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PEDIGREED FIBER FLAX.

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INTRODUCTION.

The object of the work described in this bulletin has been to improve the seed used in the fiber-flax industry and particularly to develop by selection a long-stemmed flax that would increase the yield of fiber per acre.

In this work all plants that originate from the seed of a single plant or direct descendants from a single plant are known as a selection. This definition must be qualified so as not to include the progeny of a hybrid. Selections are retained only when the plants are uniform. Flax is a self-pollinated plant, and it is therefore relatively easy by means of selection and propagation of individual plants to secure strains that are uniform.

The need for selecting long-stemmed strains of fiber flax appears more obvious than that for selecting high seed-yielding strains of wheat or other grain crops. A bushel of grain is always marketable, no matter how low the yield may be, but short fiber-flax stems have very little value, because they are difficult to harvest and work up into fiber. The general crop of fiber flax produces a stem of satisfactory length not more than two years out of three; hence the need for a tall variety that will yield a good stem length even in unfavorable years. Selections have been made in England, Canada, and Russia for increased stem length, but they are not yet a factor in the industry, because of the limited supply of seed.

The seed flax grown extensively in the Northwest for the production of linseed oil is more widely known in this country than fiber flax, which is grown in limited areas. Although there are intergrading forms, these varieties of seed flax are fairly distinct from the fiber varieties, and the relation between the two is quite like that between beef and dairy cattle. The short seed varieties will produce fiber under favorable moisture conditions, but they will not yield so much nor will it be fiber of so good a quality as the fiber strains. Similarly, the tall fiber-flax varieties when grown under seed-flax conditions will yield a fair quantity of seed but not so many bushels per acre as the seed-flax varieties.

A brief discussion of the fiber-flax plant and the processes of handling it to produce the fiber is introduced here for the better understanding of the crop of fiber flax and the type of plant desired.

The fiber-flax plant, under field conditions, has a single straight stem less than one-tenth of an inch thick, which grows 25 to 30 inches high and then sends out branches, forming the flower panicle. (Fig. 1.) Some idea as to the small size of the plant may be gathered from the fact that it takes nearly 600 of them to make an ounce of fiber.

Stems of small diameter produce the best quality of fiber and also the largest quantity per given weight of stalk. Seeding broadcast thickly, at the rate of 80 to 120 pounds per acre, tends to induce a growth of fine stems. Broadcasting results in stems of uniform size which are also desirable for good fiber production. From the heavy rate of seeding, about three times that practiced with seed flax, a stand is secured which shades out the weeds and in addition shades out the side branches on the flax plants, which would produce uneven places in the fiber.

The flax fibers are located in the cortex, and since they form part of the fibrovascular system of the plant most of them run nearly the full length of the stem. Some terminate in each leaf and many in each branch. Those in the branches are of practically no value for spinning. The fibers of the main stem are extracted by a series of processes: (1) retting, a decay process which loosens the fiber from the woody portions of the stem; (2) breaking, which breaks up the woody portions into small pieces; and (3) scutching, which removes the woody pieces, leaving the prepared fiber.

The flax stems are retted by either spreading in a meadow or submerging in a tank of water until bacterial action has proceeded long enough to loosen the cortex from the pith without weakening the fiber. After drying the stems thoroughly the process of breaking is accomplished by running the straw through a number of pairs of fluted rollers which break into small pieces the woody shell surrounding the central pith. The final process of extracting the fiber, that of scutching, is accomplished by holding the fiber over a notch in the side of a wooden stall where the pieces of pith that remain clinging to it are beaten off by a revolving wheel of blunt-edged paddles.

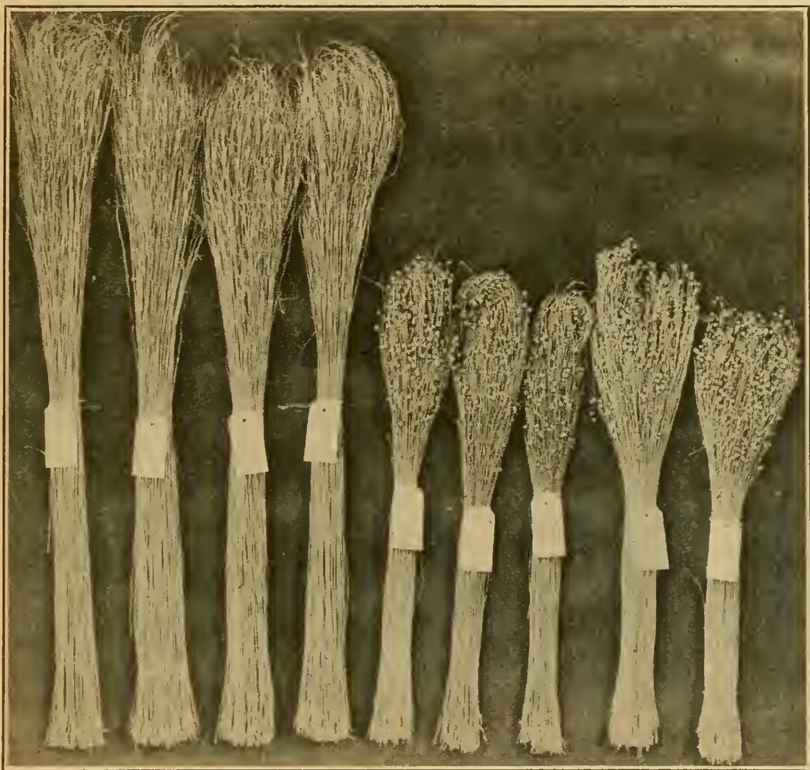

Fig. 1.—Comparison of selected and unselected fiber flax grown under the same conditions in the breeding plats in 1916. Thrashed straw of four selected strains, 35 to 37 inches high, is shown at the left. Note their similarity. The three samples in the center are unthrashed commercial Blue-Blossom Dutch fiber flax, while the two samples at the right are Minnesota No. 25, a semifiber type.

Since flax fiber runs the full length of the stem, it has been the practice in harvesting to pull it by hand. Several inches of stubble are left in the field when the flax is cut with a binder or mower, and pulling prevents this waste and also keeps the straw from being tangled. Owing to the scarcity and high cost of labor, hand pulling is becoming more and more out of the question. Two solutions of the problem are: (1) Growing a long-stemmed variety of flax which would not lose such a large percentage of its stems when cut or (2) using a machine puller. Several types of machine pullers have been used with some success during the past three seasons on well-ripened fields of flax.

The remainder of this bulletin is devoted to the solution of the problem of developing and increasing a long-stemmed variety of fiber flax.

EARLY SELECTION WORK.

The selection work with fiber flax was begun in the United States Department of Agriculture in 1909 by Mr. A. E. Mayland. He selected several thousand plants from the fields of commercial fiber flax in Michigan. (Fig. 2.) Only where a plant was distinctly taller than the surrounding plants was it selected. Each plant was weighed

Fig. 2.—The beginning of fiber-flax selection in America. These individual plants, selected because of their superiority to others in a field of fiber flax at Pigeon, Mich., in 1909, are the ancestors of the best varieties developed by the United States Department of Agriculture.

and measured separately, and fully nine-tenths of them were discarded. Only the seeds from the very heaviest plants were saved.

In 1910 Mr. Leroy V. Crandall took up the work. Seeds from each plant retained the preceding year were sown in separate plats. The rigid selection methods with the centgener tests which had been devised at the Minnesota Agricultural Experiment Station were used. (Fig. 3.) The seeds were spaced 3 inches apart each way and covered by soil to the depth of 1 inch, so that each plant would have an equal chance to develop. Notes were taken on the selections, and if at maturity any were short or uneven they were discarded. In case any were uneven and at the same time promising for height, individual plant selections were made from them for further testing. The selections which were still regarded as promising were harvested and thrashed by hand, taking pains to keep the seeds from each plat separate. Mr. Crandall continued the selections in this way in 1911 and 1912, the field work being carried on at Croswell, Mich., and Crookston, Minn.

In 1913 Mr. Frank C. Miles took up the work and continued it until the spring of 1917. As a basic stock for selection, strains which had been developed by Mr. Crandall were used, and material was added from imported seed as well as from the commercial fiber-flax fields of Michigan and Oregon. Selection plats were grown by Mr. Miles on the Potomac Flats near Washington, D. C., at Yale, Mich., on the grounds of the Northwestern School of Agriculture, Crookston, Minn., and at the Oregon Agricultural College, Corvallis, Oreg. The most important work was carried on at Yale. Improved strains decidedly superior to commercial strains were developed and attempts made to increase the seed, but in three seasons this work was interfered with by disastrous storms at Yale and at Crookston, which practically destroyed the increase plats.

FIG. 3.—Planting the first plat of fiber-flax selections. Holes are made just 3 inches apart and 1 inch deep. One seed is planted in each hole. The stakes mark the number of the parent plant. Croswell, Mich., May 10, 1910.

The flax planted on the Potomac Flats at the Arlington Experimental Farm, Va., in 1913 and 1914 made a satisfactory growth and flowered, but it produced very few seeds. Work at this point was therefore discontinued.

A number of tall plants were grown in the greenhouses at Washington, D. C., during the winter of 1913, and crosses were made between the more promising ones. These crosses were grown to the third generation, but they did not result in strains of value. This negative result may perhaps be due to the fact that only a limited number of crosses were made. The crosses between selections from the Blue-Blossom Dutch and White-Blossom Dutch varieties resulted in strains that were intermediate in resistance to flax wilt. The flax under greenhouse conditions took four and one-half to five months to mature and made an abnormal growth. Some of the plants reached a height of 170 centimeters (5½ feet), so that it was found necessary to support them on wires.

It was found impracticable to handle large numbers of selections with the centgener method, because of the time consumed in planting seeds one at a time, and flax selections after 1914 were sown in drill rows. Uniformity of growth conditions similar to those of the centgener method was secured in 1918 by thinning out the rows to one plant to the inch.

ELIMINATION OF POORER SELECTIONS.

Very early in the work those selections that were most promising were sown on a larger scale than the others, so that in 1914 enough seed had been secured from the one then considered the best to sow it at frequent intervals throughout the experimental plats. From year to year additional selections were made, as in the year 1909, and wherever one of them growing next to this standard selection has been judged inferior it has been discarded. This standard selection has been called the "check," as it acts as a check on the soil conditions. The check serves the same purpose as a ruler placed alongside a plant and is in one respect better than a ruler, for it measures the soil conditions by growing tall where the soil is rich and short where the soil is poor.

As more and more of the selections were discarded, those retained became more and more like each other, because all of them possessed in some degree each of the desired characters. (See the selections shown in Fig. 1.) Thus, it became necessary to study a larger number of characters as a means of elimination of the poorer selections. In addition to length of stem and stem weight, the following characters were added: Strength of fiber per individual stem, the amount of basal branching, the vitality of seed, and resistance to disease. The check selection has furnished a ready means of comparison between the different selections for all these characters. Data were rapidly accumulated on the check, as it was sown in many duplicate plats and measured extensively.

Strength tests were begun in 1912, and during the years 1913 to 1917 hundreds of strength tests were made under the direction of Mr. Frank C. Miles. In this way many inferior selections were eliminated. It was found that the middle portion of the stem was stronger and less likely to vary than either the basal portion or the top; so this portion was always used in making the strength tests. The stem diameter was measured at a point in the middle of the portion chosen for the test, and if several stems were of equal breaking strength the one with the smallest stem diameter was considered the strongest. In order automatically to determine the stems with the greatest strength per stem diameter, the practice of dividing the breaking strain by the diameter was adopted in 1919. This gives the strength per millimeter of diameter. The manner of making the strength tests is as follows: The stems are water retted at a uniform temperature so as to loosen from the wood of the stem the cortex in which the fibers are located. A piece 15 centimeters long is cut from the center of the stem chosen for the test. The wood is broken along the middle 2 to 3 centi-

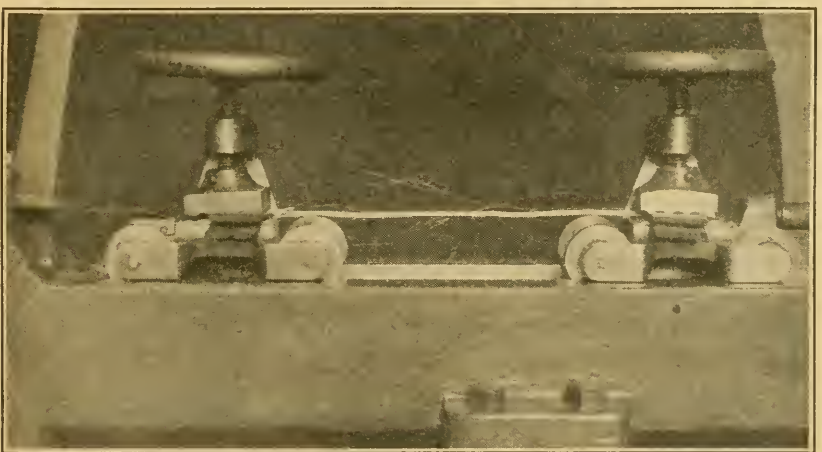

FIG. 4.—Completion of a strength test. Good fiber is indicated by breaking at several points and snapping away from the stem.

meters of this piece by rolling a glass tube over the stem without breaking the fibers. The pieces of wood are removed by working the stem with the fingers, and nothing is left but the fibers and those portions of the cortex which remain clinging to them. The strength tester (Fig. 4) is a horizontal machine with two pairs of jaws, between which the ends of the individual piece of stem are fastened. One jaw is rigid and the other, which is movable, exerts a pull on the fibers which is registered in kilos to the tenth place. This figure is known as the breaking strain.

Records for 1917 and 1918 show that the extent of basal branching is an inherited character, and it has therefore served as an eliminator. Seed-flax varieties have as a rule four or more basal branches, and the unselected fiber flaxes have two to four. The quality of fiber is poorest in the White-Blossom Dutch variety, the fiber flax with the largest number of basal branches, and the selection work has always aimed to reduce this branching habit. The manner of branching can best be studied in open drill rows where the plants, thinned down to one to the inch, are not crowded and can develop normally. In open drill rows the check selection never develops more than two basal branches, and with more than half of the plants it has none at all. Any selection having more than two basal branches was discarded.

Seed vitality received more attention as the work progressed. In addition to making germination tests and taking notes on the stand secured in the field, a study was made of the number of seeds per boll of all promising selections. The number of seeds per boll when complete fertilization occurs is 10. This number is rarely approached under field conditions. The data of 1919 and 1920 confirm the earlier work. The average number of seeds per boll is an inherited character directly associated with the vitality of the seed. For example, Selection 1923, with the best vitality of seed, has a high count of seeds per boll, and Selection 1812, with poor vitality of seed, has a low count of seeds per boll. Hence, all selections having a decidedly low count of seeds per boll were eliminated unless the count for the check selection, grown in the same part of the field, also ran very low.

In the years 1914 and 1915 marked differences in resistance to wilt were noted in fiber-flax selections when a natural survival of the more resistant selections took place. The check, Selection No. 5, was at this time superior to most of the others in resistance to wilt. In 1919 the selection plat at Croswell, Mich., was planted on soil where flax stems had been previously spread. All selections from the White-Blossom Dutch variety were completely destroyed by flax wilt, and not more than one-fourth of the plants among the selections from the Blue-Blossom Dutch variety, the other commercial fiber flax, survived. The check selection, planted in every other row, was more than 85 per cent resistant. Corroboration of the results was secured in 1920 through the cooperation of the Office of Cereal Investigations of the Bureau of Plant Industry. Plats were sown with seeds furnished from the selection plats of fiber flax by Mr. J. C. Brinsmade, jr., at Mandan and by Mr. W. E. Brentzel at Fargo, N. Dak. In Mandan the check, Selection No. 5, was over 80 per cent resistant to wilt, while the Blue-Blossom Dutch variety was 21 per cent and the White-Blossom Dutch only 1 per cent resistant. At Fargo, Selection No. 5 compared favorably with the most resistant seed flaxes in both resistance to wilt and seed yield. At both places the order of resistance of the different fiber-flax selections was approximately the same as that obtained in the selection plat in Michigan; those selections which were more resistant in Michigan were also the ones most resistant in North Dakota. This work makes it possible to eliminate all except a very few selections which show promise of wilt resistance. The fact worthy of special note is that wilt resistance is not peculiar to a restricted locality, since fiber-flax selections proved to be resistant in North Dakota as well as in Michigan.

By the year 1918 the work of elimination had brought the number of selections still being considered down to 25 or 30, all of which were tall. It was not easy to distinguish between them, and it became necessary to use the check system more rigidly than before. The check rows were sown closer together, so that not more than two varieties were grown between them. The distance between the checks was about one-twentieth the length of the row, because if farther apart the soil variation may be too great for the check to indicate accurately whether the soil between it and the next check is good or poor. The rows were increased in length from 1 to 10 rods each, because a larger plat gives more accurate results. The plants were thinned to one to the inch, in order that there might be the same number of plants in each row and each selection might have the same chance to develop. Duplicate sowings in different parts of the field were made of each selection.

Since only two varieties or selections were planted between checks, each one of them had the best selection or check growing beside it. This made it possible for notes to be taken at sight in comparing them for resistance to disease, uniformity of growth, and resistance to lodging. If a selection had more dead straws than the adjacent check row, it was considered inferior to it in disease resistance. If it lodged or bent over from rain or heavy dew more than the check row, it was marked as not resistant to lodging. If the stand was very irregular and the stand of the check growing alongside was all right, it was graded as having a low vitality.

COMPARING WITH THE CHECK BY PERCENTAGES.

For more accurate comparison of stem weights, seed weights, stem lengths, number of seeds per plant, and other measurable characters, these data have been reduced to percentages, a method adopted in the plant-breeding work in Scandinavia.[1]

These percentages have been called by Prof. Frank Spragg the coefficient of yield.[2] If we have Selection A, which yields three-fourths as much straw as the average of the check rows on each side, it is given a value of 75 per cent. If the weight of the straw of Selection B is nine-tenths that of the adjacent checks, it is given a value

[1] Newman, L. H. Plant Breeding in Scandinavia, 193 p., 63 fig. Ottawa, Ont., 1912. Literature cited, p. 188–193.

[2] Spragg, Frank A. The coefficient of yield. *In* Journ. Amer. Soc. Agron., v. 12, no. 5, p. 168–174. 1920.

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of 90 per cent. It is assumed in all cases that the check row responds to the soil conditions in the same way as the other selections. If the soil is poor the growth of both will be poor, and if the soil is rich the growth of both will be good. If these two strains A and B, grown in different parts of the field, were to be compared directly as to the actual straw weights, the poorer one might, because of better soil conditions, be apparently the better straw yielder. The use of the check prevents such a mistake, as the check rows measure the soil conditions and when percentages are calculated give the true relation between these selections, which is as 75 to 90 on straw weight.

The percentages assigned to the different selections can be reduced to straw weights as follows: Since Selection A yields 75 per cent as much as the check row alongside of it, we assume that it would yield 75 per cent as much as the average of all the check rows sown throughout the field. If the average yield in straw per acre of all the check rows is 2 tons, then, because Selection A is three-fourths as good as the check nearest to it, it is assumed that it would yield three-fourths as much if sown in all places that the checks were sown, or 1½ tons per acre. This gives what may be termed the corrected straw yield, as by means of the checks correction for soil variations has been made. In the same manner, corrected seed weight, corrected stem length, and corrected values for any number of other characters may be found.

USING THE SCORE CARD FOR THE ELIMINATION OF THE POORER SELECTIONS.

Since all the characters are not of equal importance, a score card has been devised to record the proper values for them, so that the sum total of the good and the bad points of each selection may be expressed in one figure. The following characters have been considered as sufficiently important to be used in the score card: Weight of thrashed straw, weight of seed, length of stem to the first branch, resistance to lodging, resistance to disease, and strength of fiber. When available the weight of fiber will take the place of the weight of the thrashed straw.

Resistance to lodging has been given a value of 5 per cent, because weather that would cause lodging might be expected about 1 year out of 10, and since the flax that is resistant to lodging could only be expected to stand up about half of these times, it would have an advantage of about 5 per cent over the other strains.

Resistance to disease has been given a value of 4 per cent, because loss from diseases has been a less serious factor with fiber flax than loss due to lodging.

There is left 91 per cent to be divided among weight of thrashed stems, length of stem to first branch, seed yield, and strength of fiber.

In order to cover the additional expenses of growing a crop of fiber flax it must bring in more money than a crop of seed flax. The heavy rate of sowing requires 1 bushel more of seed per acre. When pulled by hand the extra cost is $10 to $12 per acre. It is thrashed in a special manner at extra expense to keep the straw straight and unbroken. The seed yield per acre is about 3 bushels less than where the flax in the same locality is sown for seed production. Since drought is more likely to stunt the growth of the stems than to affect the seed yield materially, there is more risk involved in growing a crop of flax for fiber. Hence, there are extra expenses in seeding, harvesting, and thrashing; a diminished seed yield; and an extra risk involved in growing the crop. It is estimated that in order to cover these items the straw of a crop of flax must be three times as valuable as its seed, and the values assigned in the score card are in the ratio of 3 to 1.

Since one of the principal objects of the selection work with fiber flax has been to secure increased stem length, it has been thought best to assign to it a value slightly more than that assigned to seed yield. This value, about one-third that for weight of thrashed stems, is based in part on reason, for it has been common practice in times past to offer a premium of one-sixth to one-third for a ton of stems of extra length. In applying this value only the amount of superiority in stem length has been considered; the check selection is superior by 16.31 centimeters (6½ inches) to Blue-Blossom Dutch, the common commercial fiber flax, while Selection No. 1923 with only half this superiority scores only half as much as the check on this character.

Strength of fiber is regarded by experts as of first importance in judging flax fiber. The strong fiber can be spun into much finer threads than fiber that is of inferior strength. The price for fiber of superior quality is frequently one-sixth to one-half more than that of medium grade. Strength of fiber determines to a considerable extent the range of prices, and it has been assigned an intermediate value of one-third. It is assumed then that strength of fiber is one-third as important as weight of fiber, and when weight of fiber is not available weight of thrashed straw takes its place.

In accordance with the preceding line of thought, the remaining 91 per cent has been divided, resulting in the completed list of values shown in Table 1.

TABLE 1.—*Relative values of characters used in comparing strains of fiber flax.*

Characters compared.	Assigned value.	Characters compared.	Assigned value.
	Per cent.		*Per cent.*
Weight of thrashed stems	45	Resistance to lodging	5
Length of stem to first branch	16	Resistance to disease (flax wilt)	4
Strength of fiber	15		
Weight of seed	15	Total	100

The score card has been applied to 24 selections and to White-Blossom Dutch and Blue-Blossom Dutch, two unselected varieties of fiber flax. (Table 2.) Without exception all the selections are superior in stem length to the unselected commercial varieties. The latter are chiefly superior in seed yield only and score a total percentage lower than all except one selection which has a low yield of thrashed straw.

TABLE 2.—*Score card applied to 24 tall fiber-flax selections and 2 varieties of commercial fiber flax.*

[Based on data for the years 1914 to 1920, inclusive.]

Number or name.	Weight of thrashed straw.		Weight of seed.		Length of stem.		Breaking strain.		Resistance to—		Total score.
	Per rod row.	Score.	Per rod row.	Score.	To first branch.	Score.	Average per millimeter of diameter.	Score.	Lodging.	Flax wilt.	
	Grams.	*Per cent.*	*Grams.*	*Per cent.*	*Centimeters.*	*Per cent.*	*Kilograms.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1905	568	45	98.98	15	65.91	16	2.77	15	2	4	97
1901	577	45.7	84.6	12.68	69.2	19.2	....	15	2	0	94.58
1903	567.5	45	97.6	14.68	65.9	16	[a] 3.35	18.7	3	4	101.29
1904	641	50.16	98.6	14.81	64.5	14.6	1.74	9.43	0	1	90
1906	543	43	88.2	13.25	64.8	14.9	2.49	13.5	0	0	84.65
1907	509	40.3	85.6	12.87	65.7	15.6	[a] 2.57	13.91	0	0	82.65
1908	517	40.9	90.5	13.6	67.2	17.26	[a] 2.49	13.5	0	0	85.26
1910	640	50.8	90.3	13.58	64.9	15	2.22	12.01	0	4	95.39
1911	530	41.5	69.3	10.40	67.5	17.56	1.96	10.60	2	2.5	84.56
1812	681.5	54	99.7	14.96	66.55	16.60	2.32	12.56	2	2	102.12
1914	623	49.4	93.2	14	67.6	17.66	[a] 2.83	15.32	0	2	98.38
1915	515	40.8	83.7	12.59	67.7	17.76	2.19	11.87	0	1	84.02
1919	531	42	108.9	16.37	66.3	16.40	2.04	11.05	0	4	89.82
1920	546	43.4	67.2	10.10	67.25	17.30	[a] 2.08	11.26	0	1	86.48
1921	525	41.6	86.8	13.03	66.1	16.20	2.52	13.65	0	1	85.48
1922	400	31.7	91	13.69	62.35	12.52	[a] 2.32	12.56	2	0	72.47
1923	527	41.8	121.6	18.25	57.5	7.75	2.72	14.76	5	2	89.56
1924	497	39.4	95	14.28	64	14.13	2.18	11.80	0	1	79.61
1925	522	41.3	107.2	16.1	65.4	15.66	1.45	7.85	0	2	83.91
1926	607	48.1	110.6	16.61	59.5	9.51	2.90	15.70	2	2	93.92
1927	518	41.2	77.1	11.60	60.6	10.78	2.07	11.60	5	1	75.78
1928	490.5	38.9	74.6	11.20	58.4	8.62	[a] 3.58	19.37	0	1	79.09
1929	520	41.3	112.2	16.85	60.2	10.39	1.60	8.66	2	1	80.2
1931	597	47.2	144.2	21.7	61.7	11.86	[a] 1.69	9.2	2	0	88.76
Blue-Blossom Dutch.	449	35.6	133.3	20.5	49.6	0	[a] 1.94	10.5	5	0	72.6
White-Blossom Dutch.	547	96.5	149.4	22.4	49.25	0	[a] 1.35	7.35	0	0	72.75

[a] Record of only one year. Where no record is available the breaking-strain score of the check is inserted.

The 11 selections which the score card places at the top of the list (Table 3) may be classified in three groups, according to whether they appear superior, equal, or inferior to the check.

TABLE 3.—*Summary of 2 to 5 year averages, comparing the 10 best selections with strains of commercial fiber flax.*

Number or name.	Yield per acre. Straw. Thrashed.	Yield per acre. Straw. Unthrashed.	Yield per acre. Seed.	Height. Total.	Height. To first branch.	Breaking strength per $\frac{1}{25}$ inch of diameter.	Origin.
	Lbs.	*Lbs.*	*Bu.*	*Inches.*	*Inches.*	*Lbs.*	
1812	1,490	1,972	4.86	34.8	26.3	5.07	In 1909, from fields of Blue-Blossom Dutch, Sanilac County, Mich.
1903	1,489	1,705	4.84	38.1	26.4	a 7.40	Do.
1914	1,361	1,762	4.64	35.4	27.1	a 6.20	Do.
1931	1,305	1,964	7.17	36.0	24.7	3.71	From North Dakota, No. 155, at Fargo, N. Dak.
Saginaw (1905)	1,242	1,608	4.95	37.8	26.4	6.05	In 1909, from fields of Blue-Blossom Dutch, Sanilac County, Mich.
1910	1,400	1,812	4.48	36.5	25.9	4.86	Do.
1901	1,262	1,610	4.18	38.7	27.7	No record.	English pedigreed, imported from Australia in 1916.
1926	1,328	1,758	5.48	35.6	23.7	6.35	In 1909, from fields of Blue-Blossom Dutch, Sanilac County, Mich.
1904	1,400	1,970	4.88	37.4	25.4	1.74	Do.
1919	1,172	1,494	5.40	42.6	26.6	4.46	Do.
Commercial unimproved fiber flax from Holland:							
Blue-Blossom Dutch	983	1,333	6.62	26.5	19.6	a 4.23	Imported in 1905.
White-Blossom Dutch	1,186	1,630	7.42	32.3	20.0	a 2.96	Imported in 1917.

a Record of only one year. Where no record is available the breaking-strain score of the check is inserted.

Of those that appear superior to the check, Selection Nos. 1812, 1903, and 1914, only No. 1914 can be considered, for Selection Nos. 1812 and 1903 have a low seed vitality. Selection No. 1914 compares favorably with the check; it has good seed vitality and is somewhat taller; it has fine stems and very little basal branching. The advantage appears, however, to lie with the check, for Selection No. 1914 is more inclined to lodge than the check, and its resistance to wilt is not well established.

The second group, consisting of those that appear about equal to the check, contains Selection Nos. 1910, 1901, and 1926. All of these grade under the check on total score, but appear equal to the check when the percentages allotted to resistance to wilt and lodging are subtracted. Selection No. 1910 is very resistant to wilt, but has coarse stems and develops more basal branching than any of the other tall selections. Selection No. 1901 comes nearest to the check in this group, because of its extra-long stems, but it has a low seed vitality and its stems are slightly coarser than those of the check. Selection No. 1926 has very fine stems, even finer than those of the Blue-Blossom Dutch variety, which is 6 inches shorter, but it also has a low seed vitality and is inferior to the check in stem length.

The third group, consisting of Selection Nos. 1904, 1919, 1923, and 1931, appears inferior to the check but is analyzed in order to make sure that no one of them is worthy of seed increase. Selection No. 1904 is the most promising one of this group in stem weight; it is, however, inferior to the check in stem length, and its resistance to wilt is low. Selection No. 1919 is very resistant to wilt but its stems are coarse; furthermore, when resistance to disease is not considered it grades distinctly lower than the check. Selection No. 1923 is noticeably inferior to the check in length of stem and is not deserving of general distribution; it is, however, high in stem weight in spite of its relatively short stems and may be suited to areas where very tall growth is not desired to the exclusion of high seed yield. Selection No. 1931 is too low in wilt resistance to warrant seed increase and distribution.

It is concluded from a study of the score card and additional characters which are not used in the score card that Selection No. 1905 is the most desirable one for seed increase. Its strength of fiber is not surpassed by any selection of which more than one year's record is available. It is superior in resistance to wilt to all except two of the eleven best selections, and these are undesirable because of coarse stems and the extent of basal branching. Out of the five selections that are its equal or superior in straw weight, two have a low seed vitality, two are inferior in stem length and very low in wilt resistance, and the remaining selection is more inclined to lodge than the check.

It is recognized that the percentages alloted in this score card are more or less arbitrary and that, furthermore, they should be altered to suit the convenience of the plant breeder. If, for instance, a special attempt is made to select for resistance to lodging, it is thought that a much higher percentage should be assigned to that factor, so that it would be a determining one in deciding on the best selection.

The chief difficulty in the accurate working of the score card is that the systems of planting as well as the places where the sowings were made varied widely from year to year; also, the records on all the selections are not complete for the entire 7-year period. Efforts are made to overcome these difficulties by comparison with the check which is planted each year in many duplicate plats.

IMPROVEMENT BY CROSS-POLLINATION.

An attempt has been made, beginning in 1918 and continuing up to the present time, to combine the desirable qualities of several of the best selections by cross-pollination. Third-generation progenies of several of these crosses give promise of distinct improvement. The most definite results secured were from a cross between a tall blue-flowered fiber flax and a short pink-flowered seed-flax type. The object of the cross was to secure a tall pink-flowered fiber flax which would be distinct from the ordinary blue or white flowered types.

The blue-flowered parent, Selection No. 1831, originated as a single plant selected for height in 1910 and has shown a superiority in stem

FIG. 5.—Pink-flowered flax and parent strains. Blue-Blossom Dutch fiber flax, 110 centimeters high (on the left); pink-flowered hybrid, third generation, 90 centimeters high (in the center); pink-flowered seed flax, 65 centimeters high (on the right).

length over unselected fiber flaxes for a period of five years. It has two, rarely four, basal branches and matures in 85 to 90 days. The average total height is 100 centimeters.

The pink-flowered parent came from a single plant found as a mutation in a field of tall blue-blossom fiber flax which had been selected for height. In a field with an estimated number of 800,000 plants only one pink-flowered plant was discovered. It has four to eight basal branches and reaches maturity in 65 to 75 days. Under favorable conditions it does not grow more than 60 to 65 centimeters in total height. This pink-flowered flax is a form of *Linum usitatissimum* L. and is distinctly different from the red-flowered ornamental known as *Linum grandiflorum rubrum* Desfl.

The method of selection followed in this cross has been to rogue out all short pink-flowered flax plants in the second generation and to select all tall pink flax plants. The rest of the hybrid seed has been lumped together. In order to secure a good type it is necessary to select so as to eliminate the low count of seeds per boll, the short stem length, and the large extent of basal branching, all features which are characteristic of the pink-flowered parent. One of the tall pink flaxes selected in the second generation has bred true in the third and fourth generations and is almost half again as tall as the pink-flowered parent. (Fig. 5.) It has the reduced branching habit and late maturity of the tall blue-flowered parent combined with the pink flower color of the short parent. Since all commercial flaxes have blossoms of either blue or white, the color of this tall pink-flowered selection will serve to identify it in the field and simplify crop inspection.

INSTRUMENTS DEVISED FOR USE IN BREEDING FLAX.

Plant-breeder's forceps.—The use of a plant-breeder's forceps (Fig. 6) facilitates the work of removing the stamens. This is worn on the finger when in use. The brass ring to which the short arm is soldered is cut obliquely, so that the movement of the first joint of the forefinger will be unrestricted. The pressure of the thumb on the forefinger closes the tip against the stamen. In order that the tips may point at right angles to the direction at which the pressure is exerted, the arms of the forceps are bent. Mr. William Snyder, formerly of the Porto Rico Agricultural Experiment Station at Mayaguez, P. R., assisted materially in designing this instrument.

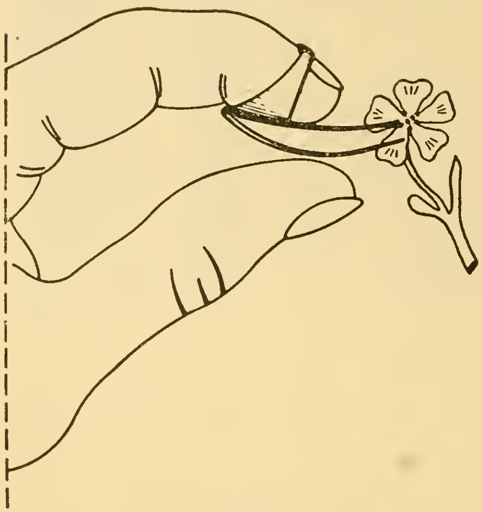

FIG. 6.—Plant-breeder's forceps.

Plant-breeder's calipers.—For measuring diameters of small plant stems the plant-breeder's calipers (Fig. 7) have been found a source of convenience with flax. The stem to be measured is inserted in the notch *N*. The scale magnifies the stem diameter 20 times, because it is 20 times as far as the stem notch from the place where the pointer is pivoted.

Plant-breeder's envelope.—These envelopes (Fig. 8) are made on a sewing machine by stitching together two sheets of oiled paper. An unstitched portion is left at the base. This is slit up the middle, and at the apex of the slit a hole is cut to fit the stem of the emasculated flower. After the stem has been inserted in the envelope the unstitched part at one side of the slit is folded at right angles and that on the other side at an angle of 45° to the base of the envelope. At the point where these folded parts overlap they are fastened with an ordinary dress snap fastener. These envelopes can not come unglued, and they have the additional advantages of being light in weight and moisture proof.

FIG. 7.—Plant-breeder's calipers.

COMMERCIAL TEST OF PEDIGREED FIBER-FLAX STRAINS.

Whether the improvement be secured through cross-pollination or by straight selection, it is necessary that the results obtained in the experimental plats be tested on a commercial scale in order to be sure that the strains are good enough for distribution. Four of the most promising of the strains of selected fiber flax were sown in a field alongside some Blue-Blossom Dutch fiber flax, the variety commonly grown for fiber both in the United States and in Canada. There was a superiority of at least 6 inches in height and in the length of fiber for all the selected flaxes over the unselected Blue-Blossom Dutch flax. The Saginaw variety, with an extra length of 8 inches, yielded 30 per cent more straw per acre than the Blue-Blossom Dutch; besides, since the stems were freer from flax wilt, it yielded a better quality of fiber. Under actual field conditions the pedigreed fiber flax yielded one-third more fiber per acre than the commercial variety, Blue-Blossom Dutch flax, and this more than outweighs the only important advantage the commercial flax has over it—that of producing one-fifth more seed. (Fig. 9.)

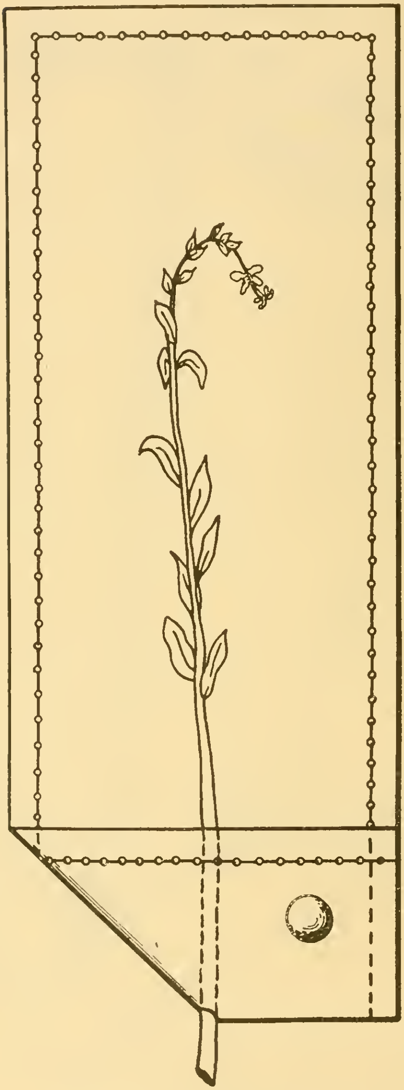

FIG. 8.—Plant-breeder's envelope.

The results of a direct comparison of these two varieties of flax are shown in Table 4.

Since this pedigreed fiber flax, grown in this country for the last 12 years, maintains the superiority shown in Table 4 over seeds freshly imported from Holland and Russia, it would not appear necessary to import fiber flax for seeding purposes, provided proper care is taken of the seed produced in this country. In this connection it may be stated that observations during the last 10 years, both in experimental-plat and commercial sowings do not show that imported seeds have any advantage over those grown in this country.

TABLE 4.—*Results of a test of flax made at Croswell, Mich., in 1919.*

Variety.	Total height.	Area.	Yield per acre.		
			Seed.	Un-thrashed straw.	Fiber.
	Inches.	*Acres.*	*Bushels.*	*Tons.*	*Pounds.*
Blue-Blossom Dutch	30.0	6.0	8.0	1.42	195.44
Saginaw	38.2	1.4	6.6	1.85	293.00

Of the three other selections tested, remarkable differences were shown in the yield and quality of the fiber. One selection which had consistently yielded a larger tonnage of straw than the Saginaw variety produced one-fourth less fiber per acre, because it yielded a low percentage of fiber. Selection Nos. 1927, 1931, and 1919 not only produced less fiber than the Saginaw variety but produced fiber of a coarser quality. It is evident that for securing accurate testing of selected fiber-flax strains straw weights are not dependable. More satisfactory results could be secured from actual yields of fiber if complete data for this character were available.

INCREASING THE QUANTITY OF PEDIGREED SEEDS.

Having decided on the best strain of fiber flax, the next step is to increase the seed as rapidly as possible. From 300 to 500 acres are required to operate a small flax mill efficiently, and in order to become a factor in the commercial field it is necessary that a strain of pedigreed fiber flax reach the point where there is enough seed to sow this area, or from 500 to 700 bushels. If a start is made with an ounce of seed and the flax is sown at the ordinary rate for fiber, 1½ bushels per acre, it is estimated that at the end of 4 years, with good crops each year, there would be not much more than a bushel produced, and that it would take 10 to 15 years to produce the required quantity. There are two ways of speeding up seed production, one by thin rates of seeding and the other by making two sowings the same year.

Increasing the yield by thin rates of seeding was carried out as follows: Up to the time when there were about 5 bushels of seed it was sown at the rate of 4½ pounds per acre in 28-inch drill rows and cultivated at frequent intervals. This was done in 1918 at East Lansing, Mich. It paid, for from 10 pounds of seed 420 pounds were obtained. By the usual method, sowing by broadcasting at the rate of 84 pounds per acre, not more than 60 pounds could have been harvested. Since with as much as 5 bushels of seed this extremely thin method of sowing is cumbersome and expensive because of the large acreage required, it was more practical after this time to follow the method used with seed flax, that of sowing in 7-inch drill rows at the rate of about one-half bushel per acre.

FIG. 9.—Fiber of pedigreed fiber flax (at left) compared with that of the Blue-Blossom Dutch variety (at right).

If by a thin rate of seeding 40 seeds could be obtained for each one planted, then each harvest season would multiply the number of pounds of seed by 40. From two harvest seasons in a year the number of seeds started with could be multiplied by 40 twice, or by 40 and again by 40, which is 1,600 times. It is necessary to grow flax as a winter crop in a southern climate in order to secure two harvests the same year, and Porto Rico gave promise of being a suitable place.

In 1917 a small trial plat of flax as a spring crop in Porto Rico gave a splendid growth, and in the spring of 1918 an increase of 26 times was secured, but owing to delay in the shipment the seed arrived too late for spring planting in Michigan. The idea was then conceived of planting a fall crop in Porto Rico, so as to allow time enough for the seed to be shipped north in the spring and arrive in due season for sowing. The flax seed which had been increased 42 times in the summer of 1918 at East Lansing was planted the last week in October at Mayaguez, P. R. An increase of only 4 times was secured, because the winter dry season caught the flax early in December, before it had completed its growth. An increase of nearly 200 times in one year from two of the selections was obtained, so that there was nearly a bushel of each, or enough for a commercial test in 1919. Flax was again grown as a winter crop in Porto Rico in 1919 and the seeding made a month earlier, in order that it might make most of its growth in advance of the dry season. The torrential downpours of the terminating rainy season drowned most of the seed and the young plants and resulted in a poor growth in the rest of the stand, so that less seed was harvested than was put in the ground. Further trials were then made in other localities.

SEED INCREASE BY GROWING TWO CROPS A YEAR.

On November 5, 1920, 2½ bushels of pedigreed fiber-flax seed which had been harvested the preceding August at East Lansing, Mich., was sown near Fairhope, Ala., 2½ miles east of Mobile Bay. The winter was mild and no temperature below 28° F. was experienced. The flax grew to a height of 6 inches by December 15 and then lay practically dormant until early in February. From that time it made a rapid growth and at maturity on April 20 had reached a total height of 3 feet. From the 2½ bushels sown about 20 bushels of clean seed was secured. The flax was thrashed on May 3 and resown in Michigan on May 18. While normally an increase of only 6 to 25 times is expected with flax, by means of the two-crops-a-year method this flax was increased 200 times. Observations do not show that there is any loss of vitality in the seed from flax which has been grown twice the same year and then replanted shortly after the second harvest.

The results from a similar sowing of the fiber flax at Paradis, La., were also favorable from the experimental viewpoint and demonstrated that under mild winter conditions a second crop of flax can be matured in the South so as to increase the supply of seed of pedigreed flax varieties.

SUMMARY.

The object of the work described in this bulletin has been to develop improved strains of fiber flax.

Parent plants for beginning the work of breeding fiber flax were first selected in the commercial flax fields of eastern Michigan in 1909.

The progeny of these selected plants was carefully bred by elimination of all except the best types through several successive generations.

The method of selection now used is based on a comparison by percentages of the various characters regarded as important and similar characters of the best strain used as a check.

In a semicommercial test the pedigreed strains proved to be superior to commercial fiber flax.

The supply of seed of the best pedigreed strains has been increased by growing two crops in one year.

Efforts are now being made to combine the desirable characters of different strains by cross-pollination. A special score card and special instruments for cross-pollinating and for measuring flax have been devised.

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