PHYSICAL PROPERTIES OF FIBERS IN THE FLAX PLANT, *LINUM USITATISSIMUM L.*, GROWN UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

By

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INTRODUCTION

In the previous papers (YANAGISAWA 1959, 1964, 1965, 1967. 1970, 1971, 1975), the properties of fibers of the flax plants grown under different environmental conditions were investigated histologically and chemically, viz. in them were treated the number, the diameter and thickness of fiber cells, and the amount of α-cellulose, $(\beta+\gamma)$-cellulose and lignin contained in crude cellulose.

The physical properties, however, have been left to research, which are practically very important to spinning process and to the quality of final product (NISHIKAWA 1960, MORTON and HEARLE 1962). Then, in this paper the author studied the physical properties of fibers such as the strength and the elongation in the flax plants grown under different environmental conditions and pursued their relationship with the other properties.

Before going further the author wishes to acknowledge the indebtedness to Dr. R. TAGUCHI for the cordial guidance throughout the study. The author desires to express his gratitude to Dr. N. KOYAMA for reading the original manuscript and to the members of our laboratory who assisted the experiment.

MATERIALS AND METHODS

The flax plants were grown under the same environmental conditions as in the previous works. The sample fibers were obtained from the middle part of flax stem after retted for 30 days (usually, the duration is said to be 7–14 days when the retting condition is adequate). The fibers were separated into a single fiber and put under a controlled condition of 14°–15°C with RH 45%

(as a rule, they are kept under the condition of 20°C and RH 65%).

KS-senimeter (Koa Co. Ltd., Kyoto) was used for the measurement of the strength and the elongation of the fiber with 1 cm long. The tensile strength was given as the breaking load per unit area of cross-section (Kg/mm^2) (MORTON and HEARLE 1962, KIRBY 1963). When the fiber broke, the amount of extension was expressed as the elongation of fiber (MORTON and HEARLE 1962, KIRBY 1963).

RESULTS AND DISCUSSION

1. The strength and the elongation of a single fiber obtained from the flax plant grown under the shaded condition

The strength of a single flax fiber in Shaded condition was evidently smaller than that of Control, though the elongation considerably larger (Table 1). The results were closely related with the histological and chemical properties of the fiber; the strength became larger as increased the thickness of the cell wall and the quantity of α-cellulose, on the contrary the amount of lignin decreased. As BONNER and GALSTON (1952) reported on the ramie fiber, the fiber having cellulose chains arranged a parallel direction to the fiber axis showed a high strength but a weak elongation. On the flax fiber, however, whether the above fact is exactly true remains not proved. The fiber became coarse and frail as the lignin content increased, and the elongation was larger than that of Control. The fact appears to be caused by the amount of lignin deposited into the spaces between the cellulose and the other cell wall constituents.

Table 1. Strength and elongation of fiber obtained from flax plant grown under shaded condition

	Strength	Elongation	Thickness of cell wall	α-cellulose	Lignin
	Kg/mm^2	%	μ	%	%
Control (100)*	22.8	3.41	7.8	85.3	9.3
Shaded (17)	9.1	4.34	4.7	75.4	16.6

* When Control condition was taken as 100 in light intensity Shaded condition became 17.

2. The strength and the elongation of a single fiber obtained from the flax plant grown under different soil moistures

As indicated in Table 2, the strength of the fiber became orderly smaller

Table 2. Strength and elongation of fiber obtained from flax plant grown under different soil moistures

Water content	Strength	Elongation	Thickness of cell wall	α-cellulose	Lignin
	Kg/mm²	%	μ	%	%
20%*	15.8	3.07	7.0	80.3	11.5
30%	26.1	3.29	8.8	88.9	10.3
40%	21.6	3.49	8.4	83.4	9.3

* The percentage of water content was exactly 18.2% per dry soil, samely in 40% condition 37.4% and in 30% condition 28.4%, respectively.

as 20% condition (15.8 Kg/mm^2) <40% condition (21.6 Kg/mm^2) <30% condition (26.1 Kg/mm^2). In the both conditions of 40% and 20%, the strength was smaller about 5 and 10 Kg/mm^2 than in 30% condition, respectively. The elongation of the fiber tended to be larger as the soil moisture increment. The fiber obtained from 30% condition was richest in α-cellulose and thickest in the cell wall. This fact agrees with Cutter's study (1978), in which the fiber of *Cannabis sativa* was much stronger in the plants grown in well-watered soil.

3. The strength and the elongation of a single fiber obtained from the flax plant grown under different densities of planting

As shown in Table 3, the strength of the fiber was biggest (52.5 Kg/mm^2) in Density 36 (Wagner pot area, 1/5000a), next (47.8 Kg/mm^2) in Density 25, and smallest (37.7 Kg/mm^2) in Density 49. The strength of the fiber had a close relationship to the thickness of the cell wall and α-cellulose content, with exception of Density 49. The smallest value of strength of Density 49 may be caused by such a high lignin content as 11.7%.

The elongation of the fiber showed almost the same tendency as in the

Table 3. Strength and elongation of fiber obtained from flax plant grown under different densities of planting

Density*	Strength	Elongation	Thickness of cell wall	α-cellulose	Lignin
	Kg/mm²	%	μ	%	%
9	41.8	4.35	9.7	85.3	10.6
16	43.2	4.90	9.6	89.1	9.8
25	47.8	4.41	9.6	89.6	7.4
36	52.5	5.01	9.9	89.9	8.2
49	37.7	3.07	9.9	89.4	11.7

* It is explained in text.

strength. It is ascertained therefore, the planting density effects greatly on the physical properties of the fiber.

4. The strength and the elongation of a single fiber obtained from the flax plant grown under solution culture with macro- and micro-element deficiency

The result is given in Table 4. The strength was largest in Control, next in N-defi. and in K-difi., and smallest in P-defi. It was smaller about 5 Kg/mm^2 in N-difi. and K-defi. and about 16 Kg/mm^2 in P-defi. than that in Control-1. The thickness of the cell wall and α-cellulose contents were smallest in

Table 4. Strength and elongation of fiber obtained from flax plant grown under solution culture with macro-and micro-element deficiencies

Regime	Strength	Elongation	Thickness of cell wall	α-cellulose	Lignin
	Kg/mm^2	%	μ	%	%
Control-1*	26.1	3.11	7.3	86.5	12.0
K-defi.	19.4	3.46	6.5	85.4	11.5
N-defi.	20.5	4.18	6.9	88.6	12.8
P-defi.	9.8	4.09	4.8	73.6	12.6
Control-2*	19.7	3.20	7.4	94.4	10.3
B-defi.	13.9	3.45	6.3	90.7	10.1
Mn-defi.	16.4	3.05	7.1	92.9	10.5
Mo-defi.	12.1	3.88	6.3	90.1	10.1

* It contains all elements.

P-defi. The fact suggests that the strength of the fiber in P-defi. is lowest.

The elongation of the fiber was largest in N-defi. and P-defi., and next in K-defi. which was smaller about 0.6% than those of the formers, whereas smallest in Control-1. The strength and the elongation were negatively related to each other. The relation was also recognized in the fibers obtained from the plants grown under the other conditions, though its degree seemed to be affect by the arrangement of the cellulose chains.

The strength was largest (19.7 Kg/mm^2) in Control-2 and was arranged orderly as Mn-defi. (16.4 Kg/mm^2)>B-defi. (13.9 Kg/mm^2)>Mo-defi. (12.1 Kg/mm^2). Each strength was in proportion to the thickness of the cell wall and α-cellulose content.

The elongation showed an increasing tendency following with decrement of the strength.

5. The strength and the elongation of a single fiber obtained from the flax

plant grown under different photoperiods

As indicated in Table 5, the strength of the fiber became largest (28.5 Kg/mm^2) in 16L 8D, while smallest (17.6 Kg/mm^2) in 8L 16D. From the results, the photoperiod is presumed to effect on the strength, viz. the shorter the daylength is reduced, the smaller the strength becomes.

Table 5. Strength and elongation of fiber obtained from flax plant grown under different photoperiods

Photoperiod*	Strength	Elongation	Thickness of cell wall	α-cellulose	Lignin
	Kg/mm^2	%	μ	%	%
8L 16D	17.6	3.16	10.3	83.9	13.1
12L 12D	21.8	4.03	7.7	80.8	9.6
14L 10D	25.6	3.64	8.2	79.7	10.4
16L 8D	28.5	4.37	8.4	80.6	11.4

* L : Photophase, D : Dark phase.

The elongation was largest in 16L 8D (4.37%) and decreased orderly in 12L 12D (4.03%), 14L 10D (3.64%) and 8L 16D (3.16%). The relationship between the elongation and the daylength was not evident, but the former had a faint tendency to decline as shortening of the latter.

6. The strength and the elongation of a single fiber obtained from the flax

Table 6. Strength and elongation of fiber obtained from flax plant grown under combinations of different daylengths

Regime	Strength	Elongation	Thickness of cell wall	α-cellulose	Lignin
	Kg/mm^2	%	μ	%	%
N*	38.1	4.03	10.9	90.4	8.7
N→8L_1**	20.2	4.81	10.5	88.4	13.8
N→8L_2	30.0	4.41	10.1	88.7	10.9
N→8L_3	35.4	5.39	9.8	88.0	9.7
8L 16D	27.4	3.15	9.9	89.5	15.9
8L→N_1***	64.4	4.05	10.6	91.0	6.8
8L→N_2	50.2	4.32	10.8	91.4	9.7
8L→N_3	23.3	4.07	10.8	89.9	11.8

* N…Control condition with natural daylength (14L 10D).

** Transferring time after germination…N→8L_1 : after 3 weeks, N→8L_2 : after 4 weeks, N→8L_3 : after 5 weeks.

*** Transferring time after exposed to 8L 16D…8L→N_1 : after 2 weeks, 8L→N_2 : after 3 weeks, 8L→N_3 : after 4 weeks.

plant grown under combinations of different daylengths

As denoted in Table 6, the strength of the fiber became larger when the transferring time from natural daylength (14L) to short day (8L) was delayed in the growth stage and also when the time from short day to natural daylength hastened. Further the strength became smaller as the period of short day became longer. In all N→8L regimes, the strength took smaller value than that in N (see the foot-note of Table 6). However, in each regime of 8L→N the eariler the transfer was operated, the greater the strength became, which took larger value than that in N.

The elongation was largest (5.39%) in N→$8L_3$, in which the transferring time was delayed. In N→8L regime the elohgation was larger than that in each 8L→N regime. The relationship between the elongation and the transferring time did not show a definite tendency as seen in the strength.

From these results, the strength of the fiber is recognized to have a closer relationship with the lignin quantity rather than the thickness of the cell wall and α-cellulose content.

SUMMARY

In the present paper, the physical properties of the fibers obtained from the flax plants grown under different environmental conditions were dealt with.

The results obtained are summarized as follows.

1) The strength of a single fiber was smaller in Shaded condition than in Natural condition, whereas the elongation was largest in Shaded condition.

2) The strength of the fiber obtained from the flax plant grown under different soil moistures was smallest in Dried condition and next in Over-watered condition. The elongation showed a tendency to become larger following with the soil moisture increment.

3) The strength of the fiber was largest in Density 36, and smallest in Density 49. When the density of the plant was sparse such as Density 9, it became weak. The elongation showed almost the same tendency as observed in the strength.

4) The strength of the fiber became small in the deficiency of each element among 3 elements of fertilizer. Particularly P-defi. had the most remarkable effect on the strength. The elongation was smaller in Control than in each element deficiency, among which it was largest in N- and P-defi.

In the micro-element deficiency, the strength was smallest in Mo-defi. and next in B-defi. On the contrary, the elongation showed an increasing tendency as the strength became weaker.

5) The strength of the fiber was smallest in 8L 16D; the shorter the daylength was reduced, the smaller the strength became. The relationship between the elongation and the daylength was not evident.

6) The strength of the fiber in each regime of N→8L and of 8L→N became smaller as the period subjected to short day was lengthened. The strength was stronger in 8L→N regimes than those in N→8L regimes. A definite relationship was not recognized between the elongation and the transferring time as seen in the strength. The elongation tended to be larger in N→8L regimes than in 8L→N regimes.

From the above results, it is ascertained that the histological and chemical properties in the flax fiber are closely related to the physical properties such as the strength and the elongation.

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