FIELD STUDIES OF COLD RESISTANCE AND OTHER CHARACTERS IN THREE WHEAT BACK CROSSES

by

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INTRODUCTION

In 1924, three back crosses were made involving Kanred in an effort to combine additional factors for winterhardiness from Kanred with those for stiff straw, high yield, and excellent quality of Kanmarq, Tenmarq, and Kanred x Marquis, Kansas No. 443. Harlan and Pope (1)[1/], and Briggs (3), have suggested that there is an important place for back crosses in small grain breeding, especially when it is desirable to concentrate in one strain factors for a single character.

According to Quisenberry and Clark (24), low temperatures cause nearly as heavy losses to the wheat crop as all wheat diseases combined. During the 28-year period, from 1901 to 1928, an average of nearly 11 per cent of the total winter wheat acreage of the United States was abandoned annually, largely because of winterkilling. The average percentage of abandonment has increased slightly in recent years. Tenmarq has a stiffer straw and produces high yields when it survives the winter than Kanred, but it is decidedly inferior to Kanred in winterhardiness.

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1/ Reference is made by number to Literature Cited, pages 84-87.

The production of a variety with the yielding ability of Tenmarq and hardiness of Kanred might have an economic value to the central sections of the hard red winter wheat belt.

Kanred not only has a weaker straw than Tenmarq, but it is more subject to lodging than most standard varieties of hard red winter wheats. With the coming of the combine, the ability of a wheat to stand well both before and after ripening becomes of increasing importance and largely accounts for the decreased acreage of Kanred during the past few years in regions where combines are used. Considered from the standpoint of stiffness of straw, Tenmarq is suitable for combining. Based upon expected results in multiple factor inheritance, from a large number of Tenmarq x Kanred segregates, one should be able to select some hybrid strains equal to Tenmarq in stiffness of straw, yield and quality and having at least some of the factors for cold resistance from Kanred.

Tenmarq is earlier maturing than Kanred and produces a flour having gluten of greater "strength". In resistance to leaf rust, Tenmarq is superior to Kanred, but it has a somewhat greater susceptibility to Hessian fly than Kanred. Kanmarq and Kanred x Marquis, Kansas No. 443, are very similar to Tenmarq aside from having slightly lower yields and the fact that Kanmarq is awnless.

The author studied in the nursery only the F_6 and F_7 generations grown during the years 1930 and 1931. In order to make the study more complete from the time the crosses were made up to the present, data on the generations previous to F_6 are included in this thesis. The crosses were made and F_3 to F_5 generations were grown and studied by Dr. John H. Parker and his assistants at the Kansas Agricultural Experiment Station, at Manhattan. Some cultures in these earlier generations were also grown at the Colby branch station.

This thesis includes studies of the inheritance of cold resistance and other characters of three wheat back crosses. In the process of selection, only the plants and selections that appeared desirable were saved and therefore it is impossible to attempt to determine any genetic ratios or determine the number of factors concerned in the inheritance of the agronomic characters which are certainly complex and governed by multiple factors. It is rather a study of some of the practical problems a plant breeder encounters in attempting to produce a new strain of wheat superior to a very good variety such as Tenmarq. The thesis will also serve as a summary of the work on the three back crosses up to the present time and should be valuable as a reference in future wheat breeding work at the Kansas station.

MATERIALS AND METHODS

The three groups of back crosses are the result of crossing Kanred x Marquis to produce Kanmarq, and Kanred x Marquis, Kansas No. 443; P-1066 x Marquis to form Tenmarq, and crossing these three winter x spring hybrids back to Kanred. In animal breeding terms, the back crosses are, therefore, three-quarters Kanred and one-quarter Marquis, with the exception of the Tenmarq cross in which P-1066, a strain similar to Kanred, was used. For the sake of brevity, the unnamed cross, Kanred x Marquis, Kansas No. 443, will be designated as Kansas No. 443 throughout the remainder of this thesis.

Clark, Martin and Ball (5), have described Kanred and P-1066 as follows:

> "Description: Plant winter habit, midseason, midtall; stem white, weak; spike awned, fusiform, middense; glumes glabrous, white, midlong, midwide; shoulders narrow, oblique to elevated; beaks 3 to 25 mm. long; awns 3 to 10 cm. long; kernels dark red, midlong, hard, ovate to elliptical; germ small; crease narrow to midwide, middeep; cheeks rounded; brush small, midlong.
>
> Kanred is very similar to Turkey, but is slightly more winterhardy and slightly earlier and can be distinguished from that variety by its longer beaks on the outer glumes and by its resistance to some

forms of both leaf and stem rust. This resistance to rust is an important factor in the ability of the variety to outyield Turkey wheat in many sections. It is also about equal to Turkey in milling and bread-making value.

History: Kanred is the product of a single head selected in 1906 from the Crimean variety (C. I. No. 1435), which had been introduced into the United States from Russia by the United States Department of Agriculture. The selection from which it descended was one of the 554 head selections made in 1906 by Dr. H. F. Roberts, of the Botany Department of the Kansas Agricultural Experiment Station.

Synonyms: P-762, P-1066 and P-1068. P-762, as shown above, was the designation under which Kanred wheat was known from the date of its selection, in 1906, until the time when it was named. P-1066 and P-1068 are two other pure-line selections developed at the Kansas Agricultural Experiment Station in much the same way as was Kanred. Both these strains have the rust resistance of Kanred and are identical in all morphological characters, but neither has been distributed for commercial growing."

Clark, Martin and Ball (5), have described Marquis as follows:

"Description: Plant spring habit, early, short to midtall; stem white, strong; spike awnless, fusiform, dense, erect; glumes glabrous, white to yellowish, short, wide; shoulders midwide to wide, usually square; beaks wide, acute, 0.5 mm. long; apical awns few, 1 to 10 mm. long; kernels red, short, hard, ovate, with truncate tip; germ midsized; crease wide, deep; cheeks angular; brush midsized, midlong.

This is a high-yielding spring wheat, and it is one of the best varieties for milling and bread making. Its high yield and popularity are due principally to its early maturity, which has sometimes enabled it to escape stem rust and drought.

> History: Marquis is of hybrid origin, having been originated by the cerealists of the Dominion Department of Agriculture at the Central Experimental Farm, Ottawa, Canada. The crossing which resulted in the origin of Marquis was done under the direction of Dr. William Saunders, former Dominion cerealist. To the present Dominion cerealist, Dr. C. E. Saunders, the credit for originating (selecting, naming, testing, and distributing) the variety is due."

Tenmarq, registration No. 264, is described in Journal of the American Society of Agronomy, 21:1173-1174, as follows:

> "Tenmarq (Kansas No. 439, C.I. No. 6936) was produced from a hybrid between Marquis and P-1066. The latter is a selection similar to Kanred, both from Crimean, C. I. No. 1435. The cross was made in 1917 from the crop of 1916-1917 at Manhattan, Kansas, and Tenmarq is the result of a selection made in 1921. It was developed by the Agronomy Department of the Kansas Agricultural Experiment Station in cooperative experiments with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture.
>
> Tenmarq is bearded and has white glabrous glumes, long beaks, and short, hard, red kernels. It is a true winter wheat, but the grain is sometimes graded as hard red spring or mixed. Its superior characters are high yield, excellent quality, early maturity, and stiff straw. Its chief defects are that it is susceptible to Hessian fly attack and has only slightly greater winterhardiness than Blackhull. Tenmarq was selected, and has been tested in nursery experiments since 1922, by John H. Parker who applied for its registration."

Salmon and Laude (26), report on comparative tests of Tenmarq with Kanred, Turkey, and Blackhull grown for seven years at Manhattan, five years at Hays, three years each at Colby, Garden City, and Tribune, and 106 cooperative experiments with farmers covering four years. From these tests, they obtained the following results:

> "Tenmarq produced higher yields than Blackhull in all cases except at Hays, where the yields are substantially the same. It also produced a higher average yield than Turkey at Manhattan, Hays, Colby, Garden City, and Tribune; a higher average yield than Kanred at Manhattan, Colby, and Garden City, slightly more at Hays, and approximately the same at Tribune. In cooperative experiments with farmers it yielded substantially more than Blackhull, Kanred, or Turkey. Its high yield record may be due in part to its slightly early maturity.
>
> The excellent yield record of this variety, its superior quality, relatively stiff straw, and resistance to leaf rust should make it of great interest to winter wheat investigators in the Great Plains. However, its marked susceptibility to Hessian fly and susceptibility to scab should be considered. The pronounced effect of seasonal variation in other cases, the clearly demonstrated lower degree of winterhardiness, as compared with Kanred and Turkey, together with the fact that recent winters have been milder than may normally be expected, would suggest caution in predicting relative yields of Tenmarq for the future."

Kanmarq (Kansas No. 440) is an awnless segregate of a Kanred x Marquis cross. It was grown as row No. 682 in the 1925 nursery at Manhattan. Kanmarq is similar to Tenmarq in quality, but is awnless, and does not yield as much as Tenmarq. It has stiffer straw than Tenmarq.

Kansas No. 443 is a Kanred x Marquis cross very similar to Tenmarq. It was grown in row No. 295 in the 1923 nursery at Manhattan. Because of the fact that Kanmarq and Kansas No. 443 have produced slightly lower yields than Tenmarq, these strains have not been tested as extensively in plots at Manhattan or at cooperating stations.

In addition to the above descriptions, a large amount of data on yield and other characters have been accumulated at the Manhattan and cooperating stations. For the ten-year period, 1922 to 1931, Tenmarq had an average yield of 39.5 bushels in rod row tests in the Agronomy Nursery, as compared to 32.3 bushels for Kanred. In plats at the Agronomy Farm, 1924 to 1931, Tenmarq averaged 40.6 bushels per acre and Kanred 35.8 bushels. The comparative yields of Tenmarq and Kanred at branch stations in Kansas, cooperative tests in Kansas, and at cooperating stations in nearby states, are given in Tables I., II., and III.

Table I. Yields of Tenmarq and Kanred at branch stations in Kansas.

Variety	Average yields in bushels per acre			
	Hays 1926-31	Colby 1929-30	Tribune 1929-31	Garden City 1929-30
Tenmarq	27.6	33.6	26.4	41.8
Kanred	25.3	28.9	25.3	40.2

Table II. Yields of Tenmarq and Kanred in co-operative experiments on farms in Kansas.

Variety	Entire state: No. of tests	Entire state: Bushels per acre	South-central Kansas: No. of tests	South-central Kansas: Bushels per acre
Tenmarq	163	25.1	82	25.9
Kanred	163	22.4	82	22.2

Table III. Summary of average yields of Tenmarq and Kanred, grown at cooperating stations in nearby states, 1931.

Cooperating station	Bushels per acre: Tenmarq	Bushels per acre: Kanred
Texas:		
Amarillo	16.4	13.5
Panhandle cooperative tests	17.5	15.9
Denton	42.4	34.7
Nebraska:		
Lincoln	49.2	46.7
North Platte	51.7	51.4
Oklahoma:		
Woodward	48.8	47.6
Illinois:		
Urbana	45.5	37.0
Kansas:		
Hays	22.5	21.7
Agronomy Farm, Manhattan	47.4	47.1
9-station average	37.9	35.1

Results of yields from the uniform winterhardiness nurseries (24) are available for the years 1926 to 1929 and are listed in Table IV. Kanred yielded higher than Tenmarq and Kanmarq at some of the northern stations where non-hardy varieties winterkilled, which accounts for the higher average yield of Kanred.

Table IV. Average yields of Kanred, Tenmarq, and Kanmarq, in the uniform winterhardiness nurseries, harvested one or more of the four years from 1926 to 1929.

	Bushels per acre		
	Kanred	Tenmarq	Kanmarq
Average (weighted)	33.0	31.0	29.0
Kharkof same years	31.1	31.1	36.8
No. of station years	57	57	14
Percentage of Kharkof	106.1	99.7	78.8

Tenmarq consistently outyields Kanred over a large area for a period of years as shown by Tables I. to III. Compared to other winter wheats, Tenmarq ranks at the top or very near the top in yield when winterkilling is not a limiting factor.

Tenmarq is among the varieties in the tender group, but apparently is not so tender as Blackhull (24), a wheat grown extensively in Kansas. The average survival of Kanred, Kanmarq and Tenmarq grown at twenty stations in the uniform winterhardiness nurseries during the period 1920 to 1929 is given in Table V. Subjected to artificial freezing (14), in which the plants were hardened for various periods of time previous to freezing, in about fifty trials, Tenmarq had an average survival of 73 per cent, as compared to 100 per cent for Kanred. When unhardened plants were frozen in the greenhouse, in seventeen trials, Tenmarq survived 46 per cent and Kanred 100 per cent.

Table V. Average percentages of survival of Kanred, Kanmarq, and Tenmarq, grown in the uniform winterhardiness nurseries during one or more of the years from 1920 to 1929, inclusive.

	Kanred	Kanmarq	Tenmarq
Average (weighted)	54.4	48.9	45.8
Kharkof same years	52.8	54.0	52.9
No. of station years	150	49	109
Percentage of Kharkof	103.0	90.6	86.6

The date of full heading, lodging percentage, test weight, and percentage of leaf rust infection of Tenmarq and Kanred in the advanced nursery test are given in Table VI. Tenmarq averaged four days earlier in heading, lodged less, had a higher test weight, and lower leaf rust infection than Kanred. At the Agronomy Farm, Manhattan, 1924 to 1931, Tenmarq lodged on an average of 8.5 per cent and Kanred 24.9 per cent.

Table VI. Agronomic data for Tenmarq and Kanred grown in the advanced nursery, Manhattan, Kansas, 1927 to 1931.

	Tenmarq	Kanred
Date full head, May	23	27
Lodging, per cent	63.3	70.0
Test weight, pounds	54.6	53.2
Leaf rust infection, per cent	31.0	52.0

Tenmarq is very susceptible to Hessian fly attack. The average percentage of plants infested over an eight-year period is given in Table VII. Counts of stinking smut were made at the North Platte, Nebraska, station for the three-year period, 1929 to 1931. Kanmarq had an average of 25.1 per cent bunted heads, Tenmarq 31.6, and Kanred 17.4. Tenmarq is also very susceptible to wheat scab, resembling Marquis in this respect.

Table VII. Infestation of wheat by Hessian fly, 1922 to 1929. (22)

	Kanmarq	Tenmarq
Average per cent of plants infested	53.7	58.4
Kanred in same tests	58.1	49.0

Kanred and Tenmarq are both good bread wheats, but Tenmarq seems to have inherited some of the excellent quality characteristics of Marquis, giving it a stronger gluten than Kanred. In a comparison of the milling and baking quality tests of wheats made by the Department of Milling Industry, K.S.C., Table VIII., Tenmarq is shown to have a higher loaf volume and a slightly better loaf texture than Kanred.

Table VIII. Milling and baking qualities of Tenmarq and Kanred, average 1925 to 1929.

	Tenmarq	Kanred
Protein, per cent	12.7	13.7
Flour yield, per cent	70.7	69.2
Ash, per cent	.402	.423
Water absorption, per cent	65	67
Loaf volume, c.c.	2037	2007
Loaf texture score, per cent	98	97

Summing up the comparison between Tenmarq and Kanred, it is evident that the superiority of Tenmarq is due to stiffer straw, earlier maturity, high yields, and better quality. Kanred is decidedly superior to Tenmarq in winterhardiness and somewhat less susceptible to Hessian fly. While Kanmarq and Kansas No. 443 are not identical with Tenmarq, they are similar to it and what has been said about Tenmarq in general applies to these two strains, except as noted above.

The three back crosses were made in the nursery at Manhattan in 1923-1924. The F_1 plants were grown in the greenhouse in 1924-1925 and notes were taken on date of heading, date ripe, number of culms per plant, number of heads per plant, height, awn type, and plumpness of grain. When the project leader returned to Manhattan from Cambridge in October, 1926, seed for the F_2 generation was sent to V. H. Florell, at Davis, California, who grew large F_2 populations under mild conditions with little or no elimination by winterkilling.

The F_3, F_4 and F_5 generations were grown in eight-foot, space-planted rows in the Agronomy Nursery at Manhattan. Some of the F_4 and F_5 lines were also grown at Colby, Kansas, under more severe winter conditions than at Manhattan. Fall and spring survival, height of plants, lodging, dates first and fully headed, date ripe, leaf rust infection, grain notes and other notes were taken during these generations. All cultures through F_5 were from individual plants. The F_6 generation lines were the first ones to be tested in rod rows. The less promising strains were discarded each year and only the better strains continued in the succeeding generations. The selections were made on the basis of previous records, field notes, general appearance in the field, and notes on kernel characters, i.e., quality of grain, especially plumpness of kernels. Many of the rows were discarded in the field and not harvested. Natural selection played a part in eliminating the less desirable plants since the tender and very weak plants did not survive the winter. Early plants were tagged in the field which aided in selection at harvest-time and in the seed-house.

At harvest-time, the plants from the promising strains were pulled. The progeny from each plant was tied in a bundle and stored in the seed-house. During July and August each year a careful examination was made of large numbers of individual plants. Usually five to ten plants were saved from each strain. The heads were clipped from each plant, counted and put in envelopes. Row number, plant number, number of heads, and special notes on individual plants were recorded on the envelopes.

The heads of the individual, selected plants were threshed in the small "Cornell" plant thresher and the grain put in coin envelopes. The notes from the large envelopes which contained the heads were transferred to the small envelopes and the grain from each plant weighed. The selection numbers were listed in an individual plant note-book, and the plant notes, notes on grain texture, kernel plumpness and yellow berry, and other special notes were recorded in this note-book. After the individual plants had been selected, the remaining plants in each bundle were threshed in bulk and grain notes taken on these samples.

It will be seen from the above discussion that the F_2 to F_6 generation plants were examined very critically. Not only were field notes and grain notes of each strain recorded, but also plant and grain notes on the individual plants selected from each strain. All of these notes were studied and used as a basis for selecting plants to be grown in each succeeding generation.

The back crosses were grown in rod rows for the first time in the F_6 generation in 1931. Since single short rows are of questionable value in determining yielding ability, the F_6 generation offered the first opportunity for making decisive yield tests. Notes were taken on stand, height, lodging, date fully headed, date ripe, percentage of leaf rust, yield, texture, plumpness, and yellow berry of grain. Special notes on plant or kernel characters and on field appearance were also recorded on many lines.

Due to a shortage of nursery ground, it was not possible to plant all of the F_6 strains in the triplicated rod row series at Manhattan, as had been planned, and accordingly 170 strains were planted in the triplicated rod row nursery and 190 strains in single rod rows. Two hundred and thirteen strains were grown in triplicated rod rows at Colby, Kansas, in 1931. Field notes were taken by Mr. L. M. Sloan, at Colby, and the harvested crop shipped to Manhattan for threshing, grain notes and further selection.

One hundred and four strains of the back crosses were grown in duplicate eight-foot rows, in 1931, at Moccasin, Montana; Redfield, South Dakota; University Farm, St. Paul, Minnesota; and Colby, Kansas, in a four-station winter-hardiness test. Spring survival notes only were taken at Moccasin, Redfield, and St. Paul. The lines grown at Colby were harvested and studied in about the same manner as the strains grown in rod rows. A sequential treatment of the back-cross selections grown during the period 1926 to 1932 is given in Tables IX., X., and XI.

Greenhouse studies on inheritance of cold resistance were made on the F_3 and F_4 generations of Kanred x Kanmarq by L. L. Davis (8). During the winter of 1930-1931, Harland Stevens made a study of cold resistance in Tenmarq x Kanred. These studies will be referred to in comparison with studies reported in other sections of this thesis. It is neither necessary nor advisable to include all of the data accumulated in the F_1 to F_7 generations in this thesis. Only averages, summaries, or statistical constants are presented. Detailed data are on file in the Crop Improvement office at Manhattan, Kansas.

Table IX. Cultures of Kanred x Kanmarq, 1926 to 1932.

Year	Gener- ation	Kind of test	No. of strains
1924-1925	F_1	Individual plants	13
1926-1927	F_2	" " Davis, Calif.	
1927-1928	F_3	Plant rows, Manhattan	210
		Greenhouse, 2070 pots	
1928-1929	F_4	Plant rows, Manhattan	150
		" " Colby	278
		Greenhouse, 850 pots	
1929-1930	F_5	Plant rows, Manhattan	166
		" " Colby	90
1930-1931	F_6	Single rod rows, Manhattan	79
		Triplicated rod rows, Manhattan	31
		" " " Colby	51
		4-station winterhardiness test	21
1931-1932	F_7	Duplicate 3-row, 8-ft. plots Manhattan	25
		Duplicate 3-row, 8-ft. plots Colby	25
		4-station winterhardiness test	25

Table X. Cultures of Tenmarq x Kanred, 1926 to 1932.

Year	Gener-ation	Kind of test	No. of strains
1924-1925	F_1	Individual plants	5
1926-1927	F_2	" " Davis, Calif.	
1927-1928	F_3	Plant rows, Manhattan	41
1928-1929	F_4	Plant rows, Manhattan	140
		" " Colby	63
		Greenhouse, 360 pots	
1929-1930	F_5	Plant rows, Manhattan	216
		" " Colby	156
		Greenhouse, 234 pots	
1930-1931	F_6	Head rows, Manhattan	42
		Single rod rows, Manhattan	62
		Triplicated rod rows, Manhattan	70
		" " " Colby	80
		4-station winterhardiness test	47
1931-1932	F_7	Duplicate 3-row, 8-ft. plots Manhattan	57
		Duplicate 3-row, 8-ft. plots Colby	49
		4-station winterhardiness test	49

Table XI. Cultures of Kanred x Kansas No. 443, 1926 to 1932.

Year	Gener- ation	Kind of test	No. of strains
1924-1925	F_1	Individual plants	14
1926-1927	F_2	" " Davis, Calif.	
1927-1928	F_3	Plant rows, Manhattan	308
1928-1929	F_4	Plant rows, Manhattan	230
		" " Colby	99
1929-1930	F_5	Plant rows, Manhattan	327
		" " Colby	179
1930-1931	F_6	Single rod rows, Manhattan	49
		Triplicated rod rows, Manhattan	69
		" " " Colby	82
		4-station winterhardiness test	35
1931-1932	F_7	Duplicate 3-row, 8-ft. plots Manhattan	49
		Duplicate 3-row, 8-ft. plots Colby	49
		4-station winterhardiness test	49

Statistical calculations were made on some of the data to show the relationship of characters and the reliability and significance of results. Unless otherwise stated, Spearman's formula for the coefficient of correlation from ranks (18) was used:

$$p = 1 - \frac{6\Sigma d^2}{N(N^2-1)}$$

The probable error of "p" was determined by the formula:

$$P.E._p = .7063 \frac{1-p^2}{\sqrt{N}}$$

Pearson (18) has shown that if scores in the two traits which are in truth normal in form are assigned ranks and "p" calculated, it will differ slightly from the "r" obtained directly from the scores. To allow for this discrepancy, p's were turned into r's by the formula:

$$r = 2 \sin \frac{\pi}{6} p$$

EXPERIMENTAL RESULTS

Cold Resistance

Winterkilling causes a serious annual loss to the winter wheat crop of the United States. Winter injury may be reduced (24) by the use of hardy varieties and by cultural practices, such as sowing in grain stubble or cornstalks, the preparation of a firm seedbed by the use of "duckfoot" fallow, sowing with furrow drills at proper rates and dates, and mulching the wheat with straw. The use of cultural practices in reducing losses due to winterkilling is a temporary solution while the use of hardy varieties is a permanent solution. The plant breeding problem of producing strains of winterhardy wheats is considered in this thesis.

As a general rule, strains of wheat which are hardiest are also late in maturity. In Kansas early-maturing wheats ordinarily average higher in yield than late-maturing strains in seasons when winterkilling or spring freezes are not serious limiting factors. The farmer, in choosing a variety of wheat, may be justified in sacrificing something in yield for an assurance that a crop will survive the winter. What the farmer really wants is an early or medium-early, winterhardy wheat, which produces high yields of good quality grain. Since no variety at present available excels in all these respects, it is the task of the plant breeder to try to produce one.

The F_1 generation of the back crosses were grown in the greenhouse which was kept above freezing at all times and, therefore, no plants were killed due to low temperatures. The F_2 grown at Davis, California, a region in which spring wheats normally live through the winter, was not subjected to freezing temperatures and there were no losses from winterkilling.

The F_3 to F_5 generations were space-planted at Manhattan and the plants counted in the fall and spring. Dividing the spring count by the fall count gives the percentage of survival. No counts were made on the F_4 generation at Colby, and only estimates of survival were made on the F_5 generation at Colby. The survival of the F_3 to F_5 generations grown at Manhattan is given in Table XII.

In the Kanred x Kanmarq cross, the Kanred checks ranked first in survival, the Kanmarq checks last, and the F_3 strains about midway between, as might be expected. The Tenmarq x Kanred strains were below both parents in survival, but only one check of each parent is included. The Kanred x Kansas No. 443 strains averaged 4.4 per cent below the Kanred checks in survival and slightly below the Kansas No. 443 checks.

The survival of the F_4 generation at Manhattan is given in Table XII. The average survival was high and winterkilling probably was caused by factors other than low temperatures as shown by the fact that Kanred checks averaged lower than Tenmarq and Kansas No. 443 checks, two

Table XII. Winter survival of F_3 to F_5 back crosses and checks, Manhattan, Kansas, 1928 to 1930.

Variety	F_3 No. of rows	F_3 Average survival %	F_4 No. of rows	F_4 Average survival %	F_5 No. of rows	F_5 Average survival %
Kanred x Kanmarq	200	83.8	139	90.5	167	96.8
Kanred checks	4	93.1	8	88.5	10	97.4
Kanmarq checks	4	72.2	7	84.6	9	93.2
Tenmarq x Kanred	41	95.3	130	87.8	216	97.3
Kanred checks	1	100.0	7	84.7	11	94.5
Tenmarq checks	1	100.0	7	86.1	11	98.0
Kanred x Kansas No. 443	296	91.0	211	90.3	325	96.5
Kanred checks	6	95.4	12	90.0	18	96.3
Kansas No. 443 checks	6	91.4	12	90.2	18	98.3

strains known to be inferior to Kanred in hardiness.

Very little winterkilling occurred in 1930 as shown by Table XII. With nearly 100 per cent survival, such small differences mean very little.

Winterkilling was more severe at Colby than at Manhattan during the winter of 1929-1930. Estimates of survival made on March 15 by S. C. Salmon and on April 17 by John H. Parker and H. M. Beachell are given in Table XIII.

Table XIII. Winter survival of F_5 back crosses and checks, Colby, Kansas, 1930.

Variety	No. of rows	Estimated average survival % Mar. 15	Estimated average survival % Apr. 17
Kanred x Kanmarq	100	62	72
Kanred checks	6	65	73
Kanmarq checks	5	46	54
Tenmarq x Kanred	158	65	75
Kanred checks	9	68	82
Tenmarq checks	9	62	70
Kanred x Kansas No. 443	177	55	71
Kanred checks	10	65	79
Kansas No. 443 checks	10	47	59

The hybrid strains in each cross averaged below the Kanred checks in survival and above the winter x spring parents. The Kanred x Kanmarq strains more nearly approached the Kanred parent in percentage of survival than the other two crosses. This may be explained by the fact that the Kanred x Kanmarq strains had been selected for cold resistance in the F_3 and F_4 generations on the basis of greenhouse freezing trials.

The winter of 1930-1931 was unusually mild with the minimum temperature reported in the state of -4° F. The wheat planted in rod rows at Manhattan and Colby, Kansas, lived through the winter practically 100 per cent. It is difficult to get good field information on hardiness at Manhattan during a series of years such as 1928 to 1931 when winterkilling is very slight. Based on field results alone at Manhattan, one might select a high-yielding strain of wheat having other desirable agronomic characters but lacking sufficient winterhardiness to be safe over a longer period of years.

To supplement the data on hardiness secured in the winter wheat nursery at Manhattan, 103 strains of the back crosses were planted in a four-station winterhardiness nursery. This nursery consisted of duplicate eight-foot rows at Colby, Kansas; Redfield, South Dakota; Moccasin, Montana, and St. Paul, Minnesota. The survival at Colby was practically 100 per cent for all strains and no notes were recorded on survival. Because of severe soil blowing injury at Redfield, South Dakota, the data were considered unreliable. Winterkilling at Moccasin, Montana, and St. Paul, Minnesota, was very marked as shown by Table XIV.

Table XIV. Winter survival of F_6 back crosses and checks, Moccasin, Montana, and St. Paul, Minnesota, 1931.

Variety	No. of strains	Average per cent survival: Moccasin, Mont.	St. Paul, Minn.	2-sta. average
Kanred x Kansas No. 443	35	32	83	57
Kanred checks	3	26	75	52
Tenmarq x Kanred	47	29	72	51
Kansas No. 443 checks	2	38	45	42
Kanred x Kanmarq	21	18	54	36
Tenmarq checks	6	17	41	29
Kanmarq check	1	23	0	12

The range of survival of individual rows was 8 to 53 per cent at Moccasin, and 0 to 100 per cent at St. Paul. The three groups of back crosses ranked in the order of Kanred x Kansas No. 443, Tenmarq x Kanred, and Kanred x Kanmarq in average survival at both stations. Twenty-three Kanred x Kansas No. 443 strains, 23 Tenmarq x Kanred strains and two strains of Kanred x Kanmarq had higher survival percentages that the average of the Kanred checks, indicating that transgressive segregation for hardiness may have occurred in the back crosses and that some progress has been made in the production of winterhardy strains.

It is important to know whether the killing at Moccasin and St. Paul was due chiefly to low temperatures or to other factors such as soil blowing, moisture content of soil, snow cover, etc. The role of soil heterogeneity as affecting survival percentages of hybrids and checks should also be considered. Strains high in survival at Moccasin also having a high survival at St. Paul, are probably actually superior in resistance to low temperatures. The survival of individual strains at the two stations is shown graphically in Figures 1, 2, and 3. The survival at St. Paul was consistently higher than at Moccasin, and strains having a high survival at St. Paul in most cases had a comparatively high survival at Moccasin. The survival percentages at the two stations had a correlation value of $r = .4926 \pm .0474$, computed by the product-moment method, using ungrouped data for 115 variants. This statistically significant correlation is fairly high and justifies one in placing considerable confidence in this test as a means of selecting cold resistant strains for future testing. Aside from winter survival, no field notes were taken at Moccasin and St. Paul. Hence the relationship between hardiness and other characters is based on studies at Colby and Manhattan.

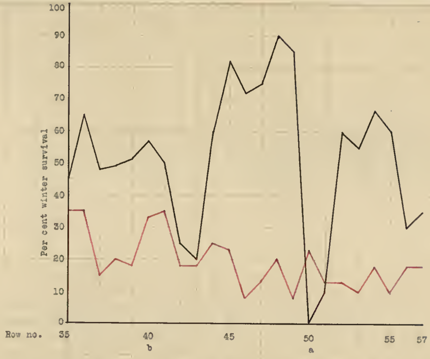

Fig. 1 Winter survival of F_6 Kanred x Kanmarq selections and checks grown at Moccasin, Montana, and St. Paul, Minnesota, in 1931.

a = Kanmarq check.
b = Kanred check.
——— (red) = Average per cent survival at Moccasin, Mont.
——— (black) = Average per cent survival at St. Paul, Minn.

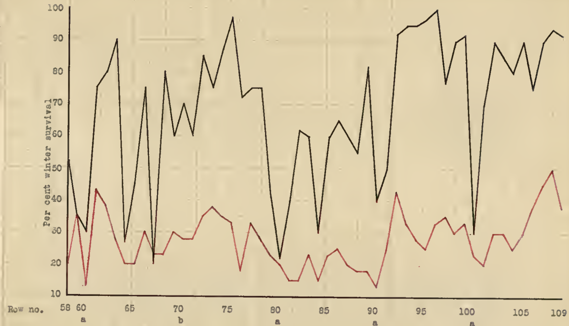

Fig. 2 Winter survival of F_6 Tenmarq x Kanred selections and checks grown at Moccasin, Montana, and St. Paul, Minnesota, in 1931.

a = Tenmarq checks.
b = Kanred check.
——— (red) = Average per cent survival at Moccasin, Mont.
——— (black) = Average per cent survival at St. Paul, Minn.

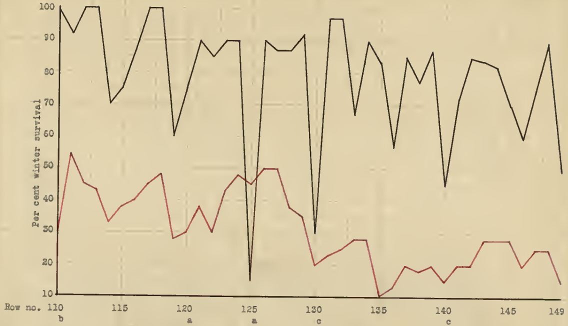

Fig. 3 Winter survival of F_6 Kanred x Kansas No. 443 selections and checks grown at Moccasin, Montana, and St. Paul, Minnesota, in 1931.

a = Kansas No. 443 checks.
b = Kanred check.
c = Tenmarq check.
(red line) = Average per cent survival at Moccasin, Mont.
(black line) = Average per cent survival at St. Paul, Minn.

In a cross between Kanred and Minturki, Quisenberry and Clark (23) found that lateness and winterhardiness usually are associated. In a large number of crosses between very hardy, late varieties such as Minhardi, Odessa and Buffum No. 17, and high-yielding, good quality wheats such as Turkey and Kanred, nearly all of the hybrids tested were too late for Kansas conditions. Quartile averages of date of full heading in the four-station winterhardiness nursery at Colby and the two-station (Moccasin and St. Paul) survival, 1931, are given in Table XV.

Table XV. Relation between the two-station (Moccasin and St. Paul) survival, and dates fully headed of the F_6 back crosses grown at Colby, Kansas, 1931.

Hardiness quartile	Kanred x Kanmarq: 2-sta. survival %	Kanred x Kanmarq: Date fully headed	Tenmarq x Kanred: 2-sta. survival %	Tenmarq x Kanred: Date fully headed	Kanred x Kansas No. 443: 2-sta. survival %	Kanred x Kansas No. 443: Date fully headed
I.	52	6/1	65	5/31	71	6/1
II.	42	6/1	58	6/1	63	6/1
III.	35	5/30	47	6/1	53	6/1
IV.	21	6/1	32	5/31	43	5/31

There is some evidence of a slight tendency for the upper hardiness quartiles to be about one day later than the lower quartiles, but the difference is too small and the relationship too inconsistent to be significant. Some of the strains grown in the four-station winterhardiness nursery were also grown in triplicate rod rows at Manhattan. A comparison of the two-station survival and earliness at Manhattan is shown in Table XVI.

Table XVI. Relation between the two-station (Moccasin and St. Paul) survival, and dates fully headed of the F_6 back crosses grown at Manhattan, Kansas, 1951.

Hardiness quartile	Kanred x Kanmarq: 2-sta. survival %	Kanred x Kanmarq: Date fully headed	Tenmarq x Kanred: 2-sta. survival %	Tenmarq x Kanred: Date fully headed	Kanred x Kansas No. 443: 2-sta. survival %	Kanred x Kansas No. 443: Date fully headed
I.	50	5/26	62	5/23	70	5/26
II.	42	5/24	55	5/24	65	5/24
III.	35	5/20	43	5/24	53	5/23
IV.	21	5/24	31	5/23	43	5/23

Except for the Tenmarq x Kanred cross, there is a tendency for the wheats in the more hardy quartiles to be later than the less hardy lines. These data, however, suggest the possibility of obtaining early, winterhardy strains. For example, the hardiest one-fourth of the Tenmarq x Kanred strains were as early as the lowest quartile group.

A winterhardy strain of wheat is of little value unless accompanied by high-yielding ability. Quartile averages of the two-station winter survival and yield in the four-station winterhardiness nursery at Colby are given in Table XVII.

Table XVII. Relation between the two-station (Moccasin and St. Paul) survival, and yield of the F_6 back crosses grown at Colby, Kansas, 1931.

Hardiness quartile	Kanred x Kanmarq: 2-sta. survival %	Kanred x Kanmarq: Bu. per acre	Tenmarq x Kanred: 2-sta. survival %	Tenmarq x Kanred: Bu. per acre	Kanred x Kansas No. 443: 2-sta. survival %	Kanred x Kansas No. 443: Bu. per acre
I.	55	35.7	67	36.1	72	37.5
II.	48	33.0	59	38.1	67	38.7
III.	42	34.9	56	36.3	61	35.9
IV.	24	37.2	44	39.4	53	31.4

In the first two crosses, the yield at Colby increased with a decrease in hardiness as tested at St. Paul and Moccasin, but the reverse is found in the last cross. Correlations between two-station survival and yield at Colby of -.3533 ± .2362 for the Kanred x Kanmarq cross, -.1235 ± .1212 for Tenmarq x Kanred, and +.4261 ± .1206 for Kanred x Kansas No. 443 shows this same relationship. These correlations were determined on relatively small numbers and for this reason should be considered as only approximations to the true relationships. Quartile averages of two-station survival and yield of the same strains in triplicated rod rows at Manhattan, Kansas, 1931, are given in Table XVIII.

Table XVIII. Relation between the two-station (Moccasin and St. Paul) survival, and yield of the F_6 back crosses grown at Manhattan, Kansas, 1931.

Hardiness quartile	Kanred x Kanmarq 2-sta. survival %	Kanred x Kanmarq Bu. per acre	Tenmarq x Kanred 2-sta. survival %	Tenmarq x Kanred Bu. per acre	Kanred x Kansas No. 443 2-sta. survival %	Kanred x Kansas No. 443 Bu. per acre
I.	49	43.2	64	46.9	71	44.9
II.	42	51.2	60	47.1	64	46.0
III.	32	48.7	53	44.4	56	47.0
IV.	15	47.7	39	46.4	43	49.5

Two-station survival and yield at Manhattan gave a correlation coefficient of -.3366 ± .1635 for Kanred x Kanmarq crosses, + .1170 ± .1453 for Tenmarq x Kanred, and -.3500 ± .1141 for Kanred x Kansas No. 443. There is some indication that hardiness at the two northern stations was associated with low yield at Manhattan except for the small positive correlation of the Tenmarq x Kanred cross. There are wide variations in yields of a strain at Colby and

Manhattan, Kansas. This would be expected due to the great differences in rainfall and other climatic and soil conditions at the two stations. Since lateness is usually associated with hardiness, and high yield associated with earliness, the negative correlation between yield and hardiness is probably partly due, indirectly, to the time of heading-hardiness relationship. Even a partial understanding of character relationships is a great aid to the plant breeder.

Greenhouse freezing trials of hybrid strains are used to supplement field tests. This method is particularly valuable at stations in the central section of the winter wheat belt, including Kansas, where severe winterkilling occurs only occasionally. Greenhouse growing conditions are very different from field conditions and it is important to know the correlation between greenhouse and field freezing before using the greenhouse freezing trials as a means of selecting cold resistant plants.

Harland Stevens (29) made extensive greenhouse freezing tests on the F_5 Tenmarq x Kanred crosses in 1930. These strains were grown at Colby, Kansas, the same year and survival notes taken in the spring. The following is a comparison of the greenhouse freezing injury and survival in the nursery at Colby:

Greenhouse injury quartile	Average per cent freezing injury in refrigeration chamber	Per cent winter survival Colby, Kansas
I.	47.6	79
II.	70.2	72
III.	75.6	69
IV.	84.2	76

Injury in the field ranked in the same order as in the greenhouse except for the high survival of 76 per cent in the field in greenhouse quartile IV., which may be due to the fact that the greenhouse tests were made on unhardened plants.

All of the Tenmarq x Kanred strains grown in the four-station winterhardiness nursery were tested in F_5 in the greenhouse freezing trials. A quartile comparison of freezing injury in the greenhouse with the two-station survival of the strains in the field is as follows:

Greenhouse injury quartile	Average per cent freezing injury in refrigeration chamber	2-station (Moccasin and St. Paul) winter survival %
I.	44.9	59.2
II.	58.2	57.1
III.	69.0	44.7
IV.	83.4	40.4

The freezing at Moccasin and St. Paul was greater and is a better measure of cold resistance than the previous years' field results at Colby. It will be noticed that the two-station survival decreased uniformly as the injury in the greenhouse increased. The survival in the greenhouse and the two-station survival of the strains gave a correlation coefficient of +.6562 ± .0393. This high correlation is significant and indicates that the greenhouse might well be used in testing hybrids for hardiness, especially in the earlier generations, e.g., F_3 to F_5. The strains of Tenmarq x Kanred showing a high two-station survival and low greenhouse freezing injury are being tested in 1932 at four northern experiment stations.

Late spring freezes at Colby seriously damaged some of the strains of the back crosses in the spring of 1931. The dates of freezing and the temperatures recorded in May, 1931, at three stations in Kansas, taken from climatological data, are as follows:

	Date May	Temperature
Manhattan	20	32° F.
Hays	12	32° F.
	20	29° F.
	22	29° F.
Colby	12	31° F.
	20	29° F.
	22	29° F.

These dates of last killing frosts in the spring are much later than normal, the average dates of last killing frosts being April 26 for Manhattan, May 2 for Hays, and April 29 for Colby, for the twenty-year period ending with 1917.

The value of resistance to late freezing or the danger of loss from such injury to early, tender wheats is dependent upon the frequency of occurrence of killing frosts late in May. The following are late dates of last killing frosts at three stations in Kansas from the establishment of weather bureau stations in 1917, inclusive:

Station	Period	Date of last killing frost in the spring	
Manhattan	1858-1917	1874	May 22
		1894	" 20
		1907	" 27
		1911	" 22
Colby	1893-1917	1894	May 19
		1901	" 26
		1915	" 21
Hays	1893-1917 (excluding 1899 and 1900)	1896	May 19
		1901	" 26
		1907	" 27

Judging from past weather records, one might expect killing frosts from May 19 to May 27 once in about every ten years. There have been few reports of damage to wheat by late killing frosts in the past, but a greater damage may be expected in the future as farmers change from growing late to early varieties.

The wheats at Colby apparently were injured by the two low temperatures of May 12 and the period May 20 to 22, and it is impossible to distinguish between injuries caused during two periods of low temperatures. The first freeze caused all of the wheat to lie flat on the ground, but all of the strains wholly or partly recovered from this condition. The second freeze occurred when the wheat was in the boot stage. Early Blackhull was fully headed at that time and was very severely damaged. Later in the season the injured strains assumed a bushy, sprangly, matted type of growth, probably due to plant injury and produced many white spikelets and heads, probably due to sterility caused by freezing of the wheat flowers.

The resistance to late spring freezing injury is probably dependent largely on the ability of the plant to withstand low temperatures and the stage of maturity of plants at the time of freezing. The relation between hardiness and late freezing at Colby is shown in Table XIX. The strains injured by freezing had a lower two-station (Moccasin and St. Paul) survival percentage than the uninjured strains, but a difference of only four per cent probably is not large enough to be significant.

Table XIX. Comparison of two-station (Moccasin and St. Paul) survival with spring freezing injury, Colby, Kansas, 1931.

Cross	Strains showing no spring freezing injury: No. of strains	Strains showing no spring freezing injury: 2-sta. survival %	Strains showing spring freezing injury: No. of strains	Strains showing spring freezing injury: 2-sta. survival %
Kanred x Kanmarq	17	36	4	37
Tenmarq x Kanred	40	51	7	47
Kanred x Kansas No. 443	27	59	8	51
Average of all strains	84	51	19	47

Results obtained in other tests indicate that injury was greatly influenced by the stage of maturity of plants at the time the freeze occurred. At North Platte, Nebraska, where the season is later than at Colby, the rye crop was practically ruined while the wheat was uninjured. Rye is more cold resistant than wheat but is also earlier and was headed at the time the freeze occurred. In nine cooperative tests located in seven counties, southeast of Colby, Early Blackhull, a very early variety of wheat, had an average of 39.5 per cent sterile florets, as compared to 0.61 per cent for Kanred which was not in head at that time. The failure of the florets to fill was apparently a result of injury to the wheat flower in those spikelets which were in bloom at the time of the freeze. South and east of this area, the temperature was apparently not low enough to cause sterility, while north and west the early varieties had not yet headed and were not injured.

The relation between time of heading at Colby and Manhattan and spring freeze injury is shown in Table XX.

Table XX. Relation of spring freezing injury to dates of heading at Colby and Manhattan, Kansas, 1931.

Cross	Strains showing no spring freezing injury		Strains showing spring freezing injury	
	No. of strains	Date fully headed	No. of strains	Date fully headed
Colby				
Kanred x Kanmarq	17	6/1	4	5/30
Tenmarq x Kanred	40	5/31	7	5/30
Kanred x Kansas No. 443	27	6/1	8	5/31
Average all strains	84	6/1	19	5/30
Manhattan				
Kanred x Kanmarq	17	5/24	4	5/23
Tenmarq x Kanred	31	5/24	6	5/22
Kanred x Kansas No. 443	27	5/25	8	5/22
Average all strains	75	5/24	18	5/22

The strains injured by the spring freeze averaged two days earlier than the uninjured strains at both stations. As the injury at Colby affected the whole plant and not just the spike, the early strains with the heavy growth would be apt to receive the greatest injury. It is possible that an early strain of wheat may evade spring freezing injury one season and in another season with a different time of maturity-date of freezing relationship, a late strain will evade freezing injury. As the season progresses the likelihood of a killing frost diminishes and a late strain of wheat stands a better chance of evading spring freezing injury than an early strain.

Early varieties have a practical value in lengthening the harvest season and, therefore, cutting down the hazards of ripe and over-ripe wheat. Since one of the characters being selected for in these crosses is earliness, one must decide whether to discard the early strains injured by the spring freeze, or keep them on the basis that they will be superior to the later strains in years when spring freezing does not occur. The Colby nursery is not a fair test of inherent yielding ability as the strains injured by freezing were greatly handicapped. Data on the same strains grown at Manhattan, Table XXI., give a fair comparison of yielding ability where spring freezing did not occur. The strains not injured by freezing at Colby yielded practically the same at Manhattan as those injured by the spring freeze at Colby, which probably would justify discarding most of the strains injured by spring freezing.

Table XXI. Comparison of spring freezing injury at Colby with yields of the same strains at Manhattan, Kansas, 1931.

Cross	Strains showing no spring freezing injury		Strains showing spring freezing injury	
	No. of strains	Bushels per acre Manhattan	No. of strains	Bushels per acre Manhattan
Kanred x Kanmarq	12	48.4	3	44.9
Tenmarq x Kanred	19	46.0	4	46.6
Kanred x Kansas No. 443	24	46.5	7	47.4
Average all strains	55	46.8	14	46.6

Field Studies of Other Agronomic Characters

High yield of grain is perhaps the most valuable characteristic of a cereal crop. It is the end result and sum total of the activities of the plant. Two main forces determine the amount of seed produced (30). These are environment and heredity. In a cross between two durum wheats, Clark and Smith (7) found yield of F_3 plants intermediate between the parents with certain F_3 strains exceeding the yield of the best parent checks.

The yields of the F_5 strains grown at Colby, 1930, are presented in Table XXII. The Kanred x Kanmarq strains were intermediate in yield between the two parents; the Tenmarq x Kanred strains averaged above, and the Kanred x Kansas No. 443 strains averaged below both parents. Kanred yielded more than the winter x spring parents. Conditions at Colby seem favorable for Kanred and it often outyields Tenmarq at that station.

Table XXII. Yields of F_5 back crosses and checks, grown in duplicate 8-ft. rows, Colby, Kansas, 1930.

Cross	No. of strains	Average yield Bu. per acre
Kanred x Kanmarq	79	40.3
Kanred checks	5	41.0
Kanmarq checks	3	25.1
Tenmarq x Kanred	123	42.0
Kanred checks	10	41.4
Tenmarq checks	8	37.6
Kanred x Kansas No. 443	125	37.3
Kanred checks	10	39.5
Kansas No. 443 checks	8	37.7
Average of F_5 strains	327	39.8

The F_5 generation was space-planted in eight-foot rows at Manhattan. A frequency distribution of yields of the three back crosses is shown in Table XXIII. The yields covered a wide range as is usually the case with space-planted rows.

Table XXIII. Frequency distribution of the yields of the three back crosses, Manhattan, Kansas, 1930.

Weight of grain grams per row	Kanred x Kanmarq	Tenmarq x Kanred	Kanred x Kansas No. 443
	"f"	"f"	"f"
50 - 59	1	1	1
60 - 69			
70 - 79	1		1
80 - 89	1	1	1
90 - 99		1	3
100 - 109	7	1	6
110 - 119	9	9	8
120 - 129	5	6	6
130 - 139	7	11	11
140 - 149	11	7	14
150 - 159	10	12	16
160 - 169	8	12	8
170 - 179	10	4	14
180 - 189	12	11	14
190 - 199	6	10	16
200 - 209	4	10	6
210 - 219	3	8	4
220 - 229	1	8	5
230 - 239	4	3	2
240 - 249	1	1	4
250 - 259		1	3
260 - 269		1	2
270 - 279		2	
280 - 289		1	1
290 - 299			
300 - 309			
310 - 319	1		

The yields of the F_6 back crosses grown in triplicated rod rows, at Manhattan, in 1931, are given in Table XXIV. The crosses in each case were intermediate in yield between the two parents. Tenmarq averaged 18.9 bushels more per acre than Kanred. The yields were similar to those obtained for the strains grown in single rod rows, Table XXV.

Table XXIV. Yields of F_6 back crosses and checks, triplicated rod rows, Manhattan, Kansas, 1931.

Cross	No. of strains	Average yield Bu. per acre
Kanred x Kanmarq	20	47.7
Kanred checks	3	34.5
Tenmarq checks	3	54.1
Tenmarq x Kanred	45	46.4
Kanred checks	2	37.7
Tenmarq checks	2	52.3
Kanred x Kansas No. 443	55	45.9
Kanred checks	2	41.2
Tenmarq checks	2	50.8
Average all F_6 strains	120	46.8
" Kanred checks	7	37.3
" Tenmarq checks	7	52.6

Table XXV. Yields of F_6 back crosses and checks, single rod rows, Manhattan, Kansas, 1931.

Cross	No. of strains	Average yield Bu. per acre
Kanred x Kanmarq	38	44.2
Kanred checks	2	43.0
Tenmarq checks	2	50.5
Tenmarq x Kanred	28	46.9
Kanred checks	2	47.9
Tenmarq checks	3	53.1
Kanred x Kansas No. 443	24	51.6
Kanred checks	3	47.7
Tenmarq checks	2	51.1
Average all F_6 strains	90	47.0
" Kanred checks	7	46.4
" Tenmarq checks	7	52.4

In triplicated rod row tests at Colby, Kansas, the F_6 crosses were intermediate in yield between the two parents, as shown in Table XXVI. Kanred checks outyielded the Tenmarq checks as in the previous year whereas the reverse was true at Manhattan. The low yield of Tenmarq at Colby may be accounted for, in part, by freezing injury. The yields of the strains grown in duplicate eight-foot rows are given in Table XXVII. Compared with the parents, these strains ranked in the same order as those grown in triplicated rod rows.

Table XXVI. Yields of F_6 back crosses and checks, triplicated rod rows, Colby, Kansas, 1931.

Cross	No. of strains	Average yield Bu. per acre
Kanred x Kanmarq	42	36.0
Kanred checks	2	39.9
Kanmarq check	1	29.6
Tenmarq x Kanred	51	37.0
Kanred checks	2	41.1
Tenmarq checks	2	33.3
Kanred x Kansas No. 443	65	37.9
Kanred checks	2	40.4
Kansas No. 443 checks	2	31.8
Average of all F_6 strains	158	37.1

Table XXVII. Yields of F_6 back crosses and checks, duplicate eight-foot rows, Colby, Kansas, 1931.

Cross	No. of strains	Average yield Bu. per acre
Kanred x Kanmarq	8	34.4
Tenmarq x Kanred	35	37.3
Kanred x Kansas No. 443	22	36.3
Kanred checks	3	39.0
Tenmarq checks	6	32.0
Kanmarq check	1	20.3

Variations in ranking of yields of check varieties between Manhattan and Colby would lead one to expect that the hybrid strains might also react differently to the environmental conditions at the two stations. To determine this, a correlation of yield was made on strains grown at the two stations. Yields of strains grown in comparable triplicated rod row nurseries at the two stations gave a correlation value of $r = -.1292 \pm .1297$. This is not a significant negative correlation, but it plainly shows that the same strains did not produce high yields at both stations. A high positive correlation might indicate wide adaptation. This correlation and the yields of the checks would indicate that Tenmarq should not be recommended as a commercial wheat for northwestern Kansas and that selections of the back crosses made under the less severe conditions at Manhattan may not be well adapted at Colby.

Reports on correlation between yield and earliness have varied greatly, depending upon location of the experiments. In a study of sixty-one hard red spring wheat strains grown at the Morris Branch Station, Minnesota, Bridgford and Hayes (2) obtained a positive correlation between yield and date of heading. Definite evidence was obtained of negative correlation between yield, and days from seeding to heading, by Goulden and Elders (10) from data collected during the season of 1925 on 146 wheat varieties grown at Winnipeg, Manitoba. Finnell (9) found no consistent relation between time of maturity and yield in variety tests at the Panhandle Experiment Station, Goodwell, Oklahoma, during the period, 1924 to 1930. Following is a quartile comparison of yield and earliness of 120 F_6 strains of the three back crosses grown in triplicated rod rows at Manhattan, 1931:

Yield quartile	Average yield Bu. per acre	Average date fully headed
I.	52.1	5/23
II.	47.8	5/22
III.	45.4	5/24
IV.	41.8	5/24

The upper two yield quartiles averaged 6.3 bushels higher in yield than the lower two quartiles, and were one to two days earlier. This relationship did not exist at Colby, as shown by the following quartile average of 155 F_6 strains grown in triplicated rod rows at Colby, Kansas, 1931:

Yield quartile	Average yield Bu. per acre	Average date fully headed
I.	41.5	5/30
II.	38.6	5/30
III.	36.2	5/30
IV.	31.9	5/30

Sixty-five strains of the back crosses grown in duplicate eight-foot rows at Colby in 1931 gave the following averages:

Yield quartile	Average yield Bu. per acre	Average date fully headed
I.	42.3	5/31
II.	39.0	6/1
III.	35.2	6/1
IV.	29.6	6/1

The strains in quartile I. headed one day earlier than the strains in the other three quartiles. Differences in earliness at Colby were so slight that little confidence can be placed in these comparisons. The late spring freeze at Colby injured the early strains. The high yield of Kanred and the low yield of Tenmarq at Colby suggest that cold resistance is of great importance there. Earliness is probably desirable but needs to be combined with hardiness.

In some wheat crosses earliness is dominant to lateness. Thus in a back cross of a late spring hybrid selection from Marquis x Kanred, to Marquis (1), the segregation for early and late heading suggested at least a two-factor difference with earliness dominant to lateness. In various crosses between six varieties of spring wheats, including Marquis (28), the mean of the F_1 population was intermediate but nearer to the early than to the later parent. The means of the F_2 generation were intermediate or tended toward the early parent. The F_2 was more variable than either parent and extended over a range approximating the combined range of both parents. The F_3 families showed almost all degrees of earliness within the limits of the parent varieties and in some crosses the extremes of both parents were exceeded.

The dates of heading of the F_4 hybrids and parents at Manhattan, 1929, are shown in Table XXVIII. The Kanred x Kanmarq crosses were earlier than either parent; the Tenmarq x Kanred crosses were equal to the Tenmarq check in earliness, and the Kanred x Kansas No. 443 crosses were two days later than the Kansas No. 443 check. The tendency toward earliness in the hybrid strains is probably due to the selection of early strains in previous generations.

Table XXVIII. Dates fully headed of F_4 back crosses and checks grown in eight-foot, space-planted rows, Manhattan, Kansas, 1929.

Cross	No. of strains	Average date fully headed
Kanred x Kanmarq	139	6/2
Kanred checks	8	6/4
Kanmarq checks	7	6/3
Tenmarq x Kanred	130	6/1
Kanred checks	7	6/3
Tenmarq checks	7	6/1
Kanred x Kansas No. 443	211	6/2
Kanred checks	12	6/4
Kansas No. 443 checks	12	5/31

In the F_5 generation, Table XXIX., the first two crosses were as early as the early parent and the Kanred x Kansas No. 443 hybrids were three days later than the Kansas No. 443 parent. In each cross the hybrids averaged two days earlier than the Kanred parent.

Table XXIX. Dates fully headed of F_5 back crosses and checks, grown in eight-foot, space-planted rows, Manhattan, Kansas, 1930.

Cross	No. of strains	Average date fully headed
Kanred x Kanmarq	142	5/31
Kanred checks	10	6/2
Kanmarq checks	9	5/31
Tenmarq x Kanred	188	5/30
Kanred checks	11	6/1
Tenmarq checks	11	5/30
Kanred x Kansas No. 443	264	6/1
Kanred checks	18	6/3
Kansas No. 443 checks	18	5/29

In the F_6, Table XXX., as in the other generations, the hybrid strains averaged nearer the early parent in date of heading than Kanred. Many of the strains headed earlier than the early parent while very few were later than the late parent. It should be possible to select from the back crosses desirable hybrid strains equal to Tenmarq in earliness.

Table XXX. Dates fully headed of F_6 back crosses and checks, grown in triplicated rod rows, Manhattan, Kansas, 1931.

Cross	No. of strains	Average date fully headed
Kanred x Kanmarq	32	5/25
Kanred check	1	5/27
Kanmarq check	1	5/24
Tenmarq x Kanred	67	5/24
Kanred checks	2	5/26
Tenmarq checks	2	5/23
Kanred x Kansas No. 443	69	5/24
Kanred checks	2	5/26
Tenmarq checks	2	5/22

Lodging is greatly influenced by the environment, especially fertility of the soil, but many strains of wheat have been produced which have the inherent ability to stand well. According to the Howards of India (15), standing power appears to be due to at least two factors; first, to strong straw, which is generally associated with very erect heads, and second, to what may be called power to form a strong root system. Lodging in Kansas appears to be due chiefly to weak straw. Salmon (25) found a high positive correlation between strength of straw, as tested with a straw-breaking machine in the laboratory and resistance to lodging in the field.

The percentages of lodging of the F_5 back crosses and checks are given in Table XXXI. The strains of each of the three back crosses were intermediate in lodging resistance between Kanred, the weak-strawed parent, and the stiff-strawed winter x spring wheat parents.

Table XXXI. Lodging of F_5 back crosses and checks, grown in eight-foot, space-planted rows, Manhattan, Kansas, 1930.

Cross	No. of strains	Average per cent lodging
Kanred x Kanmarq	167	11.2
Kanred checks	10	25.5
Kanmarq checks	9	4.4
Tenmarq x Kanred	217	9.4
Kanred checks	11	19.5
Tenmarq checks	11	2.3
Kanred x Kansas No. 443	326	19.3
Kanred checks	18	24.2
Kansas No. 443 checks	18	13.1

In 1931, the wheats in the nursery were badly lodged. The percentages of lodging of 180 hybrids and checks grown in triplicated rod rows are shown in Table XXXII. The first two crosses were intermediate in lodging between Tenmarq and Kanred, but the third cross was more resistant to lodging than the Tenmarq checks. The strains showing a high degree of lodging were discarded in the field.

Table XXXII. Lodging of F_6 back crosses and checks, grown in triplicated rod rows, Manhattan, Kansas, 1931.

Cross	No. of strains	Average per cent lodging
Kanred x Kanmarq	32	67.6
Kanred check	1	70.0
Tenmarq check	1	62.0
Tenmarq x Kanred	60	61.7
Kanred checks	2	76.0
Tenmarq checks	2	56.5
Kanred x Kansas No. 445	69	49.2
Kanred checks	2	70.0
Tenmarq checks	2	51.0

Lodging may be caused in part by a heavy yield of grain. It is impossible to distinguish between lodging due to weak straw and that due to excessive weight of heads. Wheat may appear to have stiff straw when in reality the heads are too light to break the straw. This fact makes it more difficult to produce high-yielding strains which are resistant to lodging.

In a test of 146 wheat varieties, Goulden and Elders (10) obtained a negative correlation between yield and strength of straw. Following is a quartile average of yield and lodging of 122 strains of the three back crosses grown in triplicated rod rows, Manhattan, 1931:

Yield quartile	Average yield Bu. per acre	Average per cent lodging
I.	52.1	53.4
II.	47.8	53.1
III.	45.4	57.9
IV.	41.8	56.1

High-yielding strains have been developed which are more resistant to lodging than the lower-yielding strains. High-yielding plants resistant to lodging have been selected in each generation and distinct progress has been made.

Leaf rust occurs in Kansas every year and in some years severe epidemics cause serious losses. Mains (19) estimated the average reduction in wheat yield in Kansas amounted to 14 per cent or 16,413,000 bushels for the nine years from 1919 to 1927. Johnston (16) and others (20), (2), and (10), showed that heavy infections of leaf rust greatly reduced the yield of wheat. The loss in yield was due principally to a reduction in the number of kernels produced, and in the size of the individual kernels. Leaf rust infection increases the water requirement of plants (21) and, therefore, is an important factor in regions where the supply of moisture is limited. Quartile averages of yield and percentage of leaf rust infection of the

F_6 back crosses grown in triplicated rod rows, Manhattan, 1931, are as follows:

Yield quartile	Average yield Bu. per acre	Average per cent leaf rust infection
I.	52.1	4.7
II.	47.8	7.3
III.	45.4	6.5
IV.	41.8	6.5

The upper yield quartile had the lowest leaf rust infection and quartile II. the highest, the average infection being a little lower than for the two lowest yield quartiles. Nearly all hybrids included in these comparisons are rust resistant.

The average per cent of leaf rust infection of the F_3 to F_6 back crosses is presented in Table XXXIII. In every case except one, the crosses averaged between the two parents in per cent infection. It will be noticed that the hybrids averaged nearer the rust resistant winter x spring parents, than Kanred. The back-crossed straine apparently retained some of the leaf rust resistance of the least susceptible parent, and progress has been made in the selection of rust resistant strains.

Bridgford and Hayes (2), in a study of 61 wheats, found a positive correlation between height and yield. Height was also correlated positively with heads per spike

Table XXXIII. Average per cent of leaf rust infection of F_3 to F_6 generations of back crosses, 1928 to 1931, Manhattan, Kansas.

Cross	F_3 1928 No. of strains	F_3 1928 Av. % infection	F_4 1929 No. of strains	F_4 1929 Av. % infection	F_5 1930 No. of strains	F_5 1930 Av. % infection	F_6 1931 No. of strains	F_6 1931 Av. % infection
Kanred x Kanmarq	114	28.6	138	15.4	165	28.7	32	5.6
Kanred checks	4	40.0	8	41.3	10	60.0	1	20.0
Kanmarq checks	4	27.0	7	13.6	9	13.8	1	1.0
Tenmarq x Kanred	211	28.8	131	42.2	216	36.0	69	5.9
Kanred checks	5	38.0	7	60.0	11	65.0	2	17.5
Tenmarq checks	6	28.0	7	19.3	11	8.4	2	3.5
Kanred x Kansas No. 443	37	34.1	211	47.5	113	38.5	69	5.7
Kanred checks	1	30.0	12	55.8	3	65.0	2	7.5
Kansas No. 443 checks	1	30.0	12	28.8	10	7.0		
Tenmarq checks							2	5.0

and kernels per spikelet which may largely account for the increase in yield. Following is a quartile comparison of yield and height of the F_6 back crosses grown at Manhattan in 1931:

Yield quartile	Average yield Bu. per acre	Average height inches
I.	52.1	40.4
II.	47.8	39.6
III.	45.4	39.7
IV.	41.8	39.6

The strains in yield quartile I. averaged about an inch taller than the other three quartiles which were practically equal in height. At Colby there was a greater difference in height as shown by the following quartile average of the F_6 back crosses grown at Colby in 1931:

Yield quartile	Average yield Bu. per acre	Average height inches
I.	41.5	31.6
II.	38.6	31.0
III.	36.2	30.5
IV.	31.9	30.5

The plants in yield quartile I. averaged 1.1 inches, and quartile II. 0.5 inch taller than the plants in quartiles III. and IV. In a dry season the short strains probably would more nearly equal the tall strains in yield. By selecting short strains suitable for the combine harvester, one is apt to discard a large number of the higher yielding strains.

Quality Studies

It is generally recognized that milling and baking qualities are dependent upon genetic factors, but environmental conditions profoundly influence the expression of these factors. Various wheat breeders (13), including Biffen and Engledow in England, Saunders in Canada, and the Howards in India, agree that milling quality is an heritable character. It was observed both in England and India that varieties which differed in baking qualities tended to retain their same order of flour strength at different stations. There is every reason to conclude that good milling quality can be combined with other desirable characters by crossing and subsequent selection.

Notes on grain texture, plumpness, and yellow berry were taken on all strains of the back crosses and test weights were obtained whenever a sufficient supply of grain was available. Protein determinations were made on a large number of samples and baking tests made on a few of the strains in the F_8 generation. In classifying wheats as to texture, four divisions are used; corneous, semi-corneous, semi-starchy, and starchy. All of the back-crossed strains and parental checks are described as semi-corneous.

The relationship between plumpness and yield of the F_6 generation of the back crosses is shown in Table XXXIV. The strains were divided on the basis of plumpness into two groups, the lower and upper halves. High yield was associated with plump kernels except for the Tenmarq x Kanred cross grown at Manhattan in which the average yield was 0.2 bushel in favor of the less plump group. In the other five cases, the yields were from 0.8 to 5.4 bushels higher for the plump kernel group. This agrees with the findings of Hayes, Aamodt, and Stevenson (12), who obtained a positive correlation of .6228 between plumpness and yield in winter wheat. Bridgford and Hayes (2) also found yield and plumpness to be positively correlated in spring wheats.

Table XXXIV. Relation between kernel plumpness and yield of F_6 back-crossed strains grown in 1931.

Cross	Manhattan		Colby	
	Av. % plump-ness	Av. yield Bu. per A.	Av. % plump-ness	Av. yield Bu. per A.
Kanred x Kanmarq				
Upper plumpness half	84	50.4	83.3	36.4
Lower " "	80	45.0	80.7	35.5
Tenmarq x Kanred				
Upper plumpness half	82	46.5	82.2	39.2
Lower " "	79	46.7	79.2	34.9
Kanred x Kansas No. 443				
Upper plumpness half	85	47.1	82.0	38.3
Lower " "	82	46.1	79.4	37.5

According to Hayes, Aamodt, and Stevenson (12), a simple note regarding grain plumpness is apparently of much importance in an estimate of the probable value of a new selection or hybrid variety. Selection on the basis of grain plumpness appears well worth while during the segregating generations of hybrids when accurate yield data are not available. The average plumpness of F_3 to F_5 generations and parents of bulked grain from space-planted rows is given in Table XXXV. The hybrid strains averaged higher in plumpness than the low parent except for the F_3 Tenmarq x Kanred crosses in which only one check of each parent was available, which is not a reliable comparison. The hybrid strains averaged nearer the high parent in percentage of plumpness than the low parents and in three instances averaged higher than either parent.

Test weight probably is a better measure of plumpness than is a general note taken by observation of a small sample. By bulking the grain from the three rod rows in the triplicated series, it was possible to determine the test weight for the F_6 generation, Table XXXVI. There was a close association between test weight and yield, similar to the plumpness-yield relationship for Manhattan. At Manhattan a difference of one pound in test weight accompanied an average difference of approximately one and

Table XXXV. Average percentage of plumpness of grain bulked from space-planted rows of the F_3 to F_5 generation of hybrids and checks grown at Manhattan, Kansas, 1928 to 1930.

Cross	F_3 generation		F_4 generation		F_5 generation	
	No. of strains	Av. % plumpness	No. of strains	Av. % plumpness	No. of strains	Av. % plumpness
Kanred x Kanmarq	101	86.8	80	79.5	103	86.2
Kanmarq checks	3	88.3	7	75.7	9	85.0
Kanred checks	4	86.3	8	78.1	10	83.0
Tenmarq x Kanred	37	87.3	107	76.5	119	84.7
Tenmarq checks	1	90.0	7	75.4	11	86.4
Kanred checks	1	90.0	6	75.0	11	82.7
Kanred x Kansas No. 443	193	89.2	150	80.4	146	87.1
Kansas No. 443 checks	6	90.3	8	81.1	18	88.6
Kanred checks	6	87.5	10	73.8	18	83.6

Table XXXVI. Relation between test weight and yield of F_6 hybrids grown in 1931.

Cross	Test weight quartiles	Manhattan		Colby	
		Test weight lbs.	Yield Bu. per A.	Test weight lbs.	Yield Bu. per A.
Kanred x Kanmarq	I.	61.3	49.3	60.4	36.5
	II.	60.4	48.9	59.8	37.7
	III.	59.8	47.0	59.4	37.0
	IV.	59.1	45.1	58.9	35.1
Tenmarq x Kanred	I.	60.5	47.4	60.0	40.9
	II.	59.7	48.8	59.5	37.9
	III.	59.3	45.2	59.0	38.5
	IV.	58.7	44.4	58.2	35.0
Kanred x Kansas No. 443	I.	61.3	47.4	59.4	38.1
	II.	60.8	46.2	58.8	38.6
	III.	60.1	47.5	58.4	38.5
	IV.	59.3	45.4	57.8	37.9

one-half bushels in yield. At Colby the association was less marked, however, in each cross, quartile I. had a higher yield than quartile IV.

Clark (4) concluded that there is segregation for crude protein content in wheat hybrids similar to that for other quantitative characters, including yield. His data indicate that the inheritance of crude protein content is as complex as that of yield and that environment is fully as important in determining the result in one case as in the other. In crosses between Nodak and Kahla wheats in North Dakota (7), crude protein content for F_3 strains was intermediate in comparison with the parents, with an indication of transgressive inheritance beyond that of the parents for both high and low protein content.

The average protein content of the F_6 hybrid strains and checks grown in triplicated rod rows at Manhattan in 1931, is given in Table XXXVII. The Kanmarq and Tenmarq crosses were intermediate in protein content between the Tenmarq and Kanred checks and the Kansas No. 443 cross averaged lower than the Tenmarq check. Six of the hybrid strains had a higher protein content, and thirteen had a lower protein content than either parent, showing some evidence of transgressive segregation.

Table XXXVII. Average protein content of F_6 hybrids and checks grown in triplicated rod rows, Manhattan, Kansas, 1931.

Cross	No. of strains	Average per cent protein
Kanred x Kanmarq	8	14.55
Tenmarq x Kanred	14	14.34
Kanred x Kansas No. 443	19	13.49
Tenmarq checks	5	13.64
Kanred checks	4	14.84

The average protein content of the hybrids and checks grown at Colby, Kansas, in 1931, is given in Table XXXVIII.

Table XXXVIII. Average protein content of F_6 hybrids and checks grown in triplicated rod rows, Colby, Kansas, 1931.

Cross	No. of strains	Average per cent protein
Kanred x Kanmarq	6	12.18
Kanmarq check	1	12.90
Kanred checks	2	12.20
Tenmarq x Kanred	14	12.59
Tenmarq checks	2	12.93
Kanred check	1	12.25
Kanred x Kansas No. 443	13	12.62
Kansas No. 443 checks	2	14.05
Kanred checks	2	13.25

Protein determinations were made on only one or two checks of each parent which does not make a fair comparison with the back crosses.

At Manhattan, Kanred had a higher protein content and lower yield than Tenmarq, while at Colby, Kanred had a lower protein content and higher yield than Tenmarq, indicating inverse correlation between protein and yield.

In a cross between Marquis and Kota grown in Montana, (6) yield and crude protein content were negatively correlated in both the F_2 and the F_3 generations, but in neither case was the correlation coefficient sufficiently large to be considered important from a plant breeding standpoint. Clark (4) states that the two characters are frequently but not always negatively associated. The quartile averages of protein content and yield of the F_6 generation grown in triplicated rod rows are shown in Table XXXIX. Contrasted with results from other stations, there was some tendency for high protein content and high yield to be positively associated. This is probably due in part at least to the selection in earlier generations of high-yielding strains having a high protein content.

Table XXXIX. Relation between protein content and yield of F_6 hybrids grown in triplicated rod rows, 1931.

Protein quartiles	Manhattan: Average per cent protein	Manhattan: Average yield Bu. per A.	Colby: Average per cent protein	Colby: Average yield Bu. per A.
I.	14.92	52.4	13.36	41.6
II.	14.17	50.9	12.60	42.1
III.	13.72	51.8	12.28	41.4
IV.	13.10	50.6	11.90	37.8

For wheats weighing more than 54 pounds, Shollenberger (27) found a tendency for protein to decrease as the weight per bushel increased. The wheats used in this study all had test weights above 54 pounds to the bushel. At Manhattan, Table XL., there was a gradual increase in per cent plumpness as the protein content decreased.

Table XL. Relation between plumpness and protein content of F_6 hybrids grown in triplicated rod rows, 1931.

Protein quartiles	Manhattan: Average per cent protein	Manhattan: Average per cent plumpness	Colby: Average per cent protein	Colby: Average per cent plumpness
I.	14.92	82.1	13.36	81.0
II.	14.17	82.7	12.60	80.6
III.	13.72	82.9	12.28	81.3
IV.	13.10	84.4	11.90	82.1

Wheats grown at Colby gave similar results to those at Manhattan except for a reverse order in quartiles I. and II.

According to Jones and Mitchell (17), yellow berry is the manifestation of nutritional disturbances, resulting from insufficiency of nitrogen and other elements of plant food for adequately meeting the requirement of a normally developing crop. Based on their statement, one would expect the strains of wheat high in yellow berry to have a low protein content. This is the case as shown in Table XLI. There was an increase of 6.4 per cent in yellow berry from the high to low protein content quartile of the strains grown at Manhattan and an increase of 9.3 per cent for the strains grown at Colby.

Table XLI. Relation between protein content and yellow berry of F_6 hybrids grown in triplicated rod rows, 1931.

Protein quartiles	Manhattan		Colby	
	Average per cent protein	Average per cent yellow berry	Average per cent protein	Average per cent yellow berry
I.	14.92	9.0	13.36	5.4
II.	14.17	7.1	12.60	10.0
III.	13.10	9.7	12.28	7.8
IV.	13.98	15.4	11.90	14.7

High yellow berry and high yield are associated as shown in Table XLII. Although the difference in yield between the high and low yellow berry strains are not great, in all of the comparisons at the two stations except one, high yellow berry is accompanied by high yield. Tenmarq often has a high percentage of yellow berry kernels. At Manhattan, where Tenmarq yielded much higher than Kanred, it also had a much higher percentage of yellow berry, while at Colby where it yielded less than Kanred, it also averaged higher in percentage of yellow berry than Kanred, which would indicate that the high yellow berry content of Tenmarq is at least in part due to its high yielding ability.

Eight of the back-crossed strains and one Tenmarq check grown in the Manhattan nursery in 1931 were milled and baked by the Department of Milling Industry, Kansas State College, see Table XLIII. The hybrids made fair to good loaves and all the strains tested were suitable for bread-making purposes. The three Kanred x Kanmarq crosses had higher loaf volumes than the Tenmarq check, but the five strains from the other two crosses had slightly lower loaf volumes than the Tenmarq check. Kanred x Kanmarq, mill serial No. 17005, had a loaf volume of 1710 c.c., which is 130 c.c. larger than the Tenmarq check.

Table XLII. Relation between yellow berry and yield of F_6 hybrids grown in triplicated rod rows, 1931.

Cross	No. of strains	Average per cent yellow berry	Average yield Bu. per A.
Manhattan			
Kanred x Kanmarq	10	14.4	48.7
	10	1.8	46.7
Tenmarq x Kanred	22	12.7	47.9
	22	4.4	45.0
Kanred x Kansas No. 443	27	21.6	46.3
	28	4.5	45.2
Tenmarq checks	3	17.3	55.0
Kanred "	3	4.7	38.0
Colby			
Kanred x Kanmarq	21	10.5	36.6
	21	2.2	35.3
Kanmarq checks	1	5.0	39.1
Kanred "	2	9.0	39.9
Tenmarq x Kanred	26	12.8	37.7
	26	3.3	36.5
Tenmarq checks	2	14.0	33.3
Kanred "	1	7.0	41.5
Kanred x Kansas No. 443	32	10.7	38.3
	33	3.3	37.5
Kansas No. 443 checks	2	1.5	31.8
Kanred checks	2	8.0	40.4

Table XLIII. Milling and baking data of F_6 back crosses and Tenmarq check grown in triplicated rod rows, Manhattan, Kansas, 1931.

KSC mill serial number	Variety	1931 row no. KSC	Test wgt. lbs.	Protein: Wheat %	Protein: Flour %	Flour ash %	Water absorption %	Loaf: Color score	Loaf: Texture score	Loaf: Vol. c.c.
17005	Kanred x Kanmarq	1862	61	13.9	12.0	.36	74	99	98	1710
17003	do	1849	61	14.3	12.3	.38	76	98	96	1590
17006	do	1865	62	14.8	12.7	.37	76	99	96	1590
17007	Tenmarq check	1867	61	13.6	11.5	.37	72	99	98	1580
17051	Kanred x Kansas No. 445	2020	62	13.1	11.2	.39	74	97	92	1570
17038	Tenmarq x Kanred	1976	62	13.8	12.1	.38	74	99	9[illegible]	1540
17025	do	1924	60	15.4	11.6	.40	74	98	93	1530
17028	do	1928	61	14.0	12.1	.38	76	98	90	1500
17059	Kanred x Kansas No. 445	2033	62	13.0	11.3	.37	74	98	91	1500

Tenmarq was equal to the best hybrid strain in color and texture scores, while one of the Tenmarq x Kanred strains was down to 90 in texture. All of the hybrid strains were higher in water absorption than Tenmarq. In Plate I., sample No. 5 represents the best, and sample No. 4 the poorest loaf from the Kanred x Kanmarq cross. Sample No. 7 is a Tenmarq check. Sample No. 14 represents the poorest and sample No. 15 the best loaf from the Tenmarq x Kanred cross. The picture shows distinct differences in baking value of the hybrids, and it should be possible to select back-crossed strains having excellent baking qualities.

SUMMARY AND CONCLUSIONS

1. In 1925, three back crosses were made involving Kanred, in an effort to combine additional factors for winterhardiness from Kanred with those for earliness, stiff straw, high yield, and excellent quality of Kanmarq, Tenmarq and Kansas No. 443.

2. Tenmarq has consistently outyielded Kanred over a period of years in nursery and plot tests at Manhattan, branch stations in Kansas, cooperative experiments with farmers in Kansas, and at cooperating stations in nearby states.

Plate I. Loaves of bread baked from flour of Kanred x Kanmarq and Tenmarq x Kanred crosses, and a Tenmarq check.

Nos. 5 and 4, Kanred x Kanmarq crosses.

No. 7, Tenmarq check.

Nos. 14 and 15, Tenmarq x Kanred crosses.

Plate I.

3. The superiority of Tenmarq over Kanred is due to earlier maturity, stiffer straw, higher yields, and better quality. Kanred is superior to Tenmarq in winterhardiness and is somewhat less susceptible to Hessian fly.

4. The F_2 generation of the back crosses was grown at Davis, California. The F_1 was grown in the greenhouse and F_3 to F_5 generations were grown in space-planted, eight-foot rows at Manhattan. Some strains of the F_4 and F_5 generations were also grown at Colby, Kansas. The back crosses were handled as individual plants through the F_5 generation.

5. The F_6 generation was grown in rod rows at Manhattan and Colby, Kansas. One hundred and four strains of the hybrids were also grown in duplicate eight-foot rows in four-station winterhardiness nurseries at St. Paul, Minnesota; Moccasin, Montana; Redfield, South Dakota; and Colby, Kansas.

6. Very little winterkilling occurred in the F_3 to F_6 generations grown at Manhattan. The average two-station survival at St. Paul, Minnesota, and Moccasin, Montana, ranged from 12 per cent for the Kanmarq checks to 56 per cent for the Kanred x Kansas No. 443 strains. Many of the hybrid strains had a higher survival than either parent, giving evidence of transgressive segregation for winterhardiness. The survival of the strains at Moccasin and

St. Paul gave a correlation of r = +.4926 ± .0474.

7. There was some indication that the hardiest strains were latest in maturity and that hardiness determined at the northern stations was associated with low yield as determined on the same strains grown in Kansas.

8. Freezing survival in the greenhouse and the Moccasin and St. Paul survival of the hybrid strains gave a correlation coefficient of +.6362 ± .0393, suggesting that the greenhouse might profitably be used in testing hardiness of new wheats in Kansas, where severe winterkilling in the field seldom occurs.

9. Late killing frosts occurred at Colby, Kansas, on May 20 and 22, 1931, causing sterility in some wheat flowers and abnormal plant development of some of the hybrid strains, greatly reducing their yield.

10. The hybrid strains injured by the late spring freeze averaged two days earlier in maturity and had a slightly lower two-station survival than the uninjured strains. Early maturity probably is the most important plant characteristic affecting the susceptibility to spring freezing injury. When grown at Manhattan where no late freezing occurred, the strains which were injured at Colby produced yields equal to uninjured strains.

11. The F_6 hybrid strains gave average yields intermediate between the two parents at Colby and Manhattan, Kansas.

12. Earliness was associated with high yield, the association being greater at Manhattan than at Colby. The hybrid strains averaged nearer the early parent in date of heading than Kanred. Many of the strains headed earlier than the early parent, while very few were later than the late parent.

13. The back crosses were intermediate in lodging between Kanred and the other parents. The high-yielding strains were more resistant to lodging than the lower-yielding strains.

14. The back-crossed strains apparently retained some of the leaf rust resistance of the less susceptible parent. There was some association between high yield and low leaf rust infection.

15. In 1931, the high-yielding hybrid strains produced taller plants than the low-yielding strains.

16. Yield was positively associated with test weight and percentage of plump kernels and the hybrid strains averaged nearer the better parent in kernel plumpness.

17. Tenmarq and Kanred checks showed negative cor-

relation between protein and yield and a positive correlation between yellow berry and yield.

18. High-yielding hybrid strains were developed which had a higher protein content than the low-yielding strains.

19. Protein was negatively associated with percentage plumpness of grain and yellow berry.

20. Yellow berry and yield were positively associated.

21. All of the hybrid strains tested were suitable for bread-making purposes. Some of the strains were equal to Tenmarq in baking qualities.

22. The expression of characteristics and association of characters in the back crosses probably is the joint result of inheritance, artificial selection in F_2 to F_6, and of natural selection.

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