

CHANGES IN KENAF PROPERTIES AND CHEMISTRY AS A FUNCTION OF GROWING TIME

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ABSTRACT

Kenaf Tainung 1 cultivar was grown in Madison, WI in 1994. The ratio of core to bast fiber, total plant yield, protein, ash, fiber length, extractives, lignin, and sugar content were determined as a function of growing age. Ash, protein, extractives, **L**-arabinose, **L**-rhamnose, **D**-galactose, and **D**-mannose contents decreased while lignin, **D**-glucose and **D**-xylose content increased as the plant matured. Fiber length increased in the early part of the growing cycle, then decreased, then increased again as the plant matured.

INTRODUCTION

It is well known that different parts of a plant have different chemical and physical properties. That is, the chemical composition and fiber properties of plant tissue taken from the roots, stem, trunk, and leaves are different. What is not so well known is that the chemical composition and fiber properties of plant tissue are also different at different stages of the growing season.

Plants have, in general, five stages in their life cycle: germination, growth, flowering, seed formation, and death. Annual plants go through these stages in one growing season. Biennials have a two-year cycle where in the second year, the plant grows from the root system developed in the first year. Perennial plants have the same cycle as annual plants except growth, flowering, and seed formation occur many times before the plant dies.

Various industries harvest plants for products at different times during the plant life cycle. For example, the food industry harvests young sprouts such as beans just after germination. Crops such as lettuce and asparagus are harvested during the early growing part of their cycle. The cut flower industry harvests the plant flowers at the bud stage or shortly thereafter. Seeds used for food or oil production are harvested after the flowering stage but before the seeds are allowed to drop from the seed pod. Many crops, however, are allowed to complete their life cycle before harvesting. For example, annual grain crops are allowed to field ripen and dry before harvesting.

In general, annual plants used for paper and composites are harvested at the end of the growing season, allowed to dry in the field and then processed into fiber. Fiber from trees for paper and composites is derived from logs of various ages, and fiberized by one of several methods.

There may be an advantage in harvesting fiber for paper and composites at some time earlier than from a mature plant. For example, fiber from an immature plant may be low in lignin, making it more suited for paper manufacture since there would be little chemical pulping required to remove the lignin. While the yield of early harvested kenaf may be lower, there may be advantages in reduced chemical and energy consumption during product processing. In the case of annual plants, it may be possible to harvest two crops in one season to give the same yield of fiber but with much less lignin. Fiber from juvenile plants such as jute and kenaf are reported to be "silk-like", i.e., fine textured, very flexible, and thin. Again, the yield may be lower, based on the traditional end of the season yield, but a fiber which could be used for textiles may command a higher price resulting from such early harvesting (Rowell et al. 1997).

The earliest reported literature on changes in chemical composition as a function of the growing season was done with wheat in the 1930s (Phillips et al. 1931). They found that the cellulose content was highest in the early part of the growing season and that lignin and ash content varied with the amount of fertilizer used.

In a study using several cultivars of flax, Overbeke and Mazingue (1949), found that both cellulose and lignin content increased with plant age but pectin, hemicellulose and ash content followed no systematic progression with age.

A great deal of research was done on cotton during the 1950s. Usmanov and Usmanov et al. (1957) found that the degree of polymerization (DP) of cellulose increased up to the 15th day after bloom, then slowed and stopped on approximately the 40th day. The DP 3 days prior to the opening of the boll, and 0, 1, 5, 7, 10, 12, 15 and 17 days after the opening of the boll was 2920, 3758, 4286, 4564, 4406, 4282, 4082, 3622 and 3326, respectively. Strength and DP of the cellulose were at a maximum at 5 to 6 days after the boll opened, and it was recommended that the cotton should be picked 12 to 15 days after the opening of the boll.

Ono and Ono et al. (1957) studied the relationship between cellulose, nitrogen, phosphorus, ash, wax, and pectin as they related to maturity in the cotton plant. In those reports the immature lint contained a large amount of non-cellulosic substances and, hence, lost a large amount of weight during purification. Immature cot-

ton fiber was harder to bleach and dye as compared to mature fiber. The reducing sugar content was higher in immature lint but decreased as the plant aged.

Clark and Wolff (1969) carried out the first studies on the changes in chemical composition of kenaf as a function of the growing season. This study included the chemical differences along the stem and between leaves and stem. This work reported that hot water extractives decreased as the plant aged [37% at 90 days after planting (DAP) and 13% at 244 DAP], lignin increased from 4.5% at 90 DAP to 11.4% at 244 DAP, α -cellulose increased from 10.6% at 90 DAP to 29.8% at 244 DAP, pentosan increased from 5% at 90 DAP to 20.1% at 244 DAP, and protein decreased from 25% at 90 DAP to 11.1% at 244 DAP.

MATERIALS AND METHODS

In the summer of 1994, kenaf Tainung 1 (T-1) cultivar was grown in Madison, Wisconsin in 15-m by 21-m plots. After the soil was plowed and tilled, kenaf seeds were planted approximately 1 cm deep, 7 to 10 cm apart in a row with 35 cm between the rows. The seeds were manually broadcasted in May. The soil was kept wet for three weeks after seeding. No fertilizer, herbicides or insecticides were applied.

Fifty sample plants were taken on 34 DAP, 30 samples on 42 DAP, and afterward the numbers of samples taken were reduced to 15 samples per week throughout the summer. Samples were taken between plants and, thus, the distance between plants increased as the plants grew. However, most of the thinning occurred at the early stage of the growth. The distance between the plants at the very end of the season was about 12 cm apart in a row.

The height of each plant and the diameter at the plant bottom was measured for each sample set and the values averaged. The combination of rain and high temperature increased weekly growth. The weight of mature kenaf fiber ranged from 97 to 152 grams per plant at the end of growing season, which could be extrapolated to a fiber yield of about 15.3 to 23.4 t·ha⁻¹·a⁻¹ [6.9 to 10.5 short tons per acre per year].

After each harvest, the plants were separated into a core or pith fraction and a bast fraction. The oven-dry weight ratio of bast fiber to core material was determined.

Fiber length determination was done following maceration using a modified sodium chlorite/acetic acid procedure. Following fiberization, the fibers (at least 50) were placed on a glass slide with 1/1 volume mixture of glycerol/water under a cover glass. The fibers were magnified using a light microscope (1:1 optical lens). The field was calibrated (set scale) and fiber length and width was determined manually.

Ash and protein content were determined on both bast fiber and core material before and after extraction. Kjeldahl determination for protein was performed (Han et al. 1995) on several batches of combined Klason lignin samples, and the amount of protein in the Klason lignin was measured and reported as protein.

The extraction procedure was as follows: samples of 3-6 grams were placed in tared glass thimbles, placed in a vacuum-oven for 24 hours, weighed and extracted in Soxhlet extractor for 24 hours with 2:1 toluene ethanol solvent. The thimbles were washed with ethanol and vacuum-dried at 40°C for 24 hours and weighed. Klason lignin and sugar analysis was done after extraction.

RESULTS AND DISCUSSION

The data on plant height and base diameter as a function of growing time after planting are shown in Table 3.1. Rate of plant growth will vary greatly depending on where the plant is grown, quality of the soil, fertilizer, temperature, rain fall, etc. Kenaf has been grown in Madison, WI over three different summers, researching different growing rates each year.

Table 3.1. Plant height and base diameter of kenaf.

DAP ^a	Height (cm)	Diameter (cm)	Volume Factor ^b	Volume Fraction ^c %
35	20	0.4	8	0.01
42	40	0.8	32	0.03
57	85	1.1	94	0.06
63	130	1.7	221	0.15
70	149	1.8	268	0.2
77	173	1.9	329	0.2
84	200	2.0	400	0.3
91	200	2.0	400	0.3
98	200	2.1	420	0.3
133	315	2.3	725	0.5
155	375	2.7	1013	0.7
161	377	3.4	1282	0.9
175	400	3.7	1480	1.0

^aDays after planting

^bVolume factor = height x diameter

^cVolume fraction = volume factor for a given DAP/volume factor at maturity.

The volume fraction given in Table 3.1 can be used to calculate the yield of plant mass at any given time after planting. This yield data can then be used to determine the yield of any specific fraction of the plant that may be desired.

Oven-dry weight ratio of cm-e fiber to bast fiber (core/bast) is shown in Table 3.2. The ratio increased with plant age to a maximum of about 1.8 which was reached at 175 DAP. This ratio means that, on a weight basis, there is almost twice

as much core fiber as bast fiber in a mature plant. It is difficult to measure the volume ratio of core fiber to bast fiber but kenaf is approximately 85% core and 15% bast on a volume basis at maturity.

Table 3.2. Oven-dry weight ratio of kenaf core to bast fiber.

DAP	Ratio
53	0.90
57	1.17
63	1.10
70	1.10
77	1.03
84	1.33
91	1.23
98	1.33
105	1.94
112	1.36
120	1.30
126	1.62
133	1.70
140	1.82
147	1.31
155	1.71
161	2.12
175	1.81

The fiber length of bast and core fibers are shown in Table 3.3. The data presented in Table 3.3 indicates that bast fiber length increases as the plant ages. However, more recent studies indicate that during the growing cycle, the bast fiber length first increases, then decreases, and then increases again (Han et al. 1995). This trend may be related to several factors such as the development of lignin, protein, extractives, cellulose, cell wall, etc., and after further study, this increase/decrease/increase trend in fiber length may be explained.

Table 3.3. Length of kenaf bast and core fiber.

DAP	Bast Fiber (mm)	Core Fiber (mm)
50	2.2	0.7
60	2.8	0.7
77	3.0	0.7
84	3.1	0.8
147	3.0	—
175	3.3	—

Ash contents of bast and core fiber before and after extraction are shown in Table 3.4. Ash content for both bast and core fibers decreased as the plant matures. There is a greater reduction in ash content in the bast fiber as compared to core fiber.

Table 3.4. Ash content of kenaf bast and core fiber, % oven-dry basis,

DAP ¹	Unextracted Bast	Extracted Bast	Unextracted Core	Extracted Core
49	13.08	9.54	14.52	7.77
98	7.52	6.83	5.10	4.21
147	6.24	6.00	4.55	4.44
175	3.76	3.84	2.84	2.39

¹DAP = days after planting

Protein contents of bast and core fiber before and after extraction are shown in Table 3.5. Protein content decreased in both bast and core fiber as the plant matures. There is a greater reduction in protein content in the bast fiber as compared to the core fiber.

Table 3.5. Protein content of kenaf bast and core fiber, % oven-dry basis.

DAP ¹	Unextracted Bast	Extracted Bast	Unextracted Core	Extracted Core
49	10.6	7.65	12.75	8.00
98	4.25	3.25	4.85	4.65
147	2.05	3.35	3.40	3.20
175	1.43	1.23	4.15	3.28

¹DAP = days after planting

Extractives, lignin, and sugar contents of the bast fiber as a function of plant maturity are shown in Table 3.6. The Klason lignin (Lig) values increased from about 4% at the beginning to 10% at the end of growing season. Bagby et al. (1971) reported about 10% lignin content in a mature Florida kenaf plant. This value is significantly lower than that of softwoods (26-32%) and hardwoods (20-28%) (USDA Forest Service/Forest Products Laboratory database). The actual value of Klason lignin could be lower than it appears to be due to the presence of protein in kenaf. The protein content of kenaf is between 4 to 14% of the Klason lignin depending upon the age of the plant. Only 38% of the protein was found in the Klason lignin and rest was found in the hydrolysates (unpublished FPL data).

Table 3.6. Chemical composition of kenaf bast fiber (% oven-dry basis).

DAP	Extractive	Lignin	Polysaccharides Content (anhydro sugars)					
			Ara	Rha	Gal	Glu	Xyl	Man
35	14.87	4.32	3.95	2.72	0.78	28.86	6.54	1.76
42	8.80	6.00	3.18	1.82	0.62	33.20	7.31	1.63
57	5.13	8.32	2.21	1.46	0.55	35.45	8.08	1.59
63	4.34	7.74	2.43	1.48	0.62	37.08	8.61	1.53
70	4.63	8.70	2.02	1.25	0.46	40.53	9.37	1.47
77	4.99	9.23	2.05	1.36	0.39	40.52	9.16	1.34
84	5.07	8.33	2.27	1.63	0.49	39.88	9.39	1.53
91	5.68	9.38	1.91	1.35	0.42	42.82	9.98	1.31
98	2.42	8.81	2.13	1.43	0.48	41.60	9.69	1.35
133	8.03	8.94	1.67	1.15	0.48	41.98	9.72	1.31
155	7.83	9.99	1.27	0.87	0.38	46.39	11.20	1.19
161	11.51	10.22	2.54	1.52	0.56	39.22	9.75	1.33
168	13.31	9.74	2.18	1.37	0.47	41.41	10.36	1.39
175	8.23	9.69	1.40	0.87	0.36	49.33	12.29	1.02

Extractive (Ext) content varied as a function of growth. In general, high at the beginning, decreased during the first part of the growing time and then increased again. These results are similar to those for fiber length, i.e., first increasing then decreasing and then increasing again.

L-Arabinose (Ara), **L**-rhamnose (Rha), **L**-galactose (Gal), and **D**-mannose (Man) content decreased as a function of growing age while **D**-glucose (Glu) and **D**-xylose (Xyl) content increased over this same period of time (Table 3.6). If the glucose yield is mainly due to cellulose content, then the maximum cellulose content of the plant is reached at about 70 DAP and, therefore, the lignin content reaches a maximum at about the same time.

CONCLUSIONS

The results of this study are based on growing kenaf Tainung 1 cultivar in Madison, WI over one summer in 1994. In different growing conditions, the values for the ratio of core to bast fiber, total plant yield, protein, ash, fiber length, extractives, lignin, and sugar content would be different as a function of growing age. In this study, ash, protein, extractives, **L**-arabinose, **L**-rhamnose, **D**-galactose, and **D**-mannose contents decreased while lignin, **D**-glucose and **D**-xylose content increased as the plant matured. Fiber length increased in the early part of the growing cycle, then decreased, then increased again as the plant matured.

Table 3.7 shows a summary of protein, ash, fiber length, lignin, cellulose and xylan content as a function of plant volume fraction at several different plant ages.

This table can be used to determine if harvesting at an earlier age than full maturity would give a significant yield of one desired fraction when an undesirable fraction was at a minimum. For example, for a fiber for pulping, it would be determined if harvesting at an earlier age than full maturity would give a significant yield of one desired fraction when an undesirable fraction was at a minimum. For example, for a fiber for pulping, it would be desirable to harvest the kenaf plant at about 40 days when the lignin content is low (using less pulping chemicals for delignification) and the cellulose content is high. The fiber length is somewhat shorter than it will be at maturity. While this makes sense in terms of maximizing one component, the total plant volume yield is so low that it would not be economical to harvest at that time. There may, however, be conditions where a shorter growing season for kenaf, with a lower yield, will make sense so a second crop of another plant can be grown during the same growing season.

Table 3.7. Summary of kenaf bast fiber component yield as a function of plant volume fraction.

DAP	Volume Fraction	Protein (%)	Ash (%)	Fiber Length (mm)	Lignin (%)	Cellulose (%)	Xylan (%)
35	0.01	—		<2	4.3	29	7
42	0.03	11	13	2	6	33	7
77	0.2	—	—	3	9	40	9
98	0.3	4	8	3	9	41	10
155	0.7	2	6	3	9	42	10
175	1.0	1.5	4	3	10	43	10

DISCLAIMER

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