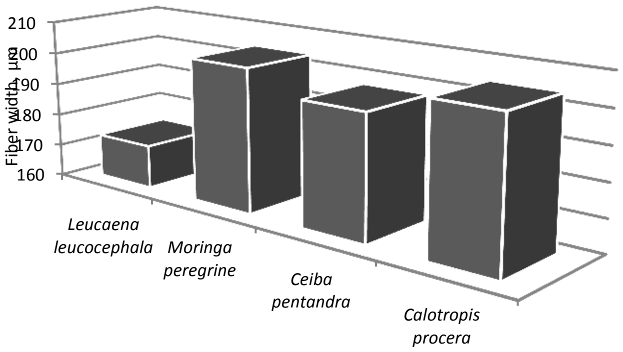

Figure 3. Width of the fibers macerated from the four lignocellulosic resources

c) Aspect Ratio (AS)

The four precursors examined exhibited different behavior regarding to the AS. However, the macerated fibers produced from the four species had low AS with a range from 2.8 for *Moringa perigrina* to 6.02 for *Ceiba pentandra* (Figure 4). Using cellulosic fibers possessing high aspect ratio means that the fibers have a high tendency for clumping together when are suspended in water. To avoid fiber flocculation that may be arisen in this case, the fiber concentration in the pulp solution must be less than about 0.01% [31].

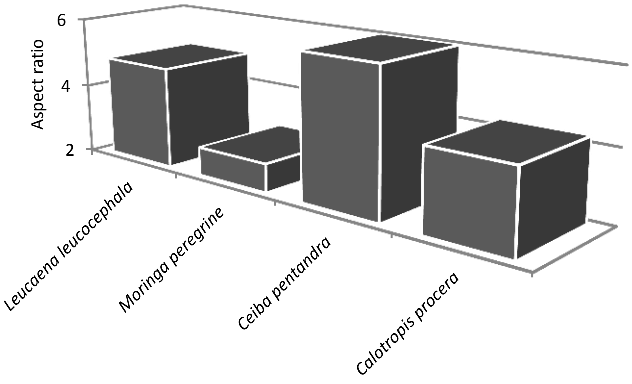

Figure 4. Aspect ratio of the fibers macerated from the four lignocellulosic resources**.**

2) Scanning Electron Microscopy (SEM)

The anatomical features of the four lignocellulosic resources are presented at Figure 5 (*Leucaena leucocephala*), Figure 6 (*Moringa perigrina*), Figure 7 (*Ceiba pentandra*), and Figure 8 (*Calotropis procera*). It is obvious that all the wood tissues belong to the hardwood anatomy in which they are porous tissue due to possessing vessel elements. It is worth mentioning that hardwood contains two types of prosenchyma cells, namely vessels and fibers as longitudinal elements [32]. In addition, the ray parenchyma, the transvers element, can be seen from the radial sections presented at Figures 6a and 7a,b. Furthermore, the fusiform ray are obvious in the tangential section of *Calotropis procera* wood (Figure 8). The border pitting system for *Leucaena leucocephala*, *Moringa perigrina*, *Ceiba pentandra* and *Calotropis procera* is clear (Figures 5-7) and well-known to act as a transverse pathway for water and gases between prosenchyma cells within the woody tissue. Furthermore, the semi-border pits that connect parenchyma cells with adjacent prosenchyma cells can be noticed for *Moringa perigrina*, *Ceiba pentandra* and *Calotropis procera* (Figures 6-8). In addition, the parenchyma cells characterized by their thin walls are connected transversely by simple pits.

a) Leucaena leucocephala

The SEM results of the *Leucaena leucocephala* wood tissue is presented at Figure 5. For the transverse section presented in Figure 5a for crude wood tissue, vessels and fibers cells are clear with a noticeable border pits. In addition, for the macerated fibers, a vessel with obvious scalariform pitting system and a clear noticeable simple perforated plate is shown (Figure 5b).These openings, cavities, and the amorphous regions within the cell wall microfibrils exhibit their own permeable structure for each cellulosic resource [10].

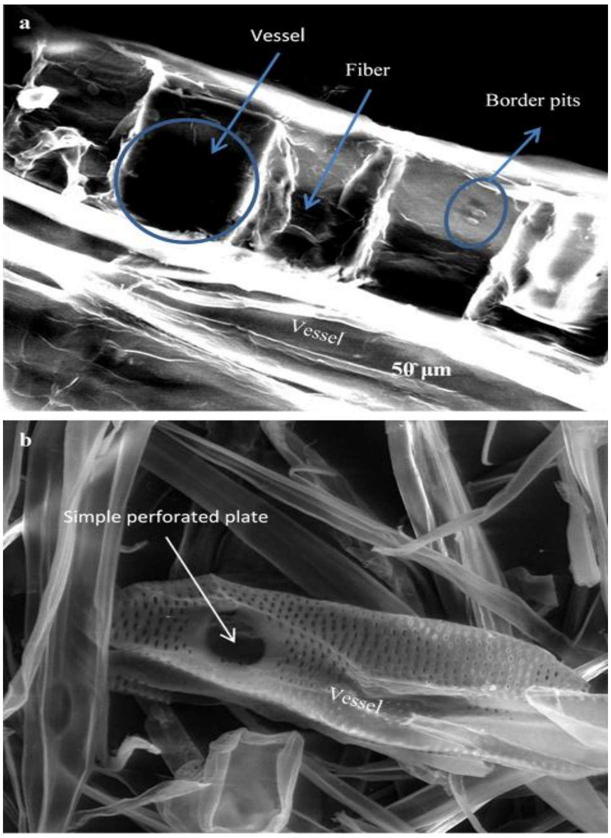

Figure 5. SEM micrograph of *Leucaena leucocephala* wood: a) transverse section showing vessels and fiber cells, and b) A vessel featured by scalable-border pitting system and a simple perforated plate.

b) *Moringa perigrina*

The radial section of *Moringa perigrina* wood investigated by SEM (Figures 6a and b) shows vessels and fibers cells that characterized by the scalable-border pitting system that increases its wood permeability. In addition, ray parenchyma can be seen in Figure 6a.

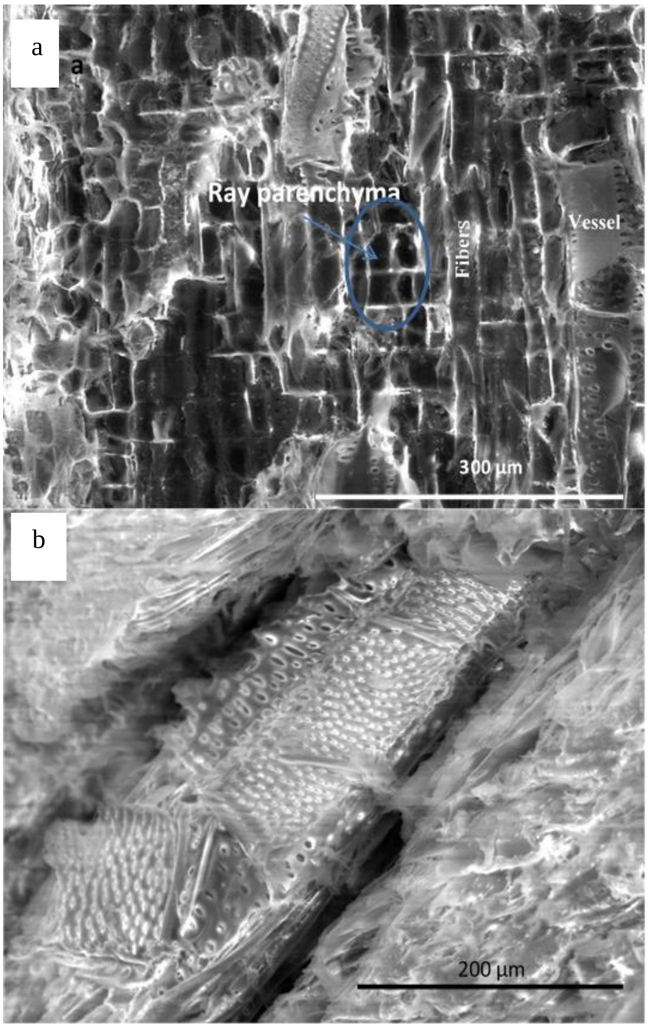

Figure 6. SEM micrograph of radial section of *Moringa perigrina* wood: a) Vessels and fiber cells, and b) A close up of a vessel with scalable-border pitting system.

c) *Ceiba pentandra*

The micro-anatomical characteristics of *Ceiba pentandra* wood as a member of hardwood architecture design is shown in Figure 7. The radial section shows the longitudinal vessels (Figures 7a) and the ray parenchyma (Figures 7a and b). The pitting system responsible for transversal movements of fluids within wood tissue is also clear in Figure 7b.

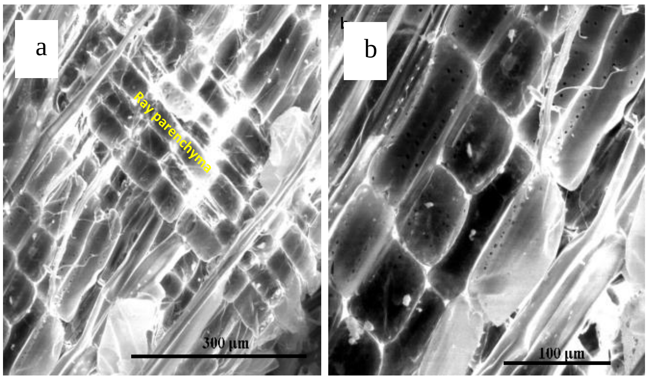

Figure 7. SEM micrograph of *Ceiba pentandra* wood: a) Radial section, and b) Ray parenchyma showing simple and semi-border pits.

d) Calotropis procera

The microstructure of *Calotropis procera* investigated by SEM-tangential section is presented at Figure 8. It is obvious that it lies within the anatomical scope of hardwood species, since it is characterized by presence of prosenchyma cells of both vessels and fibers. It was indicated by Hindi [18] that fiber cells of *Calotropis procera* had thin walls and wide lumens occupying most of the transverse section area [18].

Furthermore, its wood is a diffuse porous in which the vessels (pores) are even-sized, so that the water conducting capability is scattered throughout the ring instead of collected in the earlywood. In addition, parenchyma cells and fusiform ray are also included in the micrograph. The ray is characterized by its narrow width, differed from uniseriate to tetra-seriate with different lengths as well as its heterogeneity in which containing both upright and procumbent cells. Furthermore, it can be seen from Figure 8 presence of white flakes from dried latex when it flooded from pores to the outer atmosphere adjacent to the cut surface [18]. a high broad multiseriate ray contacting with dried latex flakes.

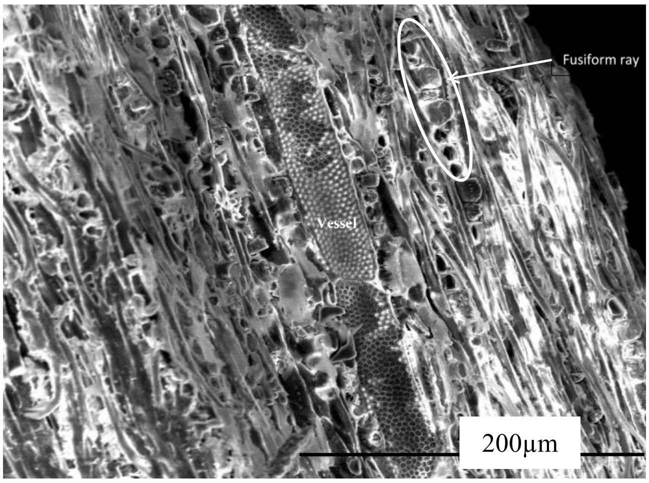

Figure 8. Tangential section in a SEM micrograph of *Calotropis procera* wood.

3) Fibers Yield (FY)

The FY values obtained from the four species were gradually decreased from Calotropis procera (39.2 %) up to Leucaena leucocephala (55.46 %) as indicated from Figure 9. This finding can be attributed to the logic relationship between the LC, TEC and AC contents of the wood precursor and their FY. The higher fiber productivity of the lignocellulosic materials will increase the interest in such materials for fiber production.

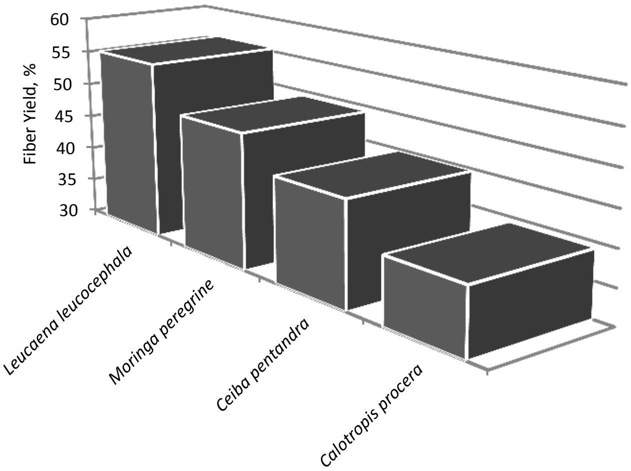

Figure 9. Fibers yield macerated from the four lignocellulosic resources

IV. CONCLUSIONS

- The lignocellulosic resources examined differed significantly in relation to all the properties studied.
- *Leucaena leucocephala* wood is the best fibrous crop among the species studied for due to it had the highest specific gravity, holocelluloses content and fiber yield as well as the lowest lignin and ash contents.
- *Moringa perigrina* had the highest lignin, the shortest and the widest fibers.
- *Ceiba pentandra* had the lowest total extractives content and the longest fibers
- Although *Calotropis procera* possessed the lowest holocelluloses content and fiber yield and the highest total extractives and ash contents, its utilization as a cellulosic precursor is not closed due to it has the lowest lignin content.
- The macerated fibers produced from the four species had low aspect ratio.
- The four species belong to the hardwood that contains two types of prosenchyma cells (vessels and fibers) as longitudinal elements.

- The vessels and fiber cells of the four lignocellulosic resources are characterized by scalariform pitting system and *Leucaena leucocephala* vessel has simple perforated plates.

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