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Effect of Using Whole Trees From Three Hardwood Species Growing in Khartoum State and Beating Time on Paper Quality

Mohannad A. A. Mohammed¹, Tageldin H. Nasroun^{2*} and Salaheldin D. Mohieldin³

¹Faculty of Forest Science and Technology, University of Gezira, Medani, Sudan.

³Institute of Engineering Research and Material Technology, National Center of Research, Khartoum.

²College of Forestry and Range Sciences, Sudan University of Science and Technology

P. O. Box 6146, Peoples Hall (Altakamul), Khartoum, Sudan

E-mail: tageldinnasroun@yahoo.com.....Tel. +249 128429043

Abstract

Material for this investigation consisted of chips from both stem wood and whole trees from three species grown in the Central Sudan. These included the following: *Acacia seyal* var. *seyal* (Talh), *Prosopis juliflora* (Mesquite). And *Conocarpus erecta* (Saudi damas). Samples from whole tree chips, from each species were chemically analyzed using TAPPI standards. Fiber morphology was also determined for stem wood and branch wood separately for each of the three species. These measurements were made for macerated fibers, using stereological techniques for determining fiber length, while cross-sectional measurements were made using the Quant meter Image Analyzer equipped with a microscope in Giad Material Research laboratory. Stem wood chips and whole tree chips were cooked separately for each species using soda-anthraquinone (AQ) pulping. The pulping process was carried out in a laboratory, cylindrical digester. Pulp yield was determined. Pulping process and pulp preparations were also carried out according to different TAPPI standards, and so were pulp beating, handsheet formation and testing. Evaluation of paper quality produced

from this investigation was based on three properties, namely: tensile index, burst index, and sheet bulk. The results showed significant differences in chemical and anatomical properties between the different parts of the three species. This was reflected in some pulp and paper properties. Although pulp yields were slightly lower than those from previous studies, the paper properties obtained were, in most cases, higher than previous results. Tensile index and burst index increased with beating time and showed only slight decrease in case of whole tree paper compared to paper from stem wood. The pulp yield ranged between 40.11% for talh and 38.0% for mesquite and 37.83 for damas. The tensile index for beaten pulp, on the other hand ranged between 80.80 Nm/g for talh stem after beating to 8 min. and the lowest value of 50.6 Nm/g for mesquite whole tree. The burst index for beaten pulp ranged between 2.6 kpa*m²/g for both talh stem and damas stem and 1.9kpa*m²/g for mesquite whole tree paper. Sheet bulk for beaten pulp ranged between 4.79 cm³/g for mesquite whole tree paper down to 4.25 cm³/g for damas stem paper.

Keywords: Whole Tree; Stem Wood; Soda Pulping; Paper Properties.

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Introduction

The demand for pulp and paper fiber resources is largely determined by the society's dependence on paper, paper boards and other related products for human welfare. Paper in society is used in education, information storage, advertising, communication, in protection transportation, and security of goods in transit; protection of human health and sanitation in form of tissues and sanitary paper products (Kamoga, 2013).

The worldwide consumption of paper is increasing steadily over the years. The paper consumption in individual countries is related to their Gross National Product and hence the further increase in paper and board consumption will be different in different countries depending on whether economic saturation or fast increasing demand is prevailing.

Wood fibers constitute about 75% percent of all the fibrous raw material supply of paper and reclaimed waste paper about 20% percent. The remaining 5 percent are non-wood fibers, from such sources as bamboo, bagasse, straw, etc. which have special significance in the developing countries. These countries often are short of wood, or the woods are mixed tropical hardwood species, whose use economically, for pulp and paper manufacture, in most cases has not been properly solved yet (FAO,1973).

Sudan has many natural resources in the form of trees and agricultural residues as material essential for the

paper industry. In spite of this Sudan did not achieve self-sufficiency in pulp and paper. It's therefore important to determine the possibility of exploiting some tree species in parts or as whole trees for this industry. This calls for investigating the suitability of some local species for the production. This started by Nasroun (1978) and followed by (Khristova and Gabir 1984; Khristova 1990; Khristova et al. 1990a, Khristova et al. 1997, Khristova et al. 1998, Khristova and Karar 1999).

There is no virgin pulp and paper industry in the Sudan. All paper industries use re-cycled paper. The paper manufactured this way gets weaker and weaker with time. This means we have to start making paper from virgin fiber using wood and agricultural residues as raw material. This investigation is an attempt to continue the search for new raw materials to widen the scope of raw material suitable for pulp and paper industry, including whole tree utilization.

Materials and Methods

Materials

The species investigated included the following:

- *Acacia seyal* var. *seyal* (Talh).
- *Prosopis juliflora* (Mesquite).
- *Conocarpus lancifolius* (Saudi damas).

Acacia seyal (Talha), *Conocarpus lancifolius* (Saudi Damas) and *Prosopis juliflora* (Mesquite) were collected from Khartoum State, Central Sudan. The material used in this investigation included chips from both stem wood and whole trees. The ages of the selected trees ranged between 6 and 8 years.

Methods

Sampling

Chips of the approximate size 1.5 cm X 1.5 cm X 2mm were prepared from the stems and the whole trees of the different species and kept separate. This adds up to six fractions of chips, two for each species (stem and whole tree chips). Three samples were randomly selected from whole tree chips of each species for chemical analysis. Three other samples were selected from each of stem chips and branch chips of each species for determining fiber anatomical characteristics. All the remaining chips were left for pulping and papermaking.

Chemical analysis

The three samples selected from each species were analyzed using proximate chemical analysis. These fibrous raw materials were analyzed according to the following standards. Ash content according to TAPPI T 211,

while cold water and hot water extracts were determined according to TAPPI T 211. Cellulose content, on the other hand, was determined according to TAPPI T 17 and lignin content according to TAPPI T 222om-96. 1%NaOH extract, however, followed TAPPI T 212.

Fiber Morphology

Three andomly selected samples of stem chips and three samples of branch chips from each species were macerated for determining fiber anatomical characteristics. The maceration process involved the addition of 5ml hydrogen peroxide, and 5ml acetic acid to the wood chips into six different test tubes for each species. These mixtures were boiled in a water bath until fibers were completely white. Subsequently, the fibers were washed gently using distilled water, kept in their separate test tubes and shaken in distilled water to liberate the fibers. One drop of safranin-O was added into each tube and left for 1 hour. A few of the individual fibers from different test tubes were taken and mounted on to a glass slide using Balsum Canada. The slides were ready for microscopic examination. The fiber length (FL), fiber diameter (FD), lumen diameter (LD), and double cell-wall thickness (DCWT) were then measured. FL was determined using stereological techniques, while the other parameters were measured using the Quant meter Image Analyzer equipped with a microscope. From these measurements some morphological indices (ratios) were calculated. All these measurements were made for the stem wood and branch wood of the three species studies. The ratios calculated included the following.

A)Slenderness ratio (Felting coefficient) (SR)

$$SR = \text{Fiber length}/\text{Fiber diameter}$$

B) Runkle Ratio (RR)

$$RR = 2 \times \text{Cell wall thickness}/\text{Lumen diameter}$$

C) Fiber Flexibility Ratio (Elasticity coefficient)(FF)

$$FF = \text{Fiber lumen diameter}/ \text{Fiber diameter}$$

D) Coefficient of Cell Rigidity (CCR)

$$CCR = 2 \times \text{cell wall thickness}/ \text{Fiber diameter}$$

Pulping and pulp evaluation

Stem chips and whole tree chips were cooked separately for each species using soda-anthraquinone (AQ) pulping. The pulping process was carried out in a laboratory, cylindrical digester. This digester includes an electrical heater, a motor actuator, and instrument required for measurement and control temperature and pressure. The pulping process was carried out using the pulping conditions shown in table 1.

Table 1 Pulping Conditions

Cooking conditions	
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Oven dry weight (g)	500
Active alkali as Na₂O %	18.5
Anthraquinone %	0.1
Liquor : fiber ratio	4:1
Max temp. °C	160
Time to max temp, min	30
Time at max temp ,min	2h

At the end of cooking the pulp was washed by water and mechanical standard terpopulper. Fibers were then disintegrated using a disintegrator according to TAPPI T 205. The cooked pulp was then screened with a screen plate according to (TAPPI T 275). The total yield, the reject and the screened yield were determined.

Beating and handsheet formation

Before handsheet formation the different pulps were beaten to different beating times in accordance to TAPPI-200-sp-01. Talh stem pulp had three beating times 0, 4 and 8 min , Talh whole tree pulp beating times were 0, 4 and 7 min. Saudi damas stem, also had three beating times 0, 4 and 8 min, while S .damas whole tree was beaten to 4 and 7 min in addition to unbeaten pulp. Mesquite stem, on the other hand had three beating times 0, 4 and 7 min, while mesquite whole tree had 0, 4 and 7 min beating times. Drainability resulting from the different beating times was measured according to TAPPI 227om-1199. The handsheets were formed for each beating time according to TAPPI 220-sp-01 Standard. The handsheets prepared were conditioned according to TAPPI 402-SP-9.

Evaluation of paper properties

Evaluation of the quality of paper produced from this investigation was based on three properties, namely: tensile index according to TAPP-404-cm-92, burst index in accordance to TAPPI-403om-97, in addition to

sheet bulk.

RESULT AND DISCUSSION

Chemical composition of the three wood species

Table 1 shows the results of the chemical analysis for the three species. Analysis of variance showed significant differences in cellulose content between the different species ($P < 0.0001$). The table shows that damas had the highest value (54.25%), followed by mesquite (50.20%) and lastly talh (46.87%0 with significant differences between all three species. Lignin also showed significant differences between species ($P < 0.0001$). Mesquite had the highest value (28.87%) with significant differences from the other two species. Ash was also significantly different between the three species, with damas having the highest value (3.69%) followed by talh (2.03%) and lastly mesquite (1.82%), with significant differences between all different species.

1% NaOH , cold water, hot water and ethanol extracts also showed very significant differences between different species ($p < 0.0001$). NaOH extract was highest with talh (26.81%) which was significantly different from the other two species. Cold water extract was highest with mesquite (10.97%) which was significantly different from the other two species, while hot water extract also highest for mesquite (9.13%) with significant difference from the other two species. Ethanol extract was highest with talh (4.87) with significant differences from the other species, while n-Hexan extract was highest with mesquite (1.48%) with significant difference between all three species.

Table 1 chemical composition(%) of the three hardwoods species

Chemical composition%	Talh	Damas	Mesquite
Cellulose(%)	46.87C	54.25A	50.20B
Lignin(%)	25.48B	25.78B	28.87A
Ash(%)	2.03B	3.69A	1.82C
1% NaOH extract(%0	26.81A	16.87B	17.17B
Cold Water extract (%)	7.73B	7.26B	10.97A
Hot Water extract(%)	6.92B	6.29C	9.13A

Ethanol extract(%)	4.87A	3.42B	3.44B
n-hexan extract(%)	1.20B	0.56C	1.48A

Fiber Morphology

Table 2 shows the fiber dimensions for the different parts of the three species. Analysis of variance (ANOVA) showed significant differences in fiber diameter between different parts of the trees ($p=0.0008$). Mesquite branch showed the highest value (10.13 μm) followed by damas stem (9.78 μm) and Talh branch (8.52 μm) without any significant difference between them. The lowest value was for Mesquite stem (6.48 μm) which was not significant different from damas branch (7.53 μm) and Talh stem (7.55 μm) without any significant difference between them, but significantly different from all other parts.

Lumen diameter also showed significant difference between species. ($P = 0.0007$). It ranged between the highest (7.74 μm) for mesquite branch followed by damas stem (6.61 μm), without any significant difference between them and the lowest value (4.48 μm) for mesquite stem with significant differences from the first two species. These results are close to those obtained by Mohieldin, (2004) for *Eucalyptus tereticornis* and *Eucalyptus camaldulensis*. ANOVA showed no significant differences in double cell wall thickness (DCWT) ($P = 0.0854$). However the multiple comparisons showed some differences. The values ranged between 3.03 μm for talh branch and 1.54 μm for damas branch.

Fiber length also showed highly significant differences between the three species ($P < 0.0001$). Talh stem with 2.13 mm had the longest fibers with significant difference from all other parts. Mesquite branch had the shortest fibers (1.18 mm) with no significant difference from all other parts except talh stem. However, the observed results were comparable to those obtained for *Ziziphus spina-christi* and *Acacia seyal* (Haroony, et al., 2017). Fiber length obtained for talh stem was longer than that obtained by Nasroun (1978), whereas it was quite close to that obtained by Nasroun and Alshahrani (1998). Fiber diameter for talh stem was also smaller than that obtained from the above mentioned investigations, which was similar to what was obtained for talh branch. Mesquite branch, however, showed close diameter to those of some eucalypts as in Nasroun (1998).

Table 2 Fiber dimensions for the different parts of the three species

Species	*FD (μm)	LD(μm)	DCWT(μm)	FL(mm) *
Talh stem	7.55BC	5.06BC	2.49AB	2.13A

Talh branch	8.52AB	5.49BC	3.03A	1.44B
Damas stem	9.78A	6.61AB	2.73A	1.47B
Damas branch	7.53BC	5.99BC	1.54B	1.18B
Mesquite stem	6.48C	4.48C	2.00AB	1.20B
Mesquite branch	10.13A	7.74A	2.51A	1.18B
Value significant	0.0008	0.3475	0.0815	0.0001

Means with the same letter down each column are not significantly different at 0.05

*(FL) Fibers length - (DCWT) double cell wall thickness – (LD) Lumen diameter

Table 3 shows the fiber ratios for the different parts of the three species: rankle ratio (RR), coefficient of cell rigidity (CCR), fiber flexibility (FF) and slenderness ratio (SR). ANOVA showed that there were no significant differences in RR between the different parts of the trees ($P = 0.0626$), but the multiple comparisons showed slight differences. The values varied between the highest (0.59) for talh branch and the lowest value (0.30) for damas branch. However, ANOVA showed significant differences in CCR between the different parts ($P = 0.0276$). The highest value was for talh branch (0.36) followed by talh stem (0.33) without any significant difference between them. The lowest value was for damas branch (0.22) which was not significantly from all other parts except for talh branch and talh stem. FF also showed significant differences between different parts of trees ($P = 0.0313$). the highest value was for damas branch (0.77) followed by mesquite brach, (0.76), damas stem (0.71) and mesquite stem (0.69) without any significant differences between them. The lowest value was for talh branch (0.64) which was not significantly different from talh stem (0.67), mesquite stem (0.69) and damas stem (0.71). CCR obtained from this study for talh stem was very close to that obtained by Nasroun (1978), while FF was slightly higher. The reasons for these differences may be due to the fact that talh used in this investigation were growing in much better growing conditions than talh used in the previous investigation cited.

Table 3 Fiber ratios for the different parts of the three species

Species	RR *	CCR	FF	SR
Talh stem	0.51AB	0.33AB	0.67BC	71
Talh branches	0.59A	0.36A	0.64C	42
Damas stem	0.43AB	0.28ABC	0.71ABC	38
Damas branc	0.30B	0.22C	0.77A	39
Mesquite stem	0.45AB	0.31ABC	0.69ABC	46
Mesquite branch	0.33B	0.23BC	0.76AB	29

Value significant 0.3389 0.0909 0.0994 -

Means with the same letter down each column are not significantly different at 0.05

*(RR) Runkel Ratio - (CCR) coefficient of cell rigidity - (SR) Selenderness Ratio - (FF) fiber flexibility

Pulp Yield

Table 4 shows the pulp yields for the different parts of the trees. The screened yield of pulps from stem wood from the three species was higher than that from branches. The stem pulp yields were close to one another. They ranged between 40.11% for talh stem to 39.61% for mesquite and 39.32 for damas. With regards to whole tree pulp yields again talh gave the highest yield (38.0%) compared to mesquite (37.83%) and damas (36.61%). The higher pulp yield for talh may be attributed to its higher cellulose content compared to the other species. It may also be due to its longer fibers, Talh branch and talh stem also had the thickest fiber wall, the largest RR and CCR without significant difference between them. However, talh pulp yield was lower than that obtained by Nasroun (1978).

Table 4 Pulp yields for the different raw materials.

Properties	Talh stem	Talh WT*	Damas stem	Damas WT	Mesquite stem	Mesquite WT
Total yield %	40.126	38.01	40.18	36.73	40.46	38.79
Reject %	0.008	0.01	0.86	0.05	0.85	0.96
Screen yield %	40.118	38.00	39.32	36.68	39.61	37.83

*WT=

Whole tree

Paper Properties

Table 5 shows the variation of bulk density of paper made from talh stem and talh whole tree with beating time. The sheet bulk from talh stem decreased from 7.57 cm³/g for unbeaten pulp to 4.47cm³/g³ for pulp beaten to 8 min. For talh whole tree pulp the bulk density for paper decreased from 7.08 /cm³/g for unbeaten pulp to

4.52 cm³/g for pulp beaten to 7 min. It was also noticed that bulk density for stem pulp and whole tree pulp were very close. The bulk densities obtained in this study were higher than those obtained by Nasroun (1978).

Table 5 Variation of sheet bulk of paper from talh stem and whole tree with beating time

Talsh stem			Talsh whole tree			
Beating time (min)	Drainability	Bulk cm ³ /g	Beating time (min)	Drainability	Bulk cm ³ /g	Brightness %
0	22	7.57	0	31	7.08	45
4	31	5.07	4	34	4.97	
8	40	4.47	7	40	4.52	

Table 6 shows the Variation of burst index of paper from talh stem and talh whole tree with beating time. The table shows that burst index for paper made from stem pulp increased from 1.3 kpa*m²/g for unbeaten pulp to 2.6 kpa*m²/g for pulp beaten for 8 min. the case of paper made from whole tree pulp, the burst index increase from 1.0 kpa*m²/g for unbeaten pulp to 2.2 kpa*m²/g for pulp beaten to 7 min. The burst index for paper made from whole tree pulp was slightly lower than that from stem pulp. This may be due to the fact that talh stem had significantly longer fibers than its branches. These results were about the same as those obtained by Mohieldin (2007) and that obtained by Khristova *et al* (2004).

Table 6 Variation of burst index of paper from talh stem and talh whole tree with beating time

Talsh stem			Talsh whole tree		
Beating time(min)	Drainability	Burst index kpa*m ² /g	Beating time(min)	Drainability	Burst index Kpa*m ² /g
0	22	1.3	0	31	1.0

4	31	1.8	4	34	1.4
8	40	2.6	7	40	2.2

Table 7 shows the Variation of tensile index of paper made talh stem and talh whole tree with beating time. Tensile index for paper made from talh stem pulp increased from 30.4 Nm/g for unbeaten pulp to 79.0 Nm/g for pulp beaten for 8 min. The tensile index from whole tree pulp increased from 28.2 Nm/g for unbeaten pulp to 71.1 nm/g for paper made from pulp beaten for 7 min. Again there was a slight decrease in tensile index of paper made from whole tree pulp compared to that from stem pulp due to the shorter fibers in the branches. This is also due to the longer fibers of talh stem wood . These results were higher than those obtained by Nasroun (1978); Mohieldin (2007); Khristova *et al* (2004).

Table 7 Variation of tensile index of paper made talh stem and talh whole tree with beating time.

Talh stem			Talh whole tree		
Beating time (min)	Drainability	Tensile index Nm/g	Beating time (min)	Drainability	Tensile index Nm/g
zero	22	30.4	0	31	28.2
4	31	50.9	4	34	52.2
8	40	79.0	7	40	71.1

Table 8 shows the Variation of bulk density of.damas paper with beating time. Like the case of talh, bulk density decreased with beating time. For damas stem it decreased from 6.0 g/cm³ for unbeaten pulp to 4.25 g/cm³ for paper made from pulp beaten for 8 min. Bulk density from damas whole tree showed the same trend with slight increase from that of stem pulp. These values were similar to those obtained for talh paper.

Table 8 Variation of sheet bulk of.damas paper with beating time

Damas stem			Damas whole tree			
Beating time (min)	Drainability	Bulk cm ³ /g	Beating time (min)	Drainability	Bulk cm ³ /g)	Brightness %
0	17	6.80	0	17	7.09	25
4	31	4.29	4	34	4.79	
8	41	4.25	7	42	4.48	

Table 9 shows the variation of tensile index of.damas paper with beating time. The values increased from 22.9 \nm/g for unbeaten pulp to 80.8 for paper made from pulp beaten for 8 min. The values for paper made from whole tree pulp increased from 22.7 Nm/g for unbeaten pulp to 78.1 Nm/g for pulp beaten for 7 min. These values are higher than those obtained by Khristova *et al* (2004) and those obtained by Mohieldin (2007). The values are comparable to those obtained for talh as mentioned above in spite of the much longer fibers in talh, which might have been compensated for by the higher fiber flexibility coefficient (FF) in case of damas and this offers greater contact areas between fibers and thereby stronger fiber-to-fiber bonds. The values obtained were also higher than those obtained by Nasroun (1978).

Table 9 Variation of tensile index of.damas paper with beating

Damas stem			Damas whol tree		
Beating	Drainability	Tensile index	Beating	Drainability	Tensile index

time (min)			time (min)		
		Nm/g			Nm/g
0	17	22.9	0	17	22.7
4	31	64.3	4	34	54.6
8	41	80.8	7	42	78.1

Table 10 shows the variation of burst index of damas paper with beating time. The values for stem pulp paper increased from 0.50 Kpa*m²/g for unbeaten pulp to 2.6 Kpa*m²/g for paper from pulp beaten for 8 min. For paper made from damas whole tree the values increased from 0.4 to 2.4, These were close to what was found for talh above. They are slightly lower than those obtained by Mohieldin (2007) and Khristova *et al* (2004).

Table 10 Variation of burst index of damas paper with beating time

Damas stem tree			Damas whole tree		
Beating time (min)	Drainability	burst index (Kpa*m ² /g)	Beating time (min)	Drainability	burst index (Kpa*m ² /g)
0	17	0.5	0	17	0.4
4	31	2.2	4	34	1.8
8	41	2.6	7	42	2.4

Table 11 shows the Variation of bulk density of Mesquite paper with beating. In case of mesquite stem paper the bulk density decreased from 5.85 g/cm³ for unbeaten pulp to 4.43 g/cm³ for pulp beaten for 8 min, For paper made from whole tree pulp the bulk density decreased from 6.62 g/cm³ to 4.79g/cm³ for pulp beaten for 7 min, This is slightly higher than that obtained for mesquite stem paper.

Table 11 Variation of sheet bulk of Mesquite paper with beating time

Properties	Mesquite stem		Mesquite whole tree			
Beating	Drainability	Bulk	Beating time	Drainability	Bulk	Brightness

time (min)		(cm ³ /g)	(min)		(cm ³ /g)	%
0	21	5.85	0	25	6.62	30
4	30	5.10	4	33	5.27	
8	40	4.43	7	40	4.79	

Table 12 shows the variation of tensile index of mesquite paper with beating. In case of mesquite stem paper tensile index increased from 13.0 Nm/g for unbeaten pulp to 67.4 Nm/g for pulp beaten for 8 min. For mesquite whole tree paper the tensile index increased from 7.0 Nm/g for unbeaten pulp to 50.6 Nm/g for pulp beaten for 7 min., which is lower than that obtained for the stem paper. This may be due to the inclusion of some bark in the chips obtained from the branches, which was very thin and difficult to remove. The values obtained were also the lowest compared to the other two species studied. However the pulp responded well to the beating process and increasing the beating time further might have improved its strength properties. The values obtained are comparable to those obtained from some species studied by Nasroun (1978).

Table 12 Variation of tensile index of Mesquite paper with beating time

Mesquite stem			Mesquite whole tree		
Beating time (min)	Drainability	Tensile index Nm/g	Beating time (min)	Drainability	Tensile index Nm/g
0	21	13.0	0	25	7.9
4	30	23.1	4	33	22.5
8	40	67.4	7	40	50.6

Table 13 shows the variation of burst index of paper made from mesquite stem and mesquite whole trees. For mesquite stem paper the burst index increased from 0.50 Kpa*m²/g for unbeaten pulp to 2.0 Kpa*m²/g for paper made from pulp beaten for 8 min. In case of paper made from whole tree pulp the burst index increased

from 0.40 Kpa*m²/g for unbeaten pulp to 1.9 Kpa*m²/g for paper from pulp beaten for 7 min. The values for the stem paper and the whole tree paper were similar. However, these values are slightly lower than the other two species and also lower than results obtained by Khritova *et al* (2004).

Table 13 Variation of burst index of Mesquite paper with beating time

Mesquite stem			Mesquite whole tree		
Beating time (min)	Freeness (⁰ SR)	burst index (Kpa*m ² /g)	Beating time (min)	Freeness (⁰ SR)	burst index (Kpa*m ² /g)
0	21	0.5	0	25	0.4
4	30	1.3	4	33	1.2
8	40	2.0	7	40	1.9

Conclusions and Recommendations

- The strength properties of paper produced from talh and damas were higher than those obtained from many other previous studies.
- These properties increased with increasing beating time.
- The differences between paper strength properties from stem wood and that from whole tree were quite small in these two species.
- Results indicated that whole trees of talh and damas can be used for paper production .
- The strength properties of paper made from mesquite were lower than the other two species and the properties made from whole trees were much lower than that produced from its stem wood.

- It is, therefore, recommended to search for more species, whose whole tree can be used for pulp and paper production for rationalizing the use of our wood resources by reducing the waste.

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