JEB
Journal of Environmental Biology

Journal Website : www.jeb.co.in
E-mail : editor@jeb.co.in
ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

Anatomical and physical characterisations of some lignocellulosic residues and their suitability for fibre production

M.A. Abdel-Aal[1,2], R.A. Nasser[1,3]*, P.R. Khan[1] and H.A. Al-Mefarrej[1]

[1]Plant Production Department, Food and Agriculture Sciences College, King Saud University, Riyadh, 11451, Saudi Arabia
[2]Forestry and Wood Technology Department, Horticulture Research Institute, Agricultural Research Center, 21545, Egypt
[3]Forestry and Wood Technology Department, Faculty of Agriculture (El-Shatby), Alexandria, 21545, Egypt
*Corresponding Author's Email : nasser67@ksu.edu.sa

Abstract

Lignocellulosic residues cause many environmental problems; therefore, conversion of these residues to pulp and paper production will reduce these problems in Saudi Arabia. Residues from *Phoenix dactylifera*, *Triticum aestivum* and *Conocarpus erectus*, in addition to woody materials such as hardwood *Tamarix aphylla* and softwood *Juniperus procera*, were evaluated using anatomical characteristics to investigate the suitability of these residues for the pulp and paper industry. The results revealed that lignocellulosic residues had fibre lengths similar to or longer than hardwood fibres, but did not reach softwood fibre length because in softwood tracheids and tracheids are longer than other fibres. Fibre from lignocellulosic residues was similar to hardwood fibre, so lignocellulosic residues can be used for pulp and paper production. The fibre distribution of *C. erectus* prunings was similar to that of hardwood (*T. aphylla*), whereas distribution of *P. dactylifera* was similar to that of softwood (*J. procera*). Regarding wheat straw (*T. aestivum*), distribution of fibre was between those of hardwood and softwood. It is expected that handsheet formed from *C. erectus* and *T. aestivum* pulp would give a smoother paper, whereas *P. dactylifera* and *J. procera* pulps would be high in most strength properties than handsheet from other species because short fibres will fill the voids in the paper sheet whereas strength properties would increase with increasing fibre length.

Publication Info

Paper received:
25 September 2013

Revised received:
26 March 2014

Accepted:
04 June 2014

Key words

Fibre length, Handsheet, Hardwood, Lignocellulosic residues, Softwood

Introduction

The availability of writing material has always gone hand in hand with the development of society. The earliest medium for writing was the stone tablet. Pulp and paper have been important in the development of mankind from prehistoric days to the present time. The development of written communication has been increasing rapidly so that a day without paper is unthinkable, but now the use of paper has been expanded to encompass not only communication but also packaging and hygiene. The major consumption of wood and lignocellulosic materials in Asia and Africa is still for fuel purposes, whereas in Europe and North America these materials are predominantly used in the production of paper and board (Monica *et al.,* 2009).

The major fibre properties that are believed to strongly affect the way paper behaves are fibre length and the cross-dimensional properties, which consist of fibre width, lumen width and cell wall thickness. Fibre length is considered as one of the most important factors in characterising the raw material for papermaking, as all strength properties increase with increasing fibre length (Mohlin *et al.,* 1996; Johnston 1997); however, an increase in fibre length above 2.0 mm does not lead to significant gain in tensile and burst strength (Broderick *et al.,* 1996). An increase in fibre length above 3 mm has a markedly negative effect on stretch. A reduction in fibre length also increases the packing tendency of fibres, and hence slightly increases the sheet density and air resistance.

Saudi Arabia, like many countries in arid and semi-arid zones, is poor in natural forest (Al-Mefarrej and Nasser, 2008). The increasing demand for forest resources to be used as fuel and in wood industries leads to continuous efforts to find an alternative raw material to forest wood. Agricultural residues are renewable resources that can be utilised as raw materials by the wood industry (Almeida *et al.,* 2002 and Olorunnisola, 2008). A wide variety of agricultural residues and non-woody materials, such as midribs of date palm, wheat straw (Al-Mefarrej and Nasser, 2008), rattan (Olorunnisola, 2008) and coconut shell of babacu (Almeida *et al.,* 2002) have been studied. Fortunately, Saudi Arabia has relatively large quantities of lignocellulosic materials, including C*onocarpus* prunings and date palm residues. No data are available about the amount of *Conocarpus* tree residues, but huge quantities of C*onocarpus* biomass are produced annually through seasonal pruning. In the Kingdom of Saudi Arabia, the number of date palm trees exceed 28 million. Much of this date palm population sheds a huge quantity of plant biomass annually from seasonal pruning, which is an essential agricultural practice. The average amount of palm residues obtained per tree annually is approximately 35 kg, resulting in approximately one million metric tons of date palm biomass being wasted annually from seasonal trimming of the palm tree population in Saudi Arabia. *Tamarix aphylla* is a forest tree of a fast-growing, drought-resistant and salt-tolerant species that is planted throughout the Kingdom. This wood species constitutes a renewable resource that could be used as a source of raw wood material required for several local uses, instead of depending totally on imported woods.

In many countries, wood is not available in sufficient quantities to meet the rising demand for pulp and paper (Judt 1993). In recent years, active research has been undertaken in Europe and North America to find a new, non-wood raw material for paper production. The driving force for the search of new pulp sources was two fold: the shortage of short-fibre raw material (hardwood) in Nordic countries that export pulp and paper and, in parallel, the overproduction of agricultural crops. At the same time, consumption of paper, especially fine paper, continued to grow, increasing the demand for short-fibre pulp (Paavilainen, 1996).

Commercial non-wood pulp production has been estimated to be 6.5% of the global pulp production and is expected to increase (Paavilainen, 1998). China produces 77% of the world's non-wood pulp (Paavilainen, 1996 and Paavilainen, 1998). In China and India, over 70% of the raw material used by the pulp industry comes from non-woody plants. The main sources of non-wood raw materials are agricultural residues from monocotyledons, including cereal straw and bagasse, a fibrous residue from processed sugar cane (*Saccharum officinarum* L.). Bamboo, reeds and some grass plants are also grown or collected for pulp industry (Paavilainen 1996).

In the current study, available residues, *i.e.,* pruning of *Conocarpus erectus,* midribs of *Phoenix dactylifera* and straw of *Triticum aestivum* were used. In addition, hardwood species *Tamarix aphylla* and softwood species *Juniperus procera* were also used to compare the properties of lignocellulosic residues with their wood pulp. The objective of this study was to evaluate the fibre properties of some lignocellulosic residues, including the length, diameter, slenderness ratio and wall thickness of fibres for pulp and paper production.

Materials and Methods

Raw materials : Residues such as date midrib fronds (*Phoenix dactylifera*), wheat straw (*Triticum aestivum*) and tree prunings of *Conocarpus erectus* were collected during 2012 from differen locations in the Kingdom for pulp and paper production. Woody materials, i.e. hardwood *Tamarix aphylla* and softwood *Juniperus procera,* were also collected from Al-Kharj and Al-Qassim. After collection, the materials were fragmented into small pieces using a band saw.

Fibre length determination : Each specimen assigned for fibre length determination was macerated in glacial acetic acid and 30% hydrogen peroxide (1:1 by volume) at 60°C for approximately 48 hr. After delignification was completed, the material was washed with distilled water several times and reduced to individual fibres by mild shaking. The macerated fibres at each sampled point were stained with safranin dye and their lengths were measured. For each point, 50 randomly selected fibres were measured in wet condition to the nearest 0.01 mm, using a fibre image projector (Franklin, 1945).

Anatomical examination, measurement of fiber diameter and wall thickness : Small pieces of lignocellulosic and woody materials were collected and fixed on the spot in formaldehyde-acetic acid-alcohol (FAA) (Berlyn and Miksche 1976). Fixed samples were cut down to suitable sizes and preserved in alco-glycerol solution (50% ethanol + 50% glycerol, V:V) for softening. Cross-sections were prepared for microscopic examination according to standard techniques using a slide microtome. These sections were examined for their main anatomical features (Moseley, 1948; Panshin and de Zeeuw, 1970; Kandeel, 1971 and Kandeel *et al.*, 1977). 50 measurements of fibre (or tracheid) length were taken for all samples, in addition to 15 measurements of fibre (or tracheid) diameter , fibre (or tracheid) lumen, and fibre (or tracheid) wall thickness were taken from each of the samples.

Specific gravity and bulk density : The basic specific gravities of wood and lignocellulosic materials were determined according to the standard methods outlined by ASTM D-1037 (1989) based on oven-dry weight and green volume measured using displacement method. The bulk density of each sample was calculated from weight and volume of the material according to ASTM E-873 (1982).

Statistical analysis : Analysis of variance (ANOVA) was carried out using a complete randomised design (CRD) according to Snedecor and Cochran (1967) to examine the variability in fibre length, fibre diameter, slenderness ratio and fibre wall thickness among species. Additionally, least significant difference method at 95% level of probability (L.S.$D_{0.05}$) was used to test the differences among the means of each parameter, if the differences were significant. The data were exported to PC-SAS data set for statistical analysis using GLM procedure.

Results and Discussion

Anatomical characteristics : The statistical analysis of the results indicated that differences among species were highly significant for all the anatomical properties of woody and lignocellulosic residues, including fibre length, fibre diameter, slenderness ratio of fibre and fibre wall thickness.

Fibre length and fibre diameter : Table 1 shows the mean values, standard deviation, and range of fibre length and fibre diameter of five raw materials evaluated for pulp and paper production. The fibre length of lignocellulosic residue was generally between those of softwood (*J. procera)* and hardwood (*T. aphylla*). *J. procera* gave the highest average values of fibre length (tracheid) (2.20 mm) with standard deviation of 0.33 and ranging from 1.53 to 2.76 mm, followed by *P. dactylifera* with a fibre length of 1.18 mm, standard deviation of 0.26 and ranging from 0.79 to 1.71 mm, while the lowest average value was that of *C. erectus* (0.75 mm), with a standard deviation of 0.13 and ranging from 0.55 to 1.07 mm. Lignocellulosic residues had fibres similar to hardwood fibres or longer, but did not reach softwood fibre length because softwood has tracheids and tracheids are longer than other fibres. As long as pulp and paper factories can use fibre from hardwood, fibre from lignocellulosic residues can be used as well, and it is expected that the sheets formed from lignocellulosic pulp would be better than the sheets formed from hardwood pulp. Approximately, 96% of the fibres of *C. erectus* prunings were 0.5 to 0.9 mm long, and this distribution was

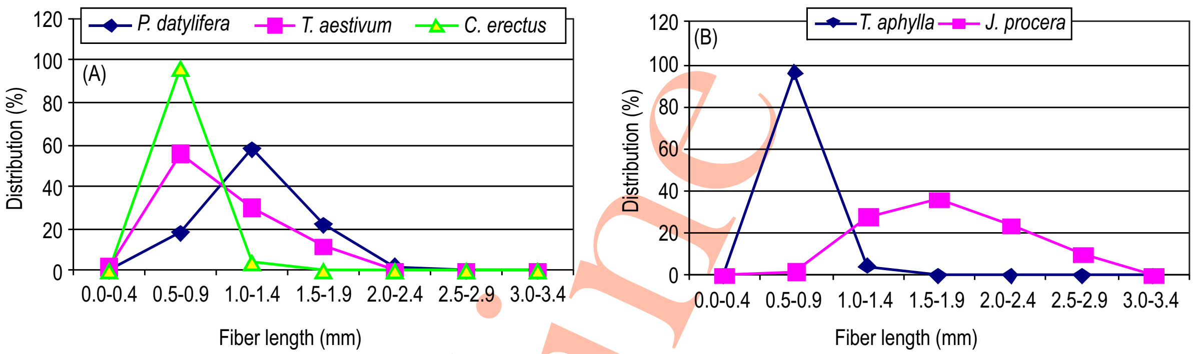

Fig. 1 : Fibre length distribution of three lignocellulosic residues (A) and two woody materials (B)

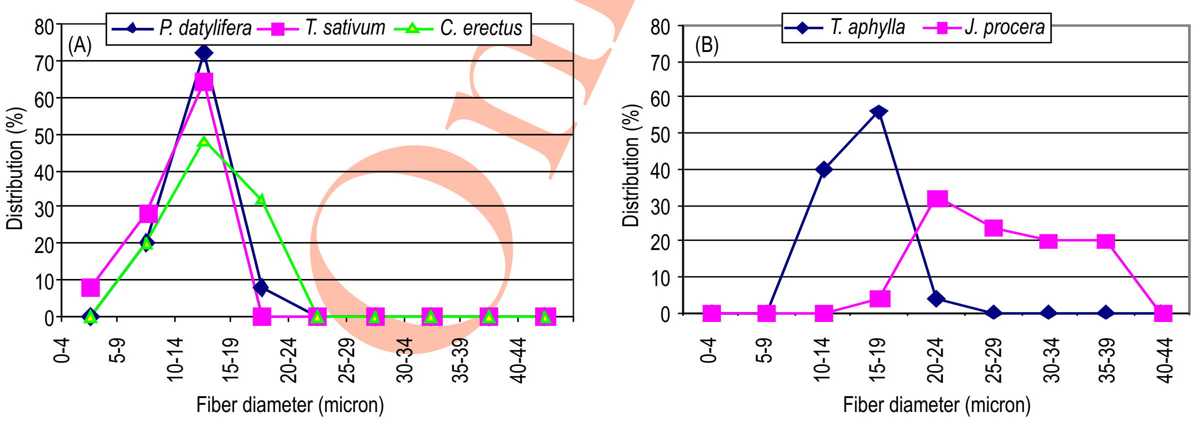

Fig. 2 : Fibre diameter distribution of three lignocellulosic residues (A) and two woody materials (B)

similar to that of hardwood (*T. aphylla*), in which 96% of fibres were 0.5 to 0.9 mm long. On the other hand, approximately 98% of fibres from date palm (*P. dactylifera)* were 1.0 to 1.9 mm long, *and* this distribution was similar to that of softwood (*J. procera*), in which 88% of fibres were 1.0 to 2.4 mm long. In wheat straw (*T. aestivum*), approximately 56% of fibres were 0.5 to 0.9 mm long, and 30% were 1.0 to 1.4 mm long; thus, the wheat straw fibre length was between those of hardwood and softwood. It is expected that handsheet formed from *C. erectus* and *T. aestivum* pulp (short fibres) would give a smoother paper because short fibres would fill the voids in the paper sheet. On the other hand, it is expected that handsheet formed from *P. dactylifera* and *J. procera* pulps (long fibres) would be higher in most strength properties than handsheet from other species because all strength properties increase with increasing fibre length (Mohlin *et al.,* 1996; Johnston 1997). The results obtained were in agreement with Abdel-Aal *et al.* (2008)**,** who found that the differences in fibre length among species were highly significant.

Lignocellulosic residues had fibre diameters smaller than those of woody materials. *J. procera* had the highest average fibre diameter (tracheid, 29.08 microns) with a standard deviation of 5.23 and ranging from 19.04 to 36.89 microns, followed by *T. aphylla* (15.32 microns), with a standard deviation of 2.83 and ranging from 10.71 to 23.80 microns, while the lowest average value was found in *T. aestivum* (10.99 microns), with a standard deviation of 2.49 and ranging from 4.89 to 14.67 microns (Table 1 and Fig. 1). Approximately, 100% and 92% of the fibre diameters of *C. erectus* and *P. dactylifera,* respectively, ranged from 5 to 19 microns, whereas 92% of *T. aestivum fibre diameters* were from 5 to 15 microns. Generally, the three lignocellulosic residues were similar to hardwood (*T. aphylla*), in which 96% of fibre diameters ranged from 10 to 19 microns. Regarding softwood (*J. procera*), the lignocellulosic residues were not similar to softwood, in which almost 100% of fibre diameters ranged from 20 to 39 microns (Fig. 2.). The difference in fibre diameter among species were in agreement with those obtained by Abdel-Aal and Hammad (2009); Abdel-Aal (2008); Hitz (2008); Ogunsanwo (2006) and Mauricio *et al.,* 2008 who found that fibre diameter and fibre wall thickness were different among species; moreover, within a single tree, they also found decrease in fibre diameter and fibre wall thickness with increasing height.

Slenderness ratio of fibre and fibre wall thickness : Generally, it can be observed from Table 2 that the slenderness ratio of lignocellulosic residues except *C. erectus* were higher than those of softwood (*J. procera)* and hardwood (*T. aphylla*). *T. aestivum* and *P. dactylifera* gave the highest average slenderness ratio (96.42 and 93.54, respectively) followed by *J. procera with* 77.18, whereas the lowest average values were from *T. aphylla* and *C. erectus* (57.97 and 61.26, respectively). From Fig. 4, it can be seen that approximately 52% of the slenderness ratios of fibres from date palm (*P. dactylifera)* and wheat straw (*T. aestivum*) were above 95, so date palm and wheat straw were better than

Table 1 : Fibre length and fibre diameter in the raw materials used in pulp and paper production

Raw materials	Species	Fiber length*			Fiber diameter**		
		Mean (mm)	SD	Range (mm)	Mean (µm)	SD	Range (µm)
Lignocellulosic residues	*P. datylifera*	1.18^{b}	0.26	0.79-1.71	12.79^{cd}	2.05	9.78-17.60
	T. aestivum	1.02^{c}	0.28	0.48-1.57	10.99^{d}	2.49	4.89-14.67
	C. erectus	0.75^{d}	0.13	0.55-1.07	13.18^{c}	2.72	7.14-16.66
Woody materials	*T. aphylla*	0.84^{d}	0.10	0.64-1.01	15.32^{b}	2.83	10.71-23.80
	J. procera	2.20^{a}	0.33	1.53-2.76	29.08^{a}	5.23	20.04-36.89

*Each value is an average of fifty samples per species; **Each value is an average of twenty five samples per species; Mean values sharing the same letter in column are not significantly different according to LSD test at 0.05% level

Table 2 : Slenderness ratio, standard deviation and range for the raw materials used in pulp and paper production

Raw materials	Species	Slenderness ratio			Fiber wall thickness		
		Mean	SD	Range	Mean (µm)	SD	Range (µm)
Lignocellulosic residues	*P. dactylifera*	93.54^{a}	18.40	54.39-135.03	2.05^{a}	0.30	1.50-2.70
	T. aestivum	96.42^{a}	25.29	35.31-153.28	1.16^{b}	0.21	0.87-1.87
	C. erectus	61.26^{c}	23.87	35.79-123.70	1.13^{b}	0.32	0.75-1.87
Woody materials	*T. aphylla*	57.97^{c}	12.79	38.77-91.90	2.06^{a}	0.39	1.37-3.12
	J. procera	77.18^{b}	13.31	56.01-105.74	2.04^{a}	0.33	1.50-2.87

Each value is an average of twenty five samples per species; Mean values sharing the same letter in column are not significantly different according to LSD test at 0.05% level

Table 3 : Specific gravity and bulk density of the raw materials used for pulp and paper production

Kind of raw material	Species	Specific gravity		Bulk density (g cm^{-3})*	
		Mean	Range	Mean	Range
Lignocellulosic residues	*P. datylifera*	0.33^{d}	0.33-0.34	0.13^{c}	0.13-0.13
	T. aestivum	0.17^{e}	0.17-0.18	0.06^{d}	0.06-0.07
	C. erectus	0.70^{a}	0.70-0.71	0.28^{a}	0.28-0.29
Woody materials	*T. aphylla*	0.47^{c}	0.40-0.55	0.25^{b}	0.25-0.26
	J. procera	0.63^{b}	0.63-0.64	0.28^{a}	0.28-0.29

Each value is an average of three samples per species; Mean values sharing the same letter in column are not significantly different according to LSD test at 0.05% level; * Bulk density of raw material particles

Table 4 : Rating of five materials used for pulp and paper with all determined properties for strength properties (1=best, 5=worst)

Property	Woody materials		Lignocellulosic residues		
	Juniperus procera	***Tamarix aphylla***	***Phoenix datylifera***	***Triticum aestivum***	***Conocarpis erectus***
Fiber length	1	4	2	3	4
Fiber diameter	1	2	3.5	4	3
Slenderness	2	3	1	1	3
Fiber wall thickness	1	1	1	2	2
Specific gravity	2	3	4	5	1
Rating	1.4	2.6	2.3	3	2.6

hardwood (*T. aphylla*), all of the fibres of which had slenderness ratio under 94 (Table 2 and Fig. 3).

P. dactylifera, T. aphylla and *J. procera* had high average fibre wall thicknesses with not much difference among them, whereas *T. aestivum and C. erectus* had low average values (Table 2). Although increasing the wall thickness of a fibre usually results in an increase in the density of raw materials, this generalisation is not true for date palm because most of the cells of date palm midrib are parenchyma, which is the reason for the decreasing specific gravity of date palm (Fig. 1). The differences among species in fibre wall thickness were in agreement with those obtained by Abdel-Aal and Hammad (2009); Abdel-Aal (2008); Hitz (2008); Ogunsanwo (2006) and Mauricio *et al.* (2008) who found that fibre diameter and fibre wall thickness were different among species (*E. camaldulensis* and *E. torquata*; *C. cunninghamiana* and *C. glauca*) and within trees (DBH, 25%, 50% and 75% of total height level). A decreases in fibre diameter and fibre wall thickness with increasing height was also observed.

Specific gravity and bulk density : The statistical analyses of the results indicate that differences among five species were highly significant for bulk density and specific gravity of woody and lignocellulosic residues. Table 3 shows the mean values and range of specific gravity and bulk density of five raw materials used in pulp and paper. *C. erectus* gave the highest average specific gravity (0.70), ranging from 0.70 to 0.71, followed by *J. procera*, which yielded an average value of 0.63, ranging from 0.63 to 0.64. The lowest average specific gravity was that of *T. aestivum* (0.17), ranging from 0.17 to 0.18. Regarding the bulk density of particles, *C. erectus* and *J. procera* had high average bulk densities (both 0.28 g cm^{-3}), ranging from 0.28 to 0.29 for both, followed by *T. aphylla* (0.25 g cm^{-3}), ranging from 0.25 to 0.26 g cm^{-3}, while the lowest average value was for *T. aestivum* (0.06 g cm^{-3}), ranging from 0.06 to 0.07 g cm^{-3}, respectively. Generally, it can be observed that the specific gravity of lignocellulosic residues was lower than that of woody materials (softwood and hardwood), except for the prunings from *C. erectus*. Low specific gravity results in bulk increase, so the lignocellulosic residues that could be cooked in the digester were lower in density than woody materials because they take up a greater volume. It is expected that handsheet formed from lignocellulosic residues (*P. dactylifera* and *T. aestivum* pulp) will give a low-strength paper because low specific gravity decreases the strength of paper sheet. On the other hand, it is expected that handsheet formed from *C. erectus* pulp (high specific gravity) would be higher in most strength properties because all strength properties increased with increasing specific gravity. It can be observed that bulk density and specific gravity follow the same trend. The results obtained were in agreement with those of Abdel-Aal *et al.* (2008). Who found that the difference in specific gravity among species were highly significant.

Table 4 summarises the properties of all five investigated raw materials and has a rating in terms of strength properties. For each property, the samples were assigned a value between 1 and 5, with 1 being the best and 5 being the worst. Note that, e.g., a

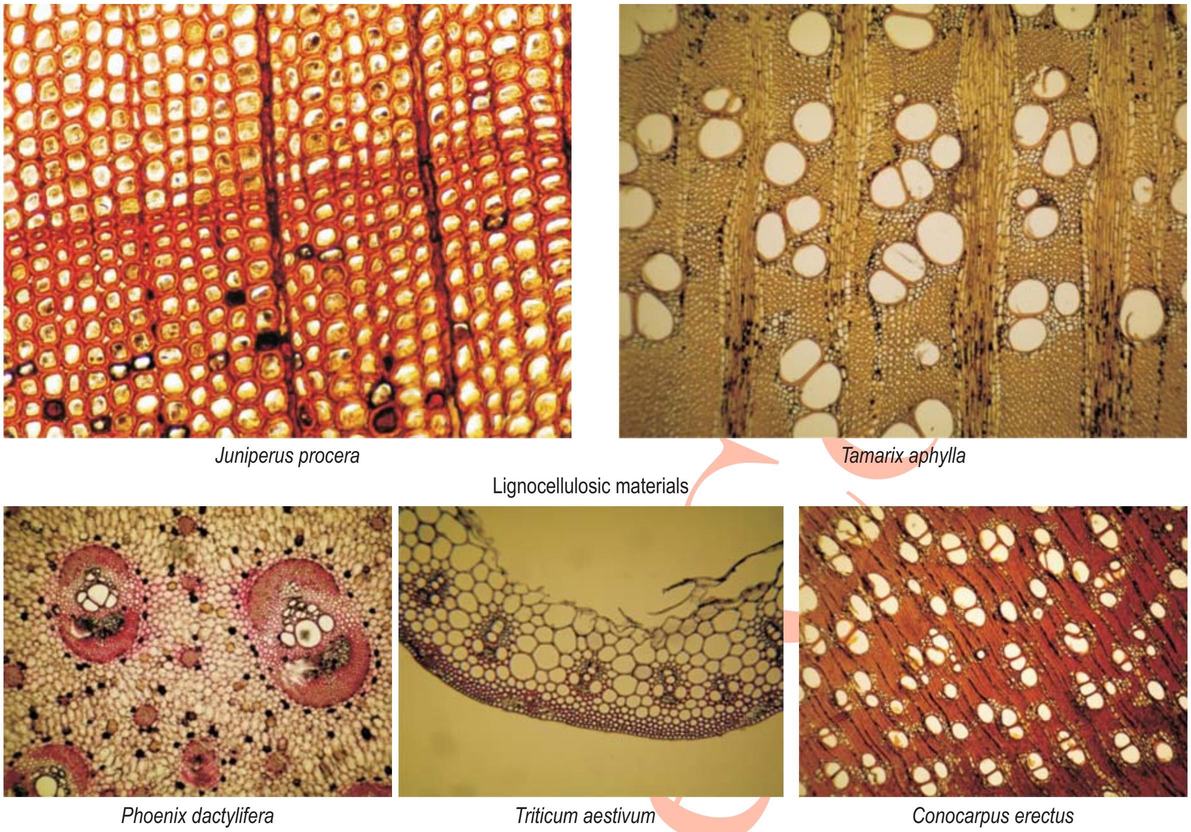

Fig. 3 : Transverse sections (X40) of *Juniperus procera, Tamarix aphylla, Phoenix dactylifera*, *Triticum aestivum* and *Conocarpus erectus*

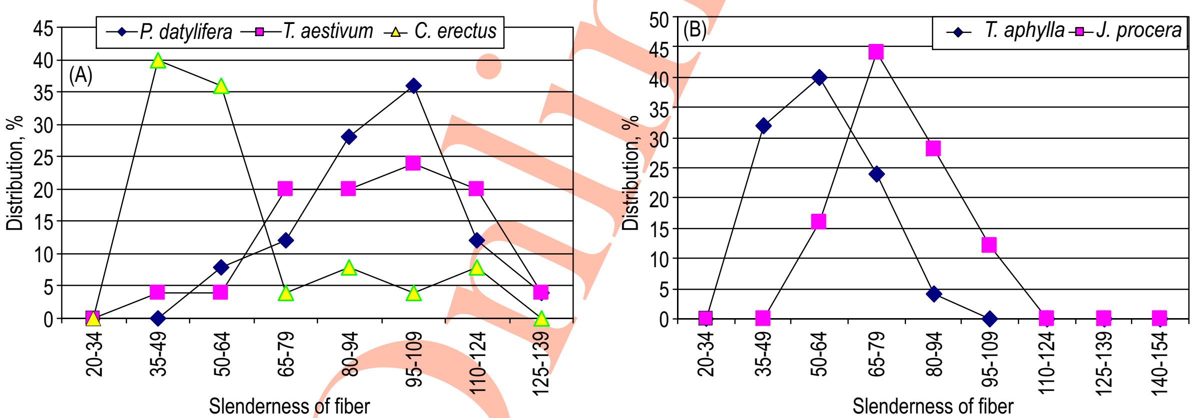

Fig. 4 : Slenderness distributions of three lignocellulosic residues (A) and two woody materials (B)

high fibre length would lead to a low value because fibre length had a positive impact on strength. The final rating value was determined as the sum of all values divided by the number of measured properties (five).

Based on the final rating value, the preferred pulp and paper species should be *J. procera* (1.4), followed by *P. dactylifera* (2.3), *Tamarix aphylla* (2.6) and *Conocarpus erectus* (2.6) and *T. aestivum* (3), respectively.

On the basis of the present study, it can be concluded that lignocellulosic residues have fibres similar or longer in length than hardwood fibres but do not reach softwood fibre length because softwood has tracheids, which are known to be longer than other fibres.

Acknowledgment

This project was supported by NSTIP strategic technologies programs, project number (11-AGR1746-02) in the Kingdom of Saudi Arabia.

References

Abdel-Aal, M.A.M.: Variation in wood anatomical characteristics of two *Casuarina* species grown in Egypt. *Egypt. J. Appl. Sci.,* **23,** 655-666 (2008).

Abdel-Aal, M.A.M. and H.H. Hammad: Anatomical variation in wood characteristics of two eucalyptus species grown in Egypt. *Egypt. J. Appl. Sci.,* **24**, 569-579 (2009).

Abdel-Aal, M.A.M., R.M.M. Sayed and M.F.M. Ismail: Variations in specific gravity and fiber length of some *Casuarinas* species grown in Ismailia. *Egypt. J. Appl. Sci.,* **23**, 169-1808 (2008).

Al- Mefarrej, H.A. and R.A. Nasser: Suitability of four lignocellulosic materials in Saudi Arabia for cement-bonded particleboard industry and effect of some treatments on their compatibility with Portland cement. *Alex. J. Agric. Res.,* **53,** 117-125 (2008).

Almeida, R.R., C.H.S. del Menezzi and D.E. Teixeira: Utilization of coconut shell of babacu (*Orbignya* sp.) to produce cement-bonded particleboard. *Biores. Technol.,* **85**, 159-163 (2002).

ASTM (American Society for Testing and Materials) D 1037: Standard methods of evaluating the properties of wood-base fiber and particle panel materials. Philadelphia, Pa. U.S.A. (1989).

ASTM (American Society for Testing and Materials) E 873: Standard test method for bulk density of densified particulate biomass fuels. Philadelphia, Pa. U.S.A. (1982).

Berlyn, G.P. and J.P. Miksche: Botanical microtechnique and cytochemistry. The Iowa State Univ. Press, Ames, Iowa (1976).

Broderick, G., I. Paris, J. Valade and J. Wood: Linking the fiber characteristics and handsheet properties of a high-yield pulp. *Tappi J.,* **79,** 161-9 (1996).

Franklin, C.L.: Preparing thin sections of synthetic resin and wood composites and a new maceration method for wood. *Nature,* **155**, 51-54 (1945).

Hitz, O.M., H. Gartner, I. Heinrich and M. Monbaron: Wood anatomical changes in roots of European ash (*Fraxinus excelsior*) after exposure. *Dendrochronologia,* **25,** 145-152 (2008).

Johnston, R.E.: Further developments of the Shallhorn and Karnis model. *Appita J.*, **50**, 400-404 (1997).

Judt, M.: Non-wood plant fibres, will there be a comeback in paper-making? *Ind. Cro. Prod.*, **2**, 51–57 (1993).

Kandeel, S.A.: Sampling for properties of wood elements. *J. Agric. Res.*, **18**, Alexandria (1971).

Kandeel, S.A., O.A. Badran and S.A. Tewfik: Sampling for fiber length in tropical hard-wood samples. *Wood Sci.*, **3**, 140-143 (1977).

Mauricio, R., J. Rodrguez, M. Peredo, S. Valenzuela and R. Mendon: Wood anatomy and biometric parameters variation of Eucalyptus globules clones. *Wood Sci. Technol., **43***, 131-141 (2008).

Mohlin, U., J. Dahibom and J. Homatowska: Fiber deformation and sheet strength. *Tappi J.*, **76**, 105-113 (1996).

Monica, E.K., G. Gellerstedt and G. Henriksson: Wood chemistry and wood biotechnology. Volume 1. Walter de Gruyter GmbH and Co. KG, Berlin (2009).

Moseley, M.F.: Comparative anatomy and phylogeny of the Casuarinaceae. *Bot. Gaz.*, **110**, 231-280 (1948).

Ogunsanwo, O.Y.: Variations in wood anatomical characteristics of Nigerian grown *Triplochiton scleroxylon* and their relationships with selected mechanical properties. *J. App. Sci. Eng. Technol.,* **6**, 68-75 (2006).

Olorunnisola, A.O.: Effects of pre-treatment of rattan (*Laccosperma secundiflorum*) on the hydration of Portland cement and the development of a new compatibility index. *Cement and Concrete Composites,* **30**, 37-43 (2008).

Paavilainen, L.: Reed canary grass. A new nordic material for high-quality fine papers. Know-How Wire. *Jaakko Poyry Mag.,* **2**, 8–11 (1996).

Paavilainen, L.: European prospects for using nonwood fibers. *Pulp and Paper Int.*, **40**, 61– 66 (1998).

Panshin, A.J. and C. deZeeuw: Textbook of wood Technology. Vol. 1, 3rd Edn. McGraw Hill Book Co., New York (1970).

Snedecor, G.W. and W.G. Cochran: Statistical Method. 6th Edn. Iawa State Univ. Press. Ames, Iawa (1967).