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Full Length Research Paper

Effects of harvest time and cultivar on yield and physical properties fibers of kenaf (*Hibiscus cannabinus* L.)

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Kenaf (*Hibiscus cannabinus* L.) is an annual non wood plant which has shown great potential as an alternative source of papermaking fiber. No information is available on kenaf cultivation in south-Iran in spite of the need to replace imported long fibers through local production of alternative sources. The purpose of this research is to investigate the effect of kenaf cultivars and harvest times on component yield and fiber quality. Six cultivar of kenaf (Cubano, Niger, Cuba 2032, 9277, 7551 and 7566) were planted on May 19, 2007 in the research farm of Agronomy Department Gorgan University. The three harvest times are 85, 105 and 135 days after planting. Result showed that bast yield, stem yield, bast: stem ratio and total dry matter, were affected by harvest time. Bast to stem ratio in second harvest time was more than any other times (40.02). Niger cultivar was the best cultivar for stem yield, bast yield and total dry material, also Cubana 2032 and Cubano were the best cultivar for bast to stem ratio with 40.41 and 40.00% respectively. Fiber morphology results showed that interaction between cultivar and harvest time was significant. The bast fiber length increased with plant age in all cultivars except Cuba 2032. Although core fiber length increased with age in 7551, 7566, 9277 and Cuba 2032 cultivars but it decreased, in Niger and Cubano cultivars. The result indicated that kenaf bast fiber were long and slender, while the core fiber were much shorter and wider. Morphology analysis indicated that bast and core fibers were significantly different. The bast fiber dimension was better than the core in the production of quality paper.

Key words: *Hibiscus cannabinus,* kenaf, harvest time, cultivar, yield, fiber morphology.

INTRODUCTION

The demand for various forest products such as pulp and paper will certainly increase because of growth population and economic development. The principal raw materials for paper manufacturing are wood, non-wood and recycled fibers. Non-wood plants could reduce the shortage of fibrous raw materials for pulp and paper industry (Atchison, 1996; Villar et al., 2001). There is a wide variety of non-wood plant fibers that are being used in the manufacture of pulp and paper all over the world. In 1950s and early 1960s, the United States Department of Agriculture (USDA) researchers selected kenaf as the most promising annual crop source of fiber for the pulp industry; various investigations have focused on the application of farming and pulping techniques. This examinations include new cultivars have been developed with greater yield potential in a wide range of growing seasons; yield and growth performance in different locations and under different cropping situations have been described. There are also other investigations of

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changes in fiber properties of kenaf at different stages of plant growth. Their results show that it produces a very high fiber yield per hectare and has proved to be a suitable material for pulp and paper industry. (Clark et al., 1967; Muchow, 1979; Han et al., 1995; Mambelli and Grandi, 1995; Ayerza and Coates, 1996; Mcmillin et al., 1998; Bledsoe and Webber, 2001; Nkaa et al., 2007).

Kenaf (*Hibiscus cannabinus* L.) is an annual fast growing non-wood plant which has been regarded as one the most promising and suitable raw material to make a variety of paper grades (Kaldor et al., 1990). As an annual fiber crop, kenaf has high biomass production capacity (14 to 22 t /ha) and a higher pulp yield than those of other non-wood and wood species (Atchison and McGovern, 1983). The kenaf plant consists of two distinct fibers. The external part or bast which is the portion used for cordage fiber is about 35 to 40% of stem by the weight and internal part, woody core which is about 60 to 65%. The fibers in the bast section are long and similar to softwood fibers but the fibers in the core section are shorter than those in the bast and somewhat shorter than those in temperate zone hardwoods (Nkaa et al., 2007). The longer bast fibers are used to manufacture products such as high grade pulps for the pulp and paper industry, composite boards and textiles. The shorter core fibers are used for products such as animal bedding, sorbents and horticultural mixes (Fisher, 1994).

The aims of this study were to determine the suitability of harvest time and kenaf cultivar in north of Iran and to compare components yield and fiber dimension properties in six kenaf cultivars. This information is necessary to admit that kenaf is a feasible alternative for farmers in north Iran where forest resources are inadequate to supply a pulp mill of economic size.

MATERIALS AND METHODS

Cultural details and measurements

This experiment was conducted at Gorgan University (latitude 35.5 north and longitude 54.4 east) on silty clay loam. The characteristics of the soil were analyzed as EC (0.6), pH (7.9), clay (36%), sand (10%) and silt (54%).

Six kenaf varieties have been used in the experiment. Six cultivars namely Cubano, Niger, Cuba 2032, 9277, 7551, and 7566, were used for the study. The field was cleared of bush, plowed and made into beds of 9 × 9 m. Kenaf seeds were planted at a soil depth of 5 cm with a spacing distance of 5 cm between plants and 35 cm between rows to give a total of 66.66 plants/m^2. In order to ensure optimum crop yield, all plots received 105 kg of urea fertilizer, 85 kg of phosphate diammonium fertilizer, and 125 kg potassium sulfate fertilizer per hectare added and mix with soil.

The crop was shown on 19 May, and five irrigations were applied during the growing season using the traditional furrow system found in the region. The harvest times were 85, 105 and 135 days after planting (DAP). Sample area (1 m^2) was harvested from the center rows of each subplot in each harvest time. After each harvest, the plants were separated into a core, bast and leaf fractions. These components were oven-dried at 70℃ f or 48 h and then oven- dried weight of stem, bast, core, total dry material (yield stem add to pluses yield leaf) and ratio of bast fiber to stem material were determined. Also plant height (cm), base stem diameter (mm) and stem diameter at 30 cm (mm) were determined.

Fiber dimensions

Stem samples for the fiber studies were obtained from the approximately fifth internodes counting from the base. For fiber length, fiber width, lumen width and cell wall thickness measurements, the material was macerated by Franklin's method in acetic acid and hydrogen peroxide (1:1) at 60℃ for 48 h. T he macerated fiber suspension was finally placed on a slid (standard, 7.5 × 2.5 cm) by means of a medicine dropper (Han et al., 1999). All fiber samples were viewed under a projection microscope. For measuring fiber length and diameter, 200 fibers were measured from 10 slides and average reading was taken (Shatalov and Pereira, 2001).

Experimental designed statistical analysis

The experiment was based on a split plot design. Three harvest time the main plot and the six Kenaf varieties as the sub-plots. Data obtained were subjected to analysis of variance and means separated using the Duncan multiple range tests.

RESULTS AND DISCUSSION

Growth parameters

Harvest time and cultivars significantly affected all agronomic traits measured except steam diameter at 30 cm (Tables 1 and 2). At 85 to 135 days after sowing, the stem yield increased from 3.5 to 8 ton ha^{-1}, and the bast yield production from 1.3 to 3 ton ha^{-1} and the plant height from 92 to 140 cm. In addition, stem base diameter increased significantly with the plant age while stem ratio decrease from 39.41 to 37.1% between the first and the third harvest time (Table 2).

Niger cultivar with 7.170 ton/ha had the highest fiber yield while 9277 cultivar with 4.851 ton/ha had the lowest yield. The ratio of bast to stem fibers was varied by cultivar. Cultivars Cuba 2032 and Cubano had the highest percentage of bast fiber and 7551 had the high percentage of core fiber (Table 1). Statistical analysis showed that there was no significant interaction between harvest time and cultivars.

Fiber dimensions

The effect of harvest time on dimensional properties in six cultivars is shown in Tables 3 and 4. In Table 3, the bast fiber length increased with age except Cuba 2032 cultivar which decreased with age. The longest fiber was from Cubano cultivar with an average of 3.14 mm in the third harvest. The shortest fiber was from 9277 cultivar,

Table 1. Effect of cultivar on yield parameters of six Kenaf cultivars.

Cultivar	Stem yield (kg/ha)	Bast yield (kg/ha)	Total dry material (kg/ha)	Bast: stem ratio	Plant height (cm)	Base stem diameter (mm)	Stem diameter at 30 cm (mm)
7551	6411.7^{ab}	2370.6^{ab}	10134.7^{abc}	37.7^{c}	121.7^{ab}	8.6^{ab}	6.9
7566	6248.3^{abc}	2371.3^{ab}	10488.8^{ab}	38.2 ^{c}	125.5^{a}	8.3^{b}	6.9
Cubano	5806.0^{bc}	2293.8^{b}	9516.4 ^{bc}	40.0^{ab}	117.2^{b}	8.3^{b}	6.5
Niger	7170.7^{a}	2759.4^{a}	11833.3^{a}	38.7^{bc}	124.0^{a}	8.8^{a}	6.9
Cuba 2032	5300.8^{cd}	2138.0^{bc}	8834.5^{c}	40.4^{a}	112.9^{c}	8.6^{ab}	6.6
9277	4851.2^{d}	1824.7^{c}	8207.6^{c}	38.3^{c}	113.9^{c}	7.6^{c}	6.6

Table 2. Effect of harvest time on yield parameters of six Kenaf cultivars.

Fiber/ age (days)	Stem yield (kg/ha)	Bast yield (kg/ha)	Total dry material (kg/ha)	Bast: stem ratio	Plant height (cm)	Base stem diameter (mm)	Stem diameter at 30 cm (mm)
At 85 day after planting	3506.7^{c}	1378.8^{c}	6276.2^{c}	39.4^{ab}	92.9^{c}	7.3^{c}	5.5^{b}
At 105 day after planting	6196.6^{b}	2460.8^{b}	10346.2^{b}	40.0^{a}	124.6^{b}	8.4^{b}	7.1^{ab}
At 135 day after planting	8190.9^{a}	3039.3^{a}	12875.3^{a}	37.2^{b}	140.1^{a}	9.4^{a}	7.4^{a}

with average of 2.40 mm in the first harvest (Table 3). Cubano and Niger core bast fiber lengths were the least and both decreased with age while other cultivars increased with age. The longest core fiber was from 9277 cultivar with 0.88 mm length and the shortest core fibers from Cubano cultivar with 0.68 mm length at the third harvest.

The fiber diameter in core was much more than the bast fibers diameter in all cultivars. In most cultivars, bast and core fiber diameter increased with age with the exception of Cubano and Cuba 2032 cultivars (Table 3).

Both lumen width and cell wall thickness increased age in core tissue, additionally lumen width increased with age in bast fiber excepted Niger cultivar besides cell wall thickness increased with age of bast tissue except Cubano and Cuba 2032 cultivars. Finally, the lumen width is greater in core fibers as compared to that of bast fibers (Table 4).

DISCUSSION

This experiment has shown that kenaf productivity was highly affected by harvest time and cultivar. Fiber yield increased with growing season. These results were consistent earlier reports that fiber yield increased with plant age (Ayerza and Coates, 1996; Bledsoe and Webber, 2001).

Stem yield was positively affected with stem diameter and stem height. These results were in agreement with previously reports that stem diameter increased with increasing plant height and plant height is an important factor as a contributor to total or stem dry matter (Dempsey, 1975; Webber, 1993; Mambeli and Grandi, 1995; Mcmillin et al., 1998; Rouxlene, 2004). We found that fiber yield (bast, core and total dray material) were more closely relationship with stem diameter and plant height. These factors may have supported the yield difference found among the various cultivars.

The data presented in Table 2 indicates that during the growing cycle, the bast: stem ratio first increased, then decreased, these results were consistent with earlier works that the ratio of core fiber to bast fiber increased with age (Han et al., 1999). We found that bast: stem ratio were significantly affected by harvest time and cultivar. However, in contrast to conclusions of Muchow (1979), that revealed bast content is improved by irrigation and not affected by cultivar. The bast: stem ratio of cultivars Cubano and Cuba 2032 was similar to that reported by Ayerza and Coates (1996).

The fiber dimensional properties of both kenaf core and bast were affected by harvest time and cultivar interaction (Tables 3 and 4). There was a big difference in lengths of fibers coming from the bast and core tissues. The bast fibers average length (2.4 to 3.1 mm) is in the range of soft woods, whilst the core fiber length (from 0.68 to 0.88 mm) is like that of hardwoods (Miller, 1965; Nkaa et al., 2007). Therefore, papers made from kenaf bast fibers are expected to have increased mechanical strength and thus be suitable for writing, printing, wrapping, and packaging purposes (Ververis et al., 2004; Shakhes et al 2011). The length of bast fibers was found to be double the length of the core fibers. Fiber length and strength have been shown to be particularly important for tearing resistance (Wangaard and Williams, 1970). The results of this experiment show that bast fiber length increases with plant age, except in cuba 2032 cultivar where bast fiber length decreases with plant age.

Table 3. Effect of harvest time on fiber length and fiber diameter of six Kenaf cultivars.

Fiber/age (Days)	Variety/ fiber type	Fiber/age (Days)			
		At 85 day after planting	At 105 day after planting	At 135 day after planting	Mean
			7551		
	Core	0.763	0.810	0.852	0.808
	Bast	2.441	2.583	2.792	2.605
			7566		
	Core	0.828	0.834	0.837	0.833
	Bast	2.504	2.651	2.649	2.601
			Cubano		
	Core	0.755	0.699	0.682	0.712
Fiber length	Bast	2.437	3.054	3.141	2.877
			Niger		
	Core	0.778	0.752	0.721	0.750
	Bast	2.807	2.705	2.770	2.760
			2032		
	Core	0.785	0.759	0.815	0.763
	Bast	2.712	2.545	2.521	2.592
			9277		
	Core	0.759	0.809	0.880	0.816
	Bast	2.403	2.411	2.480	2.431
			7551		
	Core	23.04	25.64	28.81	25.83
	Bast	16.19	16.63	17.12	16.64
			7566		
	Core	20.37	22.27	24.81	22.48
	Bast	15.82	16.04	16.98	16.28
			Cubano		
	Core	24.55 [c]	26.42	28.64	26.53
Fiber diameter	Bast	15.83	16.91	15.95	16.23
			Niger		
	Core	24.30	26.85	29.89	27.01
	Bast	17.12	17.38	17.99	17.49
			2032		
	Core	24.53	25.71	27.29	25.84
	Bast	17.44	17.17	16.44	17.01
			9277		
	Core	21.91	22.61	24.36	22.96
	Bast	16.15	16.33	16.49	16.32

Clark et al. (1967), demonstrated that the bast fibers are longer than the core fibers and that both decreases in length with age. However, in contrast to findings of Han et al. (1995), that average length of bast and core fiber increased with age. Another study described that irrigation and harvest time had no significant effect on bast fiber morphological properties while cultivar had a significant influence on fiber length and wall thickness (Villar et al., 2001). In general, these findings indicate that of both harvest time and cultivar was significant on the fiber dimensional properties.

The thickness of the fiber wall has an important bearing on most paper properties, with thick-walled fibers forming bulky sheets of low tensile, burst, and folding endurance but with a high tearing strength (Haygreen and Bowyer, 1996). The strength properties of papers were found to positively correlate with the slenderness ratio (fiber length/ fiber diameter). Lumen width and fiber diameter of

Table 4. Effect of harvest time on fiber lumen and cell wall thickness of six Kenaf cultivar.

Fiber/age (Days)	Variety/fiber type	Fiber/age (Days)			
		At 85 day after planting	At 105 day after planting	At 135 day after planting	Mean
			7551		
Fiber lumen diameter	Core	15.08	17.32	20.15	17.51
	Bast	4.51	5.64	5.95	5.36
			7566		
	Core	14.48	15.84	17.41	15.91
	Bast	5.30	5.18	6.53	5.67
			Cubano		
	Core	17.62	19.10	21.05	19.25
	Bast	4.01	6.36	6.02	5.46
			Niger		
	Core	18.65	20.54	23.03	20.74
	Bast	7.63	6.28	5.37	6.42
			2032		
	Core	16.85	17.48	17.38	17.23
	Bast	6.18 [a]	5.74	4.56	5.49
			9277		
	Core	15.26	14.95	15.24	15.15
	Bast	4.66	5.02	5.24	4.97
			7551		
Fiber wall thickness	Core	3.98	4.15	4.33	4.15
	Bast	5.84	5.49	5.58	5.63
			7566		
	Core	2.94	3.21	3.70	3.28
	Bast	5.26	5.42	5.22	5.30
			Cubano		
	Core	3.65	3.65	3.79	3.69
	Bast	5.91	5.27	4.96	5.38
			Niger		
	Core	2.82	3.15	3.43	3.13
	Bast	4.74	5.55	6.31	5.33
			2032		
	Core	3.84	4.11	4.95	4.30
	Bast	5.63	5.71	5.94	5.76
			9277		
	Core	3.32	3.83	4.56	3.90
	Bast	5.74	5.67	5.26	5.55

cultivar was similar to that reported by Clark et al. (1967). Results showed that core fiber wall thickness is lower than bast fiber wall thickness and this finding is in contrast to conclusion of Clark et al. (1967).

In general these finding exhibited that the variability of bast fiber dimension in some cultivars may be due to their different reactions to environmental conditions. Unlike bast fibers, core fibers are less affected by environmental conditions and show almost constant behavior.

Conclusions

This research confirms the possibility of producing kenaf for fiber and other products in north Iran. Also a conception of the changes in yield and quality of kenaf fiber during the growing season is essential for determining suitable variety for pulp and paper industry. Our result indicates that kenaf fiber yield was significantly affected by harvest time and cultivar. Fiber yield increases with plant age. Among the cultivars, Niger was better than other cultivars from the crop yield point of view.

Result based on morphology display that bast and core fiber fractions in kenaf stem are significantly different. And both core and bast fiber were affected by harvest time and cultivar interaction. In general, the bast material has a higher fiber length, lower fiber diameter, higher cell wall thickness and lower lumen width and would be expected to give better paper properties than core material.

Harvest time seems to play an important role in determining not only the stem yield but also Fiber properties. The data strongly suggest that planting of kenaf in Gorgan (Iran) earlier (early spring) could increase growth and result in yield increase in Grogan zone.

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