CHAPTER 14

VALIDITY OF PLANT FIBER LENGTH MEASUREMENT-A REVIEW OF FIBER LENGTH MEASUREMENT BASED ON KENAF AS A MODEL

James S. Han, Theodore Mianowski, and Yi-yu Lin

ABSTRACT

The efficacy of fiber length measurement techniques such as digitizing, the Kajaani procedure, and NIH Image are compared in order to determine the optimal tool. Kenaf bast fibers, aspen, and red pine fibers were collected from different anatomical parts, and the fiber lengths were compared using various analytical tools. A statistical analysis on the validity of the fiber length measurements of each method was obtained. Using this analysis, a relationship was developed between fiber length, growth, and pulping conditions.

INTRODUCTION

The fiber length of kenaf *(Hibiscus cannabinus* L.) has been reported by various researchers between 3 mm to 7 mm. A specific average length is not used because of the wide variability in the samples studied. The reason attributed to this variability is unclear in the literature.

Kenaf is an annual plant having many known cultivars that are grown within a wide range of climatic conditions. An accurate estimate of fiber length must be based upon where, when and how a given cultivar is grown and harvested.

The physical dimensions of the fiber are among the most important factors in pulping and other industries. With increasing interest in non-wood pulping in this country, it is essential to know the fiber length, or at least how to interpret the variability. The state of kenaf fiber dimension is treated as a function of growth and height. Also, the most popular measuring techniques are compared in this study.

MATERIALS AND METHODS

Samples and Sampling

On May9, 1994, seeds of Cuba 108 (C-108), Tainung 1, Everglades 45-9, and Everglades 71-1 were planted on a plot of land located on the campus of University of Wisconsin-Madison. The plants were less vulnerable to frost and winds due to the surrounding buildings. The first frost occurred on October 10 but did not kill the plants. The total number of growing days at this location was 175 days after planting (DAP).

The samples were kept in a freezer. Tainung 1 was selected for measurement of fiber length in the summer of 1997. The whole stalk of one randomly chosen plant from each of three harvest dates was cut into 305-mm (12-in.) sections. The bottom 25 mm (1 in.) of each section was then macerated and the fiber length measured in 50-70 samples.

The maceration technique consisted of the application of a method suggested by Spearin and Isenberg 1947) using acetic acid and sodium chlorite with some modifications. It was noted by the investigators that most of the purchased kenaf fibers showed considerable damage in fiber length. It was difficult to assess whether the damage was caused by the maceration process; however, the home-grown kenaf exhibited less damage (Isenberg 1947). It was reported in the literature that in some instances the fiber length was as long as 7 mm, but this is rare.

In order to observe trends, the length of kenaf fiber was compared to that of aspen (Populus grandidenta) and red pine (Pinus resinosa) grown in Wisconsin. Two samples were collected from Marquette County, Wisconsin (location: Adams-Columbia Electric Power Co-op, Sub-station "R" Roslin, South-central Marquette Co.). The samples of aspen studied were from a 40-year old tree, and the red pine samples were from a 22-year old tree. Each sample was cut into ten pieces from top to bottom, as opposed to exactly 305-mm sections for kenaf. Samples one-half inch in thickness were cut from the bottom of each 305-mm section, and a block 25 mm in width was cut from the center. The blocks measured 12.7 mm in thickness, 25 mm in width, and its length corresponded to the diameter of tree trunk. Similarly, the blocks obtained from the pith were cut into 25-mm pieces (Figure 14.l). A thin section was cut from each piece - at a location close to the pith - and macerated for measurement.

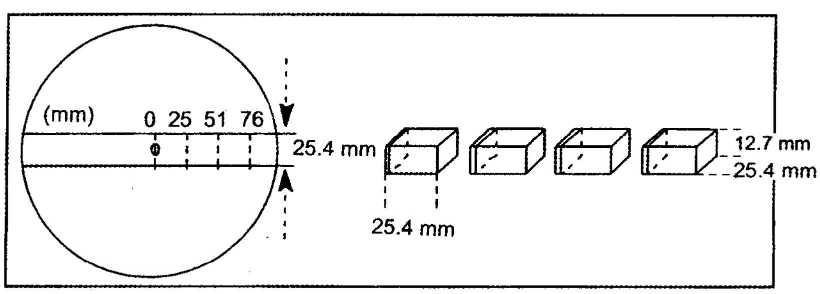

Figure 14.1. Dissection of wood.

Sample Preparation

Maceration

Sections of plant stems or other anatomical parts, rarely convey an accurate conception of the real nature of the cells of which they are composed. One method which reveals cells in their cellular structure is the dissociation method. The target plant is treated with chemicals which dissolve the middle lamella and allow the cells/fibers to become separated from one another. It should be emphasized that in some types of plants, the mild maceration process will not completely dissociate to a single fiber unit, resulting in an aggregate of fibers. These aggregates of fibers have the appearance of a single fiber. The maceration process is actually small-scale pulping. Sometimes it is referred to a “test-tube pulping”. The pulping processes such as kraft pulping, soda pulping, etc., are excluded in this discussion. Some processes result maceration as well as bleaching. The following is a list of some useful techniques.

Maceration techniques

- Schulze’s (1857) method consists of the application of a combination of various concentrations of nitric acid with a small quantity of potassium chlorate. The mixture is allowed to stand at room temperature or is heated slightly to initiate the reaction. There are some variations of Schulze’s methods.
- Jeffrey (1917) proposed an alternative method for milder treatment by using a mixture of equal portions of freshly combined 8 to 10% nitric acid and chromic acid. Although maceration at a cold temperature often gives best results, the mixture may be warmed slightly to hasten the reaction. Jeffrey’s technique has become widely known. Schmid (1982) made sonification and other improvements on Jeffrey’s method. Large (up to pencil-size) pieces of wood are macerated in Jeffrey’s solution.
- Franklin (1945) method uses acetic acid and hydrogen peroxide.
- Spearin and Isenberg (1947) method uses sodium chlorite and acetic acid.
- Burkart (1966a,b) method consists of treatment with triethylene glycol containing an organic catalyst, such as phenolsulfonic acid or p-toluenesulfonic acid at 130°C.

Slide preparation

The method of preparing slides varies considerably. Usually the macerated fiber suspension can be placed on a slide (standard, 7.5 x 2.5 cm) by means of a needle or medicine dropper. The T401 sm-93 standard can be found in TAPPI official test methods, or in Bright (1926).

The slides are then dried and a cover glass (22 x 30 mm) placed over the fiber and the fiber length can be measured. The fibers can be treated with 1:1 glycerol solution to prevent further drying; or, various staining processes can be applied in order to enhance the visibility, and to preserve the fiber and the slides. In this investigation, multiple measurements were obtained using the slurry from the macerated sample. Computer-enhanced image processes rarely require staining, and the enhancement software allows for ease of measurement. If permanent slides are desired, the desk top computer can store the image in a bagged-image file format (TIFF) file, which is used to exchange files between applications and computer platforms.

Methods of Measurement

The actual measurement of fiber dimension can be achieved by various methods. The most economical process is shining the image from a microscope on a wall or on a board and the fiber dimension can be measured manually or by means of a digitizer. Digitizing is achieved by identifying (using the electronic indicator) both ends of the fiber. Alternatively, the outline of the fiber can be traced, although this is a labor-intensive process. More advanced imaging technologies are available at a considerable cost. Most digitizing programs are IBM-compatible computer-based, and the U.S. National Institute of Health (NIH) Image software (public domain) is Macintosh-based.

In the Forest Products Laboratory (FPL) (Madison, WI), image system samples are magnified with the use of a light microscope and a 1:1 optical lens. A Vicon Industries Inc. video camera, Model No. VC 2200-24, was mounted to the microscope. The image is captured using a Scion Frame Grabber (LG-3) and then analyzed using NIH Image software.

Measurement

Usually about 80 or more fibers are selected and measured in this study. The hardwood fiber with average fiber length of about 1.3 mm are less vulnerable to damage, and most of the fibers will maintain their integrity. Yet, nonwood fibers, such as kenaf and jute, with fiber lengths of 3 to 7 mm, will be damaged by either the maceration process or exposure to dryness. It is suggested that the morphology of the fiber be investigated and only undamaged fibers be measured. An argument can be made against using this procedure because it could result in biased data on fiber length. However, one of the purposes of this study is to determine the actual fiber length as a function of growth and location. Thus, it is desirable to select the undamaged fibers exclusively. This fiber length was then compared to the results of Kajaani process (TAPPI 1993).

RESULTS AND DISCUSSION

The results shown in Tables 14.1 through 14.3 indicate that the fiber length of Tainung 1 (T-l), as a function of height, is not linear. At 147 days after the planting (Figure 14.2), the fiber length is approximately 2.5 mm at the bottom of the plant, and the fiber length increases to more than 3 mm at a plant height of 1219 mm (48 in.). It then decreases to about 2.5 mm at a height of 1829 mm (72 in.). At the top of the plant, the fiber length increases to about 3.5 mm. Measurements were performed on fibers from two other plants (Figures 14.3 and 14.4) and the same pattern was observed: shorter fibers were at the bottom compared to the top. Figure 14.5 shows the average fiber lengths of three different plants at different growing stages, showing similar patterns.

Table 14.1. Fiber length of kenaf (T-l) at 147 DAP, 2896 mm in height.

Stalk Height (mm)	Fiber Length			
	Average 95% CI (mm)	Average 90% CI (mm)	Maximum (mm)	Minimum (mm)
0	2.45 ± 0.069	2.45 ± 0.058	3.28	1.89
304	2.85 ± 0.068	2.85 ± 0.057	3.73	2.26
610	2.84 ± 0.088	2.84 ± 0.073	3.99	1.93
914	2.85 ± 0.077	2.85 ± 0.064	3.69	2.21
1219	3.09 ± 0.071	3.09 ± 0.060	3.93	2.49
1524	2.93 ± 0.065	2.93 ± 0.054	3.51	2.32
1829	2.42 ± 0.074	2.42 ± 0.062	3.42	1.67
2134	2.55 ± 0.076	2.55 ± 0.063	3.16	1.81
2438	2.49 ± 0.086	2.49 ± 0.072	4.02	1.80
2743	3.51 ± 0.153	3.51 ± 0.128	5.48	2.10

Clark et al. (1967) measured the fiber dimension of kenaf at different stages of plant growth (Table 14.4). In their study, the fiber length actually decreased as the plant matured; however, he did not measure the fiber length at different stalk heights. Therefore, viable comparisons between our data and their (Clark at al 1967) cannot be made.

Table 14.2. Fiber length of kenaf (T-l)at 161 DAP, 2273 mm in height.

Stalk Height (mm)	Fiber Length			
	Average 95% CI (mm)	Average 90% CI (mm)	Maximum (mm)	Minimum (mm)
0	2.51 ± 0.066	2.51 ± 0.055	3.19	1.85
304	3.14 ± 0.082	3.14 ± 0.069	4.29	2.33
610	3.31 ± 0.094	3.31 ± 0.079	4.28	2.52
914	3.09 ± 0.067	3.09 ± 0.056	3.83	2.44
1219	2.96 ± 0.102	2.96 ± 0.086	4.79	2.06
1524	2.47 ± 0.080	2.47 ± 0.067	3.66	1.70
1829	3.02 ± 0.088	3.02 ± 0.074	5.41	2.37
2134	3.54 ± 0.118	3.54 ± 0.099	4.64	2.29

Table 14.3. Fiber length of kenaf (T-1) at 175 DAP, 3327 mm in height.

Stalk Height (mm)	Fiber Length			
	Average 95% CI (mm)	Average 90% CI (mm)	Maximum (mm)	Minimum (mm)
0	2.67 ± 0.075	2.67 ± 0.063	3.69	2.04
304	2.90 ± 0.079	2.90 ± 0.066	3.73	2.24
610	2.91 ± 0.073	2.91 ± 0.061	3.49	2.20
914	2.84 ± 0.076	2.84 ± 0.063	3.64	2.15
1219	3.02 ± 0.074	3.02 ± 0.062	3.99	2.36
1524	2.82 ± 0.078	2.82 ± 0.065	3.66	2.06
1829	2.59 ± 0.081	2.59 ± 0.067	3.70	1.95
2134	2.68 ± 0.113	2.68 ± 0.095	4.27	1.58
2438	2.67 ± 0.065	2.67 ± 0.055	3.25	2.08
2743	3.16 ± 0.207	3.16 ± 0.173	5.11	1.39
3048	3.16 ± 0.132	3.16 ± 0.110	4.51	1.99

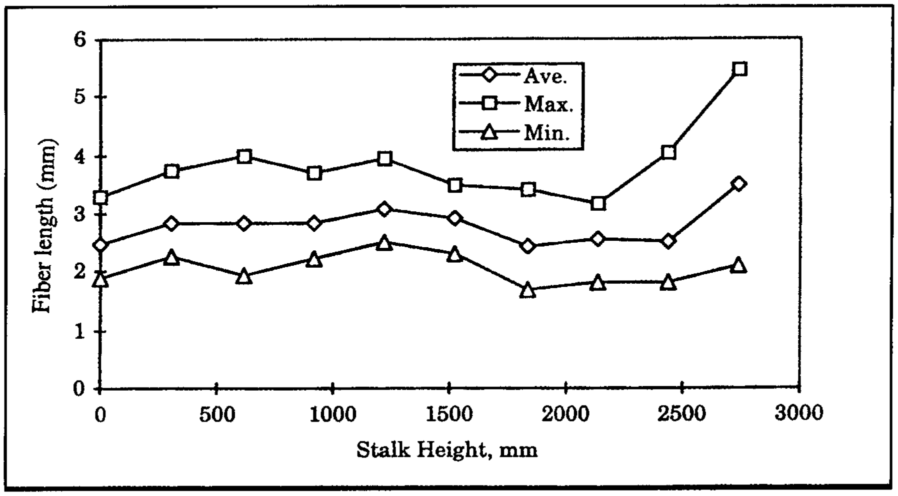

Figure 14.2 Fiber length of kenaf at 147 DAP, height 290 cm.

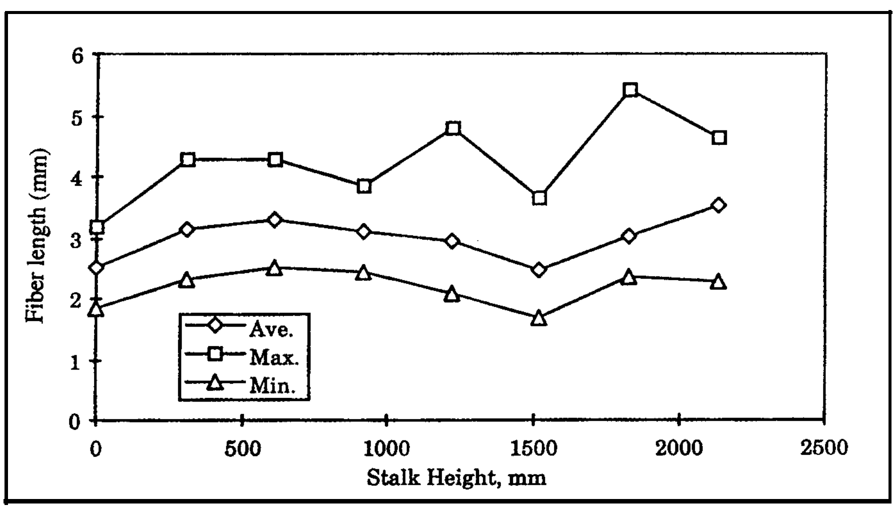

Figure 14.3. Fiber length of kenaf at 161 DAP, 227 cm in height.

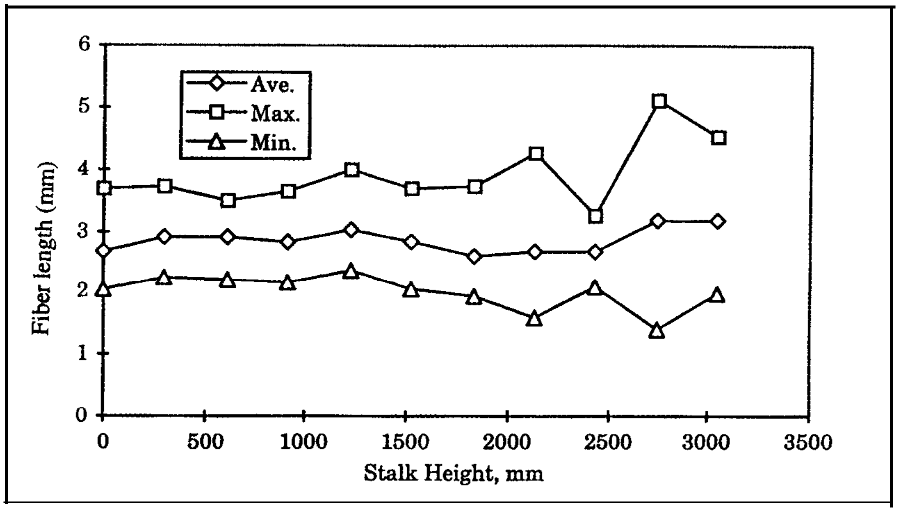

Figure 14.4. Fiber length of kenaf at 175 DAP, 333 cm in height.

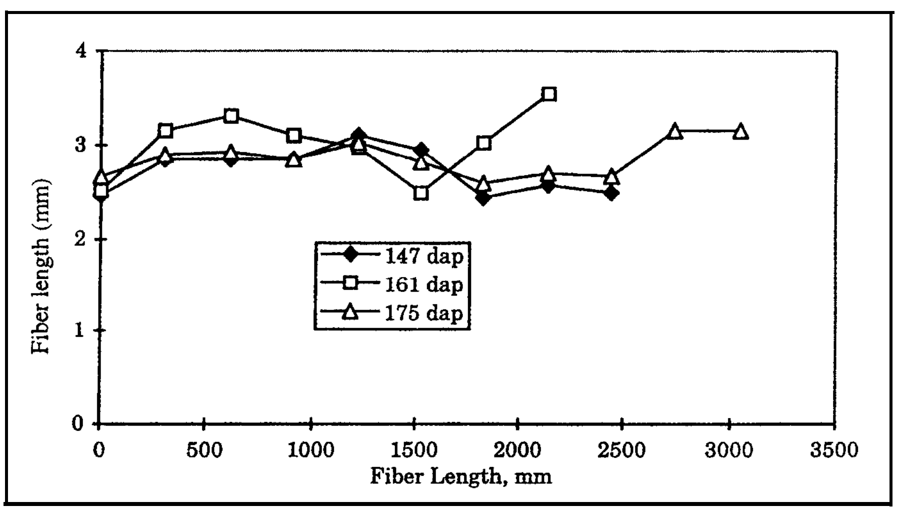

Figure 14.5. Average fiber length at various heights, combined.

Table 14.4. Kenaf fiber length, mm at various DAP (Clark et al. 1967).

DAP	Fiber Length Florida[a] (mm)	Florida[b] (mm)	Illinois[a] (mm)	Illinois[b] (mm)
90	3.34	3.75	3.00	2.14
120	2.28	2.15	1.97	1.93
150	2.16	2.12	2.32	1.82
180	2.42	1.77	—	—

[a] Stalks minus top 610 mm (2 ft).
[b] Tops only.

The data indicates that variations of average fiber length are likely to occur as a function of growth state and stem height. Furthermore, the standard deviation increased as the height increased (Table 14.5), which indicated there was greater variability in fiber length near the top of the plant. Some generalization can be also made in regard to overall fiber length measurements throughout the plant. The data displayed an S-shape, indicating longer fibers were found at lower and higher portions of the stalk, with shorter fibers found between those two areas.

Table 14.5. Standard deviation of kenaf T-1 fiber length (N = 80) at various stalk heights and at three DAP.

Stalk Height (mm)	Standard Deviation of Fiber Length (DAP/T-1 Kenaf) 147/T-1 (mm)	161/T-1 (mm)	175/T-1 (mm)
0	0.013	0.094	0.330
304	0.036	0.366	0.313
610	0.391	0.421	0.324
914	0.342	0.301	0.338
1219	0.319	0.457	0.329
1524	0.289	0.359	0.348
1829	0.330	0.393	0.360
2134	0.339	0.527	0.506
2438	0.383	—	0.292
2743	0.682	—	0.924
3048	—	—	0.588

A sample of mature kenaf was pulped at 170°C for one hour in a stainless bomb with 16% sodium hydroxide (NaOH) and 20% sodium sulfide (Na_2S) (Cho et al. 1997). The cooked fibers were fiberized and the fiber length was measured using Kajaani Procedure (Figures 14.6 and 14.7). The weighted average in this procedure was 2.73 mm, length weighted average 2.23 mm, and numerical weighted average 1.66 mm. All of these values are lower than the measurements by FPL-Image system, which is 2.90 mm (average fiber length). By studying the Kajaani plots of weight or population distribution, some fibers are as long as 7 mm. The effectiveness of Kajaani measurement is its ability to measure a vast number of fibers in a short time. The distribution of the fiber length can then be assessed. Whereas the Kajaani process gives a better overall picture of the fiber length within the plant, the microscopic measurement is selective and time consuming.

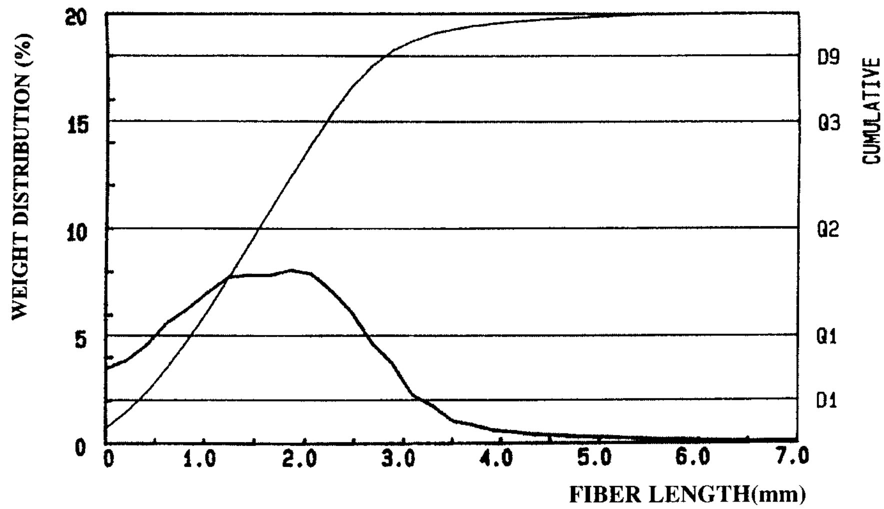

Figure 14.6. Fiber length analysis by Kajaani FS-100, weight distribution.

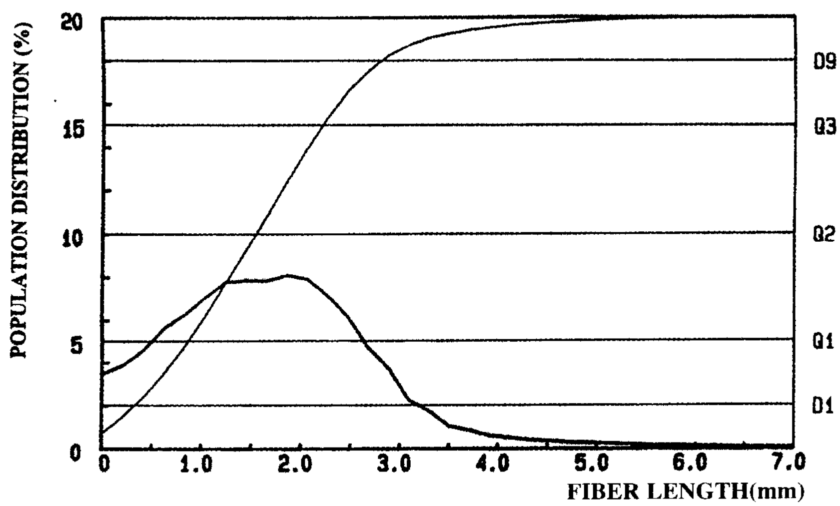

Figure 14.7. Fiber length analysis by Kajaani FS-100, population distribution.

CHARACTERISTICS (TOTAL FIBERS = 3630)

CHAR	WEIGHTED[a]		ARITHMETIC[b]		
D1	1.04		0.33		
Q1	1.53		0.86		
Q2	2.11		1.54		
Q3	2.72		2.21		
D9	3.53		2.81		
AV	2.23[c]	2.73[d]	1.66[e]	/	0.050[f]
%1	0.28		7.16	<	0.200[g]

[a] Weighted: Larger fibers given more weight, some of small fibers (fines) are excluded from average

[b] Arithmetic – average of all fibers includes small fines.

[c] Length Weighted Average

[d] Weight Weighted Average

Large fibers given most weight; most small fines are excluded.

[e] Numerical Average

[f] Low Limit Value: Shorter fibers than 0.150 mm are not accepted when calculating average.

[g] Percent Low Limit: The values of cumulative curves when fiber length is 0.200 mm. There are 0.28% (weighted) and 7.16% (arithmetic) shorter fiber than 0.200 mm

[f,g] If these values are equal to zero they are not reported.

Red pine

Table 14.6 shows three dimensional fiber length distribution of red pine. At the bottom of the tree (height of 610 mm), five samples were taken starting from the center. Each 25-mm section was taken and fiber length measured. At the top of the plant (10.9 m), the radius was 51 mm and only two sets of samples were taken. Even at the same height, there were considerable differences in fiber length: longer fibers were found at the center. As the height increased, the fiber length decreased. Table 14.7 shows the trend, indicating that fibers are longer at the center and at the bottom of red pine. The total fiber dimension was 2.59 mm. This dimension is less than the 3.4 mm reported by Isenberg (1951). The difference could be due to the fact that only mature trunks 102 mm or more in diameter were used in pulping. In this study, measurements of fiber length were based upon use of the whole trunk. Figures 14.8, 14.9 and 14.10 are graphical illustrations of the trends for the red pine in the change of fiber length with respect to height. Considering the fact that the diameter of the tree was much less than that of the height, the fiber length distribution within the same heights were significant. For example, at 7.2 m, the fiber length was 3.51 mm at the pith and 1.33 mm at the 102-mm zone; thus, the difference was more than 2 mm within the same height.

Table 14.6. Fiber length of red pine.

Tree Height (cm)	Tree Radius (mm)	Fiber Length: Average 95% CI (mm)	Average 90% CI (mm)	Maximum (mm)	Minimum (mm)
61	0	2.96 ± 0.093	2.96 ± 0.077	3.94	2.13
	25	3.42 ± 0.101	3.42 ± 0.085	4.36	2.49
	51	3.26 ± 0.085	3.26 ± 0.071	4.09	2.25
	76	2.69 ± 0.092	2.69 ± 0.077	3.78	1.88
	102	2.08 ± 0.067	2.08 ± 0.056	3.40	1.45
231	0	3.18 ± 0.102	3.18 ± 0.085	4.05	2.30
	25	3.43 ± 0.109	3.43 ± 0.091	4.39	2.23
	51	3.04 ± 0.106	3.04 ± 0.089	3.95	1.52
	76	2.53 ± 0.077	2.53 ± 0.064	3.56	1.95
	102	2.09 ± 0.060	2.09 ± 0.050	2.98	1.60
404	0	2.98 ± 0.119	2.98 ± 0.100	4.02	1.72
	25	3.39 ± 0.138	3.39 ± 0.115	4.16	1.68
	51	2.41 ± 0.082	2.41 ± 0.069	3.48	1.62
	76	2.07 ± 0.058	2.07 ± 0.048	2.68	1.35
	102	1.25 ± 0.057	1.25 ± 0.048	2.14	0.68
566	0	3.37 ± 0.118	3.37 ± 0.099	4.18	1.76
	25	3.45 ± 0.068	3.45 ± 0.057	4.36	2.73
	51	2.66 ± 0.070	2.66 ± 0.058	3.21	1.72
	76	2.62 ± 0.082	2.62 ± 0.068	3.43	1.83
	102	1.17 ± 0.041	1.17 ± 0.034	1.62	0.69
721	0	3.51 ± 0.084	3.51 ± 0.070	4.65	2.47
	25	3.38 ± 0.095	3.38 ± 0.079	4.22	2.14
	51	3.21 ± 0.085	3.21 ± 0.071	3.97	2.16
	76	2.52 ± 0.076	2.52 ± 0.064	3.62	1.82
	102	1.33 ± 0.038	1.33 ± 0.032	1.78	0.78

Table 14.6. continued

Tree Height (cm)	Tree Radius (mm)	Fiber Length: Average 95% CI (mm)	Average 90% CI (mm)	Maximum (mm)	Minimum (mm)
978	0	3.77 ± 0.093	3.77 ± 0.077	4.59	2.50
	25	2.89 ± 0.104	2.89 ± 0.087	4.00	1.80
	51	2.19 ± 0.048	2.19 ± 0.040	2.67	1.59
	76	1.91 ± 0.070	1.91 ± 0.059	2.78	1.32
1034	0	2.94 ± 0.108	2.94 ± 0.090	3.96	1.93
	25	2.54 ± 0.074	2.54 ± 0.062	3.27	1.20
	51	2.11 ± 0.064	2.11 ± 0.054	2.62	1.27
	76	1.25 ± 0.048	1.25 ± 0.040	1.69	0.81
1168	0	3.06 ± 0.079	3.06 ± 0.066	3.80	2.06
	25	2.23 ± 0.084	2.23 ± 0.070	3.20	1.49
	51	1.84 ± 0.045	1.84 ± 0.038	2.37	1.32
1306	0	2.30 ± 0.072	2.30 ± 0.060	3.29	1.48
	25	1.43 ± 0.056	1.43 ± 0.047	2.02	0.88

Table 14.7. Three dimensional average fiber length of red pine.

Distance from tree pith (mm)	Tree heights (cm): 61	231	404	566	721	978	1034	1168	1306	Average fiber length (mm)
	Fiber length (mm)									
0	2.96	3.18	2.98	3.37	3.51	3.77	2.94	3.06	2.30	3.12
25	3.42	3.43	3.39	3.45	3.38	2.89	2.54	2.23	1.43	2.91
51	3.26	3.04	2.41	2.66	3.21	2.19	2.11	1.84		2.59
76	2.69	2.53	2.07	2.62	2.52	1.91	1.25			2.23
102	2.08	2.09	1.25	1.17	1.33					1.58
Average	2.88	2.85	2.42	2.65	2.79	2.69	2.21	2.38	1.87	2.59[a]

[a] average of 38 values in table.

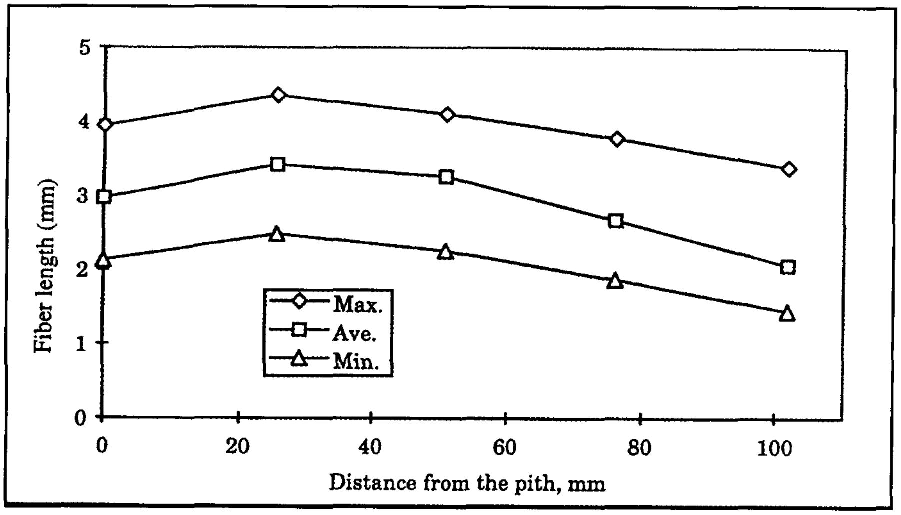

Figure 14.8. Fiber length of red pine at 61 cm.

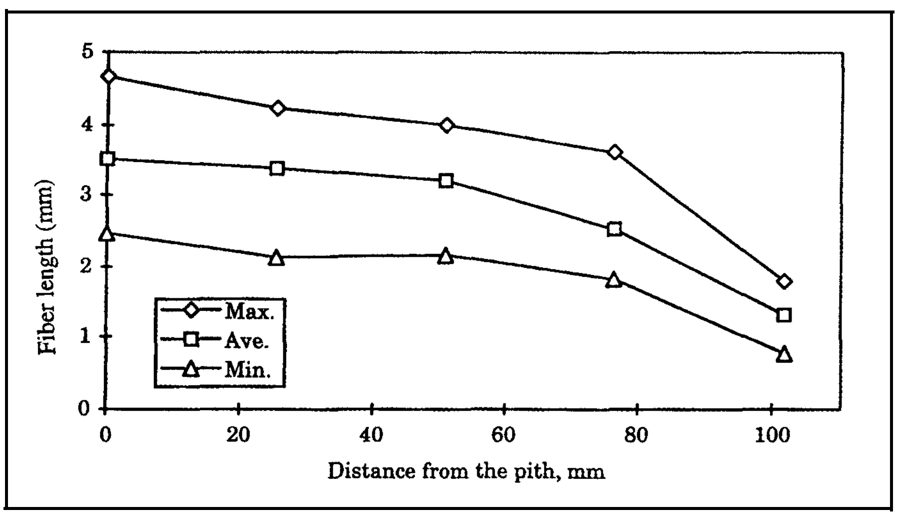

Figure 14.9. Fiber length of red pine at 721 cm.

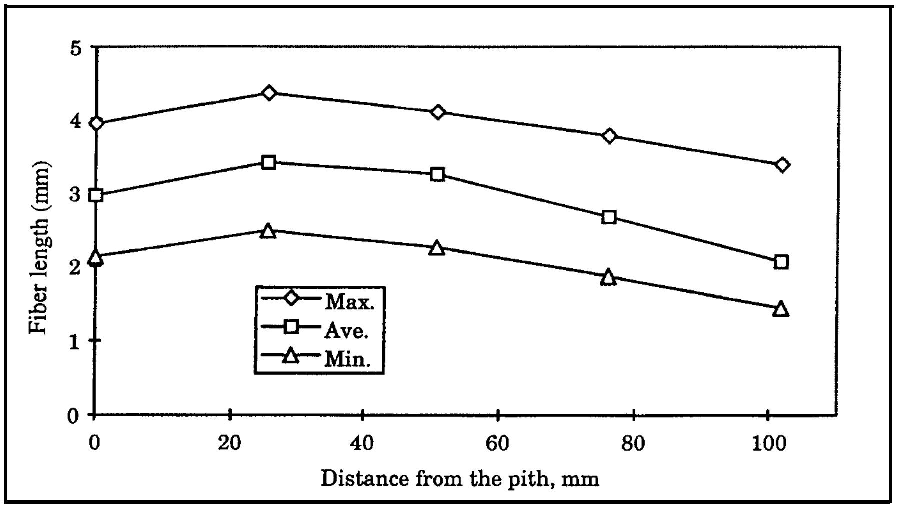

Figure 14.10. Fiber length of red pine at1034 cm.

Aspen

Tables 14.8 and 14.9 shows fiber distribution within an aspen tree. The same trend can be observed. The overall average fiber length was 1.03 mm, and the fiber length reported by Isenberg (1951) was 1.04 mm. Aspen was not a good model for the study of trends in fiber length, presumably due to the tree being small. The fiber length increased gradually up to a tree height of approximately 7.6 m, whereas the rest of the data did not follow any defineable pattern. Nonetheless, the distribution within the same height showed a trend which was noticed in red pine (Figure 14.13).

The average fiber length at 95% CI for the aspen was 1.03 ± 0.034 mm (Table 14.8), red pine was 2.53 ± 0.80 mm, and kenaf was 2.90 ± 0.094 mm.

CONCLUSIONS

Fiber lengths for kenaf, in general, were shorter at the bottom of the stalk and longer at the top. The increase in length from the bottom to the top was not gradual, but S-shaped. There are more variations of the fiber length at the top of the stalk. Also, the longest fibers are located at the top. The fiber length, as a function of growth, seems less variable than the height of the plant. The general trend of having short fibers at the bottom and long fibers at the top was opposite to the that noted for a softwood (red pine) and a hardwood (aspen).

Table 14.8. Fiber length of aspen.

Tree Height (cm)	Tree Radius (mm)	Fiber Length Average 95%CI (mm)	Average 90% CI (mm)	Maximum (mm)	Minimum (mm)
46	0	1.24 ±0.051	1.24 ± 0.042	1.92	0.84
	25	1.05 ±0.039	1.05 ± 0.033	1.43	0.68
	51	0.99 ±0.032	0.99 ± 0.027	1.39	0.67
	76	0.91 ±0.043	0.91 ± 0.036	1.41	0.51
196	0	1.20 ±0.044	1.20 ± 0.037	1.78	0.85
	25	1.09 ±0.038	1.09 ± 0.032	1.44	0.71
	51	1.00 ±0.032	1.00 ± 0.027	1.39	0.68
	76	0.82 ±0.032	0.82 ± 0.027	1.33	0.49
345	0	1.25 ±0.041	1.25 ± 0.035	1.93	0.92
	25	1.11 ±0.039	1.11 ± 0.033	1.77	0.65
	51	0.94 ±0.027	0.94 ± 0.022	1.26	0.70
	76	0.81 ±0.025	0.81 ± 0.021	1.09	0.59
498	0	1.07 ±0.042	1.07 ± 0.035	1.79	0.67
	25	0.92 ±0.038	0.92 ± 0.031	1.40	0.55
	51	0.79 ±0.027	0.79 ± 0.022	1.05	0.53
650	0	1.02 ±0.031	1.02 ± 0.026	0.27	0.60
	25	0.80 ±0.033	0.80 ± 0.027	1.31	0.50
	51	0.59 ±0.022	0.59 ± 0.018	0.77	0.31
800	0	1.03 ±0.038	1.03 ± 0.032	1.46	0.69
	25	0.80 ±0.030	0.80 ± 0.025	1.10	0.54
917	0	1.43 ±0.031	1.43 ± 0.026	0.88	0.60
	25	0.98 ±0.023	0.98 ± 0.019	0.70	0.45
998	0	1.07 ±0.025	1.07 ± 0.021	0.83	0.57
	25	0.96 ±0.022	0.96 ± 0.018	0.67	0.50
1095	0	1.57 ±0.037	1.57 ± 0.031	0.90	0.52
	25	1.34 ±0.032	1.34 ± 0.027	0.75	0.51

Table 14.9. Three dimensional average fiber length of aspen.

Distance from tree pith (mm)	Tree heights (cm) 46	196	345	498	650	800	917	998	1095	Average fiber length (mm)
	Fiber length (mm)									
0	1.24	1.20	1.25	1.07	1.02	1.03	1.43	1.07	1.57	1.21
25	1.05	1.09	1.11	0.92	0.80	0.80	0.98	0.96	1.34	1.01
51	0.99	1.00	0.94	0.79	0.59					0.86
76	0.91	0.82	0.81							0.85
Average	1.05	1.03	1.03	0.93	0.80	0.92	1.21	1.02	1.46	1.03[a]

[a] Average of 26 values in table.

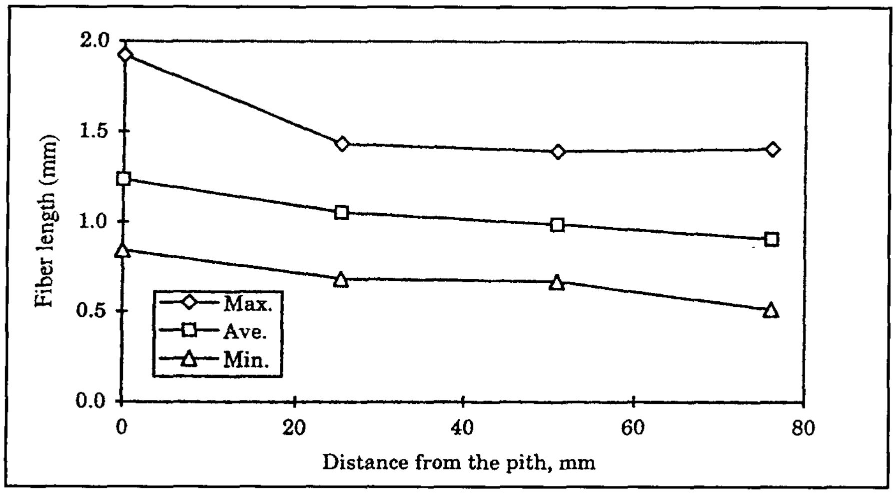

Figure 14.11. Fiber length of aspen at 46 cm.

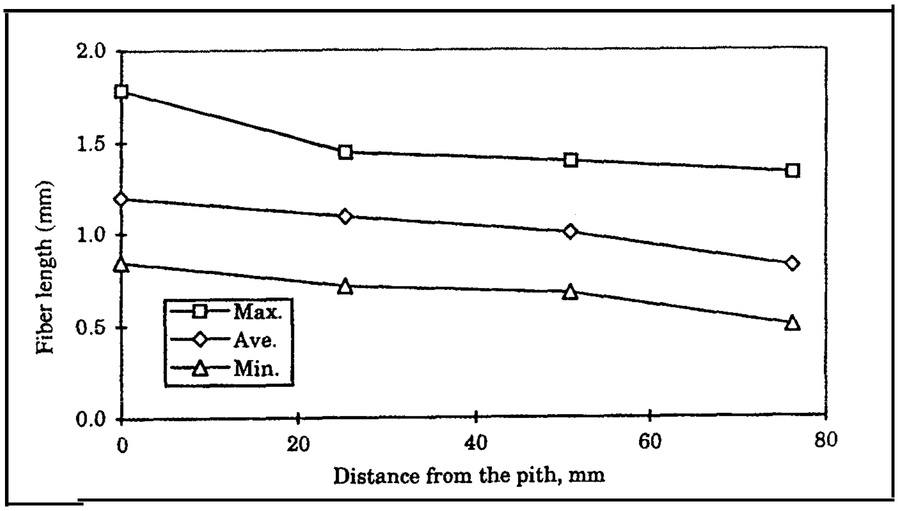

Figure 14.12. Fiber length of aspen at 196 cm

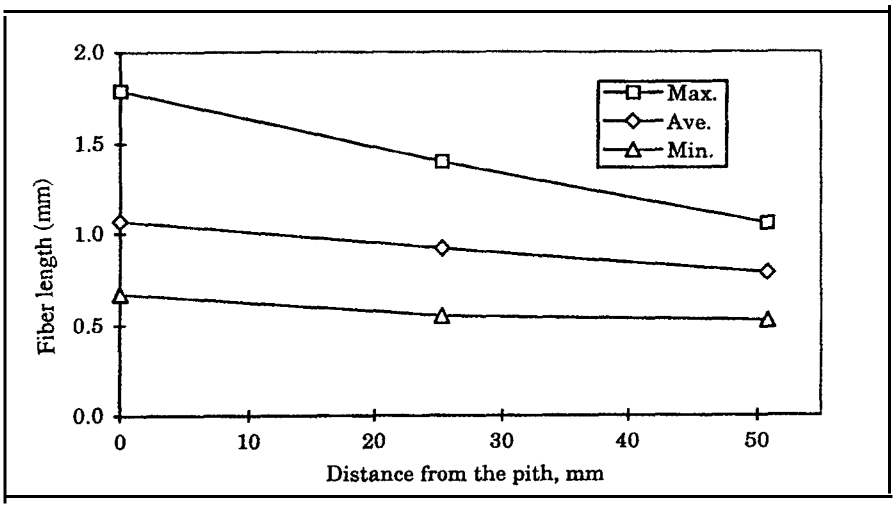

Figure 14.13. Fiber length of aspen at 650 cm.

ACKNOWLEDGEMENT AND DISCLAIMER

Appreciation is extended to Carl E. Syftestad of the FPL for helping in cutting the trees during the cold weather.

The USDA-Forest Service, Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright.

REFERENCES

Bright, C.G. 1926. Pulp Paper Ma. Can. May 27 issue.

Burkart, L.F. 1966. Forest Prod. J. (16)7:52

Burkart, L.F. 1966. Stain Technol. 1966. 41(5):355.

Cho, J., Y. Park, B. Lee, J.S. Han, and E.S. Miyashita. 1997. Properties of kenaf from vanous cultivars, growth, and pulping conditions. Abstracts, Fifth Chem. Congress of North Amer., Cancun, Mexico, No. 2001.

Clark, T.F., S.C. Uhr, and I.A. Wolff. 1967. Tappi 50:11.

Franklin, G.L. 1945. Nature 155:3924-3951.

Isenberg, I.H. 1951. Institute of Paper Chemistry. Appleton, WI.

Jeffrey, E.C. 1917. The Anatomy of Woody Plants. University of Chicago Press, Chicago, IL.

Schmid, R. 1982. Stain Technol. 57(5):293-299.

Schultze, F. 1857. Chem. Zentr. 28:321.

Spearin, W.E., and I.H. Isenberg. 1947. Science 105:214.

TAPPI. 1993. T401 om-93 Standard. Tappi Press, Atlanta, GA.

In: Kenaf Properties, Processing and Products; Mississippi State University, Ag & Bio Engineering, 1999. pp. 149-167. ISBN 0-9670559-0-3. Chapter 14