EVALUATION OF HARVESTING TIME EFFECTS AND CULTIVARS OF KENAF ON PAPERMAKING

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This study investigates effects of six kenaf cultivars named Cubano, Niger, Cubano 2032, 9277, 7551, and 7566 and three harvesting time stages on the properties of pulp and handsheet paper made from kenaf. Six cultivars of an Iranian kenaf (*Hibiscus Cannabinus L.*), were planted on 19 May 2007, and harvested after 85, 105, and 135 days. It was understood that with the increase of plant age, fiber yield increased. Maximum yield at each of three harvesting time stages was related to Niger. Consequently, if a high fiber yield is sought, Niger can be recommended, but for a paper with high strength properties, Cubano 2032 is strongly suggested. This cultivar produces a paper with significant burst, tear, breaking length and fold endurance even though its yield was somewhat lower than that of Niger at short harvesting times. Moreover, at second harvesting time stage, maximum strength properties of handsheets such as burst, tear, and breaking length, were seen in Cubano, though the fiber yield of this cultivar was a bit lower than Niger, but still more than Cubano 2032. We showed that a minor positive change in the handsheet properties could be achieved through harvesting kenaf at the third stage as compared to the first and second stages.

Keywords: Cultivars of Kenaf; Harvesting time; Papermaking; Mechanical properties; Niger; Cubano

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INTRODUCTION

The use of non-wood plants for papermaking purposes has been a subject of debate for some time. Some nonwood plants are often proposed as effective solutions for the growing shortage of raw materials or even as substitutes intended to avoid tree felling. An increase in worldwide consumption of wood-based products and a decrease in forest resources have raised potential demands for supplemental nonwood fiber sources. Kenaf (*Hibiscus cannabinus L.*) is an annual plant with a high fiber yield. It is an herbaceous annual plant grown in many parts of the tropics and in some sub-tropical and warm temperate areas for its bark fibers used as a substitute for jute in cordage and sacking. The kenaf plant contains two distinct fiber components, bark and core. The bark (bast) fibers constitute 35–40%, and the core (woody) fibers compose 60–65% by weight of the stalk (Khristova et al. 2002; Touzinski et al. 1973; James and McCamley 1981; Kaldor et al. 1990). Therefore, the plant has been considered as an alternative fibrous crop to wood-based products, particularly in pulp and paper-making industries (Kaldor 1989; Kaldor et al. 1992; Ohtani et al. 1994; Pande and Roy 1996, 1998; Calamari et al.

1997; Mazumder et al. 1998, 2000a; Zeinaly et al. 2008). Furthermore, growing global environmental concern has led to increasing interest in kenaf as a source of cellulosic fiber for its high CO_2 fixation ability (Lam et al. 2003). Therefore, the use of kenaf as an alternative raw material to wood will contribute to protecting some forest resources from further deforestation, and to environmental stabilities. The separation of the bark and core by simple mechanical and screening treatments has made possible the use of bark alone to produce a high quality long fiber pulp (Watson and Gartside 1976; James and McCamley 1981).

The success of kenaf in papermaking has relied on its high yield per hectare (about 20 t/ha yr) and the quality of its bast fibers, with a low lignin content, which provides paper with a strength exceeding that of paper from conifer fibers. Kraft and soda processes have been the most frequently used for kenaf pulping (Touzinsky et al. 1972; Touzinsky et al. 1973; Kaldor 1988, 1989; Villar et al. 2001; Feng and Alén 2002; Khristova et al. 2002; Ashori 2006; Ashori et al. 2006a). Also, other pulping processes, including non conventional methods, have been tested (Villar et al. 2009, Myers and Bagby 1995). Kenaf bast fibers provide kraft pulp with excellent strength related properties, particularly as regards tear index, as a consequence of the high fiber length (Villar et al. 2001; Khristova et al. 2002; Ashori et al. 2006b). Harvesting time of each variety of kenaf is a factor affecting kenaf properties, along with differences related to plant populations and varieties (Wood et al. 1983; Zhou et al., 1997). Therefore, different harvesting times for different varieties of kenaf bast are very important to use kenaf bast fibers widely as an industrial raw material for papermaking. However, the available literature references contain few papers describing kenaf paper at different harvesting ages (Morrison et al. 1999a,b; Dehghani-Firouzabadi et al. 2008).

Thus, in this study the influence of harvesting time and effect of varieties of kenaf bast on the pulp properties of different varieties of kenaf bast have been studied in the soda pulping process. Furthermore, handsheets were produced with the kenaf bast pulp prepared in different cultivars-harvesting times. It should be noted that dimensional evaluations of fibers of these cultivars have recently been conducted (Shakhes et al. 2008). However, we believe that to maximize the exploitation of these fibres for pulp production, a more complete understanding of its cultivars is required.

EXPERIMENTAL

Raw Material

Seeds of kenaf (*Hibiscus Cannabinus L.*) were collected from Central Agricultural Research of Iran. Six cultivars, namely Cubano, Niger, Cubano 2032, 9277, 7551, and 7566, were used for the study. The kenaf bast used in the study was obtained from cultivating these seeds for periods of 75, 105, 135 days as harvesting times on a farm run by the Gorgan University (latitude 35.5 north and longitude 54.4 east) on silty clay loam in the north of Iran. The crop was planted on 19 May 2007, and five irrigations methods were applied during the growing season using the furrow system, which is traditionally used in the region. The sampling area ($1m^2$) was selected from the central rows of each subplot in each harvesting time. After each harvest, the plants were divided into core and bast fractions. Before pulping, the kenaf bast was individually cleaned, cut, and pieces of approximately 3 cm length were selected and sun-dried.

Analysis of Raw Materials and Pulps

The starting materials and the products obtained were characterized according to the following standard methods: Pulp yield was determined gravimetrically following drying at 105 ^{o}C ± 2 for 24 h. Test methods of the Technical Association of the Pulp and Paper Industry (Tappi, 2006-2007) were used for measurements of freeness (method T 227 0m-99), Kappa number (T 236 om-99), handsheets of 60 g/m^2 formation (T 205 sp-02), and determination of physical and optical properties (T 220 sp-01). Also, handsheet properties were evaluated in accordance with standard methods of TAPPI. The handsheets were conditioned at 23 ^{o}C and 50% RH for at least 24 h before testing.

Experimental Design

A split plot design was used for the experiments. The main factors of these experiments consisted of three harvesting times as the main plot and the six cultivars of kenaf as the sub-plots. Harvesting time and cultivars were considered as two investing factors. Responses of pulp and handsheet properties to the process variables (three harvesting times and six cultivars of Kenaf) were analyzed using SAS statistical software. The analysis of variance techniques were applied to the data, and Duncan tests were used for investigation of significant difference of variances among the group means.

Pulping and Papermaking

Pulps were made in a 2.3-L batch cylindrical mini digester (stainless steel 321). The mini digester includes an electrical heater, a motor actuator, and required instruments for measurement and control of pressure and temperature. In a typical experiment, 100 g of oven-dried bast fiber (moisture content 9.56%) was weighed and charged into the mini digester. The solid/liquor ratio was fixed (1/10 d. w.) and the activated alkaline in the cooking liquor was set at 25%. After the mini digester was loaded with bast fiber and the cooking liquor, it was heated to the operating temperature (165 ^{o}C), which was then maintained throughout the experiment. The cooking time of all main runs of pulping was approximately fixed to reach a special pulp with equal kappa number of approximately 20. The cooking time for each cultivar was determined at all harvesting times by preliminary trials.

RESULTS

The characteristics of the pulp and handsheet paper obtained in the 18 pulping runs (each repeated four times) are summarized in Table 1. Evaluations of these cultivars were done by means of analysis of variance of results and detecting the significance between six cultivars after measurement of pulp and handsheet paper characteristics. By means of initial trials, cooking time was detected for each cultivar to reach an equal kappa number (≈ 20). This method is suitable for evaluation of the pulps with equal lignin content but different holocellulose content and morphological properties. The main reason for selection of this procedure was to evaluate the effects of morphological and chemical differences of cultivars with equal lignin content on handsheet properties. Tables 1 gives the mean values for yield, burst index, and tear index, as well as the breaking length and fold endurance for the kenaf pulps provided by the soda process.

Table1. Conditions and Results of Soda Pulping of Bast Fiber of Kenaf and the Properties of the Paper Handsheets*

Run	Cultivar	Harvesting Time	Kappa Number	Yield (%)	Cooking Time (min)	Thickness (mm)	Burst Index (kN/g)
1	7551	85	20.10	^{A} 43.06 ^{d}	^{B} 105 ^{a}	^{A} 0.123 ^{bc}	^{A} 5.81 ^{ab}
2	7566	85	20.27	^{A} 43.34 ^{d}	^{C} 79 ^{e}	^{A} 0.120 ^{c}	^{A} 6.17 ^{ab}
3	Cubano	85	20.07	^{B} 45.59 ^{b}	^{C} 88 ^{c}	^{A} 0.128 ^{a}	^{A} 5.26 ^{b}
4	Niger	85	20.00	^{B} 47.14 ^{a}	^{C} 84 ^{d}	^{B} 0.121 ^{c}	^{A} 5.97 ^{ab}
5	Cubano 2032	85	20.17	^{A} 45.60 ^{b}	^{B} 94 ^{b}	^{B} 0.120 ^{c}	^{A} 6.35 ^{a}
6	9277	85	20.23	^{B} 44.68 ^{c}	^{C} 94 ^{b}	^{A} 0.127 ^{ab}	^{A} 5.30 ^{b}
7	7551	105	20.07	^{A} 43.03 ^{e}	^{B} 105 ^{ab}	^{A} 0.121 ^{abc}	^{A} 6.45 ^{a}
8	7566	105	19.93	^{A} 43.50 ^{d}	^{B} 85 ^{c}	^{A} 0.119 ^{c}	^{A} 6.26 ^{ab}
9	Cubano	105	20.13	^{A} 46.24 ^{b}	^{B} 103 ^{b}	^{B} 0.120 ^{bc}	^{A} 6.48 ^{a}
10	Niger	105	20.07	^{AB} 47.26 ^{a}	^{B} 101 ^{bc}	^{AB} 0.127 ^{a}	^{A} 6.09 ^{ab}
11	Cubano 2032	105	20.23	^{A} 45.49 ^{c}	^{A} 108 ^{a}	^{B} 0.123 ^{abc}	^{A} 5.97 ^{ab}
12	9277	105	20.03	^{A} 45.25 ^{c}	^{B} 105 ^{ab}	^{AB} 0.126 ^{ab}	^{A} 5.54 ^{b}
13	7551	135	20.00	^{A} 43.22 ^{e}	^{A} 117 ^{a}	^{A} 0.118 ^{c}	^{A} 6.37 ^{ab}
14	7566	135	20.07	^{A} 43.33 ^{e}	^{A} 96 ^{c}	^{A} 0.116 ^{c}	^{A} 6.88 ^{ab}
15	Cubano	135	20.20	^{AB} 46.17 ^{b}	^{A} 109 ^{bc}	^{B} 0.118 ^{c}	^{A} 6.91 ^{a}
16	Niger	135	20.17	^{A} 47.45 ^{a}	^{A} 111 ^{b}	^{A} 0.129 ^{a}	^{A} 6.71 ^{ab}
17	Cubano 2032	135	20.07	^{A} 45.46 ^{c}	^{C} 88 ^{d}	^{A} 0.129 ^{a}	^{A} 6.29 ^{ab}
18	9277	135	19.97	^{AB} 45.10 ^{d}	^{A} 113 ^{b}	^{B} 0.125 ^{b}	^{A} 6.35 ^{ab}

Run	Tear Index (mNm^2/g)	Breaking Length (km)	Fold Endurance	$Freeness_{-ini}$ (CSF)	$Freeness_{\_sec}$ (CSF)	PFI (revolution)
1	^{B} 18.41 ^{ab}	^{A} 71.35 ^{bc}	^{A} 436.00 ^{c}	^{B} 605 ^{b}	403	^{B} 2000 ^{b}
2	^{A} 19.67 ^{a}	^{AB} 73.90 ^{ab}	^{B} 497.00 ^{ab}	^{B} 630 ^{a}	391	^{A} 2000 ^{b}
3	^{B} 19.13 ^{ab}	^{B} 64.12 ^{cd}	^{B} 430.33 ^{c}	^{A} 600 ^{c}	409	^{B} 1400 ^{c}
4	^{A} 19.99 ^{a}	^{A} 70.43 ^{bc}	^{A} 486.33 ^{ab}	^{C} 590 ^{d}	385	^{B} 1400 ^{c}
5	^{A} 20.21 ^{a}	^{A} 80.26 ^{a}	^{A} 512.33 ^{a}	^{B} 630 ^{a}	391	^{A} 2100 ^{a}
6	^{B} 18.24 ^{b}	^{B} 63.01 ^{d}	^{B} 446.33 ^{cd}	^{B} 595 ^{e}	385	^{A} 1400 ^{c}
7	^{A} 20.81 ^{a}	^{A} 74.10 ^{a}	^{A} 509.67 ^{ab}	^{A} 610 ^{c}	409	^{B} 2000 ^{b}
8	^{B} 21.23 ^{a}	^{B} 73.01 ^{a}	^{AB} 505.00 ^{ab}	^{B} 630 ^{b}	405	^{A} 2000 ^{b}
9	^{A} 21.27 ^{a}	^{A} 75.42 ^{a}	^{A} 547.00 ^{a}	^{B} 600 ^{e}	393	^{A} 1600 ^{c}
10	^{A} 20.74 ^{a}	^{A} 71.01 ^{a}	^{A} 520.00 ^{ab}	^{B} 600 ^{e}	405	^{B} 1400 ^{d}
11	^{B} 19.83 ^{a}	^{B} 73.63 ^{a}	^{A} 495.00 ^{b}	^{A} 635 ^{a}	397	^{A} 2100 ^{a}
12	^{B} 18.96 ^{a}	^{B} 64.78 ^{b}	^{AB} 474.33 ^{b}	^{A} 605 ^{d}	403	^{B} 1300 ^{e}
13	^{A} 21.87 ^{ab}	^{A} 71.81 ^{ab}	^{A} 509.33 ^{ab}	^{A} 611 ^{b}	398	^{A} 2150 ^{a}
14	^{A} 21.34 ^{abc}	^{A} 77.46 ^{ab}	^{A} 514.67 ^{a}	^{A} 637 ^{a}	403	^{A} 2000 ^{b}
15	^{AB} 21.50 ^{bc}	^{AB} 73.96 ^{ab}	^{A} 528.33 ^{a}	^{A} 605 ^{c}	397	^{A} 1600 ^{c}
16	^{A} 21.38 ^{bc}	^{A} 69.22 ^{b}	^{A} 484.67 ^{ab}	^{A} 605 ^{c}	389	^{A} 1600 ^{c}
17	^{A} 23.79 ^{a}	^{A} 82.27 ^{a}	^{B} 465.67 ^{b}	^{A} 637 ^{a}	405	^{A} 2100 ^{ab}
18	^{A} 18.34 ^{c}	^{A} 74.97 ^{ab}	^{A} 496.67 ^{ab}	^{A} 605 ^{c}	409	^{A} 1400 ^{d}

*: The large letters (left hand of numbers) show the significant difference between three harvesting times for each of cultivars and The small letters (right hand of numbers) show the significant difference between six cultivars at each of the three harvesting times, $Freeness_{-ini}$: Initial Freeness, $Freeness_{\_sec}$:Secondary Freeness.

Cooking Time

In general, cooking time is an important variable for the pulping process. Variations of cooking time of cultivars of kenaf bast are shown in Table 1. It should be noted that the variation of cooking times between six cultivars were significant at the 5% level so that, in order to reach an equal kappa number ≈20, the longest cooking time was related to 7551 at the third harvesting time stage under fixed cooking conditions for other stages in this research. Compared to the first and second stages, the third stage showed significant differences in paper properties. However, the shortest cooking time was related to 7566 at the first harvesting time stage (Fig. 1). Statistically, in terms of the effect of three harvesting times on cooking time, 9277, Niger, Cubano, and 7551 at the first harvesting time plus Cubano 2032 at the third harvesting time had the least cooking time and were significantly different from the others.

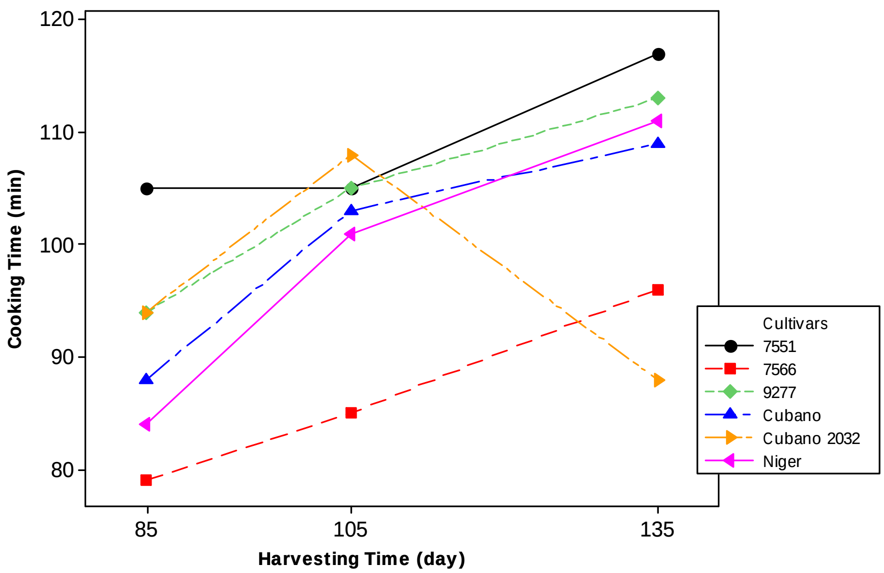

Figure 1. Interaction plot of cultivars and harvesting time on cooking time

Freeness

Freeness is related to the rate at which water drains from a stock suspension through a wire mesh screen or a perforated plate. The freeness typically should be in the range of 300 to 450 mL CSF for papermaking. The initial freeness of the unbeaten pulps was 612 ± 25 mL CSF. As can be seen in Table 1 and Fig. 2, the distribution of initial freeness values indicate what is happening during beating. Commonly, higher freeness values are caused by long fibre generation of kenaf base. Moreover, in order to reach the freeness to achieve efficient drainage and formation similar to standard papermaking conditions, the initial freeness was reduced by means of beating with PFI mill to 398 ±10ml CSF. The highest final freeness among the beaten pulps was below 410 mL. Regardless of the type of cultivar, i.e. Cubano or 9277, the unbeaten freeness showed no significant increase with longer harvesting time. However, as can be seen from PFI numbers, some cultivars such as Cubano 2032 required more beating as compared to others, which is expected, as differences in PFI numbers were closely related to the initial freeness.

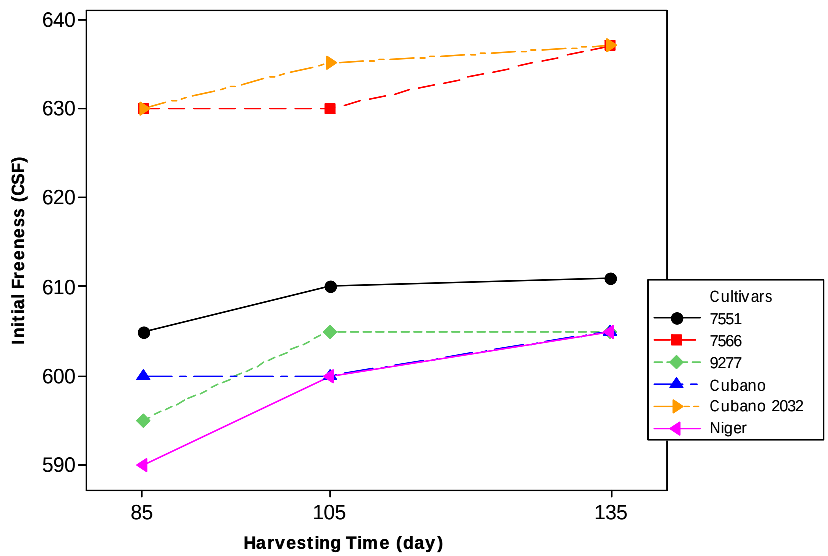

Figure 2. Interaction plot of cultivars and harvesting time on initial freeness

Yield

Yield is an important factor in pulping different raw materials in order to reach equal kappa numbers under similar cooking conditions. Table 1 lists the product yields. In terms of the main effects on yield, it is interesting that maximum yield at each of three harvesting time stages was achieve with the Niger cultivar (Fig. 3). Statistical analyses of six cultivars show that maximum yield was with Niger, followed by Cubano 2032 and Cubano, 9277, 7566 and 7554, respectively at three harvesting times. However in terms of the effect of increasing harvesting time, no significant difference was noticed between three harvesting times.

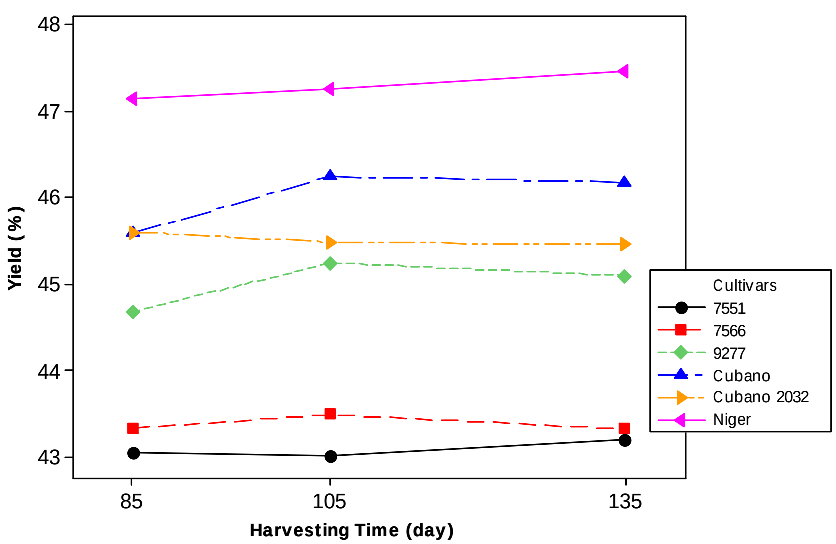

Figure 3. Interaction plot of cultivars and harvesting time on yield of pulp

In terms of obtaining the maximum yield between three harvesting time stages for six cultivars, we noted that Niger had the greatest yield, followed by Cubano, and 7551 had the least. A similar interpretation can be applied to other properties of the six cultivars with different harvesting time stages.

Burst Index

Burst index is a critical factor for paper products. This factor can be affected by lignocellulosic material when conditions of cooking and pulp preparation are the same. In terms of the effects of cultivars on burst, it is surprising that maximum burst at first, second and third harvesting time stages were different (Fig. 4). It means that the maximum value were Cubano 2032, Cubano, and Cubano at the first, and second, and third harvesting time stages, respectively (Table 1).

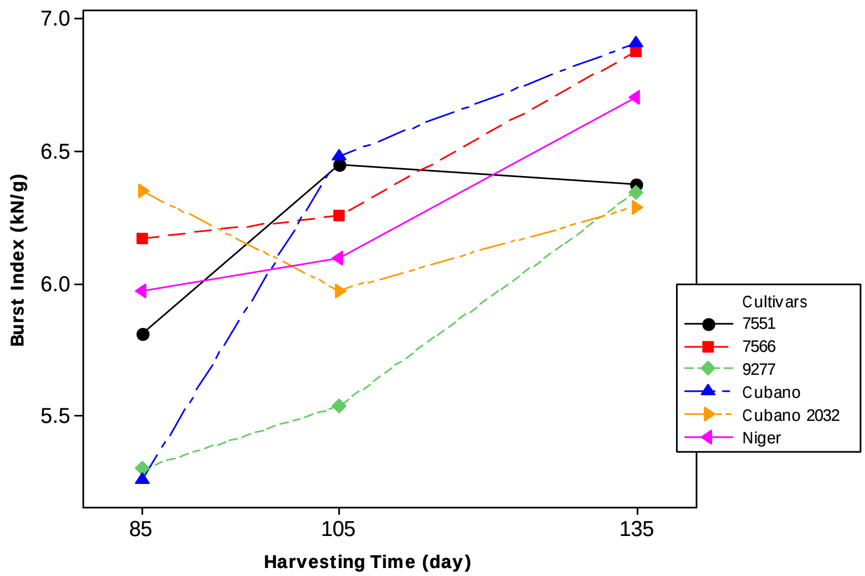

Figure 4. Interaction plot of cultivars and harvesting time on burst index

Statistical analyses of six cultivars at first harvesting time showed that maximum burst was obtained with Cubano 2032, and there were no significant differences between 7566, Niger, and 7551. Besides, the least values of burst index were found for 9277 and Cubano. Moreover, at the second harvesting time stage, the burst of Cubano and 7551 were statistically significant, while at the third harvesting time stage the burst of Cubano was exclusively significant. However, the other cultivars showed no significant difference in burst index.

Tear Index

In terms of the effects of cultivars on tear index, it is surprising that Cubano 2032, Cubano, and Cubano 2032 were the greatest at the first, second, and third harvesting time stages, respectively (Fig. 5). It has however been established that tear strength is a function of both fiber strength and fiber bonding (Wan Rosli et al. 2002; Page and

MacLeod 1992; Seth and Page 1988). The dependence on harvesting time is most probably related to these parameters.

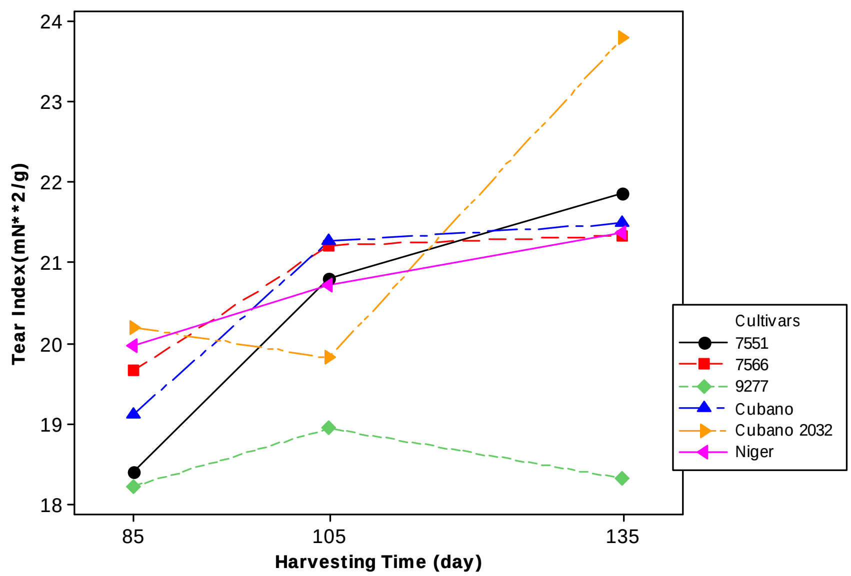

Figure 5. Interaction plot of cultivars and harvesting time on tear index

At short harvesting time, the degree of lignifications is relatively high in comparison to others; hence a considerable amount of lignin is still left in the pulp, resulting in lower bonding and consequently reduced tear strength. Statistically, although the tear of Cubano 2032 was significantly different from other cultivars at the first and third harvesting time stages, at second harvesting time stages there were no significant differences between cultivars at the 5% level (Table 1). It is noticeable that cultivar 9277 had the least tear index for all of the three harvesting times (Fig. 5).

Breaking Length

Generally, all pulping parameters influence the burst index and breaking length. As regards to breaking length, the greatest values were obtained with Cubano 2032 at first and second harvesting time stages, although the highest values at third harvesting time stage were obtained with Cubano (Fig. 6).

A statistical comparison of cultivars in each harvesting time stage indicated that Cubano 2032 as raw material obtained from the first and third harvesting time stages can reach significant breaking length. Statistically, all cultivars except 9277 affected the breaking length equally, with the second harvesting time stage. However, the long fiber products had a significantly higher breaking length at the target freeness. This result is similar to that reported by Roberts (1998). The results show no remarkable increase in breaking length with longer harvesting time when comparing first with third harvesting time stages (Table 1).

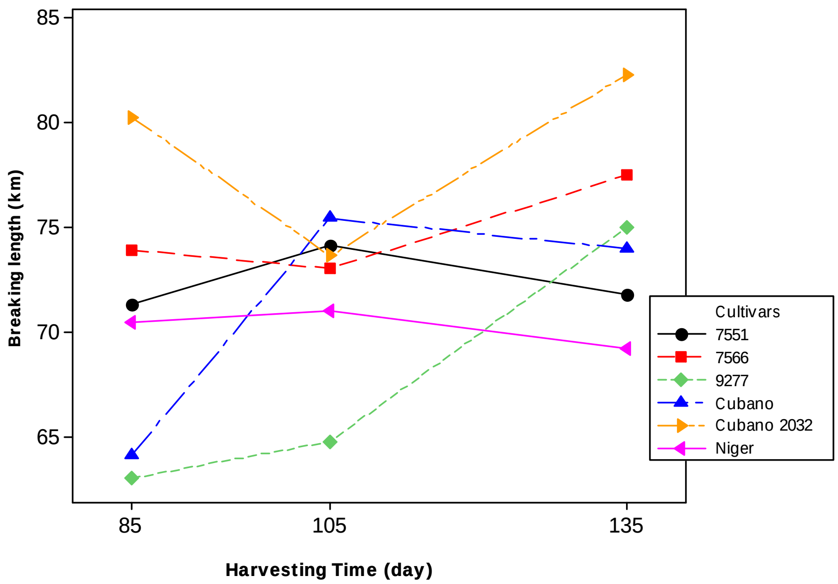

Figure 6. Interaction plot of cultivars and harvesting time on breaking length

Folding Endurance

Of the six cultivars, 7551 was not significantly different from the others in any harvesting time stage for folding endurance. Although 7566 was not significantly different in terms of fold endurance at the first and second harvesting time stage, it was so at the third harvesting stage. In spite of the fact that Cubano showed no significant effects on fold endurance at first harvesting time, but it showed significant effects at the second and third harvesting times. Besides, Niger was not significantly different for fold endurance at all the harvesting time stages. In a reverse manner, Cubano 2032 had significantly affected the fold endurance at the first harvesting time stage (Table 1). Statistically**,** these results show that Cubano and 7566 had significant effects on folding endurance in comparison to others after third harvesting time stage. However, the results in Fig. 7 show that the highest values were obtained with Cubano 2032, Cubano, Cubano 2032 at the first, second, and third harvesting time stages, respectively.

DISCUSSION

The results of this study clearly indicate that hand sheets properties in a narrow range of CSF, about 398± 10 ml, could be obtained by beating the pulps in a PFI mill with various speeds. As seen in Table 1, although differences in yield between three harvesting time stages are not particularly considerable, implying that any cultivars of kenaf or their harvesting times had no influence on promoting the ratio of holocellulose to lignin, but the greatest yield was obtained by Niger at each of three harvesting time stages. Therefore, if the goal is high yield, Niger can be recommended.

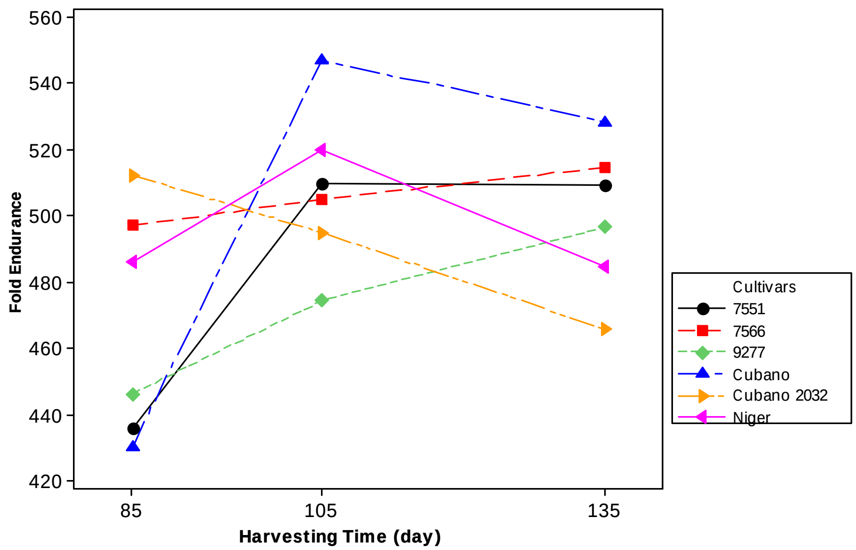

Figure 7. Interaction plot of cultivars and harvesting time on fold endurance

As Table 1 indicates, if a paper with high strength is to be requested, Cubano 2032 is strongly associated with significant burst, tear, breaking length and fold endurance, even though its yield is a bit less than Niger at short harvesting times. Subsequently, at the second harvesting time stage, maximum strengths of handsheets such as burst, tear, breaking length, and fold endurance achieved with Cubano, and although the yield of this cultivar was a bit less than Niger, it was still more than Cubano 2032. According to the recent research, these cultivars are significantly different in terms of fiber length, flexibility ratio, and Runkel ratio. Also, in comparison of fibres of six cultivars, fibres of Cubano 2032 had significantly different flexibility and Runkel ratio, while fibres of Niger had larger diameters (Shakhes et al., 2008). Therefore, it can be concluded that these anatomical and morphological properties affect handsheet strength.

Apparently, harvesting at the third stage as opposed to the first and second stage had a slight positive effect on handsheets properties. However, the improvement was not proportionate to the time spent for growing the plant.

When comparing results of this study to other results on kinds of pulps of different raw materials, this kind of pulp can be used for a variety of paper products, even for bleaching and derivation of secondary products. For this, Niger, Cubano 2032, and Cubano can be recommended as suitable cultivars with a harvesting time of around of 85 days.

CONCLUSIONS

It is known that the pulp of kenaf bast can be used as an efficient fibre source for mixing with other pulps to improve the end use performance of paper products. For this reason, a number of important cultivars of kenaf were evaluated to help understand the best cultivar and the best harvesting times for increasing efficiency and profit of papermaking. In this context, by means of initial trials, cooking times were detected for each cultivar to reach an equal kappa number of approximately 20. The results showed that the Niger cultivar achieved maximum yield at each of three harvesting time stages. Hence, for the goal of high yield, we recommend Niger. In addition, if a paper with high strength properties is desired, Cubano 2032 achieved significant advantages in burst, tear, breaking length, and fold endurance, even though its yield was a bit less than Niger at short harvesting times. Moreover, at the second harvesting time stage, maximum strength properties of handsheets such as burst, tear, breaking length, and fold endurance were obtained with Cubano, even though the yield of this cultivar was a bit lower than Niger, but still it was more than Cubano 2032. We showed that the third harvesting time stage had a minor positive effect on the handsheet properties relative to the earlier harvesting times.

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REFERENCES CITED

Ashori, A., (2006). "Pulp and paper from kenaf bast fibers," *Fibers Polym*. 7, 26-29.

Ashori, A., Harun, J., Zin, W. M., and Nor, M. (2006a). "Enhancing dry-strength properties of kenaf (*Hibiscus cannabinus*) paper through chitosan," *Polymer-Plastics Technology and Engineering* 45, 125-129.

Ashori, A., Harun, J., Raverty, W. D., and Yusoff, M. N. M., (2006b). "Chemical and morphological characteristics of Malaysian cultivated kenaf (*Hibiscus cannabinus*) Fiber," *Polymer-Plastics Technology and Engineering* 45, 131-134.

Calamari, T. A., Tao, W. Y., and Goynes, W. R., (1997). "A preliminary study of kenaf fiber bundles and their composite cells," *Tappi J.* 80, 149-154.

Dehghani-Firouzabadi, M. R., Shakhes, J., and Namakiyan, R. (2008). "The effects of harvesting times on fiber morphological properties and kenaf yield," The 1St Iranian Conference on supplying Raw materials and Development of Wood and Paper Industries, Gorgan University of Natural Resources and Agriculture, 2&3 Dec 2008.

Feng, Z., and Alén, R. (2002). "Selectivity of soda-AQ pulping of kenaf bark," *Cell. Chem. Technol*. 36, 367-374.

James, K. R., and McCamley, J. (1981). "Separation of core and bark from forage harvested knead," I. M. Wood, G. A. Stuart (eds.), *Proceedings of the Kenaf Conference (Kenaf as a Potential Source of Pulp in Australia)*, Brisbane, Queensland, pp. 69–72.

Kaldor, A. F. (1989). "Preparation of kenaf bark and core fibers for pulping by the Ankal method," *Tappi J.* 58, 137-140.

Kaldor, A. F., Karlgren, C., and Verwest, H. (1990). "Kenaf, a fast growing fiber source for papermaking," *Tappi J.* 72, 205-209.

Kaldor, A. F., Brasher, B. S., and Fuller, M. J. (1992). "A strategy for the development of a kenaf-based pulp and pulp industry," *Tappi J*. 75, 87-91.

Khristova, P., Kordsachia, O., Patt, R., Khider, T., and Karrar, I. (2002). "Alkaline pulping with additives of kenaf from Sudan," *Industrial Crops and Products* 15, 229-235.

Lam, T. B. T., Hori, K., and Iiyama, K., (2003). "Structural characteristics of cell walls of kenaf (*Hisbiscus cannabinus* L.) and fixation of carbon dioxide," *J. Wood Sci*. 49, 255-261.

Mazumder, B. B., Ohtani, Y., and Sameshima, K., (1998). "Normal pressure pulping of jute, kenaf and mesta bast fibers," *Sen'-I Gakkaishi* 54, 654-660.

Mazumder, B. B., Ohtani, Y., Cheng, Z., and Sameshima, K. (2000a). "Combination treatment of kenaf bast fiber for high viscosity pulp," *J. Wood Sci*. 46, 364-370.

Mazumder, B. B., Izumi, A., Kuroda, K., Ohtani, Y., and Sameshima, K. (2005). "Evaluation of harvesting time effects on kenaf bast lignin by pyrolysis-gas chromatography," *Industrial Crops and Products* 21, 17-24.

Morrison, W. H., Akin, D. E., Archibald, D., and Raymer, P. L. (1999a). "Characterization of kenaf core and bast using pyrolysis mass spectrometry," Sellers Jr, T., and Reichert, N. A. (eds.), *Kenaf Properties, Processing and Products*, Mississippi State University, Mississippi, pp. 169-186.

Morrison, W. H., Akin, D. E., Archibald, D. D., Dodd, R. B., and Raymer, P. L., (1999b). "Chemical and instrumental characterization of maturing knead core and bast," *Ind. Crops Prod.* 10, 21-34.

Myers, G. C., and Bagby, M. O. (1995). "Feasibility of using kenaf chemithermo-mechanical pulp in printing and writing paper," *Tappi Journal* 78, 156-161.

Ohtani, Y., Noguchi, T., and Sameshima, K. (1994). "Influence of anthraquinone addition method on alkaline pulping of kenaf bast," *Sen'-i Gakkaishi* 52, 175-179.

Pande, H., and Roy, D.N. (1996). « Delignification kinetics of soda pulping of kenaf," *J. Wood Chem. Technol*. 16, 311-325.

Page, D. H., and MacLeod, J. M. (1992). "Fiber strength and its impact on tear strength," *Tappi Journal* 75(1), 172-174.

Roberts, J. (1998). "Wastepaper yields more treasure: There's more to be extracted from wastepaper than just fibre," *Pulp and Paper Europe (PPE)* (5), 33-34.

Seth, R. S., and Page, D. H. (1988). "Fiber properties and tearing resistance," *Tappi Journal* 71(2), 103-107.

Shakhes, J., Dehghani-Firouzabadi, M. R., and Namakiyan, R. (2008). "Investigating the effect of cultivar on morphological properties kenaf bast fiber," *The 1St Iranian Conference on Supplying Raw materials and Development of Wood and Paper Industries*, Gorgan University of Natural Resources and Agriculture, 2&3 Dec 2008.

Touzinsky, G. F., Clark, T. F., Tallent, W. H., and Kwolek, W. F. (1973). "Soda pulps from kenaf bark and from core," *TAPPI Alkaline Pulping-Nonwoody Plant Fibers Conference*, Atlanta, pp. 49–53.

Touzinsky, G. F., Clark, T. F., and Tallent, W. H. (1972). "Characteristics of sulfate pulps from kenaf bark and core, Non-wood plant fiber pulping, Progress Report n◦3, Committee Assignment Report n◦43," TAPPI, Atlanta, pp. 26–53.

Villar, J. C., Poveda, P., and Tagle, J. L. (2001). "Comparative study of kenaf varieties and growing conditions and their effect on Kraft pulp quality," *Wood Sci. Technol*. 34, 543-552.

Villar, J. C., Revilla, E., Gómez, N., Carbajo, J. M., and Simón, J. L. (2009). "Improving the use of kenaf for kraft pulping by using mixtures of bast and core fibers," *Industrial Crops and Products* 29, 301-307.

Wan Rosli, W. D., Law, K. N., Zainuddin, Z., and Asro, R. (2004). "Effect of pulping variables with on the characteristics of oil-plam frondfiber," *Bioresource Technology* 93, 233-240.

Wood, L. M., Muchow, R. C., and Ratcliff, D. (1983). "Effect of sowing date on the growth and yield of kenaf (*Hibiscus cannabinus*) grown under irrigation in tropical Australia. II. Stem production," *Field Crops Res*. 7, 91-102.

Zeinaly, F., Shakhes, J., and Dehghani-Firouzabadi, M. R., (2008). "Investigation of paper properties from kenaf stalk," *The 1St Iranian Conference on Supplying Raw materials and Development of Wood and Paper Industries*, Gorgan University of Natural Resources and Agriculture, 2and 3 Dec 2008.

Zhou, C., Ohtani, Y., Sameshima, K., and Zhen, M. (1997). "Selection of kenaf (*Hibiscus cannabinus L.*) varieties for papermaking on arid hillside land in China," *Mok. Gakkais.* 43(9), 770-777.

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