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Breeding Better Flax Varieties For Minnesota

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BREEDING BETTER FLAX VARIETIES FOR MINNESOTA[1]

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Introduction

Flax for seed production has been a fairly important crop in Minnesota and the acreage devoted to growing it has increased somewhat during recent years. In Table 1 are given in thousands of acres the areas devoted to the growing of flax in the states leading in the production of the crop and in the United States from 1901 to 1935 inclusive.

TABLE I. FLAX ACREAGE HARVESTED FOR SEED IN THE THREE STATES LEADING IN THE PRODUCTION OF THIS CROP AND IN THE UNITED STATES

Period	Minnesota	North Dakota	South Dakota	United States
1901–05	566	1,468	345	2,934
1906–10	451	1,566	534	2,519
1911–15	354	989	424	2,186
1916–20	287	832	160	1,726
1921–25	501	1,068	354	2,156
1926–30	710	1,373	599	3,071
1931–35	698	724	126	1,752

In Minnesota, conditions for flax production are generally somewhat more favorable than in the Dakotas. Rainfall during the growing season is usually more abundant and more evenly distributed. The large acreage of corn grown in the state each year provides land fairly free from weeds on which to grow the flax crop. These favorable conditions for flax seed production in Minnesota have resulted in average yields of between nine and ten bushels per acre. Since seed flax is an important crop in the state, the development of high yielding varieties is a distinct aid to the growers. The processors of flax desire a high percentage of oil in the seed and satisfactory quality in the oil extracted from the seed in order to meet the demands of the consumers for good paints and other linseed oil products. This makes it essential to give attention to the development of varieties of flax that produce oil of high quality in addition to high yields of seed per acre. High quality oil as extracted from flax seed is oil that dries relatively rapidly when exposed to the air. The quality of linseed oil is indicated by its iodine absorption number. An iodine number of 177 to 180 or higher indicates high quality while 170 to 165 or lower indicates oil of relatively low quality.

[1] Paper number 1,458 of the Journal Series, Minnesota Experiment Station.
[2] In cooperation with the United States Department of Agriculture, Division of Cereal Crops and Diseases, and with the Division of Plant Pathology and Botany, Minnesota Experiment Station.

Early Flax Improvement Work

Flax improvement work was begun in Minnesota in 1896. By 1904 the variety, Primost, originating from a single plant selection, was distributed to farmers in the state. At that time the cause of plants dying off when planted on fields for the second time, even though other crops intervened, was not known. At about this time, however, Bolley [3, 4] demonstrated that the cause of the wilting of the flax was *Fusarium lini*. Primost was not resistant to flax wilt and further work was necessary.

In 1922, two new varieties, Winona and Chippewa, both resistant to wilt were distributed to farmers in Minnesota. They were developed by selecting wilt resistant and otherwise desirable plants out of flax that varied in these characters. Winona was selected out of North Dakota No. 1221 and Chippewa out of Primost.[5, 6] In 1924 another variety, Redwing, a selection from a Russian flax, was placed on the recommended list but distribution was delayed in order to make further improvements by selection.

Up to 1930, all the varieties of flax grown widely in Minnesota and in the other flax seed producing states in the Northwest produced high quality oil. Hence, there had been no breeding problem as far as quality of oil was concerned up to that time.

New Variety Brings Quality Problem

In 1930 Redwing was distributed to growers in the state. It was considerably superior to any of the Minnesota productions distributed previously. Redwing had high yielding capacity, produced seeds of medium size, weighing 4 to 4.5 grams per 1000 and, having been selected from the type of flax grown in the Northwest, produced high quality oil.

The same year there came up for consideration the variety, Bison, which had been developed by the North Dakota Experiment Station and seed distributed to farmers beginning in 1926.[7] Bison had been tested in Minnesota and found to be superior to other varieties in several respects. It had a more sturdy plant type, better able to cope with weeds than the more slender growing varieties. In yield, Bison was equal to Redwing. In seed size, Bison surpassed Redwing, the weight per 1000 seeds being about 5.5 grams and with larger seed went increased oil content by one and one-half to two per cent. The outstanding qualities of Bison led to its adoption as a recommended variety for the state although it was known at the time to be somewhat lower in quality of oil than was desired. The rugged plant type of Bison, together with other good qualities, wilt

[3] Bolley, H. L. Flax wilt and flax sick soil. N. Dak. Agr. Exp. Sta. Bul. 50. 1901.

[4] Bolley, H. L. Resistant seed flax and how to get it. N. Dak. Agr. Exp. Sta. Press Bul. 23:1–4. 1907.

[5] Barker, H. D. A study of wilt resistance in flax. Minn. Agr. Exp. Sta. Tech. Bul. 20:1–42, illus. 1923.

[6] Stakman, E. C., Hayes, H. K., Aamodt, O. S., and Leach, J. G. Controlling flax wilt by seed selection. Jour. Amer. Soc. Agron. 11:291–298. 1919.

resistance, high yielding ability, medium large seed size and high oil content, has made it popular with growers and crushers alike. By 1931, according to Dillman and Stoa,[7] Bison had become the leading commercial variety in the United States. Somewhat later than that, Bison became the most widely grown variety in Minnesota.

Breeding for Oil Quality

In the summer of 1929 Bison was used as one of the parents in a cross with Redwing and in 1930 with Common Pink, C. I. No. 479[8] with the expectation of obtaining from the progenies varieties combining the rugged plant type, high yielding ability and medium large seed size of Bison with the high oil quality of the other two. Selections were made in the second and following generations of individuals with the rugged plant type and medium large seed size of Bison. In 1933 iodine determinations of the oil were made from the seed of the fourth generation progenies of the Bison x Redwing cross and the third generation progenies of the Bison x Common Pink cross. The results are given in Table II.

TABLE II. FREQUENCY DISTRIBUTIONS FOR IODINE NUMBERS OF THE OIL FROM SEED OF THE PARENTS OF TWO CROSSES, BISON x REDWING AND BISON x PALE PINK, AND FOR FOURTH AND THIRD GENERATION HYBRIDS FROM THEM

Cultures		Iodine Number Classes										
		160–62	163–65	166–68	169–71	172–74	175–77	178–80	181–83	Total Number	Mean	σ
	Bison x Redwing											
Parents	Redwing						1	5	4	10	179.60	2.010
	Bison	4	2	4						10	163.60	2.913
Hybrids	Blue		5	11	25	37	27	13	8	126		
	Light Blue			4	8	13	14	6	2	47		
	Blue and light blue			3	4	8	6	5	3	29		
	Total		5	18	37	58	47	24	13	202	173.70	4.292
	Bison x Pale Pink											
Parents	Common Pink							4	6	10	181.10	1.100
	Bison		5	5						10	165.10	1.791
Hybrids	Blue				10	17	24	10	6	67		
	Pink			7	12	33	16	12		80		
	Blue and Pink				3	7	14	8		32		
	Total			7	25	57	54	30	6	179	174.55	3.460

The oil of Redwing ranged in iodine number from 176 to 182 and that of Bison from 160 to 167 with the difference between the means of the two 16.00 points.

[7] Dillman, A. C. and Stoa, T. E. Flaxseed production in the North Central States, United States Dept. of Agric. Farmers' Bul. 1747:1–18. 1935.

[8] C. I. No. 479 is the number assigned to Common Pink on the records of the Division of Cereal Crops and Diseases, United States Department of Agriculture.

In the other cross the oil of Common Pink varied in iodine number from 180 to 183 and Bison from 163 to 168 with the difference between the two means again 16.00 points. For each of the crosses, the difference between the means of the parents for iodine number is significant. The distributions of the hybrids classified according to flower color for each of the crosses do not differ from each other greatly, indicating independent inheritance of iodine number and flower color. The distribution for the total number of hybrids from each cross shows individuals ranging as high as the high iodine parent but not as low as the low iodine parent. No individual hybrid from either of the crosses ranged higher in iodine number than its high iodine parent. Using twice the standard deviation on each side of the mean of the high iodine parent as the limits of significant differences with odds of 19:1, 71 hybrids or about one-third of the total number from the Bison x Redwing cross and twenty-four or about one-seventh the total number from the Bison x Common Pink cross may be considered about equal to the high iodine parents in oil quality.

The results given in Table II make it appear relatively simple to obtain new varieties producing high quality oil. There are, however, several forces operative to make difficult complete realization of obtaining selections having as large seeds as Bison and as high iodine number as Redwing or Common Pink. Myers[9] found for the cross, Redwing x 770B, that multiple factors were responsible for seed size. In all probability seed size in these crosses was conditioned in a similar manner. This would limit recovery of the full seed size of Bison from these two crosses to a very limited number of the lines, and would make doubly difficult obtaining a line with the desired seed size and high iodine number of the oil in addition.

Johnson[10], working with a number of flax varieties, found significant correlation between weight per 1000 seeds and iodine number of the oil. Low weight per 1000 seeds was found to be linked with high iodine number. If linkage between low seed weight and high iodine number was operative in these crosses, this would prove another obstacle in the way of obtaining the desired combination of characters in one new variety.

Correlation coefficients were calculated between iodine number and 1000 seed weight of the hybrids to determine possible association between these two characters. The results for these determinations are given in Table III.

Three of the four correlation coefficients were found significant. The negative coefficients indicated that in these crosses, low seed weight and high iodine number were associated. This association

[9] Myers, W. M. A correlated study of the inheritance of seed size and botanical characters in the flax cross Redwing x Ottawa 770B. Jour. Amer. Soc. Agron. 28: 623–635. 1936.

[10] Johnson, I. J. Correlation studies with strains of flax with particular reference to the quantity and quality of the oil. Jour. Amer. Soc. Agron. 24: 537–544. 1932.

TABLE III. CORRELATION COEFFICIENTS BETWEEN IODINE NUMBERS AND 1,000 SEED WEIGHT FOR FOURTH AND SIXTH GENERATION LINES SELECTED FROM THE CROSSES BISON x REDWING AND BISON x COMMON PINK

Cultures	Fourth and Third Generations		Sixth and Fifth Generations	
	Number of Lines Tested	Correlation Coefficient	Number of Lines Tested	Correlation Coefficient
Bison x Redwing	202	—.2777	223	—.4050
Bison x Common Pink..	179	—.0382	170	—.3677

between small to medium seed size and high iodine number tended to make it difficult to obtain selections combining medium large seed size and high iodine number of the oil.

There is still another force operative in certain crosses that makes difficult the securing of new varieties producing high quality of oil combined with other desirable characters. In Table IV frequency distributions are given for iodine number of yellow and brown seeded segregates from the cross Redwing x 770B and for the parents. 770B is a yellow seeded variety with medium high iodine number. The mean for the iodine number of Redwing, 181.96, is significantly higher than the mean, 175.88, for 770B with odds of 19:1. The distribution for iodine number of the segregates with yellow seeds is through the same classes as that for Redwing with one higher and one lower in addition. The mean iodine number for the

TABLE IV. FREQUENCY DISTRIBUTION OF BROWN AND YELLOW SEEDED INDIVIDUAL PLANTS FROM SEGREGATING F_3 LINES OF THE CROSS REDWING x 770B IN 1933.

Seed Color		Iodine Number Classes									Total	Mean	σ
		163–165	166–168	169–171	172–174	175–177	178–180	181–183	184–186	187–189			
Parents	Redwing						10	28	10		48	181.96	1.675
	770B			2	12	25	11				50	175.88	2.163
Hybrids	Yellow seeded......					9	12	7	5	4	37	180.95	3.836
	Brown seeded......	9	17	26	31	29	14	5			131	172.73	4.581

segregates with yellow seeds is 180.75, which is only one point lower than the mean for the Redwing parent. The brown seeded hybrids have a distribution similar to that of the 770B parent but somewhat wider in range. The mean for iodine number for the brown seeded hybrids is slightly lower than the mean for the 770B parent. Accepting odds of 19:1 as the lower level of significance, the difference between the means for iodine number for the yellow and the brown seeded segregates is not significant although it is larger than the difference between the means of the parents.

In Table V are given the segregations of the hybrid individuals for seed color, the ciliate character and for iodine number with X^2 for goodness of fit to the expected 3:1 ratio.

TABLE V. GOODNESS OF FIT FOR SEGREGATION FOR SEED COLOR, CILIATE-SMOOTH FALSE SEPTA AND IODINE NUMBER TO THE EXPECTED 3:1 RATIO IN SEGREGATING F_3 FAMILIES OF THE CROSS, REDWING x 770B

	Yellow	Brown	X^{2*}	P
Seed color	131	37	.794	.30+
	Ciliate	Smooth		
Ciliate character	123	45	.296	.50+
	Low	High		
Iodine number	122	46	.510	.50—

* For P = .05 and N = 1, X^2 = 3.841 Fisher.[11]

The false septa in the flax boll are either ciliate, showing hairs along their edges or smooth. Myers[9] has shown that, in a number of families of the cross Redwing x 770B, segregation occurs for blue and white flower color in the ratio of 3:1. In this cross white flowered segregates have yellow seeds and blue flowered segregates have brown seeds. Also he has shown that segregation for ciliate-smooth false septa in the same cross is in the ratio of 3:1. The hybrids were separated into two classes on iodine number by taking as the dividing point the average iodine number of the two parents. This gives 122 individuals with low and 46 with high iodine number and a satisfactory fit to a 3:1 ratio as shown by a X^2 of .510 with a P value of .50—. Since the segregation of individuals for high and low iodine number in this cross approximates a 3:1 ratio, a single major factor apparently is responsible for this character.

In Table VI is given the X^2 test for independent inheritance of the three characters studied.

TABLE VI. INDEPENDENCE OF INHERITANCE OF SEED COLOR, THE CILIATE CHARACTER AND IODINE NUMBER IN SEGREGATING F_2 FAMILIES OF THE CROSS REDWING x 770B.

Characters Studied	Segregation **				X^{2*}	P
	yc	ys	bc	bs		
Seed color and ciliate-smooth false septa	24	113	99	32	.82	.80+
	yh	yl	bh	bl		
Seed color and iodine number	27	10	19	112	49.61	.01—
	ch	cl	sh	sl		
Ciliate smooth false septa and iodine number	39	86	9	36	2.05	.50+

** y and b designate yellow and brown seed color, h and l designate high and low iodine number, c and s designate ciliate and smooth false septa.
* For P = .05 and N = 1, X^2 = 3.841 Fisher.[11]

[11] Fisher, R. A. Statistical methods for research workers. Edinburgh: Oliver and Boyd Fourth Edition. 1933.

For seed color and the ciliate-smooth false septa and for the ciliate-smooth false septa and iodine number, P is .80+ and .50+ respectively, indicating that the characters in each one of these pairs are inherited independently For the character pair, seed color and iodine number, the X^2 of 49.61 is higher than the accepted lower level of significance and P is less than .01. This indicates linkage in this cross between the two genes responsible for seed color and iodine number.

That this linkage is probably rather loose is indicated by the fact that all the varieties of flax except Bison that have been widely grown on farms in the North West Central States have had brown seeds and high oil quality. While linkage between iodine number and seed color was not a factor in the cross, Bison x Redwing, both of these varieties having brown seeds, and apparently not to any great extent in the Bison x Common Pink cross although the latter variety has mummy brown seeds, it has been a real hindrance in other crosses where the high iodine parent had yellow seeds. Although a new flax variety with yellow seeds and satisfactory in other respects would be an acceptable farm variety, none of those tested so far have come up to expectations.

Weights per 1000 seeds were made on the parents and progenies of the Bison x Redwing and Bison x Common Pink crosses and these data are included in Table VII.

TABLE VII. FREQUENCY DISTRIBUTIONS FOR WEIGHT PER 1,000 SEEDS IN GRAMS OF THE PARENTS OF TWO CROSSES, BISON X REDWING AND BISON X COMMON PINK, AND FOR FOURTH AND THIRD GENERATION HYBRIDS FROM THEM

Cultures	Seed Weight Classes										Total	Mean	σ
	3.3–3.5	3.6–3.8	3.9–4.1	4.2–4.4	4.5–4.7	4.8–5.0	5.1–5.3	5.4–5.6	5.7–5.9	6.0–6.2			
					Bison x Redwing								
Parents													
Redwing				7	3						10	4.43	.2057
Bison								6		4	10	5.76	.2066
Fourth gen. hybrids													
Blue				14	11	45	34	18	1	3	126		
Light Blue				6	4	10	13	11	1	2	47		
Blue and Light Blue				2	2	9	9	7			29		
Total				22	17	64	56	36	2	5	202	5.03	.3967
					Bison x Pale Pink								
Parents													
Common Pink	2	8									10	3.56	.0843
Bison								3		7	10	5.88	.1931
Third gen. hybrids													
Blue				7	5	31	15	9			67		
Pink		3	8	34	7	21	7				80		
Blue and Pink				3	1	18	8	2			32		
Total		3	8	44	13	70	30	11			179	4.76	.9390

The weight per 1000 seeds of Redwing varied from 4.2 to 4.7 grams while those of Bison varied from 5.6 to 6.0 grams. The difference, 1.33 grams, between the means for 1000 seed weight of the two parents is significant with odds of 19:1. The distribution of the seed weight of the hybrid progenies equaled that of both the parents. This did not appear to vary greatly for the two homozygous flower color classes or for the heterozygous color class. The mean seed weight for the 202 progenies was about intermediate between the means for the parents.

The Common Pink parent varied in weight from 3.4 to 3.6 grams and Bison varied from 5.6 to 6.0 grams per 1000 seeds. Again the difference, 2.32 grams per 1000 seeds, between the means of the two parents is significant with odds 19:1. Again the two pure color classes and the mixed color class of flower color did not differ materially in the distribution of seed weight per 1000. The mean seed weight for the 179 hybrid progenies was close to being half way between that of the two parents.

The oil percentages of the parents and hybrids of the Bison x Redwing cross is given in Table VIII.

TABLE VIII. FREQUENCY DISTRIBUTION FOR OIL PERCENTAGE IN THE SEEDS OF THE PARENTS, BISON AND REDWING, AND FROM FOURTH GENERATION HYBRIDS OF THE CROSS BETWEEN THEM

Culture	33.3–33.6	33.7–34.0	34.1–34.4	34.5–34.8	34.9–35.2	35.3–35.6	35.7–36.0	36.1–36.4	36.5–36.8	36.9–37.2	37.3–37.6	Total	Mean	σ
Parents														
Redwing		2	2	2	4							10	34.60	.4967
Bison						3	3	2	2			10	35.94	.4321
Fourth gen. hybrids														
Light Blue	3	3	4	10	4	5	6	4	9			48		
Blue	3	6	3	11	18	22	24	15	15	2	6	125		
Blue and Light Blue		2	2	3	2	6	3	4	3	4		29		
Total	6	11	9	24	24	33	33	23	27	6	6	202	35.52	.9600

The spread in oil content of the Redwing parent was from 33.9 to 35.2 per cent while for the Bison parent it was from 35.3 to 36.6. The hybrids had a spread in oil content from 33.3 to 37.6 per cent which is somewhat wider in both directions than that of both parents. The difference between the means of the two parents in oil content, 1.34 per cent, is significant with odds of 19:1. Examination of the distribution for oil content of the seeds of the progenies of the homozygous blue, the homozygous white and the blue and white color classes shows no apparent interrelationship between flower color and oil content. The mean oil content of the seed for the progenies is nearer to that of the Bison than to that of the Redwing parent.

Heights in inches for the parents and hybrids of the cross, Bison x Common Pink, are given in Table IX.

TABLE IX. FREQUENCY DISTRIBUTION FOR HEIGHT IN INCHES FOR THE PARENTS OF THE CROSS BISON x COMMON PINK AND FOR THE THIRD GENERATION HYBRIDS FROM IT

Cultures	Height in Inches								Total	Mean	σ
	23	24	25	26	27	28	29	30			
Parents											
Common Pink		2	2	3	3				10	25.7	1.158
Bison	1	2		5	2				10	25.5	1.353
Third generation hybrids											
Blue	3	4	9	12	19	11	4	5	67		
Pink	1	5	10	20	14	14	11	5	80		
Blue and Pink.......	2	2	6	4	9	2	5	2	32		
Total	6	11	25	36	42	27	20	12	179	26.8	1.738

The mean heights of the parents are very similar. Taking two times the standard deviation on either side of the mean height of Common Pink as the limits of significant differences, about 32 plants might be considered as being taller than either parent. However, the number of determinations on each of the parents is probably too small to be certain that there was transgressive segregation among the hybrids in the direction of increased height. The mean height of the progenies was 1.1 inches taller than Common Pink. The mean heights of the progenies in the three color classes were not calculated since there appeared to be no marked indication of inter-relationship between flower color and height.

The families retained in 1933 from the crosses Bison x Redwing and Bison x Common Pink were subjected to further selection during 1934. In 1935 they were grown in rod row trials and in the wilt nursery to obtain their reaction to this disease. Results obtained for five of the lines are given in Table X.

TABLE X. RESULTS WITH SELECTIONS FROM THE BISON x REDWING AND THE BISON x COMMON PINK CROSSES GROWN IN ROD ROW TRIALS AND IN THE WILT NURSERY AT UNIVERSITY FARM IN 1935

Cultures	Yield per Acre Bu.	1,000 Seed Weight Grams	Iodine Number of Oil	Wilt Resistance
II-29-11	18.1	4.8	181	good
II-29-6	20.3	5.4	180	good
II-29-14	19.5	4.8	181	excellent
II-30-5	20.3	5.2	178	good
II-29-7	20.1	5.5	178	good
Redwing	16.7	4.3	178	poor
Bison	....	5.6	165	medium

Results of the yields of these lines for one year are considered only as indications of what may possibly be expected from them over a three-year period at different locations in the state. In 1000 seed weight they were higher than Redwing but not equal to Bison. Each one of the lines equaled or exceeded Redwing in iodine number of its oil. In wilt resistance each of the five lines exceeded the parents, Redwing and Bison.

Summary

Minnesota has produced since 1901, except during the war period, about half a million acres of flax annually.

The introduction of the variety Bison brought an oil quality problem. However, Bison has proved so valuable a variety in other respects that it has become the leading variety grown on farms in the state.

Linkage between low weight per 1000 seeds and high iodine number was found to occur in segregates from the crosses Bison x Redwing and Bison x Common Pink. This has made difficult the recovery in the hybrids from these crosses of individuals in which was combined the medium large seed size of Bison and the high quality of oil of the other parents.

In segregating families of the cross Redwing x 770B, the individuals with yellow seeds averaged considerably higher than those with brown seeds. Linkage between seed color and iodine number was determined by the X^2 for independence test.

Segregation of individuals in hybrid material from the cross Redwing x 770B in the ratio of three low to one high in iodine number of the oil has been shown by the X^2 test.

Lines have been selected from the crosses Bison x Redwing and Bison x Common Pink which equal the high iodine parents in quality of oil. None of these lines is equal but some of them approach to Bison in seed size.

DROUGHT RESISTANCE OF GREEN ASH AS AFFECTED BY GEOGRAPHIC ORIGIN

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The Shelterbelt project has greatly stimulated interest in tree planting in the Prairie-plains region. Obviously trees which are to be planted in this region must possess a high degree of resistance to drought if they are to survive and form a protective barrier against wind. It, therefore, becomes a matter of prime importance to collect

[1] Maintained by the United States Department of Agriculture, St. Paul, Minnesota, in cooperation with the University of Minnesota.