THE RELATIONSHIP OF SELECTED CHARACTERS TO YIELD OF FIBER, STRAW AND SEED IN FIBER FLAX, *LINUM USITATISSIMUM L.*

by

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THE RELATIONSHIP OF SELECTED CHARACTERS TO YIELD OF FIBER, STRAW AND SEED IN FIBER FLAX <u>LINUM USITATISSIMUM L</u>.

INTRODUCTION

Fiber flax, one of the oldest crops known to man, has received the attention of plant breeders for several decades. A breeding program has been carried on at the Oregon Experiment Station for the past 25 years, where emphasis has been placed on the development of high yielding, disease resistant varieties.

Considerable time and effort have been spent and various techniques have been developed to facilitate hybridization, selection and testing. The successes of the plant breeder are well known, but new techniques are still being sought for hastening the development of improved strains.

To be able to recognize yield potentials by the observance of some morphological character would be extremely valuable to a flax breeding program. It would facilitate early selection of lines in the breeding program. If a relationship should exist between a phenotypic character such as straw stiffness and grain or fiber yield it might serve as a valuable marker in obtaining higher yielding strains at less cost. Cultural and processing methods have an important influence on yield in fiber flax, however, morphological markers might still be important in differentiating higher yielding types from those that are low yielding when differences were due mainly to genetic factors.

In assessing the value of a fiber flax variety, both fiber and seed yields are important considerations. The yield per acre and the amount of fiber and seed contained in the straw is important since these factors govern the efficiency and economy of converting the raw material into a useable fiber.

In this study an attempt was made to determine the relationship between the plant characters: uniformity, height, maturity, straw weakness and yield of straw fiber and seed. The associations were determined by calculating correlation coefficients. The association of yield factors with each other were determined by the same method.

REVIEW OF LITERATURE

Flax (Linum usitatissimum) is one of the oldest crops known to man. Legett (8, p.11) indicates that it existed during the Swiss Lake dweller period, 12,000 B.C. According to Robinson (14, p.2) flax was one of the first crops grown by the Cavaliers at Jamestown and by the Pilgrims at Plymouth. In a historical study of flax in Oregon by the Works Progress Administration (22, pp.9-10) it was found that flax was first grown in Oregon in 1844 near Tualatin. It has been produced on a small scale in the Willamette Valley since that time, and at the present time the production represents less than 1% of the world's acreage.

A breeding program to improve and develop varieties was initiated by the U. S. Department of Agriculture in Oregon in 1932. The ability to recognize superior strains by the observance of some morphological character would be valuable to any plant breeding program. Associations between characters have been studied in many different crops. Many workers have conducted investigations to determine what plant characters, if any, may be associated with crop yield. Once a plant breeder is able to separate associations which are erratic and not dependable from those which are stable he will have provided himself with a valuable tool for selection work.

Wright (23, pp. 1-38) found that longer flax straw was associated with high fiber percentage, high straw, and high fiber yield per acre. His results were based on data of certain flax crops processed by the New Zealand Linen Flax Corporation.

Keller (6, pp.940-953) found yield in corn to be associated with ear size, number of ears, and ligule height. Robinson (16, pp.282-287) also found corn yield to be associated with ears per plant but found no inherited relationship between yield and husk length, husk score, ear length, and ear diameter. Martin (9, pp.1177-1182), studying associations in sorghum, found yield to be more closely correlated with heads per acre than with size of head or weight of grain per head. He also found a high correlation between height of stalks and grain yield, within a given variety, and between grain and stover.

Quisenberry (12, pp.492-499) observed little relationship in wheat between number of heads per acre and size of heads or plumpness of grain, but the number of heads per unit area was one of the most important factors in determining yield. The number of kernels per head or size of head was more closely associated with yield than was plumpness of grain and weight of 1,000 kernels. Characters associated with yield in rye were studied by Warren (20, pp.12-29) who presented evidence showing highly significant associations between yield and stooling vigor and percentage of fruitfulness. In the same study a highly significant correlation was found to exist between weight per bushel and pollen sterility and between percent fruitfulness and weight per 1,000 kernels.

Many workers have attempted to find an association of characters which would serve as an index to strength of straw in certain crops. Garber and Olson (3, pp.173-186) found no correlation between yield and lodging or between height of plant and lodging in wheat. Hamilton (4, pp.646-676) and Garber and Olson (3, pp.173-186) observed that wheat with stronger straws contained a slightly larger number of vascular bundles. Ramiah (13, pp. 880-994), however, found no relationship between lodging in rice and number and size of vascular bundles. Hamilton (4, pp.646-676) found that a high degree of lodging in oats tended to be associated with a high percentage of lignin, or vice versa, and concluded that there may be several factors associated with strength and that they may be inter-related.

Many have studied the relationship between plant or seed characters and the composition of flax seed. Leather (7, pp.1-38) indicated that there was no relationship between oil content and seed size; however, his conclusions were based on samples produced under different climatic conditions and, therefore, may be doubted by some. Eyre and Fisher (2, pp.120-134), Coleman and

Fellows (1, pp. 4-7), and Johnson (5, pp. 537-543) all concluded that oil content was positively correlated with weight of 1,000 kernels. Weiss (21, pp.289-297), working with soy beans, found no appreciable association between seed size and oil content, or between seed size and protein content. Maturity date was not associated with iodine number of oil. Johnson (5, pp. 537-543) showed that there was a positive correlation between oil content of flax seed and number of days from full bloom to maturity. He also presented evidence to show negative correlations between iodine number and percentage of oil and weight of 1,000 seeds, date ripe, and number of days from full bloom to maturity. Since percentage of oil in flax is correlated with certain variables studied, it indicates that oil content may be dependent on the factors that condition seed size, date ripe, and number of days from full bloom to maturity. Since iodine number in flax is not correlated with the other characters, it may be inherited independently of plant and seed characters.

Weiss (21, pp. 289-297) found large seed size in soy beans was correlated with low iodine number and that lateness of maturity was correlated with high oil content and low protein content. High oil content was correlated with low iodine number of oil and high protein content was correlated with low oil content.

Ross (17, pp. 372-379) found that height of sunflower plants was positively correlated with percentage of oil and yield of seed and seed yield to be positively correlated with percentage of oil. Negative correlations existed between yield of seed and number of leaves, and yield of seed and number of branches. Ross (17, pp. 372-379) concluded that in varietal improvement of sunflower, a tall non-branching type, was worthy of consideration.

Wright (23, pp. 1-38), working with flax, and Paskovic (11, pp. 62-83), working with hemp, found straw length was associated with thickness of stem. The longer straw was thick and the short straw was thin. Wright (23, pp. 1-38) also found higher fiber percentage in flax to be associated with lodging. This was in agreement with the work of Sieben (19, pp. 101-106), who found a correlation between the variety means for stiffness of flax straw and fiber content. The stiff straw contained less fiber than the weak straw.

Searle (18, pp. 1-6) measured cross-sections of the stems of flax and found a correlation between the area of fiber bundles and the area of the stem. However, he found no correlation between area of stem and length of straw, indicating that it was possible to select for tallness without getting a corresponding thick stem. Neither did he find a correlation between length of straw and percentage of fiber (area of fiber in area of stem). This indicates that an increase or decrease in the height of the plant was not necessarily accompanied by an increase or decrease in its percentage of fiber in the area of the stem.

Miller (10, pp. 269-281) found that as flax straw increases in diameter, the number of fibers, the number of bundles, and the number of fibers per bundle increase. The correlation was greatest between fiber number and stem thickness, that is, large stems have fewer fibers per unit of area than small stems and large stems have coarser fiber than small stems.

Robinson (15, pp. 30-44), in an intensive study, found a correlation between number of seeds per plant and plants that had long panicles upon thick stems. A correlation was found also to exist between fiber weight and length of stem but only a slight relationship between seed yield and length of stem.

MATERIALS AND METHODS

A study to measure the relationship of certain plant characters to yield in fiber flax was conducted in 1950, 1951, and 1952. An attempt was made to determine the correlation of characters with each other and to yield of straw, fiber, and seed, and to percentages of fiber and seed contained in the straw. The plant characters studied were uniformity of growth, maturity, plant height, and straw stiffness.

Ten varieties were selected that represented the extremes of plant characteristics and yields. The same varieties were grown in 1950 and 1951; however, in 1952 four varieties with a wider range in characteristics were used to replace four grown the preceding two years. Trials in each location and for all years were designed as randomized blocks. All plots were planted with a V-Belt seeder and consisted of three rows 12 inches apart and 20 feet long. Weed growth was controlled by cultivation between the rows. Prior to harvest, one foot was trimmed from each end of the plots. The center row was harvested for yield. The two outside rows of each plot were grown to equalize border effect. All yields were obtained by weighing to the nearest gram on a Toledo balance and were converted into pounds per acre for a more understandable interpretation.

1950 Experiments: In 1950, one trial of four replications was located on the College East Farm one mile east of Corvallis and one test of three replications was located on land adjacent to and belonging to the Santiam Flax Growers Cooperative, approximately four miles northwest of Jefferson, Oregon. The soil on both locations is of the Chehalis series, which is high in inherent productivity and is considered ideal for flax production. The growing season was ideal for flax except for an insufficient rainfall during the critical growing period. Supplemental water was applied to both trials by the overhead sprinkler method, which compensated for the lack of rainfall.

1951 Experiments: One trial of four replications each was grown on the College East Farm, the Hyslop Agronomy Farm located six and one-half miles northwest of Corvallis, and a farm belonging to Mr. Lawrence Bunning one mile west of St. Paul, Oregon, and one trial of three replications on a farm belonging to Mr. Hal Reeves, four and one-half miles northwest of Jefferson, Oregon. All soils were of the Chehalis series except that on the Hyslop Farm, which is Willamette silty clay loam. While the Willamette soil is not as suitable for flax as Chehalis, several thousand acres of flax for commercial purposes has been grown on this soil type. 1951 was considered an ideal year for the production of flax and a high quality fiber was produced at all locations.

1952 Experiments: In 1952, four replications each were planted on land belonging to the Santiam Flax Plant, four and one-half miles northwest of Jefferson, Oregon, the Hyslop Agronomy Farm, and two trials using the same number of replications on the College East Farm. The East Farm trials were planted three weeks apart. Except for the Willamette soil type on the Hyslop Farm, all trials were located on the highly fertile Chehalis soil. Although the growing season was satisfactory, it was necessary to irrigate for maximum yields. All trials were irrigated except that on the Hyslop Farm, where no irrigation facilities were available.

Evaluation of Plant Characters:

Uniformity: Uniformity was measured by visual observation on a scale from 1-5 after the plants had reached maximum height and the seed bolls were fully formed. Plots which were most nearly uniform in growth habit, particularly height, were rated 1. Plots that were very uneven were rated 5.

Maturity: In assessing maturity values, plots were rated as being very early, early, medium, late, and very late, depending upon the time of flowering. Maturity data were collected for each plot at the time of flowering. Those rated as very early would be nearly through blooming when those rated as very late would be in full bloom.

For purposes of calculation values were given as follows: very early, 1; early, 2; medium, 3; late, 4; and very late, 5.

Height: Height was measured in inches from the ground level to the top of the average plants within the plot. All measurements were taken after the plants had reached full maturity.

Straw Stiffness: Stiffness was judged according to visual observation. Strains that were weakest and had the greatest tendency to lodge were rated at 10, while those with a stiff, erect straw were rated 1. Values were given after the plants attained maximum height, and when one-half the seed bolls had ripened. During this stage straw weakness appears to be more pronounced. Frequently plants with a tendency to lodge during this period will become erect when fully mature.

Yields: The yield data in the study were determined as follows:

Pulled Straw: The plots were harvested when most of the leaves had fallen. Harvesting was accomplished by hand pulling rather than cutting. Pulling results in maximum straw yields and preserves the longest possible line fiber, since the fiber extends from the lower part of the panicle to nearly ground level. The pulled straw was shocked immediately after harvesting, thus exposing it to the sun for drying and bleaching. Air dry straw weights were recorded for each plot.

Seed: Special threshing equipment is required for handling fiber flax since the straw must be kept parallel and straight for subsequent processing operations. The seed was removed from the straw by use of the Whipper flax de-seeding machine. The machine used consisted of a pair of steel rollers, each of which was fastened to the end of a shaft. One roller was power driven, which in turn drove its twin roller by friction. Only the tip ends of the straw were passed between the revolving rollers, which action removed the seed bolls, but did not disturb the parallelism of the straws. The seed was cleaned in a small fanning mill customarily used for cleaning experimental seed lots.

Retting: The de-seeded straw had to be retted before the fiber could be removed from the pith. Retting is the bacterial decomposition of the encrusting substances which bind the fibers together and to the inner woody portion of the straw. Retting bacteria are naturally present on the straw as harvested. A string with an attached metal tag was tied around each bundle in order to maintain the identify of the plots during and after the retting process. Straw from each location was retted separately in tanks that were equipped with automatic temperature controls. The bundles were placed in an upright position in the tanks, which were then filled with cold water. The cold water was allowed to remain on the straw for four hours, after which it was drained. Fresh water at a temperature of 92°F., without the addition of chemicals, was allowed to enter the tank. This temperature, which is considered optimum for the development of retting organisms, was maintained throughout the retting process. Twenty percent of the water was replaced daily to lower the acidity, thus maintaining an optimum condition for the development of retting bacteria. The straw was tested periodically during the ret to determine the proper time to stop the retting action. The test is based on empirical knowledge and depends upon the ease with which the fiber separates and comes off the woody core. If the ret is stopped prematurely, it is difficult to remove the woody material in the later refining process because of the adhesive nature of the remaining encrusting materials. If the straw remains in the water too long it becomes over-retted, which means that the fiber bundles may break down into ultimate cells and the commercial strands of fibers will have a low tensile strength. Immediately after the ret had been completed, the retting liquor was drained and the straw was rinsed with cold water to arrest further bacterial action. The tanks were then drained and the straw was taken to the drying field where it was exposed to the sunlight. Drying was hastened by "wigwamming" individual bundles, that is, flaring out the butt ends to serve as a base for the bundle while in an upright position. After drying, the straw was stored until climatic conditions were favorable for the scutching process.

Scutching: Scutching is a process of removing the woody material and short fibers from the long line fiber, and was always done during a period of high humidity. Under this condition the straw has a high moisture content which adds flexibility to the fiber so that there is less breakage and loss of long fibers in scutching. All material was scutched in a commercial Van Hauewert machine. In this unit the pith was broken and removed in a subsequent action by rotating beaters. The speed of the beaters was kept constant for each trial, thus eliminating variation due to scutching speed. The scutched clean fiber known as line was weighed immediately as it left the machine. The tow, or short fibers, removed in the scutching operation, were separated from the shives or woody material in a separate cleaning unit. The tow and line fiber together made up what is known as total fiber.

Percentage yields: In the production of fiber flax, not only is the yield of straw, fiber, and seed important, but also the percentage of fiber and seed contained in the straw. In this study, percentages of seed and fiber are based on the pulled straw weight. In 1952, the percentage of wax in the line fiber was determined. Wax is objectionable since it accumulates on spinning equipment causing year breakage. All wax determinations were made by the Department of Agricultural Chemistry, Oregon State College, Corvallis, Oregon.

Method of Analysis

Means for characters and yields were calculated for all locations. The degree of association between each character and each yield was determined by calculating the intra-annual correlation coefficient. The correlation coefficients were calculated by computing the sums of products and sums of squares for each plant character and yield factor. The sums of products may be defined as the sum of the products of the deviation of x and y from their means, where x represents one plant character or yield factor and y represents another. The sums of products were calculated as follows:

$$\frac{S\ (xy)\ ---\ S\ (x)\ S\ (y)}{N}$$

The formula then for computing the correlation coefficient is as follows:

$$r = \frac{\text{Sums of Products}}{\text{ssy X ssy}}$$

Varieties

Stormont Cirrus: This variety was developed by the Ireland Ministry of Agriculture, Belfast, County Antrim, Ireland. The exact origin is not known. The variety was released in 1932 and represented an important part of the commercial acreage grown in Oregon between 1933 and 1940. It is blue-flowering, early in maturity, and has medium stiff straw. It is resistant to wilt and susceptible to several races of rust. It was a leading commercial variety in Western Europe for many years.

Percello: This variety is a result of a cross (Concurrent x Texala) made by J. Hijlkema of Holland. Percello is similar to Cirrus except that it is much more uniform and somewhat taller growing.

23A: (Oregon Selection 7107421) 23A was selected in 1937 at the Oregon Experiment Station by E. G. Nelson and is from a cross of Oregon 46123 x (1904 x 1923-21). The origin of the parents is not known. The variety is blue-flowering, medium in straw stiffness, medium early in maturity, fairly tall growing, and is a high straw yielder. It is susceptible to wilt and to many races of rust.

Concurrent: Concurrent was selected from a white-flowering flax by Dr. J. C. Dorst, Council for Plant Breeding, Leewuarden, Netherlands. The white-flowering flax from which it was selected had been grown in Friesland province for a century. The original white-flowering type was a result of a selection made in 1816 by a Friesland farmer in a blue-flowered flax of Russian origin. Concurrent is white-flowering, uniform, medium early in maturity, has a fairly stiff straw, and is susceptible to rust and wilt. It has been one of the most widely used commercial varieties in Oregon and Western Europe and is considered to be one of the most valuable contributions of plant breeding to the world's flax industry.

Norfolk Queen: This variety is from a selection made in 1935 at Lambeg, Ireland, from a plot that had been planted with mixed seed obtained from Professor H. L. Bolley of North Dakota. Norfolk Queen is blue-flowering, tall growing, had a weak straw, is not uniform, and is a high producer of fiber but is low in seed yield. It is resistant to wilt, but is susceptible to some races of rust.

Cascade: Cascade was selected by E. G. Nelson in 1937 at the Oregon Agricultural Experiment Station from a cross made by B. B. Robinson between two promising selections. Cascade is blue-flowering, late in maturity, has weak straw, is not uniform, and is resistant to wilt and immune to races of rust found in Oregon. It achieved an important place in Oregon's flax industry soon after its release in 1945.

Hollandia: This variety is the result of a cross by J. Hilkema of Holland. The parents were F6 x Texala. Hollandia is early in maturity, has a blue flower, produces a short straw, is fairly uniform, and has extremely stiff straw. It is susceptible to wilt and many races of rust.

Liral Dominion: Liral Dominion was developed by the Linen Industry Research Association, Lambeg, Ireland. The parentage is not known. It is blue-flowering, early maturity, has a medium stiff straw, and is fairly uniform in growth. It is a high producer of seed but is low in line fiber yield.

Liral Prince: This variety is from a cross made at the Linen Industry Research Association, Lambeg, Ireland, between Liral Beatall and Liral Monarch. It has a blue flower, is early maturing, is fairly uniform, and has a medium stiff straw. It is very susceptible to many races of rust.

Formosa: This variety is a result of a cross of F6 x Texala, made by P. J. Hilkema, Holland. It is white-flowering, has a weak straw, is late in maturing, is fairly uniform, is tall growing, and is susceptible to both wilt and rust.

Talmune: Talmune is a hybrid developed at the University of Minnesota and is from a cross of Ottawa

770B x Saginaw. The cross was made by A. W. Henry and one of the selections made in 1924 was named Talmune. It has a white star shaped flower, is very late in maturity, has a very stiff straw, and is fairly uniform. It is resistant to wilt and is immune to rust in Oregon. It is a very high yielder of straw but the straw contains a low percentage of fiber.

1A (Oregon Selection 87903): This strain was selected by the writer in 1948 from a cross of Highboll x (Cascade x Bison) made by E. G. Nelson in 1942. It is blue-flowering, late in maturing, has a very weak straw, and is non-uniform. It is susceptible to wilt and rust in Oregon but is a very high producer of line fiber.

Wiersema: The variety was obtained for the Oregon Station by the Bureau of Plant Exploration and Introduction from Wageningen, Holland. Later it is believed to have been named Wiera. Wiera is the result of a cross, Concurrent x Hercules, and was made by J. P. Wiersema, Netherlands. Wiersema is blue-flowering, is medium early, fairly uniform, has a medium stiff straw, and is tall growing. In 1954 it accounted for 66% of the fiber flax acreage in Holland.

7A: This variety was selected in 1937 and reselected in 1943 by E. G. Nelson from a cross made by B. B. Robinson which consisted of Cirrus and an unknown selection. The strain is blue-flowering, has a weak straw, is tall growing, medium early in maturity, and is fairly uniform. It is susceptible to wilt and rust in Oregon.

EXPERIMENTAL RESULTS

All varieties used in these trials were pure lines and the means for characters and yields for all locations by years are shown in Tables 1, 2, and 3. In order to determine the degree of association between each character and each yield factor, intra-annual correlation coefficients were calculated. The correlation coefficients are presented in Table 4. Values required for significance at the .05 and .01 level are + or - .632 and + or - .765, respectively.

Uniformity: There was no significant association between uniformity of growth and yield factors. The non-uniform growth was associated with straw weakness in 1950 and approached a significant relationship in 1951 and 1952. It is of interest to note that while not significant, there was a trend toward a negative relationship between non-uniform straw growth and wax content of line fiber, with the value being -.4958.

Maturity: The association of late maturity with plant height was significant at the .01 level in 1950 and at the .05 level in 1952, and the same relationship approached significance in 1951. Maturity was not related to fiber or straw yields. These data indicate that late maturing varieties, even though taller growing, are not necessarily higher yielders of straw and fiber. Late

Table 1

Average All Locations - 1950

Variety	Maturity	Height	Uniformity	Stiffness	Pounds per Acre: Pulled Straw	Pounds per Acre: Line Fiber	Pounds per Acre: Seed	Pounds per Acre: Total Fiber	Percentage in Pulled: Line	Percentage in Pulled: Seed	Percentage in Pulled: Total
Stormont Cirrus	2	29.3	3.0	4	2177	183	297	374	8.40	13.80	17.15
Percello	3	30.9	1.0	4	2666	294	285	507	11.20	10.80	19.10
23 A	3	30.8	1.5	5	2708	285	351	486	10.65	13.00	18.00
Hollandia	2	28.8	2.0	1	2719	280	332	500	10.20	12.30	18.30
Liral Dominion	2	27.5	3.0	3	2762	266	423	469	9.90	14.90	16.45
Liral Prince	1	29.5	3.0	5	2521	277	302	470	11.15	12.00	18.65
Concurrent	3	29.5	2.0	5	2547	268	361	464	10.85	14.25	18.35
Norfolk Queen	3	32.5	4.0	10	2700	340	244	528	12.80	9.10	19.60
Cascade	4	33.0	4.0	8	2953	300	339	528	10.35	13.50	18.00
Formosa	4	32.0	3.0	6	2831	298	292	478	10.70	10.40	17.00
Total	27	303.8	26.5	51	26584	2791	3226	4804	106.20	124.05	180.60

Table 2

Average All Locations - 1951

Variety	Maturity	Height	Uniformity	Stiffness	Pounds per Acre: Pulled Straw	Pounds per Acre: Line Fiber	Pounds per Acre: Seed	Pounds per Acre: Total Fiber	Percentage in Pulled: Line	Percentage in Pulled: Seed	Percentage in Pulled: Total
Stormont Cirrus	2	30.9	3.0	4	2668	291	382	416	10.40	14.15	15.17
Percello	3	31.7	1.0	4	2659	292	317	446	10.47	11.87	16.50
23 A	3	30.5	1.5	6	2853	317	378	482	10.55	13.37	16.80
Hollandia	2	28.0	2.0	1	2492	274	344	421	10.60	13.93	16.55
Liral Dominion	2	28.5	3.0	2	2538	257	394	386	9.52	14.97	15.92
Liral Prince	1	30.9	3.0	5	2798	299	381	456	10.22	13.60	16.30
Concurrent	3	30.4	2.0	5	2549	288	371	448	10.90	14.30	17.60
Norfolk Queen	3	32.5	4.0	10	2677	345	243	498	12.30	9.00	18.40
Cascade	4	33.2	4.0	8	2792	308	267	481	10.30	9.97	16.62
Formosa	4	31.0	3.0	5	2569	275	297	445	10.37	11.52	17.00
Total	27	307.6	26.5	50	26595	2946	3374	4479	105.63	126.68	166.86

Table 3

Average All Locations - 1952

Variety	Maturity	Height	Uniformity	Stiffness	Pounds per Acre: Pulled Straw	Pounds per Acre: Line Fiber	Pounds per Acre: Seed	Pounds per Acre: Total Fiber	Percentage in Pulled: Line	Percentage in Pulled: Seed	Percentage in Pulled: Total	% Wax
Stormont Cirrus	2	32.6	2	7	5554	741.0	473.7	889	12.09	8.6	15.1	3.57
Percello	3	32.5	1	3	5497	601.5	679.5	779	9.70	12.6	13.8	3.24
Liral Prince	1	32.3	3	5	5993	673.2	752.2	850	9.99	12.7	12.6	3.33
Concurrent	3	31.3	2	5	5337	586.7	788.5	756	9.88	15.1	14.0	3.49
Norfolk Queen	3	32.6	4	10	5259	662.7	661.2	823	11.30	12.9	14.6	3.00
Cascade	4	33.5	3	6	5998	650.7	743.5	899	9.64	12.7	14.3	3.62
Talmune	5	36.0	3	1	6349	543.7	660.7	869	7.57	11.0	13.0	3.17
1 A	4	33.7	5	10	5423	685.5	619.2	841	10.89	11.2	14.8	3.10
Wiersema	3	33.4	3	3	5666	629.7	680.2	882	9.86	12.1	15.1	3.22
7 A	3	34.3	3	8	5735	785.0	541.0	937	12.48	9.5	14.2	3.07
Total	31	332.2	29	58	56811	6559.7	6599.7	8525	103.40	118.4	141.5	32.8[illegible]

maturity was negatively associated with seed weight and percentage of seed in the pulled straw in 1951 only. There was no relationship between maturity and straw weakness, wax content, total fiber weight, percentage of total fiber, or uniformity of growth.

Plant Height: These results indicate a significant relationship between plant height and straw weakness in 1950 and 1951; however, there was a non-significant negative relationship in 1952. Tall growing flax is thought to be indicative of greater yields of straw; however, in this study that relationship was significant in 1952 only. In 1951 there was a significant relation between height and line and total fiber yield. There was also a negative association significant at the .01 level between tall straw and percentage of seed in 1951, and a negative relationship in the same year between height and seed yield. Plant height was not associated with uniformity, percentage of line in the pulled straw, percentage of total fiber, or wax content.

Straw Weakness: There was a highly significant relationship between straw weakness and line fiber in 1950 and 1951, and the association was significant at the .05 level in 1952. The inter-annual correlation coefficient was calculated for weakness and line fiber and was found to be + .8278 which is highly significant. Percentage of line fiber based on the pulled straw yield was associated with straw weakness and was significant at the .01 level in 1952 and the .05 level in 1951. Straw weakness was negatively associated with seed weight and with percentage of seed in 1951. The association of weakness with total fiber yield was highly significant in 1951, and there was a significant relationship between weakness and percentage of total fiber in the pulled straw for the same year. Straw weakness was more closely associated with more yield factors than was uniformity, plant height, or maturity. It was closely related to plant height in 1950 and 1951 and to uniformity in 1950. Weakness was not associated with maturity.

Yield Factors with Yields:

Pulled Straw: Correlation coefficients were calculated in order to determine the degree of association between the yield factors. Total pulled straw yield was correlated with the yield of line fiber in 1951 and with total fiber in 1950 and 1951 and was negatively associated with percentage of total fiber in 1951. Pulled weight had no significant relationship to line weight in 1950 and 1952 and was not associated with seed yield, percentage of seed, percentage of line, uniformity, maturity, wax content, or straw weakness for any year.

Line Fiber: It is of interest to observe that line fiber was negatively associated with seed yield for 1950 and 1952 and with percentage of seed for all three years. Since it is a component of total fiber, it was, as expected, highly significant in its association with total fiber weight for 1950 and 1951 but was not significantly associated with percentage of total for any year. Line yield per acre was positively associated with percentage of line in 1950 and 1951. It was not related to wax content, uniformity, or maturity. The strongest relationship was to straw weakness for all years.

Seed Weight: Seed weight was associated with percentage of seed for all three years. Seed yield was negatively associated with total fiber in 1951 and with percentage of line fiber in 1952. It was not related to wax content, percentage of total fiber, or pulled straw yield for any year.

Total Fiber Weight: The yield of total fiber was associated with percentage of line fiber in 1950 and 1951, and was negatively correlated with percentage of seed for 1951 and 1952. Total fiber was associated with percentage of total in 1951 only, in spite of the fact that it is a component of the percentage yield. It was not associated with wax content, uniformity, or maturity for any year.

Percentage of Line Fiber: It will be seen from the negative relationship that as the percentage of line increased, the percentage of seed decreased in 1950 and 1951.

A positive relationship existed between percentage of line and percentage of total in 1950 and 1951. There was also a strong trend for the same relationship in 1952, which might have been anticipated since total fiber is partially made up of line fiber. The percentage of line was not associated with maturity, uniformity, plant height, pulled straw yield, or wax content for any year. There were positive relationships between percentage of line and straw weakness for 1951 and 1952 and to line and total fiber yields for 1950 and 1951.

Percentage of Seed: Percent seed in the pulled straw was not related to uniformity of growth, pulled straw yield, percent of total fiber, or to was content for any year. It was negatively associated with maturity, plant height, and straw weakness in 1951, and line fiber yield for all three years, to total fiber in 1951 and 1952, and with percentage of line in 1950.

Percentage of Total Fiber: There was a significant relationship between percentage of total fiber and straw weakness and between total fiber yield in 1951 and percentage of line in 1950 and 1951. There was a negative relationship between percent of total fiber and pulled straw yield in 1952. It was not related to uniformity of growth, maturity, plant height, fiber yield, or percentage of seed.

Table 4. Correlation Coefficients, 1950 - 1952.

		Uniformity	Maturity	Height	Weakness	Pulled Straw	Line	Seed	Total Fiber	Percent Line	Percent Seed	Percent Total	Percent Wax
Uniformity	1950		.1169	.3481	.6352*	.1568	.1486	.1724	.0764	.0893	.0978	.1187	
	1951		.1111	.4042	.5283	.1244	.2802	-.4661	.2044	.2053	-.4848	.1349	
	1952		.2844	.3434	.5969	.0291	.2241	-.0647	.2822	.1463	-.0958	.1986	-.4958
Maturity	1950			.7671**	.5263	.5897	.1582	-.4253	.4362	.2222	-.2458	.0025	
	1951			.5349	.1551	.0430	.2212	-.6685*	.4637	.2322	-.6316	.4576	
	1952			.6853*	-.1609	.2641	-.4507	-.4657	.0666	-.4811	.0001	.0782	-.2111
Height	1950				.8226**	.4524	.5886	-.5976	.5412	.5004	-.6053	.4135	
	1951				.8630**	.6074	.7079*	-.6781*	.7525*	.4261	-.8074**	.3327	
	1952				-.2413	.6817*	-.0783	-.3124	.5999	-.3293	-.5154	-.1557	-.3829
Weakness	1950					.2705	.8259**	-.4876	.4036	.5934	-.4680	.3907	
	1951					.5834	.8815**	-.6819*	.8846**	.6673*	-.8144**	.6266	
	1952					-.5859	.6922*	-.3552	.1268	.7850**	-.1834	.4884	-.2358
Pulled Straw	1950						.2541	.2041	.8453**	.4290	.2035	.0221	
	1951						.6557*	-.0794	.6596*	.0572	-.3202	.0732	
	1952						-.2320	-.1012	.5072	-.5841	-.2238	-.6441*	.1536
Line	1950							-.8046**	.9206**	.8931**	-.6375*	.5508	
	1951							-.5338	.8995**	.7821**	-.6863*	.5690	
	1952							-.6742	.5960	.2897	-.6345*	.3987	.0648
Seed	1950								-.1204	-.4427	.8550**	-.6143	
	1951								-.6258	-.6055	.9645**	-.6111	
	1952								-.5431	-.6336*	.9333**	-.4799	.1922
Total Fiber	1950									.7554*	-.4695	.5430	
	1951									.6695*	-.7356*	.6803*	
	1952									.2984	-.7355*	.1875	-.0191
Percent Line	1950										-.7138*	.7561*	
	1951										-.6112	.7927**	
	1952										-.4532	.5638	-.1103
Percent Seed	1950											-.6026	
	1951											-.5878	
	1952											-.2771	.1203
Percent Total	1950												
	1951												
	1952												.0291

* Significant at .05 level
** Significant at .01 level

DISCUSSION

The varieties used in this experiment were selected because they represented wide variations in morphological characteristics and yield. In the production of fiber flax not only is the yield per acre of straw, seed, and fiber important, but also the amounts of seed and fiber contained in the straw. The yield of straw per acre is important to the producer since straw is sold by the ton. The yield of fiber and seed is of consequence to the processing company because they represent the saleable products and the amount contained in the straw influences the efficiency and economy of their operation. Flax breeders throughout the world are interested in developing varieties that are good yielders of high quality straw, seed, and fiber, and at the same time possess other desirable characters. If significant correlations should exist between morphological character and straw high in fiber or seed content, it would facilitate the elimination of poor lines in a flax breeding program.

Uniformity:

In this study, uniformity of growth was measured to determine if it was associated with maturity, straw weakness, plant height, or with yield of straw, seed or fiber. The results indicate that uniformity of growth was not related to maturity or plant height. These results indicate that either tall or short types may be uniform or lack uniformity. Likewise, it would be feasible to expect late maturing varieties to be as uniform as those that mature early.

One might speculate that uniformity of growth would be associated with straw yield since it applies mostly to height within a plot. This study did not support that speculation. Perhaps this could be attributed to the fact that non-uniform varieties produce enough taller growing plants to offset the loss in yield caused by the short straws.

The lack of association between uniformity and line fiber yield and percentage of line fiber might be difficult to explain except for the fact that very few plots contained extremely short straws which are usually not delivered as line fiber in the scutching operation. It might be stated that favorable growing conditions produced long enough straw to be converted into line, even though it was not uniform within the plot.

Non-uniform straw appeared to be the weakest straw. The association between the two characters was significant in 1950 and nearly significant in 1951 and 1952. There is no explanation for the relationship. The lack of association between uniformity and total fiber and seed yields indicates that those yields probably cannot be increased by merely obtaining a uniform growing type. Similarly it might be stated that selecting for a uniform growing straw would probably not result in an increased yield of total fiber or seed.

Even though uniformity appears to have little effect on yield, its importance should not be minimized since the fiber is ultimately spun into yarn, at which time the character might become important. If the fiber is not uniform greater loss would probably be experienced in hackling, drawing, and spinning.

Spinners agree that some fiber contains enough wax to be objectionable in the spinning operation. The wax rubs off the fiber and accumulates as the sliver passes over certain parts of the spinning equipment, causing stoppage. There appeared to be a negative trend between non-uniform straw and wax content for one year that wax content was determined. This relationship was not significant but it might be worthwhile to further explore the possibilities of such an association, inasmuch as uniformity would be an obvious marker and would, therefore, be extremely valuable to an improvement program.

Maturity:

Maturity is one of the most easily measured characters since determination is based on the presence or absence of conspicuous blossoms. In this study late maturing varieties were found to be taller growing, although the relationship was not significant in 1951. Late maturing varieties have a longer growing period and they might logically be expected to be taller growing. Late maturing varieties in this study were not associated with straw or fiber yields for any year and in 1951 there was a negative relationship between late maturity and seed yield. The negative relationship with seed yield may be due to the adverse ripening conditions for the late varieties which resulted in light, shriveled seed which was later lost in the cleaning operation. Perhaps the lack of association between late maturity and pulled straw yield is due in part to low seed yields. Lack of association between maturity and fiber yield merely indicates that fiber yield is dependent upon factors which may or may not include maturity. A plant breeder should not consider maturity alone when selecting for increased fiber yield; however, he might select for maturity and not reduce fiber yields. No relation between maturity and straw weakness was found which might be a valuable lead inasmuch as a plant breeder might select for maturity without introducing straw weakness. There appeared to be no relation between maturity and wax content. However, it might be emphasized that wax content was determined for only one year.

Height:

For the years 1950 and 1951, the association of tall growing types with straw weakness was significant at the 1 percent level. In 1952, when varieties with a wider range of characteristics were introduced, there was no significant relation between the two characters. It appears, therefore, that height is not associated with weakness in all cases and under all conditions. Plant height was associated with pulled straw yield in 1952 and there was a trend toward a positive relationship in 1950 and 1951. Tall growing varieties are often expected to produce a greater yield of line and total fiber by virtue of their length alone. The relationship existed in 1951 and there was a strong positive trend in 1950. There was a negative relationship between plant height and seed yield, but the relationship was significant in only 1951. The negative relationship between height and seed yield indicates that the shorter varieties produce the most seed, which supports the validity of the theory of selecting short strawed flaxes for maximum seed yields. It might be stated that selecting tall growing flax types for maximum fiber yield has resulted in a reduction of seed yield. In this study, height was not related to percentage yields of line or total fiber. The lack of association of height with line may be due to the fact that all straw was of sufficient length to be converted into line, that is, was not so short as to be lost in the scutching operation. The percentage of total fiber was not affected by height, which indicates that percentage of fiber is dependent upon factors other than height. Height was not related to wax content of line fiber, which may indicate that short growing types may contain as high a percentage of wax in the line as tall growing types.

Weakness:

The association of weakness and yield of line fiber was significant at the 1 percent level in 1950 and 1951 and at the 5 percent level in 1952. The inter-annual correlation coefficient for the same association was found to be highly significant. This agrees with Sieben's work (19). Weakness was also related to the line percentage yield in 1951 and 1952 and was close to being significant in 1950. This work indicates that straw that tends to lodge contains more fiber than stiff straw. Straw weakness may be a barrier towards the development of strains with a high fiber content. Lodged straw is more difficult to harvest with mechanical pulling machines, is more subject to deterioration prior to harvest, and would be more difficult to convert into fiber. If weak straw indicates high fiber yield it would be a valuable marker for the plant breeder. High yielding lines could be detected early in the breeding program before sufficient pure line seed could be obtained for plot testing. Such a marker would obviate the necessity of testing many lines since stiff strawed types could be eliminated early in the breeding program if the object was high fiber yield. This association should be studied in detail to determine the chances of developing a stiff strawed variety that would be a high yielder of line fiber. Perhaps an anatomical study of the weak straw types would provide the reason for their lodging. A study devoted to the inheritance of weak straw might also provide valuable information. The relationship was negative between weakness and seed yield but was significant in 1951 only. The fact that weakness was not associated with pulled straw weight and wax content could be of value to a flax breeder since it points up the necessity of using other markers or methods for detecting these values. This lack of association also indicates that pulled yield might be increased and not be accompanied by weak straw.

It is of interest to note that weakness was associated with total fiber in 1951 only. Weakness was not associated with percentage of total. The chances appear good for the development of a weak strawed type, which could very well be a high line yielder, but not necessarily a high total fiber yielder. Further, the weak straw may produce a stronger fiber which may provide the reason for the association with line yield. Strong fiber would endure the beating action of the scutcher and would result in less tow.

Pulled Straw:

The data indicate that the yield of pulled straw was associated with line yield in 1950, with total fiber in 1950 and 1951, and negatively with percentage of total in 1952. Of these associations the one with total fiber appears strongest since it was significant in 1950 and 1951 and nearly significant at the 5 percent level in 1952. Since pulled straw weights were not associated with seed weights, percentage of line, percentage of seed, or wax content, one might justifiably minimize its importance insofar as being an indicator of its yield factors. Most processors of flax are aware that high straw yield doesn't necessarily result in high fiber and seed yield since the amount of waste materials, shives, chaff, and soluble gums are affected by the variety's genetic make-up and environmental influences. It appears advisable, therefore, to consider straw yield as an independent character not associated with its yield components, seed and fiber. This might infer that a fiber flax breeder interested in increasing straw yield should consider seed and fiber as separate objectives.

Line Fiber:

As the yield of fiber increased, the yield of seed decreased and vice versa. These relationships were significant all three years for percent seed and in 1950 and 1952 for seed yield. In the improvement of fiber flax some attention has been given to the development of a dual purpose flax, i.e., one superior in both fiber and seed yields. Information on the inverse relationship obtained in this study seems to point to the impracticability of such an undertaking. Line was included in the calculation of total fiber yield and was highly significant in its association with total fiber in 1950 and 1951, and close to being significant in 1952. The relationship of line to percent total was not significant for any year, probably because the percentage factor was based on line and tow, and the yield of the latter did not necessarily vary directly with line yield. Since high line yield does not appear to result in a high percentage yield of total fiber it would appear advisable to consider it independently in an improvement program.

The lack of association between line and wax content offers the possibility of increasing line yield without introducing an objectionable increase in wax. Line was associated with percentage of line in 1950 and 1951, but not in 1952. The positive association is feasible and easily explained on the basis of line being a component of the percentage figure. The lack of association in 1952 was probably due to the introduction of varieties with a high pulled straw yield but with a correspondingly low line yield.

Seed Yield:

There was a highly significant relationship between seed weight and percentage of seed, as might be expected since the weight is a component of the percentage yield. The non-significant negative trend in the relationship of seed weight to total fiber and to percent total and percent line fiber may indicate that if a strain is selected for high yield of seed the yield of total fiber might be sacrificed. This again offers evidence as to the improbability of developing a dual purpose variety. The negative relationship of seed weight to percent line fiber was significant in 1952.

Total Fiber Weight:

The negative association of total fiber weight with percentage of seed agrees with the negative association of seed and fiber cited above. This adds further to the impracticability of breeding for high yield of both seed and fiber. The fact that total fiber was associated with percentage of line in 1950 and 1951 suggests the possibility of determining total fiber, perhaps on a laboratory basis, which would furnish an indication as to the percentage of line. It might then be possible to determine line fiber percentage yield and at the same time obtain an indication on the total fiber yield. The lack of a relationship between the two factors in 1952 might cast a doubt on such a possibility. Even though the percentage of total fiber is dependent upon the weight of total fiber, the two yield factors were significant in their relationship in 1951 only. This emphasizes the fact that a high yielder of total fiber does not necessarily mean a correspondingly high percentage yield since the other components of pulled straw, seed, chaff, shives, and water soluble materials, may vary inversely with total fiber weight. Undoubtedly environment plays an important part in the composition of the pulled straw, which may account for some of the differences between years.

Percentage of Line Fiber:

It is of interest to note that percentage of line fiber was not associated with wax content. These data, based on one year, do indicate the possibility of breeding for high line yield without necessarily changing the wax content. The relationship of high percentage line yield is negative with percentage of seed again indicating that the increase in percentage yield of one results in the decrease in percent yield of the other. This is plausible since both percentage yields are based on pulled weight. The percentage yield in fiber flax cannot be over emphasized since processing costs are largely dependent upon the fiber and seed contained in the straw. In a varietal improvement program, a flax breeder should decide upon an objective. If the objective is to develop a high fiber yielding variety, low seed yield may be anticipated.

Percentage Seed:

Considering the negative association of percentage of seed and percentage of total, it appears improbable to develop a strain superior in both percentage of seed and percentage of total. The lack of association between wax content of line fiber and percentage of seed appears logical since seed yield was not related to wax.

Percentage of Total:

In addition to the relationships discussed in the foregoing paragraphs, the percent total fiber was not associated with wax content of line fiber. Since wax was not related to line and to percentage of line, there was no reason for expecting it to be related to percentage of total fiber. Based on the one year's data, it appears possible to breed for straw high in total fiber content without increasing the wax content in the line fiber.

SUMMARY AND CONCLUSIONS

A study was undertaken to determine the degree of association of certain plant characters with each other and with yield of straw, seed, and fiber in flax, and to determine the relationship of yield factors to each other. The characters studied included uniformity of growth, maturity, plant height, and straw stiffness. Ten varieties were selected that represented the extremes in range for characters and yields. Field trials were designed as randomized blocks and were grown in several locations over a three-year period. Associations were determined by calculating correlation coefficients.

The following is a summary of the associations:

Uniformity: Uniformity was not associated with any yield factor nor with any plant character except straw weakness in 1950. The character does not appear to be valuable as an indicator of potential yield in flax.

Maturity: Maturity was positively correlated with height in 1950 and 1952, and negatively with seed in 1951. Maturity had no influence on fiber yield.

Height: Height was associated with weakness in 1950 and 1951, with pulled straw yield in 1952, and with line and total fiber in 1951. It was negatively associated with seed and percent seed in 1951.

Weakness: Weakness was associated with line yield in all three years and with percent line in 1951 and 1952. It was negatively associated with seed and percent seed in 1951 and was positively related to yield of total fiber in 1951.

Pulled Straw: Pulled straw was associated with line in 1951, with total fiber in 1950 and 1951, and negatively with percent total in 1952.

Line: The yield of line was negatively associated with seed yield in 1950 and with percent seed for all years. It was positively correlated with total fiber and percent line in 1950 and 1951.

Seed: Seed yield was associated with percent seed for all years and negatively with percent line in 1952.

Total Fiber: The yield of total fiber was associated with percent of line in 1950 and 1951, and with percent total in 1951. It was negatively associated with percent seed in 1951 and 1952.

Percent Line: Percent of line was associated with percentage of total in 1950 and 1951 and negatively with percent seed in 1950.

BIBLIOGRAPHY

1. Coleman, D. A. and H. C. Fellows. Oil content of flax seed with comparisons of tests for determining oil content. Washington, U. S. Government Printing Office, 1927. 14 p. (U. S. Department of agriculture. Bulletin 1471.)

2. Eyre, J. V. and E. A. Fisher. Some considerations affecting the growing of linseed as a farm crop in England. Journal of agricultural science 7:120-134. 1915.

3. Garber, R. J. and P. J. Olson. A study of the relation of some morphological characters to lodging in cereals. Journal of the American society of agronomy 11:173-186. 1919.

4. Hamilton, D. G. Certain oat culm characters and their relationship to lodging. Scientific agriculture 21:646-676. 1941.

5. Johnson, I. J. Correlation studies with strains of flax with particular reference to the quantity and quality of oil. Journal of the American society of agronomy 24:537-543. 1932.

6. Keller, K. R. Evaluation of some morphological characters of corn in respect to their use in forecasting yield. Journal of the American society of agronomy 34:940-953. 1942.

7. Leather, J. W. The composition of the oil seeds of India. Memoirs Department Agriculture India, Chemical Series 1:1-38. 1907.

8. Legett, William F. The story of linen. Brooklyn, N. Y., Chemical publishing company, 1945. 103 p.

9. Martin, John H. Plant characters and yield in grain sorghums. Journal of the American society of agronomy 20:1177-1182. 1928.

10. Miller, Julian H., Burton M. Gwendolyn, and Troy Manning. A statistical study of the relations between flax fiber numbers and diameters and sizes of stems. Journal of agricultural research 70:269-281. 1945.

11. Paskovic, F. Morphological and biological investigations of some of our varieties of hemp. Abstracted in Imperial bureau of plant breeding and genetics, XII, No. 2:142 (Abst. No. 500) 1942.

12. Quisenberry, Karl S. Some plant characters determining yields in fields of winter and spring wheat in 1926. Journal of the American society of agronomy 20:492-499. 1928.

13. Ramiah, K. and S. Dharmalingam. Lodging of straw and its inheritance in rice. Indian journal of agricultural science 4:880-994. 1934.

14. Robinson, B. B. Flax fiber production. Washington U. S. Government Printing Office. 1945. 28p. (U. S. Department of agriculture. Farmer's Bulletin 1728.)

15. Robinson, B. B. Unpublished results of the relationship of certain important characters in fiber flax. U. S. Department of agriculture, Division of cotton and other fiber crops and diseases. 1924-1925.

16. Robinson, H. F., R. E. Comstock, and P. H. Harvey. Genotypic and phenotypic correlations in corn and their implications in selection. Journal of the American society of agronomy 43:282-287. 1951.

17. Ross, A. M. Some morphological characters of Helianthus annua L. and their relationship to the yield of seed and oil. Scientific agriculture 19:372-379. 1939.

18. Searle, G. O. and Adelaide G. Davin. A botanical study of the flax plant. Lambeg, Ireland. Linen industry research association. 6 p. 1922. (Research Institute Memoir #4.)

19. Sieben, J. W. The correlation between resistance of lodging and fiber content in flax. Euphytica 2:101-106. 1953.

20. Warren, F. S. and H. K. Hayes. Correlation studies of yield and other characters in rye polycrosses. Scientific agriculture 30:12-29. 1949.

21. Weiss, M. G., et. al. Correlation of agronomic characters and temperature with seed compositional characters in soybeans as influenced by variety and time of planting. Journal of the American society of agronomy 44:289-297. 1952.

22. Works Progress Administration. Flax in Oregon. Portland, Oregon. June 1939. 19 p.

23. Wright, G. M. A statistical study of linen crops records. Wellington, New Zealand. Department of scientific and industrial research, 1951. 38 p. (Bulletin No. 104.)