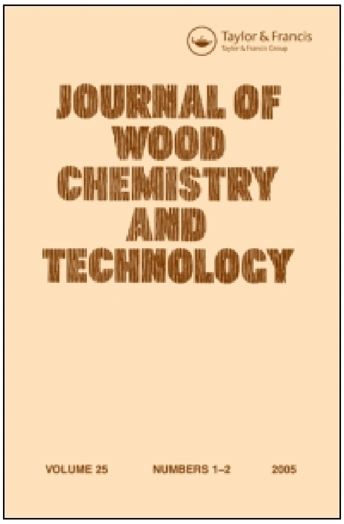

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EFFECT OF HARVESTING AGE ON THE CHEMICAL PROPERTIES OF HEMP PLANTS

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ABSTRACT

With the increasing scarcity of available forest for harvesting, there is a potential need for alternatives to wood fibers for pulp and paper production. Hemp is considered to be a good source of long and strong fibers. In this study, the effect of the harvesting age of hemp stems on their chemical composition and the biomass produced by the plants were studied. Hemp stems were harvested at ages of 30, 60, 90, and 120 days. Standard TAPPI procedures were used for chemical analyses of the stems. There was little variation observed in the percentage of the constituents such as lignin, hemicellulose, and α-cellulose with the plant growth. However, a very significant decrease was seen in the percentages of extractives, ash, and silica with plant growth. The rate of increase of biomass was higher in the first half of the growing period, i.e., from 30 to 60 days, compared to the second half, from 60 to 90 days. On the basis of the chemical constituents and the biomass

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produced, it is concluded that hemp grown for the pulp and paper industry should be harvested between 60 and 90 days for optimal results.

Key Words: Hemp; Harvesting age; Cellulose; Lignin; Extractives; Pulp; Paper

INTRODUCTION

Originally, paper was made from non-wood fibers such as hemp, flax, cotton, etc. In the first half of the 19th century, however, the use of wood fibers became more common for the production of pulp and paper. At present, only about 7.5% of the world's pulp comes from non-woody fibers.[1] A major portion of the non-wood pulp supply is used in developing countries like China and India. Approximately 80% of the non-wood pulp actually originates in China, where forest resources are very limited and not readily available for pulp production. With increasing concerns over the effects of deforestation, fiber-based industries like pulp and paper have begun investigating alternative sources of raw material.

One such source of raw material is hemp (*Cannabis sativa* L.), an annual plant that grows in temperate regions. There have been concerns regarding the use of hemp due to its connection to unlawful marijuana, a plant with high levels of the narcotic compound, tetrahydrocannabinol (THC). Industrial hemp, however, has a very low THC content (0.03%) and is not useful for narcotic purposes.[2] Other than this primary concern, hemp is a good source of long and strong fibers. The paper industry evaluates their potential fiber raw materials primarily on the basis of chemical composition, physical properties, and cost of the fiber. For example, hemp fiber having a low lignin content, and high holocellulose and α-cellulose contents can result in higher yield of pulp, thus lowering the raw material cost.

It is known that the chemical composition and the physical properties of plants change during the growth of the plant. The intent of this study was to measure the chemical changes that occur during the growth of hemp plants. It is important to know the variation in chemical constituents associated with the growth of hemp, in order to determine the optimal time for harvesting a hemp crop grown as a raw material for the pulp and paper industry.

EXPERIMENTAL

The experimental work for this research was divided into a field study and a greenhouse study. For the field study, the hemp plants were harvested

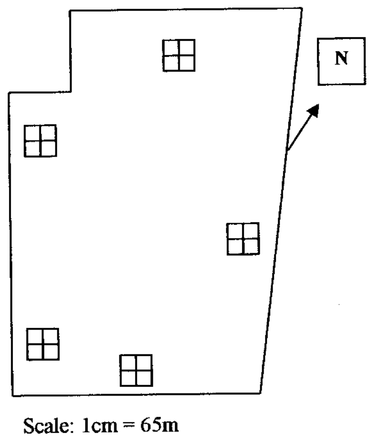


Figure 1. Sampling design in the field.

from a field operated by Hempline Inc., located near the town of Delware near London, Ontario, Canada (43° 01′N, 81° 10′W). The hemp seeds were sown at an average density of 75 kg/hectare. The hemp rows were between 18 and 19 cm apart with between 1.25 and 5 cm spacing between each plant in the row. Prior to seeding, the field soil was fertilized with a nitrogen/phosphorus/potassium mix of 134-101-101 N-P-K kg/hectare. The field samples of the crop were harvested at 30, 60, 90, and 120 days of growth from five 4-m^2 plots selected at random near the outer edge of field to facilitate access to the field. Figure 1 illustrates the sample locations within the field. From each of these plots, a 1-m^2 area was harvested at each time interval.

For the greenhouse study, plants were grown in the greenhouse facility at the Faculty of Forestry, University of Toronto. In the experiments, 12 rectangular pots of dimensions 53 × 39 × 44.5 cm (L × W × D) were used. Seeds were sown in five rows within the pots. Planting was started about 3.8 cm from the edge of the pots. Each row was separated from the adjacent rows by 11–43 cm. In each row, plants were spaced at 2.5 cm. Figure 2 shows the design of greenhouse planting. To avoid any edge effect, plants along the outer edges of each pot were not collected for the study. In order to avoid any micro-environmental effects, the pots were shifted within the bench every 20 days. The greenhouse plants were harvested at 30, 60, 90, and 120 days of growth.

Following harvesting, the leaves and roots of the plants were removed and the stems were air-dried at room temperature (21°C) for 15 days. On the 15th day, the biomass (stems only) produced was measured. The stems were then chopped and ground using a Wiley Mill (40 mesh) for analysis.

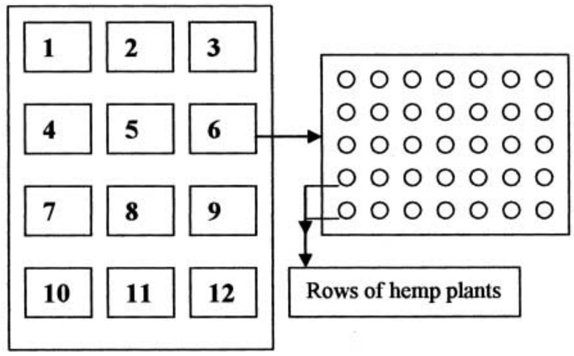


Figure 2. Arrangement of pots in greenhouse.

The standard test methods of TAPPI were employed for analyzing lignin (T 222 om-83 and UM250), extractives (T 264 om-82 and T204 os-76), ash (T 211 om-93), and silica (T 245 om-94). The holocellulose and α-cellulose analyses were done using a method pioneered by Zobel.[3]

Pilot-scale pulping for handsheet formation was carried out on only two of the field groups (i.e., the 60-day and 90-day old samples). There was not enough biomass material in the 30-day sample to carry out pulping. The 30-day-old plants were small (in diameter and height) and as such, a greater number of plants would have been needed to produce adequate amount of pulp for strength testing. In a commercial operation this would be economically unfeasible. Also, it was not possible to obtain enough material for pulping at 120 days. This was due to the fact that by that time almost all the plants of hemp were into the flowering stage, which is not permitted under the terms of the hemp-growing license.

Hemp stems were pulped with the kraft process using an active alkali of 15% and sulfidity of 20%. The pulp was disintegrated and screened, and 15 handsheets were made for testing physical properties. A British hand sheet former was used for making hand sheets. Each sheet with diameter of 200 cm^2 had a basis weight of about 60 g/m^2. The hand sheets were tested in the research laboratory of Donohue Inc.

RESULTS AND DISCUSSION

Figure 3 shows the average biomass produced in the field (kg/m^2) after 30, 60, and 90 days. The increase in the biomass observed from the 60 to 90 days of growth is substantially less than experienced between 30 and 60 days

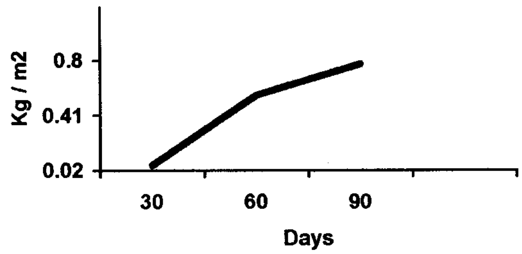


Figure 3. Bio-mass (stems) produced by air-dried hemp plants (field).

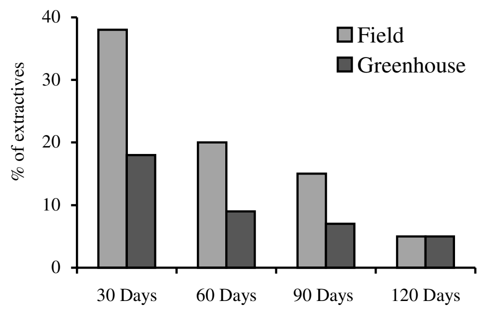


Figure 4. Percent of extractives in air-dried hemp stem from field and greenhouse.

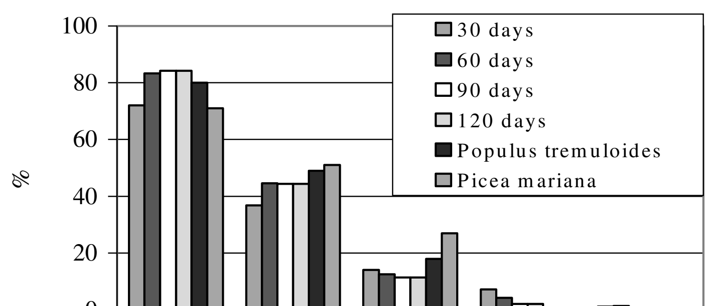
of growth. The biomass produced by hemp on an annual basis (biomass per unit area) is higher than that of woody plants used in the pulp and paper industry.[4]

Chemical analyses and evaluation of fiber properties of the hemp stems were used to assess the hemp's potential for substitution for woody raw materials used in pulp and paper production. The lignin, cellulose, ash, and silica contents were measured on the extractive-free stems. Figure 4 summarizes the measurements of the extractives of hemp stems grown in the field and the greenhouse. The extractives content in the hemp stems from both the field and greenhouse significantly declined from the 30-day old plants to the 120-day old plants (statistical significance with p value = 1.47E-25). This reduction in extractive content with the age of the plants was expected to some extent. Reduction in the extractive content with age has also been reported for bamboo and kenaf[5] and should be beneficial for the pulp and paper industry.

The very high amount of extractives observed in 30-day plants could possibly be attributed to the large amounts of proteins and chlorophyll that were also extracted during the extraction process. It should also be noted that all the stems used in the analysis were air-dried for just 15 days. It is possible that additional drying of the stems, as is usually practiced in industry, would reduce the amount of proteins and chlorophyll. Moreover, no retting took place on the sampled specimens. Retting is a biological process where stems are soaked in water to remove pectins and other soluble material from the stems, thus separating the bast and core fibers from each other. In this process, naturally some extractives are also lost. Following this process would likely have helped in reducing the amount of extractives in the younger plants.

Figure 5 shows the results of chemical analyses of air-dried hemp stems grown in the field. In Fig. 5, the percentage of extractive displayed represents the fraction of extractives in the total stem fiber. The percentages of holocellulose, α-cellulose, lignin, ash, and silica are expressed on the basis of extractive-free stem fiber, which better represents the raw material required by industry.

Holocellulose exhibited some variation as a function of growth. In the first part of the growing season, i.e., 30–60 days, there was an increase in holocellulose content with the age of plant, but in the second part of the growing season, i.e., 60–120 days, the percentage of holocellulose did not



	Holocellulose (%)	Alpha-cellulose (%)	Lignin (%)	Ash (%)	Silica (%)
30 days	72	37	14	7.28	1.22
60 days	83	45	13	4.28	1.40
90 days	84	44	11	2.19	0.09
120 days	84	44	11	2.19	0.09
Populus tremuloides	80	49	18	0.4	
Picea mariana	71	51	27	0.2	

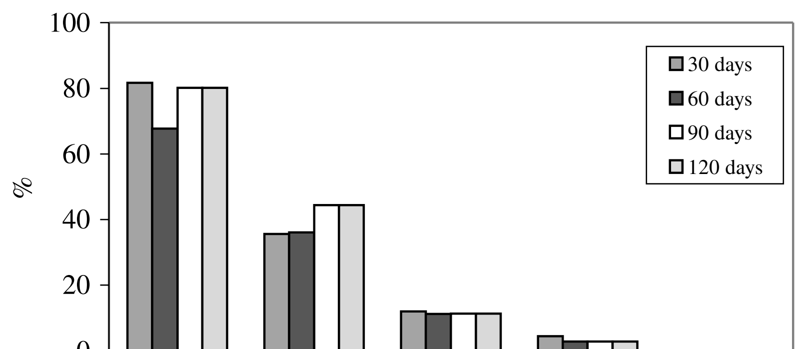
Figure 5. Chemical analysis of air-dried hemp stems grown in the field (% of extractive free fiber).

change appreciably. A similar trend was observed in the α-cellulose content with the age of the plants. In general, hemp contains more holocellulose and α-cellulose compared to softwood and hardwood species. This higher cellulose content would be beneficial in pulp and paper production.

As seen in Fig. 5, the lignin content decreased significantly with the age of the plants (statistical significance with p value = 1.65E-19). It is important to note that most of the non-woody plants complete their life cycle within 4–6 months and are highly affected by the environmental conditions prevailing during their growing season. The variation seen in hemp at different ages may also be as a result of microclimate changes rather than purely genetic or physiological reasons.

Silica is considered to be a challenge when using non-woody fibers for pulp production. The results of this study showed that there was a significant decrease in the ash and silica contents with plant growth (statistical significance with p value for ash = 1.53E-07 and p value for silica = 2.21E-05). Decreases in the ash content with plant age have also been reported for jute, bamboo[6] and kenaf.[7,8] Compared to other non-woody fibers like rice, the silica content is very low in hemp fibers.

Figure 6 summarizes the results of measurements of the constituents in the plants grown in the greenhouse. These results are comparable to previously published data.[9] The difference between the field and greenhouse



	Holocellulose (%)	Alpha-cellulose (%)	Lignin (%)	Ash (%)	Silica (%)
30 days	82	36	12	4.44	0.11
60 days	68	36	11	2.83	0.19
90 days	80	44	11	2.82	0.01
120 days	80	44	11	2.82	0.01

Figure 6. Chemical analysis of air-dried hemp stem grown in the greenhouse (% of extractive free fiber).

Table 1. Physical Properties of Hand-Sheets from Unbleached Pulp from 60- and 90-Day Field Hemp

Properties	60-Day	90-Day
Bulk (cm^3/g)	1.2	1.2
Brightness (% ISO) (glossy side)	18	19
Burst index ($Kpa.m^2/g$)	49	46
Tensile strength (kN/g)	59	56

samples is mostly due to the environmental factors, which affect physical and metabolic activities within the plants. In the first month, hemp in the greenhouse showed a very fast growth rate compared to the hemp in the field, but the later growth of greenhouse plants was somewhat slower than field plants. Cellulose composition is dependent on photosynthesis (growth), and this may explain the difference between the cellulose contents in the field and the greenhouse samples.

The paper made from the hemp whole stem shows characteristics comparable to paper made commercially using hardwood fibers. P. K. Ray et al. observed higher tensile and burst factors in 120-day old plants (as compared to plants harvested earlier) of *Hibiscus sabdariffa*, which is possibly due to the higher crystallinity of the pulp in 120-day plants.[10] In the current data, however, no significant variations in the tensile strength were seen in the handsheets made from hemp pulp obtained from 60-day and 90-day field samples, as seen in Table 1.

CONCLUSION

Based on the chemical analysis, it is evident that hemp stems contain high levels of α-cellulose and hemicellulose. The lignin content of the hemp stem is very low compared to other raw materials used by the pulp and paper industry. Based on these two factors (high cellulose and low lignin), hemp is a prime candidate for additional raw material for pulp and paper production.

In this study, the variation observed in chemical constituents and physical properties of hemp stems, as a function of plant growth, (though statistically significant) is not a very important consideration for the pulp and paper industry. Thus, as far as chemical constituents and strength properties of handsheets are concerned, hemp crops for use in the pulp and paper industry, could potentially be harvested earlier in their growth period. However, since the biomass production reaches the highest levels during 60–90 days of growth, maximum benefit will be obtained if the crop is harvested during the 60–90 day period. Thus, depending on the duration of favorable cultivation conditions, one additional crop of hemp could be grown within a single season. As a result, the availability of hemp fibers in the market could be increased, leading to a reduction in the current high cost of hemp fibers. This new influx of hemp fiber in the market could promote increased substitution of hemp as a raw material for pulp and paper production, thereby alleviating some of the pressure on some regional forests.

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