A STUDY OF THE INHERITANCE OF COLD RESISTANCE AND OTHER CHARACTERS IN THE CROSS, KANRED X BLACKHULL

by

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INTRODUCTION

The Kanred x Blackhull and reciprocal crosses used in this study were made by B. B. Bayles in the Agronomy Nursery at Manhattan in 1922. The F_0 seeds were sown in the Agronomy Greenhouse in the fall of 1922 and sixteen F_1 plants were harvested in the spring of 1923. The F_2 generation was not grown until the winter of 1926-1927.

Kanred and Blackhull were the two most widely grown varieties in Kansas at the time this cross was made. Both varieties had a number of desirable characters and a number of undesirable ones. By growing sufficient numbers and by proper selection, it was thought that a higher yielding, moderately stiff strawed and more winterhardy wheat for Kansas might be produced from this cross.

As reported by Clark and Salmon (1), Kanred is a pure line selection from Crimean wheat developed at the Kansas Agricultural Experiment Station. It is bearded and has glabrous white glumes. In appearance it closely resembles the Turkey and Kharkov varieties from which it can usually be distinguished by the longer beaks on the outer glumes. The beaks of Kanred wheat vary from one-eighth of an inch to an inch in length. In all other respects, Kanred is similar to Turkey and Kharkov except that it is slightly

earlier, slightly more winter resistant and is remarkably resistant to some forms of leaf rust and to some forms of black stem rust. Kanred has out-yielded Turkey and Kharkov by an average of about four bushels per acre over a ten-year period. It is grown on about two million acres in Kansas. The undesirable characters of Kanred are its weak straw and its susceptibility to Hessian fly.

Blackhull wheat, as reported by Salmon, Swanson and Laude (2), was originated by Earl G. Clark of Sedgwick, Kansas, and first distributed by him in 1917. This variety is now grown on about four million acres in Kansas. Blackhull possesses some very desirable characters. It excels Kanred in stiffness of straw, in resistance to Hessian fly attack, in test weight and in yield. Blackhull heads several days earlier than Kanred. In nine years of nursery trials it has yielded on the average 3.31 bushels more per acre than Kanred; the grain is softer in texture; the gluten or protein, although equal in quantity, is not so strong, and hence, is not so satisfactory in commercial bakeries as is Kanred wheat.

Both Kanred and Blackhull are only medium early in maturity.

While each of the varieties carries genes for several valuable agronomic characters, neither excels the other in any one character sufficiently to lead one to expect a super wheat in quality, earliness, yield, stiffness of straw, disease resistance, insect resistance, or in winter-hardiness.

REVIEW OF LITERATURE

Cold Resistance in Wheat

Clark, Martin and Parker (3) state that low temperatures cause severe losses in the winter wheat growing regions of the United States and that lack of winterhardiness is probably responsible for a large proportion of the ten per cent abandonment of wheat acreage each year, in Kansas.

Martin (4) found that hardy wheats differ from non-hardy wheats in that they have a lower moisture content in their leaf tissue during the winter, a juice with a higher per cent of total solids, a higher osmotic pressure when the plants are growing rapidly, a juice with a higher percentage of bound water, a lower rate of respiration at low temperatures and frequently longer periods of vegetative growth. During the hardening of wheats, the moisture content decreases, there is an increase in the total solids

in the sap and imbibing pressure of the cell colloids. The quantity of juice is positively correlated with moisture content, while percentage of total solids and freezing point depression of the juice are negatively correlated with moisture content. The factors influencing the cold resistance of a plant may vary widely among different varieties at different seasons and under varying conditions.

Klages (5) reports that extreme depressions of temperature, -13° to -21° C. from greenhouse temperatures of 18° C., and low soil moisture, due to its retardation of the life processes of plants, exert a protective influence during the first part of exposure to low temperatures. After killing once sets in on soils with a low moisture content, it progresses rapidly. The more active the plants are at the time of freezing, the more marked is the protective influence of low soil moisture content during the early periods of exposure. More plants survive on soils with a high moisture content than on woils with a low moisture content. Plants on soils containing 40 to 50 per cent moisture were always the last to reach the point of complete killing.

Newton(6) found no constant relation between depression of freezing point, specific conductivity or hydrogen

ion concentration of the cell sap and relative frost hardiness nor was the relation between dry matter content and hardiness constant.

The sugar content did not correspond uniformily with the known hardiness. The percentage of sugar decreased between November 12 and December 9, falling lowest in the tender varieties. Sucrose was apparently the only disaccharide present. Plants of all varieties studied were entirely free of starch.

In a second paper, Newton (7) states that the imbibition pressure of fresh leaves in the winter-hardened condition was in most cases directly related to hardiness. Unhardened leaves showed no relation between imbibition pressure or volume of press juice and hardiness. The moisture content of hardened tissues tends to be inversely proportional to the hardiness. There is some evidence that in hardy varieties it fluctuates less with changes in weather conditions.

Study of F_2 Generation

L. L. Davis (8) made a study of the progenies of the Kanred x Blackhull and reciprocal crosses in the F_1 and F_2 generations.

In the F_1 he reports on plant height, date of heading and number of culms. The sixteen hybrids grown averaged 60.5 inches in height as compared with an average height of 55 inches for Kanred and 54 inches for Blackhull. Only four plants of each of the parents were grown. Heterosis was evident in the F_1 plants.

The average number of culms per plant was 4.5, 3.5, and 4.5 for the Kanred, Blackhull and the F_1 hybrids, respectively.

The heading dates show the F_1 hybrids to be intermediate, as compared with the parents.

Beak Length. In the F_2, Davis reports as follows: The parents differed markedly in beak length. In every case but one, the average beak length of the hybrids was intermediate to that of Kanred and Blackhull. The one exception, family F_1-5a, may not be a hybrid. Each plant in the family had a beak length of 1 mm. Families F_1-1b and F_1-2b are the only reciprocal crosses of Kanred x Blackhull, and these two families showed the shortest beak length of any of the families. The range for the fifteen F_2 families, excluding F_1-5a, was considerable; namely, from 6 mm. to 14.8 mm.

No clear Mendelian ratio was shown, probably due to the lack of sufficient numbers, and to the quantitative nature of the character under observation.

A distribution of the beak lengths of F_2 hybrids shows sixty-four that are short, ninety-five intermediate, and twenty that are long, indicating rather clearly that the short beak length is dominant. Davis shows, by combining the short and intermediate beak lengths, that a ratio approaching 15:1 gives the closest fit. The calculated ratio is 168.8:11.2 or a deviation of 8.8±2.18. This is 4.04 times the probable error, and is of doubtful significance.

Heading Dates. A study of heading dates showed the average of the F_2 families to be May 18, or three days earlier than Kanred and five days earlier than Blackhull.

Individual families showed an average heading date much earlier than that of either parent.

Families F_1-5b and F_1-1a were twelve and thirteen days earlier than the average of the parents, respectively.

Plumpness and Yellow Berry. A study of the plumpness of the kernels and per cent yellow berry of the grain produced by the F_2 hybrids shows individual plants ranging from 25 to 95 per cent plump, and 0 to 90 per cent yellow

berry. Families F_1-5a and F_1-2a showed the greatest range in plumpness notes, 57.2 and 88.8, respectively.

Kernels of Kanred and Blackhull had average plumpness notes of 76.9 and 72.2, respectively. The average per cent yellow berry of Kanred and Blackhull is 18 and 2.8 per cent, respectively. This difference is in agreement with observations made on samples grown in the field over a period of years.

Number of Heads and Culms per Plant. The number of tillers and heads per plant showed considerable variation in the F_2 families. The per cent of culms producing heads ranged from 38.7 per cent for family F_1-5a to 87 per cent for family F_1-3c.

Habit of Growth. The Kanred and Blackhull parents of this cross are classed as having a prostrate and semi-erect growth habit, respectively. Habit of growth notes were taken when the F_2 plants were approximately six inches high. The F_2 hybrids at this stage showed all possible gradations from prostrate to erect. Different families showed striking differences. Of the total population, 105 were classed as prostrate, 84 as semi-erect and 11 as erect. The greatest differences were between families

F_1-22-1d and F_1-3c in which all plants were as prostrate as Kanred, and family F_1-2b in which all plants were semi-erect, similar to the Blackhull parent.

MATERIALS AND METHODS

The equipment used in this study was a steam-heated greenhouse, about two thousand four-inch clay pots, and a thermostatically controlled low temperature machine. Seeds were sown in four-inch clay pots filled with a screened mixture of one part decomposed manure, one part of sand, and three parts of a black clay loam garden soil.

The pots were kept on sanded benches approximately thirty-eight inches from the floor. While the plants were small and after their removal from the freezing chamber, they were watered each morning sufficiently to keep them from wilting.

Greenhouse temperatures of 50° to 65° F. were maintained throughout the winter except for two unusually cold nights when the temperature dropped to 40° F. for a few hours.

Freezing studies in the greenhouse were made by means of a direct expansion, automatically regulated, carbon dioxide refrigeration machine. The cooling was effected by means of nine coils of pipe surrounding the sides, ends

and bottom of the interior of the freezing chamber which was approximately ten feet long, four feet wide, and three feet deep. A thermostat was adjusted and used to automatically regulate the machine at a desired temperature, turning it on and off within a range of 3° C. Approximately eighty-five potted plants were placed in the machine at a time. Each freezing lot consisted of an equal number of plants of each family and from five to ten plants of each of the two parents to serve as checks or controls.

A few hours before freezing as much water was added to the soil as it would readily take up. After freezing, the plants were set on greenhouse benches and kept under the usual greenhouse conditions as to temperature and watering.

EXPERIMENTAL RESULTS

F_3 Greenhouse Cultures, 1927-1928

In October, 1927, the seed of the eighty-two F_2 families of the Kanred x Blackhull cross was planted. Ten seeds from each of the families were planted in as many pots. One hundred kernels of each of the parents were sown to be used as checks on the results obtained from the hybrids.

Plants Placed Out-of-doors. On November 6, 1927, all of the pots were placed out-of-doors. They were placed on a flat, level strip of ground protected on the south and west sides by greenhouses and on the northeast by a small clump of trees. The plants when placed out-of-doors were approximately four inches in height and had hardly begun to tiller. The lateness of the season and the danger of freezing temperatures indicated that it was best to put them out at this stage of growth so that they might have a chance to acquire a certain degree of hardiness. Had they been kept indoors until further tillers had developed, the change from greenhouse to outdoor conditions might have been severe enough to kill the plants before they had had a chance to become hardened. Two rather severe cold spells on December 7 and 11 and December 15 to 17 resulted in the loss of all plants of both hybrids and parents. All of the plants were moved into the greenhouse on December 17 and the killing became apparent a few days later. The first indications of the death of the plants were the yellowing and drying of the plant leaves.

To eliminate any possibility of there being a shortage of plant food, a nutrient solution was added, using a formula suggested by Dr. M. C. Sewell. The stock solution consisted of 236 grams of $Ca(NO_3)_2.4H_2O$ in a liter,

136.1 grams of $KH_2PO_4 \cdot 4H_2O$ in a liter and 246.3 grams of $MgSO_4$ in a liter. From this stock solution, 22.7 c.c. of of $Ca(NO_3)_2$, 30.1 c.c. of KH_2PO_4, and 8 c.c. of $MgSO_4$ were taken and made up to one liter and as much applied to each plant as the pots would hold, which was somewhat less than half a pint.

In a few plants the yellowing seemed to be checked for a time. Others that had been more severely injured showed no signs of having been benefited by the nutrient solution. Dr. E. C. Miller suggested that the yellowing may have been due to freezing injury to the roots. Roots of a number of the yellowed plants were washed free of soil and examined. In every case, the crown had begun to blacken and rot and the roots were of a dull grey color, as compared with the bright, healthy appearance of the roots of normal, unfrozen plants grown in the greenhouse.

Preliminary notes on freezing injury were taken on the plants a few days after they were moved indoors. The injured leaves of frozen plants were non-turgid and greenish black in color, depending on the degree of injury. Tips of the leaves were injured before the lower parts of the leaves were affected. Old leaves showed injury sooner than the young leaves. Estimates of injury in percentages were based on the amount of leaf injury. Zero indicated

no visible injury. Plants with leaves completely killed were graded as 100 per cent injured.

A second and final set of notes was ordinarily taken about seven to fourteen days later. In some cases, only one set of notes was taken. These were found to check very closely with the preliminary notes, except where yellowing of the leaves had interfered.

The percentage of injury varied from 76.6 per cent for families F_1-1a-11 to 100 per cent for sixteen other families. The average per cent injury for 666 plants in the eighty-two families placed out-of-doors was 97.1 as compared with the average per cent injury of Blackhull, 100 per cent and Kanred 99.2 per cent.

Due to the severe amount of yellowing, a second set of notes was not taken. No plants of the first planting survived so that further studies could not be made.

Table I. shows a temperature range from 81° F., on November 10 to 3° F. on December 7 during the forty-two days that these plantings were out-of-doors. No appreciable damage was noticed before the five days of cold weather on December 7 to 11, inclusive, during which time the minimum temperatures were respectively 3°, 6°, 12°, 8° and 11° F. On December 15, the minimum temperature was 42° F. and the maximum was 58° F. Two days later, on December 15, 16 and

Table 1. Temperatures during period in which Kanred, Blackhull and F_3 hybrid plants were outside greenhouse.

November, 1927			December, 1927		
Date	Degrees, F. Max.	Min.	Date	Degrees, F. Max.	Min.
6	64	29	1	44	16
7	59	40	2	33	9
8	58	26	3	61	23
9	55	40	4	46	17
10	81	44	5	53	19
11	73	32	6	60	36
12	50	21	7	37	3
13	62	34	8	12	6
14	68	36	9	35	12
15	37	24	10	28	8
16	41	21	11	24	11
17	38	26	12	52	21
18	35	23	13	58	42
19	36	29	14	52	27
20	51	33	15	38	9
21	69	44	16	36	4
22	53	29	17	30	9
23	33	28			
24	35	22			
25	63	35			
26	60	43			
27	52	38			
28	64	32			
29	62	41			
30	43	27			

17, the temperature dropped to 9°, 4°, and 8° F., respectively. All plants were moved indoors on December 18. The two cold periods so close together were severe enough to fatally injure all plants, though some of the plants did not die for a month or more. The nearly optimum greenhouse temperatures allowed the less severely injured plants to survive for a time while those more severely injured died immediately.

Very little was learned from this planting except that a few families F_1-1a-15, F_1-1b-3, F_1-1b-8 and F_1-3a-2 contained a comparatively large number of plants, six or more of the ten plants per family, that showed a lower preliminary freezing injury than did other families.

Plants Kept in the Greenhouse. A second and duplicate planting was made of the eighty-two F_2 families of this Kanred x Blackhull cross. This second planting was grown in the greenhouse. Plants were allowed to grow until four to six inches high or until they had begun to tiller. They were then frozen in an automatically regulated freezing machine for a twelve-hour period. The mean temperature chosen, after a series of preliminary freezing trials on Kanred and Blackhull, was -8.5° C. or 16.7° F. In each freezing lot, five or more plants of each parent were included as standards to be used as a comparison of the

amount of injury to the hybrids. The temperatures selected were such as would cause rather severe injury to Blackhull, the less hardy parent, and only slight injury to the Kanred plants. At these temperatures the majority of the hybrids were expected to be injured more than Blackhull and less than Kanred. A small proportion of the F_3 plants was expected to be less hardy than Blackhull, and it was thought that another portion might show more cold resistance than Kanred. Such was found to be true, as will be shown later.

Preliminary freezing trials indicated that differential freezing results were harder to get when plants were frozen for a few hours at a low temperature than when frozen for a 10-12 hour period at a higher temperature. It was found that at very low temperatures, the period of time between no injury and complete killing of a variety was too short for accurate determination. Twelve hours proved to be a convenient schedule for freezing two sets of plants each day. The degree of freezing injury was found to be considerably affected by the amount of moisture in the soil at the time of freezing. Plants in a moist soil were less injured than those in a dry soil. An explanation of this may be that dry soil is a better conductor of cold since it contains more air. Such a soil

when placed in the freezing chamber allowed the temperature to drop more rapidly than would the same soil if it were wet. Plants frozen for twelve hours in a dry soil will be at an average lower minimum temperature for more hours than will similar plants frozen in a wet soil.

Each lot of approximately eighty-five plants in the freezing box required from four to six hours of continuous refrigeration to lower them to the mean minimum temperature of -8.5° C. Once the minimum of -10° C. was reached, the temperature alternated over a range of 3° C., i.e., from -10° C. to -7° C., every fifteen to thirty minutes. The periods of alternation became slower towards the end of each twelve-hour period as the soil temperature approached a constant.

Eight to ten days after freezing, a preliminary set of freezing injury notes was taken, based on the visible amount of leaf injury. Zero was used to indicate complete survival or no injury, fifty per cent referred to such plants as had approximately half of the tissue above ground killed, and 100 per cent was used to indicate complete killing.

A second set of notes was taken on some of the plants ten to fourteen days later. Many of the plants yellowed so badly as to prevent the taking of an accurate second

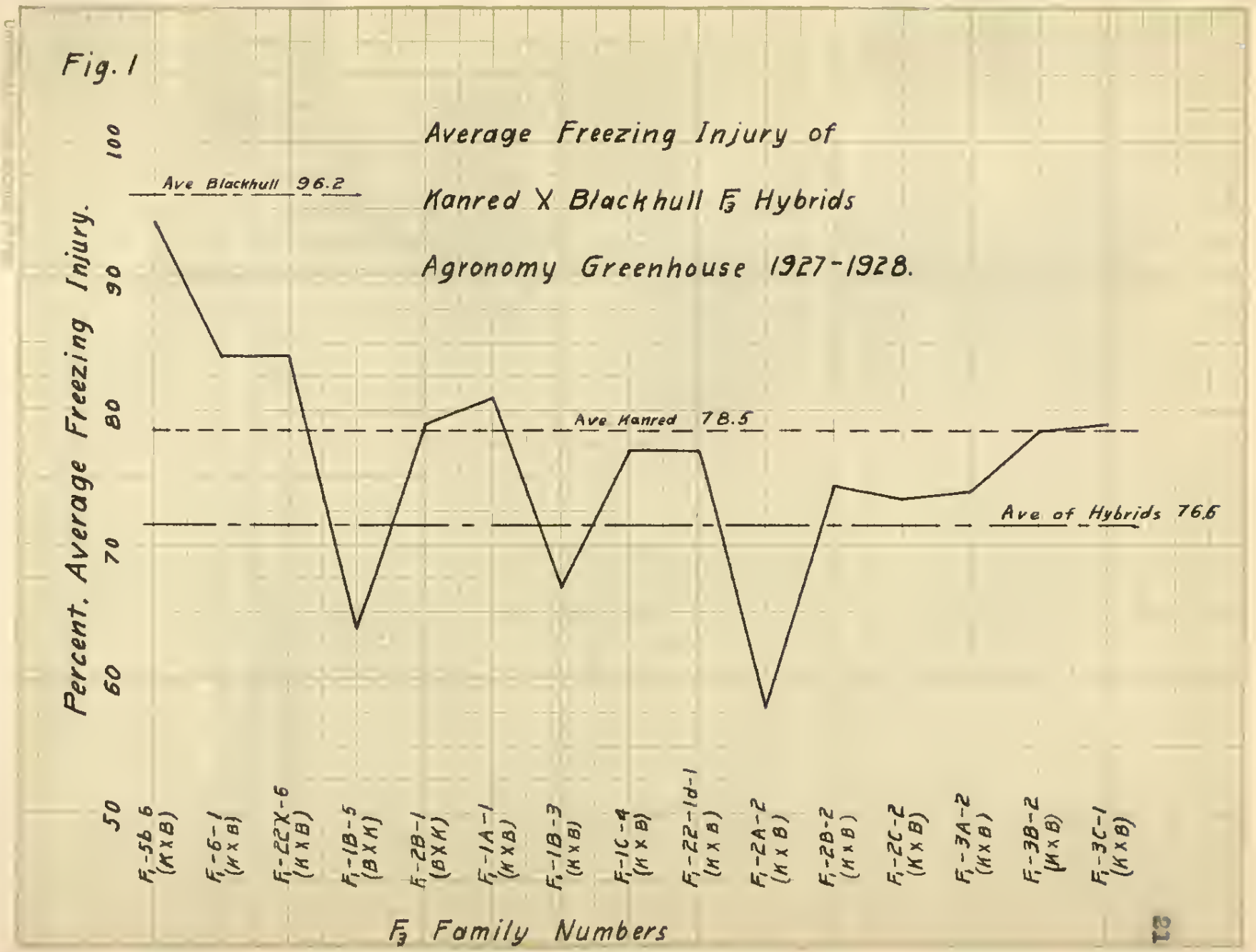
note. The second readings that were taken checked very closely with the first set.

In an attempt to prevent plants from yellowing, a nutrient solution similar to the one used in the plants kept out-of-doors was added to the plants grown in the greenhouse. The results were similar to those previously described. Some of the plants survived, others seemed to recover for a time but died later, and others showed no signs of improvement. The plants that survived were grown to maturity. Habit of growth and date of heading notes were taken on all these plants. At the time of harvest, notes were taken on height of plants, number of culms, and number of heads. No differences in glume coloring were apparent. The greenhouse conditions evidently were not such as to develop the black glume color in the Blackhull parental variety.

Winterhardiness. The artificial freezing studies made in the greenhouse showed some appreciable differences between the Kanred and Blackhull checks and between F_3 hybrid families.

Figure 1 indicates that the greatest amount of freezing injury, 93.9 per cent, occurred in family F_1-5b-6 and that the least injury, 58 per cent, occurred in family F_1-2a-2.

Fig. 1


Average Freezing Injury of
Kanred X Blackhull F3 Hybrids
Agronomy Greenhouse 1927-1928.
Ave Blackhull 96.2
Ave Kanred 78.5
Ave of Hybrids 76.6
Percent. Average Freezing Injury.
100
90
80
70
60
50
F1-56 6 (K x B)
F1-6-1 (K x B)
F1-22X-6 (K x B)
F1-1B-5 (B x K)
F1-2B-1 (B x K)
F1-1A-1 (K x B)
F1-1B-3 (K x B)
F1-1C-4 (K x B)
F1-22-1d-1 (K x B)
F1-2A-2 (K x B)
F1-2B-2 (K x B)
F1-2C-2 (K x B)
F1-3A-2 (K x B)
F1-3B-2 (K x B)
F1-3C-1 (K x B)
F3 Family Numbers

The average injury of the fifteen families tested was 76.6 per cent, as compared with 96.2 per cent, the average of Blackhull, and 78.5 per cent for Kanred.

Transgressive segregation was evident. The eight families F_1-1b-5, F_1-1b-3, F_1-1c-4, F_1-22-1d-1, F_1-2a-2, F_1-2b-2, F_1-2c-2 and F_1-3a-2 showed less average freezing injury than the average of the Kanred plants and considerably more cold resistance than the average of the Blackhull checks. The average per cent of freezing injury of Blackhull was higher than that of any one of the fifteen hybrid families. There were, however, individual plants from a number of families that were less hardy than were many of the individual plants of Blackhull. A single plant is not considered a reliable index of the cold resistance of a variety or of a hybrid family.

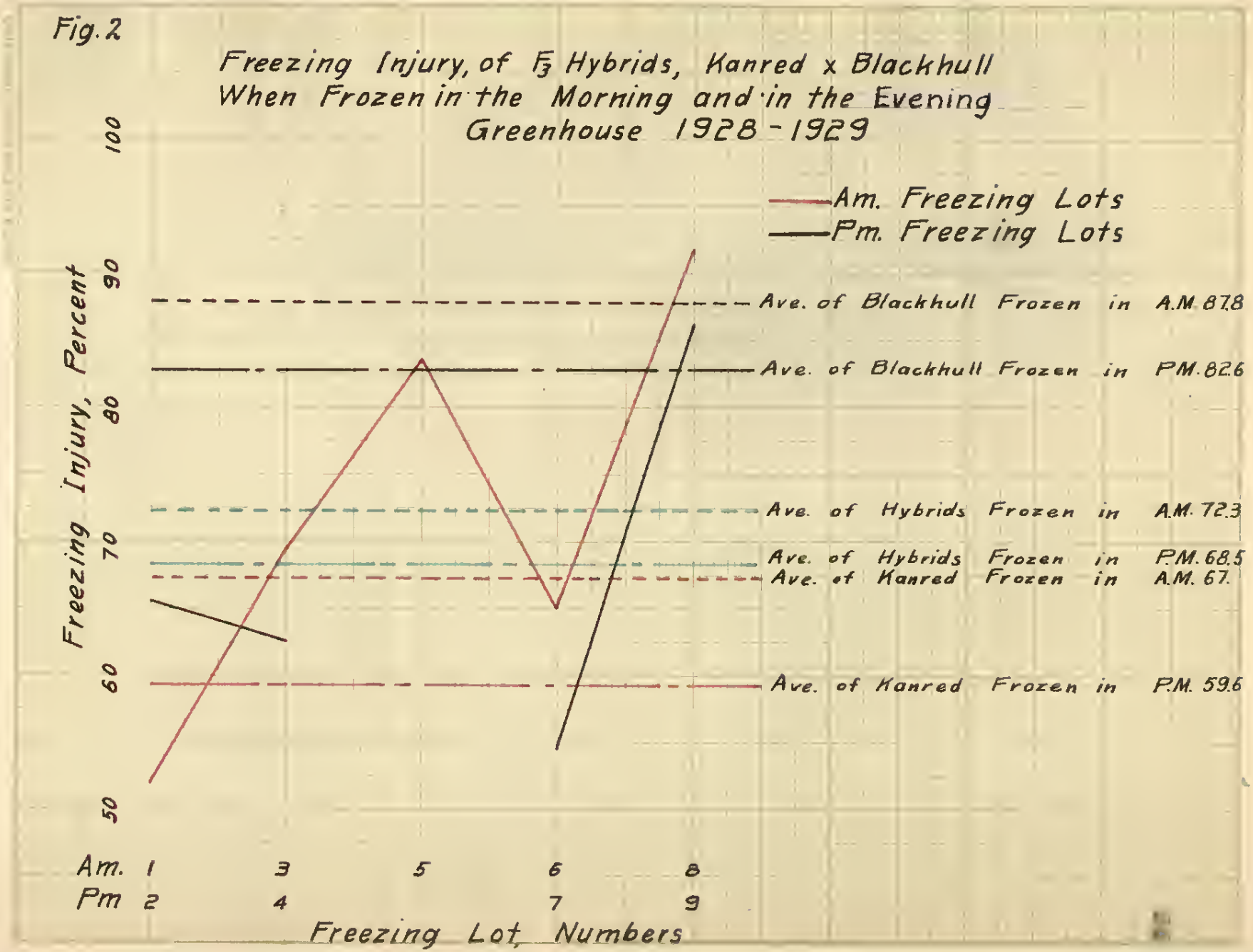
Relative Freezing Injury to Plants Frozen in the Daytime and at Night. Table II. shows that of nine lots of hybrid plants frozen, five during the day and four during the night, that the plants in the five daytime freezing lots received a higher degree of injury than did the lots frozen at night. The average per cent injury of those frozen during the daytime was 86.6 per cent, as compared with an average of 62.4 per cent for the lots frozen at

Table 2 Comparative injury to Kanred, Blackhull and F_3 hybrids, frozen during the day and at night,

Agronomy Greenhouse, Manhattan, Kansas, 1927-1928.

Plants frozen 7 A.M. to 7 P.M.			Plants frozen 7 P.M. to 7 A.M.		
Lot No.	No. of plants	Ave. % injury	Lot No.	No. of plants	Ave. % injury
KANRED					
1	6	95.5	2	5	77.0
3	5	98.8	4	5	83.8
5	4	100.0	6	5	72.0
7	5	100.0	8	8	30.0
9	34	76.5			
Total and Average	54	94.2		23	65.7
BLACKHULL					
1	6	100.0	2	5	99.2
3	4	99.5	4	5	91.6
5	5	100.0	6	5	95.6
7	5	100.0	8	7	82.4
9	33	94.2			
Total and Average	53	98.7		22	92.2
F_3 HYBRIDS					
1	90	86.6	2	87	57.3
3	90	89.9	4	84	71.9
5	93	94.1	6	73	70.4
7	81	93.3	8	89	50.2
9	20	69.2			
Total and Average	374	86.6		333	62.4

Fig. 2


Freezing Injury, of F_3 Hybrids, Kanred x Blackhull
When Frozen in the Morning and in the Evening
Greenhouse 1928 - 1929
Am. Freezing Lots
Pm. Freezing Lots
Freezing Injury, Percent
100
90
80
70
60
50
Ave. of Blackhull Frozen in A.M. 87.8
Ave. of Blackhull Frozen in PM. 82.6
Ave. of Hybrids Frozen in A.M. 72.3
Ave. of Hybrids Frozen in P.M. 68.5
Ave. of Kanred Frozen in A.M. 67.
Ave. of Kanred Frozen in P.M. 59.6
Am. 1 3 5 6 8
Pm 2 4 7 9
Freezing Lot Numbers

night. Blackhull and Kanred plants frozen in the same tests show similar results. Five lots of Blackhull frozen at night averaged 92.2 per cent injury. Four lots frozen during the daytime averaged 98.7 per cent. Kanred plants averaged 85.7 per cent and 94.2 per cent injury for the night and day freezing lots, repsectively.

Figure 2 shows graphically that plants frozen during a twelve-hour daytime period are injured more by freezing than are plants that are frozen at the same temperature for a twelve-hour period at night. The data in Figure 2 are not identical with those given in Table II., but the differences are always in the same direction; i.e., more severe freezing injury to the plants frozen in the daytime.

A probable explanation for this may be that plants frozen during the night have had a chance, during the day, to manufacture carbohydrates and to increase their cell sap concentration, while plants frozen during the day, after a period of relative inactivity during the night, have not had this chance of building up a reserve food supply. During the night, plant foods manufactured the previous day have been utilized by the rapidly growing plants or have been distributed through the plant so that plants frozen

during the day may have a lower cell sap concentration with which to resist low temperatures than plants that are frozen at night.

Frequency Distribution of Percentages of Freezing Injury. A frequency distribution of the freezing injury of the F_3 hybrids is shown in Table III. and in Figure 3. The per cent of freezing injury of the plants included in Figure 3 is shown to range from 5 per cent to 98 per cent. The freezing injury curve is bimodal with the modes at 70 per cent and 100 per cent. Two classes of plants seem to have been present; those that were as hardy or a little less hardy than Blackhull, and those that approached Kanred in cold resistance.

Habit of Growth of F_3 Plants and Parents. Differences in the growth habit of the Kanred and Blackhull parents led to a study of this character in the F_3 hybrids. When the plants were approximately six inches tall, they were grouped into three classes according to their habit of growth. These classes were erect, semi-erect and prostrate or spreading. Plants showing an upright habit of growth were classed as erect. Those classed as prostrate were decidedly flat and spreading. The plants that were more or less intermediate in type of growth were termed semi-erect.

Table 3 Freezing injury of Kanred, Blackhull and F_3 hybrids, Agronomy Greenhouse, Manhattan, Kansas, 1927-1928.

	Freezing injury, percent (0 = no injury) (100 = killed)																	Total No. of plants	Ave. % injury
	5	10	20	30	40	50	60	65	70	75	80	85	90	95	98	99	100		
Kanred	2	2	1		3	3	5	1	6	8	10	4	4	5	5	2	16	77	77.5
Blackhull							1		5	2	4	2	4	6	13	6	35	76	94.8
F_3 hybrids	1	6	24	32	33	36	51	6	99	33	47	23	38	46	47	29	160	711	76.6

Fig. 3


Freezing Injury of F3 Hybrids, Kanred x Blackhull
Greenehouse 1927-1928.
Number of Plants
0
20
40
60
80
100
Ave of (711) Hybrids 76.6
Ave of (76) Kanreds 78.5
Ave of (75) Blackhull 96.2
0
5
10
20
30
40
50
60
65
70
75
80
85
90
95
98
99
100
Freezing Injury, Percent.

Every plant of Kanred was classed as having a prostrate growth habit. Blackhull plants were classified as semi-erect. The number of F_3 plants placed in each class is shown in Table IV.

TABLE IV. GROWTH HABIT OF F_3 HYBRIDS, KANRED X BLACKHULL, AGRONOMY GREENHOUSE, 1927-1928

Erect	Semi-erect	Prostrate	Total Number of Plants
15	193	54	262

The plants classed as erect and semi-erect were combined and compared with those classed as prostrate in growth habit. The observed ratio was 208 erect and semi-erect to 54 prostrate.

The growth habit of individual families and of individuals within a family varied from an erect habit of growth to as prostrate a growth habit as that of Kanred, although as Table IV. shows, the semi-erect growth habit of Blackhull was dominant.

Only minor differences in leaf and culm color, leaf type, and general appearance of the hybrid plants were noticed. As far as the writer could observe, most of the hybrids were intermediate to the Kanred and Blackhull parents in leaf shape, color and general appearance.

Date of Heading of Kanred, Blackhull and F_3 Hybrids.

A study of the heading dates showed that some families have a much earlier average heading date, and some plants a much later average heading date, than either parent. The date of heading varied from May 7 for family F_1-1a-1 to May 20 for family F_1-2c-10. Individual plants showed a still greater variation in date of heading. One individual in family F_1-22-1d-5 headed April 20, and as an extreme in the opposite direction, one plant in family F_1-3c-3 did not head until May 26. The average date of heading for 186 F_3 plants that survived the freezing treatment and grew to maturity was May 14. This date proved to be two days later than the average for 21 Kanred plants that reached maturity, and twelve days later than the average of four Blackhull plants that reached maturity.

These dates are contrary to expectation as Blackhull usually heads but two to three days earlier than Kanred. The four surviving Blackhull plants were probably early ones and should not be taken as an average for the variety. The number of plants of Kanred and Blackhull is too small to serve as a reliable index as to average date of heading of these varieties. The freezing treatment given the hybrid plants very likely altered their normal development and date of heading, also.

Height of Plants Which Survived the Freezing Treatment. At the time of harvest, the height of all plants was measured. The data on height of plant are presented in Table V. and Figure 4. The hybrids varied from an average of 16.4 inches for the family F_1-1a-6 to 22.6 inches for family F_1-2b-1. The average height of the plants in forty-seven families was 19.8 inches as compared with 19.2 inches for Blackhull and 18.6 inches for Kanred. Ten families had an average height that was lower than the average of Kanred. Seventeen families had an average height less than the average of Blackhull. Twenty-seven families had an average height greater than that of Blackhull and thirty-five families averaged taller than the average of Kanred. It is not known whether or not this slightly increased height of the F_3 hybrids is the result of hybrid vigor or of inherited genes for increased height.

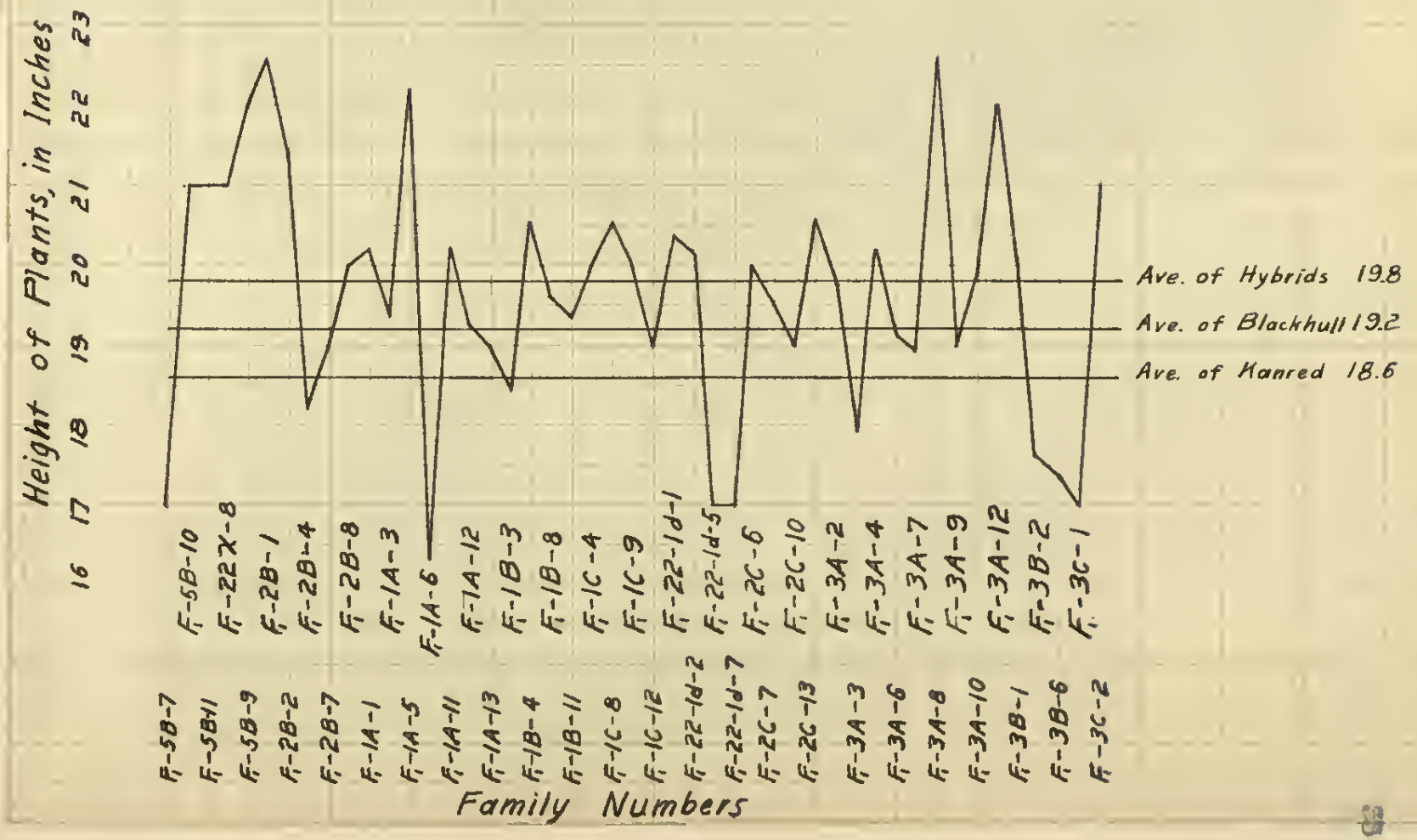
Height measurements were also studied with the intention of determining whether or not freezing had any effect on the height of plants. As is shown in Table V., the plants that were frozen in the refrigeration machine produced shorter culms on the average than those of unfrozen plants. The average of the plants in family F_1-5b is an exception to this in that the frozen plants averaged 0.4 of an inch taller than the unfrozen ones.

Table 5 Effect of freezing on the height of Kanred, Blackhull and F_3 hybrids, Greenhouse, Manhattan, Kansas, 1927-28.

	Ave. height, inches: Frozen	Unfrozen
Kanred		
	18.6	20.0
No. of plants	21	5
Blackhull		
	19.2	20.2
No. of plants	4	5
F_3 hybrids		
F_3 Culture No.		
F_1 - 5b	19.3	18.6
F_1 - 6		18.3
F_1 - 22 x	21.0	20.5
F_1 - 1b (B x K)	22.0	21.0
F_1 - 2b (B x K)	20.3	22.3
F_1 - 1a	19.45	21.9
F_1 - 1b	19.2	21.0
F_1 - 1c	19.95	20.8
F_1 - 22 - 1d - 1	19.25	23.0
F_1 -2a - 2		21.7
F_1 - 2b		22.0
F_1 - 2c	19.8	23.8
F_1 - 3a	19.1	23.1
F_1 - 3b	18.4	24.2
F_1 - 3c	18.8	20.8
	19.7	21.5
No. of plants	190	82

Fig. 4

Height of F_3 Plants, Kanred X Blackhull
Agronomy Greenhouse, 1927-1928



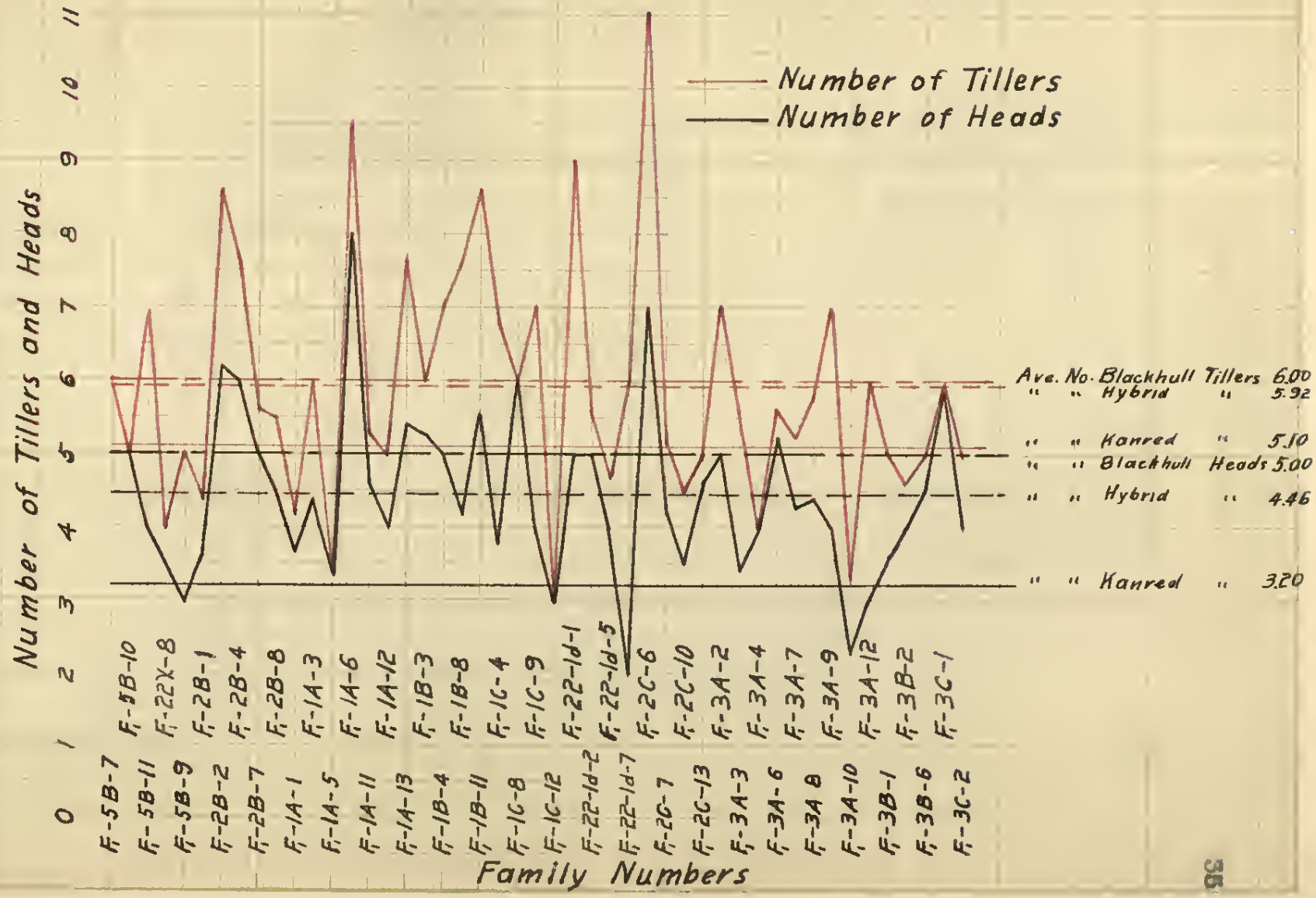
The averages of the various families in the unfrozen lots varied from 18.3 inches for family F_1-6 to 23.8 inches for family F_1-2c. The average height of the plants of the fifteen unfrozen families was 21.5 inches and that of the plants of frozen families was 19.7 inches. The two parent varieties showed a similar difference in height of plants. Those that had been frozen were not as tall as those that were grown to maturity without freezing. Frozen plants of Blackhull averaged 19.2 inches and the unfrozen plants averaged 20.2 inches. The Kanred plants averaged 18.6 inches for the plants that had been frozen and 20.0 inches for the plants not frozen.

The averages shown are not entirely reliable due to the small number of individuals that survived the freezing tests. Only eighteen plants were available for obtaining the average height of the unfrozen F_3 hybrids and only forty-eight for obtaining the average of the plants that had been frozen for twelve hours.

Number of Culms and Heads per Plant. It was expected that there would be a close relation between the number of culms and the number of heads that were produced by a plant. Figure 5 shows a graph of these two characters and averages of the number of culms and the number of heads produced by the F_3 hybrids and by each parent. In harvest-

Fig. 5

Number of Tillers and Number of Heads, of Kanred X Blackhull, F_3 Hybrids
Agronomy Greenhouse, 1927-1928.



ing these plants only those heads were taken which were at least moderately well filled and nearly fully matured. An increase in the number of culms is nearly always followed by an increase in the number of heads produced.

The family F_1-1c-12 produced the lowest average number of tillers, three, although it averaged 3 heads per plant. The family F_1-8c-6 produced the greatest number of tillers, 11, but averaged only 7 heads per plant. Two heads was the least average number produced by a family. This family, F_1-22-1d-7, produced an average of 6 tillers per plant. Family F_1-1a-6 averaged the greatest number of heads, 8, from an average of 9.5 culms per plant.

The average number of tiller and heads per plant produced by the F_3 hybrids was 5.9 and 4.5, respectively, for the forty-seven families, as compared with an average of 6.0 tillers and 5.0 heads for Blackhull, and 5.1 tillers and 3.2 heads for Kanred. Table VI. shows a highly significant correlation of .9819±.0009 for these two characters.

Effect of Freezing Injury on Number of Tillers and Heads per plant. A study made of the plants frozen in a refrigeration machine for twelve hours and of unfrozen plants, indicates that freezing causes an increase in the

Table 6 Correlation between number of culms and number of heads per plant, F_3 hybrids of Kanred x Blackhull
Agronomy Nursery, Manhattan, Kansas, 1928.

No. of culms	No. of heads: 2.0 to 3.9	4.0 to 5.9	6.0 to 7.9	8.0 to 9.9	10.0 to 11.9	12.0 to 13.9	14.0 to 15.9	16.0 to 17.9	18.0 to 19.9	20.0 to 21.9	22.0 to 23.9	24.0 to 25.9	26.0 to 27.9	28.0 to 29.9	f
4.0- 5.9	1	7													8
6.0- 7.9		10	21												31
8.0- 9.9		7	52	46											105
10.0-11.9		1	10	67	34		1								113
12.0-13.9			7	31	55	31									124
14.0-15.9			4	15	38	35	13	1							106
16.0-17.9				6	15	31	15	10							77
18.0-19.9				1	6	13	26	12	4						62
20.0-21.9					3	4	5	13	7	1					33
22.0-23.9							1	8	1	4					14
24.0-25.9								2	2	11					15
26.0-27.9						1		1		1	1				4
28.0-29.9								2		3	1	1			7
30.0-31.9							1			1	1	2	1	1	7
32.0-33.9											1	1			2
34.0-35.9												1			1
36.0-37.9													1		1
f	1	25	94	166	151	115	62	49	14	21	4	5	2	1	710

$r = .9819 \pm .0009$

number of tillers produced by a plant and a decrease in the number of heads produced. Table VII. shows that the frozen hybrids of the twenty-one families studied produced an average of 5.9 tillers per plant compared with an average of 5.1 tillers per unfrozen plant. Blackhull produced an average of 6.0 tillers per plant when frozen and only 4.0 when unfrozen. Kanred produced an average of 5.1 tillers per plant when frozen and 4.5 when unfrozen.

Table VII. and Figure 6 show the range in the number of heads produced and the decreased number of heads that are produced by plants that have been frozen during an earlier stage of their growth. Plants of twenty-one unfrozen F_3 hybrid families averaged 5.1 heads per plant, compared with only 4.1 heads per plant when frozen. Kanred averaged 3.2 heads per frozen plant and 4.0 heads per unfrozen plant. Blackhull, in this case, is an exception, as the frozen individuals produced an average of 5 heads per plant as compared with the average of 4 heads per plant produced by the unfrozen individuals. The number of plants of Blackhull available was not sufficient for a reliable comparison.

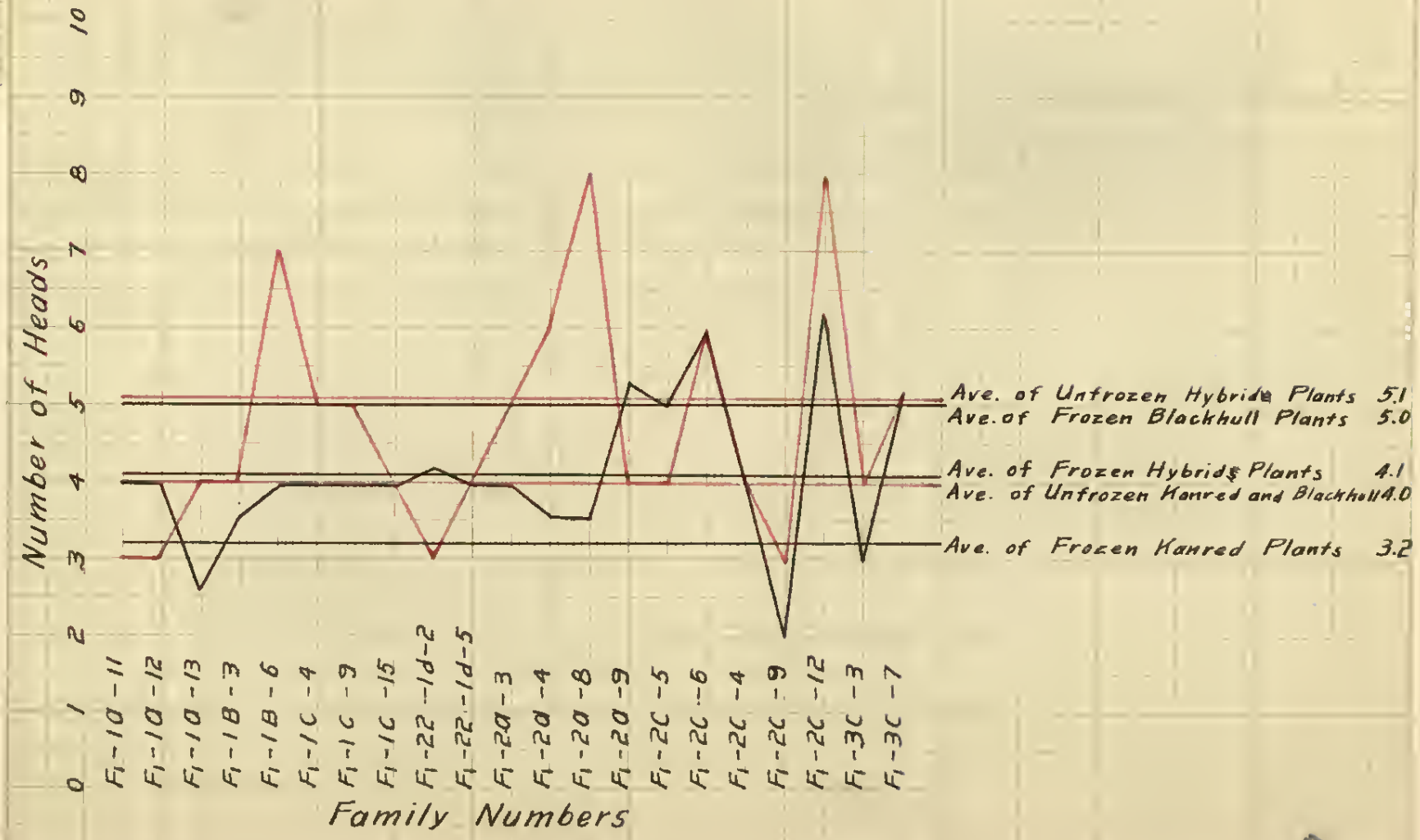
Glume Color. In some seasons, the glumes of Blackhull wheat are black. As yet the nature of the pigment or

Table 7 Number of tillers and heads of frozen and unfrozen plants of Kanred, Blackhull and F_3 hybrids, Greenhouse, Manhattan, Kansas, 1927-1928.

	No. of Tillers		No. of Heads	
	Frozen	Unfrozen	Frozen	Unfrozen
Kanred	5.1	4.5	3.2	4.0
	(21 plants frozen, 5 plants unfrozen)			
Blackhull	6.0	4.0	5.0	4.0
	(4 plants frozen, 5 plants unfrozen)			
F_3 Hybrids				
F_3 Culture No.				
F_1-1a-11	5.5	3.0	4.0	3.0
" 12	4.0	3.0	4.0	3.0
" 13	3.6	4.0	2.6	4.0
F_1-1b- 3	6.6	4.0	3.6	4.0
" 6	4.0	10.0	4.0	7.0
F_1-1c- 4	10.0	5.0	4.0	5.0
" 9	4.0	5.0	4.0	5.0
" 15	4.0	4.0	4.0	4.0
F_1-22-1d-2	4.7	4.0	4.2	3.0
" 5	7.0	5.0	4.0	4.0
F_1-2a- 3	4.0	5.0	4.0	5.0
" 4	5.0	6.0	3.6	6.0
" 8	5.0	8.0	3.6	8.0
" 9	6.8	4.0	5.3	4.0
F_1-2c- 5	8.0	4.0	5.0	4.0
" 6	9.0	6.0	6.0	6.0
F_1-3a- 4	9.0	5.0	4.0	4.0
" 9	4.0	4.0	2.0	3.0
" 12	8.5	8.0	6.2	8.0
F_1-3c- 3	4.0	5.0	3.0	4.0
" 7	6.7	5.0	5.2	5.0
Ave. of (49) F_3 plants	5.9	5.1	4.1	4.7

Fig. 6

Number of Heads on Frozen and Unfrozen F_3 Hybrids, Kanred x Blackhull Agronomy Greenhouse 1927-1928.



the conditions necessary for the expression of this character are not known. In the 1927-1928 greenhouse plantings, no color was evident in the glumes of either the Blackhull parent or in the F_3 hybrids so that no study of the inheritance of glume color could be made.

Plumpness of Kernels. Notes on plumpness of kernels were taken on the grain of 265 individual F_3 plants. Table VIII. shows that the per cent plumpness of kernels of the F_3 plants ranged from 20 per cent to 98 per cent, with the mode at 90. The average plumpness note of the 265 F_3 plants was 75.1 per cent. The average plumpness of kernels of 28 Kanred plants was 84.5 per cent as compared with 76.5 per cent for the 10 Blackhull plants. Blackhull wheat, when grown under average field conditions, usually has a higher test weight than Kanred.

Individual families showed a wide range in average per cent plumpness. Family F_1-2c-10 had the lowest average per cent plump note, 32.5 per cent, and family F_1-1a-11 had the highest average per cent plump note, 91.6 per cent. One plant in each of the families F_1-1b-11 and F_1-3c-3 produced the shrivelled kernels grading only 20 per cent plump. Four families, F_1-6-3, F_1-1c-7, F_1-22-1d-5 and F_1-2c-13 produced individuals having kernels that were 98 per cent plump. The kernels of many of the F_3 hybrids

TABLE VIII. PLUMPNESS OF KERNELS OF KANRED, BLACKHULL, AND F_3 HYBRIDS, AGRONOMY GREENHOUSE, MANHATTAN, KANSAS, 1927-1928

	Plumpness of kernels, per cent													Total number of plants	Average per cent plump
	20	30	40	50	60	65	70	75	80	85	90	95	98		
Kanred			1					3	5	8	8	3	1	28	84.5
Blackhull					1	1	2	2		2	2			10	76.5
F_3 Hybrids	6	4	15	13	15	7	35	24	31	40	43	27	5	265	75.1

resembled Blackhull in plumpness and in general appearance. A few F_3 plants produced kernels of a dark, hard, lustrous appearance, characteristic of Kanred and Turkey. Most of them, however, had a dull, opaque, semi-hard appearance that is characteristic of Blackhull.

Winter Wheat Nursery

In September of 1927, seed of eighty-two F_3 hybrid families were sown in the winter wheat nursery at Manhattan. Twenty-five kernels of each family were spaced-planted in eight-foot rows. The rows were twelve inches apart. Kanred and Blackhull checks were alternated every twenty-fifth row.

Winter Survival of F_3 Hybrids. Approximately a month after planting, counts were made of the number of plants growing in each row. In the spring a similar count was made. From these figures, winter survival percentages were calculated.

Table IX. shows average percentages of survival of 90.0 for Kanred, 79.5 for Blackhull and 91.4 for the F_3 hybrids or an advantage of 1.4 per cent for the hybrids as compared with Kanred.

Family F_1-2b had the lowest average per cent survival, 68.8, as compared with the highest average per cent survival

TABLE IX. WINTER SURVIVAL PERCENTAGES OF KANRED, BLACKHULL AND F_3 HYBRIDS
AGRONOMY NURSERY, 1928

Variety	59 to 75	76 to 77	78 to 79	80 to 81	82 to 83	84 to 85	86 to 87	88 to 89	90 to 91	92 to 93	94 to 95	96 to 97	98 to 99	100	Total number of rows	Average per cent survival
Kanred				1										1	2	90.0
Blackhull			1	1											2	79.5
F_3 Hybrids	.5	1	4	2	1	2	5	7	5	9	7	10		24	82	91.4

100, for family F_1-1c. Individuals within a family showed a still greater range. Twenty-four rows showed 100 per cent survival as compared with 59.0 per cent for family F_1-2b-7.

Figure 7 is a frequency distribution of the survival percentages of the F_3 hybrids of Kanred x Blackhull. No F_3 family showed complete killing and the mode was in the 96-100 survival class. The number of check rows of Kanred and Blackhull was too small to give a reliable picture of the winter survival of these two varieties, although the data obtained are in agreement with many other comparisons of these two varieties.

Height of Plants. As in the F_2 generation and in the F_3 greenhouse planting, the F_3 hybrids sown in the nursery were taller than either of the parental varieties.

Table X. shows that the average height of Kanred plants is 36.5 inches, Blackhull 37.1 inches and the F_3 hybrids, 37.6 inches.

Individual families showed a range of 7 inches. Family F_1-22-1d-1 was the shortest, with an average height of 34 inches as compared with the 41-inch averages of families F_1-1b-9, F_1-2b-1, F_1-2b-2 and F_1-2b-7.

Fig. 7

Winter Survival of F_3 families of Kanred X Blackhull

Eight foot Rows, No's. 7819 - 7904

Agronomy Nursery 1928.

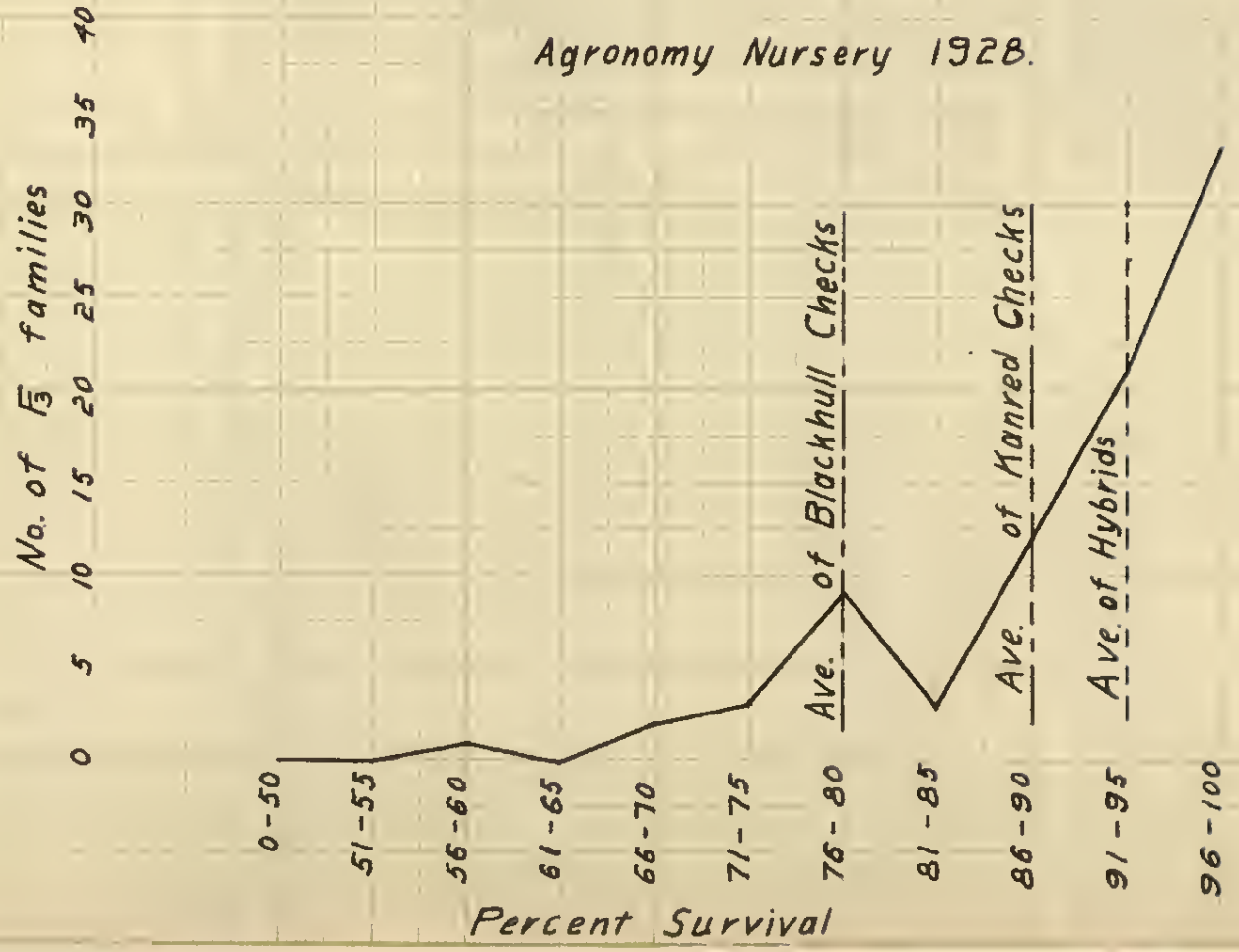


TABLE X. HEIGHT OF KANRED, BLACKHULL AND F_3 HYBRID PLANTS
AGRONOMY NURSERY, 1928

Variety	34	35	36	37	38	39	40	41	Total number of rows	Average height in inches
*Kanred			1		1				2	36.5
*Blackhull				1	1				2	37.1
F_3 hybrids	1	5	15	17	24	12	4	4	82	37.6

* Average height of the Kanred and Blackhull checks in the advanced winter wheat nursery.

The same results are shown graphically in Figure 8. The mode is at 38 inches. The curve falls away gradually on either side; i.e., approaches the normal or bell-shape curve.

Date of Heading. The F_3 families were dated first headed when the lower florets of about 10 per cent of the heads in the row had appeared above the leaf sheaths.

The average date of first heading for the F_3 hybrids was May 24, as compared with May 20 for the Kanred and Blackhull parents. In most years Blackhull heads two to four days earlier than Kanred, as was the case in 1928 in the check-rows of these two varieties grown in direct comparison with the crosses.

Table XI. shows that a number of F_3 families had an earlier date of first heading than Blackhull, but that the average for the hybrids was four days later than for Blackhull and Kanred.

The earliest average date of first heading of any of the F_3 families was May 20. Three families, F_1-5b-7, F_1-1b-4 and F_1-2a-6 headed on this date as contrasted with two families, F_1-2a-8 and F_1-2a-9, that headed on May 29, the latest average date of first heading.

Date of Ripening. As the individual rows of each

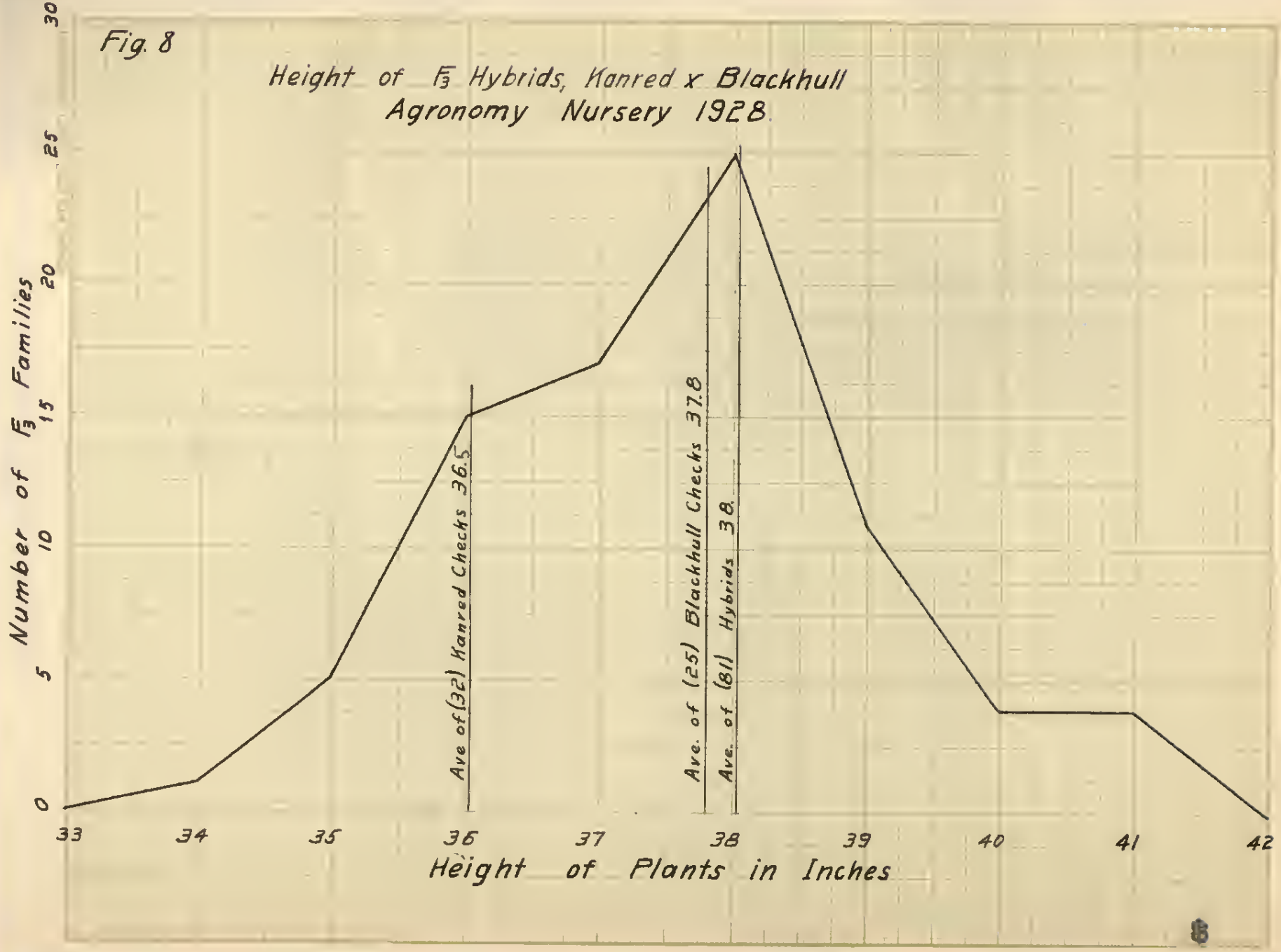


Fig. 8
Height of F3 Hybrids, Kanred x Blackhull
Agronomy Nursery 1928
Number of F3 Families
0
5
10
15
20
25
30
33
34
35
36
37
38
39
40
41
42
Height of Plants in Inches
Ave of (32) Kanred Checks 36.5
Ave. of (25) Blackhull Checks 37.8
Ave. of (81) Hybrids 38.

TABLE XI. DATE OF HEADING OF KANRED, BLACKHULL AND F_3 HYBRIDS

AGRONOMY NURSERY, 1928

Variety	June 20	June 21	June 22	June 23	June 24	June 25	June 26	June 27	June 28	June 29	Number of rows	Average date of first heading
*Kanred							1	1			2	20
*Blackhull			1	1							2	20
F_3 hybrids	3	6	13	9	5	8	22	7	1	2	76	24

*Average date of first heading of Kanred and Blackhull in the advanced winter wheat nursery.

family matured and became ripe enough to harvest, a date of ripening note was assigned to each.

The average date of ripening of the F_3 hybrids was July 3 which was five days later than Kanred and seven days later than Blackhull. As with date of first heading, the range among individual families was large. Some F_3 plants ripened earlier than the average of Blackhull, though most of them ripened later than Kanred, the later parent.

Table XII. shows only a two-day range in the date of ripening of the F_3 hybrids; i.e., from July 2 to July 4. This illustrates the fact that heading dates are more reliable measures of inherent earliness than are ripening dates. The hot weather that usually occurs in Kansas at harvest time tends to ripen nearly all lines at about the same date, even though they headed at different dates.

TABLE XII. DATE OF RIPENING OF KANRED, BLACKHULL AND F_3 HYBRIDS, AGRONOMY NURSERY, 1928

Variety	July 2	July 3	July 4	Number of rows	Average date of ripening
*Kanred				2	June 28
*Blackhull				2	June 26
F_3 hybrids	24	36	8	68	July 3

*Average ripening date of Kanred and Blackhull in the advanced winter wheat nursery.

These data indicate that the F_3 families were comparatively homozygous and uniform for date of ripening, although as stated above, environmental influences tend to mask hereditary differences.

Leaf Rust. Leaf rust notes indicate that some of the hybrids are more resistant than either parent. Leaf rust percentages were estimated, based on the amount of leaf tissue that was covered with rust pustules. Zero was used to indicate complete absence of pustules and 100 per cent indicated a very large number of pustules per square centimeter of leaf area. The scale used for estimating rust percentages is the one commonly used by field men of the Office of Cereal Crops and Diseases, United States Department of Agriculture.

Kanred showed an average of 58 per cent leaf rust, Blackhull averaged 59 per cent and the hybrids 44.4 per cent.

Table XIII. shows that the average percentage of leaf rust on F_3 families varied from 30 to 70 per cent. Only one family averaged 70 per cent of leaf rust as compared with 12 families that showed an average of 30 per cent leaf rust. No leaf rust notes were taken on individual plants. Within an F_3 row, leaf rust infection sometimes varied from

10 to 90 per cent, indicating that such a family was heterozygous for rust resistance.

TABLE XIII. LEAF RUST INFECTION OF KANRED, BLACKHULL AND F_3 HYBRIDS, AGRONOMY NURSERY, 1928

Variety	30	40	50	60	70	Number of rows	Average per cent leaf rust
*Kanred		2				2	58.0
*Blackhull		1	1			2	59.0
F_3 Hybrids	12	28	15	13	1	69	44.4

*Average per cent leaf rust infection on Kanred and Blackhull in the advanced winter wheat nursery.

Number of Culms and Number of Heads per Plant. As the individual plants were harvested in the field, counts were made of the number of culms and the number of heads per plant. The averages of the plants from each row were calculated and are shown graphically in Figure 9 which shows that a plant producing a large number of culms usually produced a large number of heads per plant.

Family F_1-3c-6 (row 7901) averaged the most culms, 23.8, and had 19 heads per plant. Families F_1-3a-4 (row 7884) and F_1-3c-1 (row 7896) are disregarded because only one plant occurred in each of these rows. The lessened competition for space and soil moisture was no doubt respon-

Fig. 9

Average Number of Culms, Heads, and Weight of Grain per Plant
Kanred X Blackhull, F_3 Hybrids
Agronomy Nursery 1928.

Average No. Culms per Plant
Average No. Heads per Plant
Average Weight of Grain per Plant, in Grams.

Number of Culms per Plant
Number of Heads per Plant
Weight of Grain per Plant in Grams.

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Ave. No Culms 14.4
Ave. Wt. 12.
Ave. Heads 11.4

7819 7821 7822 7823 7824 7825 7826 7827 7828 7829 7830 7831 7832 7833 7834 7835 7836 7837 7838 7839 7840 7841 7842 7843 7844 7845 7846 7847 7848 7849 7850 7851 7852 7855 7856 7857 7858 7859 7860 7861 7862 7864 7865 7866 7867 7868 7875 7876 7877 7878 7879 7880 7882 7883 7884 7885 7886 7887 7888 7889 7890 7891 7892 7893 7894 7895 7896 7897 7898 7899 7900 7901 7902 7904

Row Numbers

sible for the greater development of these individual plants. Family F_1-1a-5 (row 7844) produced the lowest average number of culms and heads per plant, 9.1. Six other families produced a lower average number of heads per plant, but in each case more than 9.1 culms were produced. Family F_1-6-2 (row 7826) produced the lowest average number of heads per plant. The seventy-four F_3 hybrid families produced an average of 14.4 culms and 11.4 heads per plant. A comparison of these two plant characters showed them to be intermediate to Kanred and Blackhull. Blackhull averaged 13.9 culms and 10.7 heads per plant. Kanred averaged 15.3 culms and 12.4 heads per plant.

Correlation Between Number of Heads per Plant and Weight of Grain per Plant. In Figure 9 there is a close relationship shown between the number of heads and the weight of grain produced per plant. The same family that produced the greatest number of culms and heads per plant also produced the greatest weight of grain per plant. Family F_1-6-2 (row 7826) which produced the lowest average number of heads per plant produced the lowest yield of grain per plant. Probably the fact is of little importance that 66 of the 74 families produced more grams of grain per plant than they did number of heads per plant. The F_3

hybrids produced an average of 12.0 grams of grain per plant, compared with 8.5 and 8.7 grams of grain per plant for Blackhull and Kanred, respectively. The close correlation between number of heads and weight of grain per plant is shown in Table XIV., in which the correlation coefficient is .8954±.0054.

Beak Length. Before threshing the heads, the beak length of each plant in the seventy-four F_3 families was measured by means of a small millimeter rule.

Figure 10 shows that the average beak length of the F_3 hybrids was intermediate to the average beak length of the parents. The average beak length for Blackhull was 4.2 mm., for Kanred it was 10.4 mm. and the average for the F_3 hybrids was 7.3 mm. Individual hybrid families showed a wide variation in beak length; i.e., segregation for this character was definite and clear cut. Family F_1-3a-4 (row 7884) had the longest average beak length, 23.0 mm., and family F_1-2b-4 (row 7839) had the shortest average beak length, 1.0 mm.

A study was made of the correlation between beak length and yield of grain per plant. This correlation surface is shown in Table XV. The correlation coefficient is very low, .0767±.0279 and is not significant.

Table 14 Correlation between number of heads and weight of grain per plant,
F_3 hybrids of Kanred x Blackhull,
Agronomy Nursery, Manhattan, Kansas, 1928.

No. of heads per plant	Weight of grain per plant																f
	1.0 to 2.9	3.0 to 4.9	5.0 to 6.9	7.0 to 8.9	9.0 to 10.9	11.0 to 12.9	13.0 to 14.9	15.0 to 16.9	17.0 to 18.9	19.0 to 20.9	21.0 to 22.9	23.0 to 24.9	25.0 to 26.9	27.0 to 28.9	29.0 to 30.9		
2.0- 3.9	1																1
4.0- 5.9	1	6	10	5													22
6.0- 7.9		3	28	40	7	1											79
8.0- 9.9		2	11	57	50	21	2										143
10.0-11.9			1	11	33	58	24	2	2								131
12.0-13.9				2	5	36	36	20	1								100
14.0-15.9					2	4	16	23	10	1							56
16.0-17.9						3	6	14	12	4	3		1				43
18.0-19.9							1	2	4	4	1						12
20.0-21.9								1	4	4	6						15
22.0-23.9											1	1	2				4
24.0-25.9												1	4				5
26.0-27.9												1			1		2
28.0-29.9															1		1
f	2	11	50	115	97	123	85	62	33	13	11	3	7	0	2		614

$r = .8954 \pm .0054$

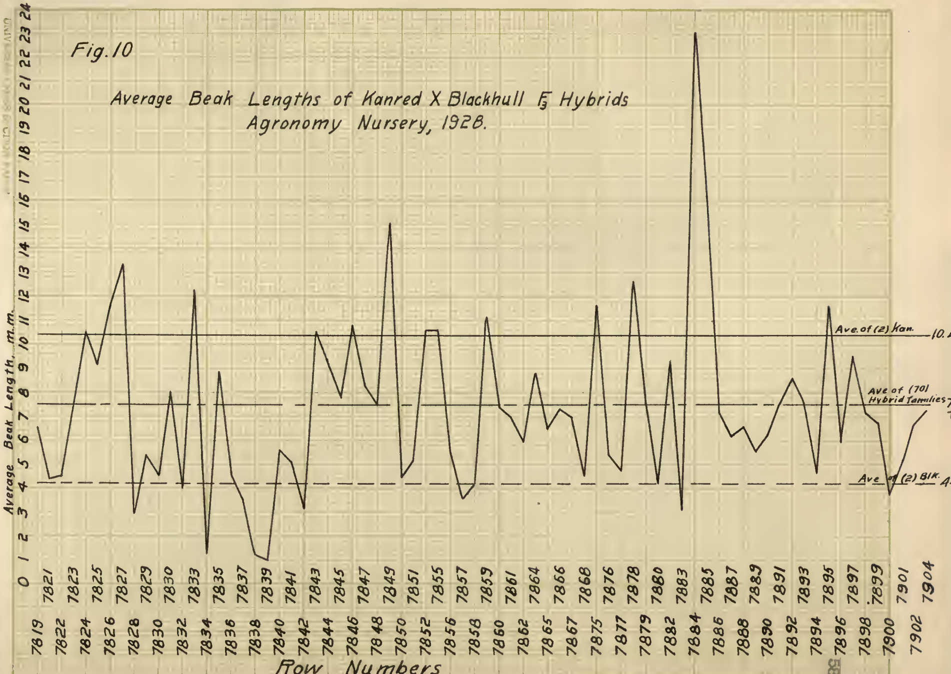


Fig. 10

Average Beak Lengths of Kanred X Blackhull F_3 Hybrids
Agronomy Nursery, 1928.

Table 15 Correlation between beak length and weight of grain per plant, F_3 hybrids of Kanred x Blackhull
Agronomy Nursery, Manhattan, Kansas, 1928.

Beak Length, m.m.	Weight of grain per plant, grams															
	1.0 to 2.9	3.0 to 4.9	5.0 to 6.9	7.0 to 8.9	9.0 to 10.9	11.0 to 12.9	13.0 to 14.9	15.0 to 16.9	17.0 to 18.9	19.0 to 20.9	21.0 to 22.9	23.0 to 24.9	25.0 to 26.9	27.0 to 28.9	29.0 to 30.9	f
1.0- 2.9		1	6	14	4	8	9	6	6		1					55
3.0- 4.9		2	10	25	24	27	8	10	2		1	1	1			111
5.0- 6.9	1	1	6	21	24	25	22	17	11	6	3		4	1		142
7.0- 8.9		1	7	24	17	24	14	10	5	3						105
9.0-10.9	1	3	3	9	10	7	5	7			1				1	47
11.0-12.9		2	3	15	4	9	10	4	2	2	1	1				53
13.0-14.9			5	3	5	6	5	4	3		1					32
15.0-16.9		1	3	1	3	3	4	1	1		2		1		1	21
17.0-18.9				1	1	1										3
19.0-20.9																0
21.0-22.9			1		2											3
23.0-24.9			1									1				2
25.0-26.9							1									1
f	2	11	45	113	94	110	78	59	30	11	10	3	6	1	2	575

$r = .0767 \pm .0279$

Glume Color. No reliable data were obtained on the inheritance of glume color because of the fact that the conditions under which the plants were grown were not favorable for the expression of glume color in all of the Blackhull plants. The optimum conditions for the production of glume color are not known. Only a small number of Blackhull plants and F_3 hybrids produced black glumes. In the range from black to white glumes, two intermediate classes were noted. One contained plants having medium black glumes and the other, plants having only a trace of black color in the glumes.

Table XVI. shows the range of glume color. All of the 18 Kanred plants that reach maturity had white glumes. Of the 13 Blackhull plants, 2 had white glumes, 2 had a trace of black, 4 had glumes classed as medium black and 5 were classed as black. Six hundred fourteen F_3 hybrid plants were classified as to glume color. Of these, 335 plants had white glumes, 200 showed a trace of black color, 74 were classed as medium black and only 5 plants produced black glumes.

TABLE XVI. GLUME COLOR OF KANRED, BLACKHULL AND F_3 HYBRIDS, AGRONOMY NURSERY, 1928

Variety	Number of Plants				Total number of plants
	White	Trace of black	Medium black	Black	
Kanred	18				18
Blackhull	2	2	4	5	13
F_3 hybrids	335	200	74	5	614

Until the enviromental factors necessary for the production of black color in the Blackhull parent are known, it will be impossible to make an accurate study of the inheritance of this character.

Study of Association Between Beak Length and Glume Color. A study was made to see whether there was any association between beak length and glume color. The data on these two characters are presented in Table XVII. The supposition was that all of the Kanred plants would have white glumes and long beaks while the Blackhull plants would have black glumes and short beaks. The F_3 hybrids would be expected to have beaks of varying lengths and glumes ranging from colorless, like Kanred, to those as black as those of Blackhull.

All of the Kanred plants had white glumes and long beaks. Blackhull, on the other hand, produced glumes

Table 17 Beak length and glume color in Kanred, Blackhull and F_3 hybrids, Agronomy Nursery, Manhattan, Kansas, 1928.

	Beak length in m.m.																					Total No. of plants	Average beak length
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Kanred																							
White						2	1	3		5	4	1			1	1							18	10.0
Trace																							0	
Medium																							0	
Black																							0	
																							Ave.	10.0
Blackhull																							
White						1	1																2	6.5
Trace			1				1																2	5.0
Medium			2	1	1																		4	3.75
Black			4		1																		5	3.4
																							Ave.	4.66
F_3 hybrids																							
White	9	23	34	32	29	41	37	29	20	17	7	27	12	10	6	5		1		2	1		335	7.35
Trace	10	7	12	27	25	30	20	16	6	6	4	8	12	5	5	3		1				3	200	7.14
Medium	5	1	5	4	7	16	9	4	5	1	3	6	2	2	2		1					1	74	7.39
Black						3		1			1												5	7.40
																							Ave.	7.32

ranging from white to a trace of black, medium black and black. Beak lengths of most Blackhull plants were shorter than those of Kanred. The average beak length of the Blackhull plants over-lapped the lower beak length range of the Kanred plants. No linkage or association seems to exist between long beak length and color of glumes.

Plumpness of Kernels. After threshing, plumpness notes were taken on the grain of each of the F_3 plants. Figure 11 and Table XVIII. show that individual plants produced seeds ranging from 30 per cent to 98 per cent plump. Six hundred forty-one F_3 hybrids had an average plumpness note of 89.6 per cent which was an advantage of 2.7 per cent over Kanred and 3.1 per cent over Blackhull. Most of the F_3 hybrids, 574 of the 641 plants, were 85 to 95 per cent plump. In general appearance, grain of many of the hybrids resembled Blackhull in that the kernels had the same characteristic plump, opaque and semi-hard appearance. Kanred, on the other hand, produced kernels that were usually not quite so plump but which had more of a dark, hard, lustrous appearance.

Kernel Type of F_3 Hybrids. Blackhull kernels ordinarily have but very little crease or have a rather

Table 18 Kernel plumpness of Kanred, Blackhull and F_3 hybrids, Agronomy Nursery, Manhattan, Kansas, 1928.

	Plumpness of kernels, percent															Total No. of plants	Ave. % plump
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	98		
Kanred		1				1					1		6	9		18	86.9
Blackhull											5	3	7			13	86.5
F_3 hybrids	2	2	2	0	2	1	1	2	7	9	38	85	217	272	1	641	89.6

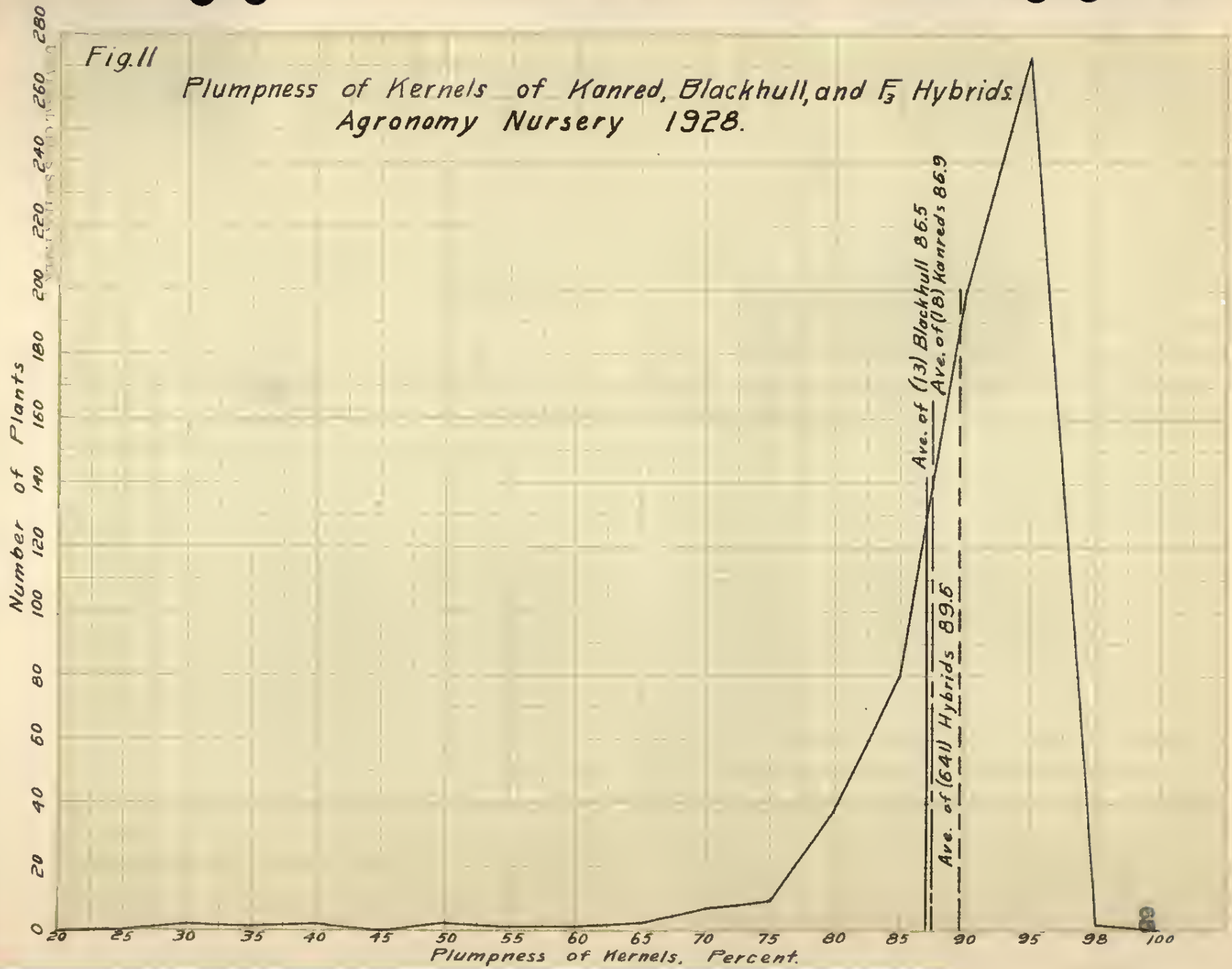


Fig. 11
Plumpness of Kernels of Kanred, Blackhull, and F3 Hybrids.
Agronomy Nursery 1928.
Number of Plants
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
98
100
Plumpness of Kernels. Percent.
Ave. of (13) Blackhull 86.5
Ave. of (18) Kanreds 86.9
Ave. of (641) Hybrids 89.6

flat belly. Kanred kernels usually have a more prominent "v" shaped crease. The grain of each of the F_3 families was examined and was classified as "K" if it resembled Kanred and as "B" if it resembled Blackhull. Table XVIIIa shows that in type of crease, 42 of the hybrid progenies resembled Kanred, 24 resembled Blackhull and 17 were intermediate and were classed as doubtful.

TABLE XVIIIa. KERNEL TYPE OF F_3 HYBRIDS OF KANRED X BLACKHULL, AGRONOMY NURSERY, 1928

Variety	Similar to Blackhull	Similar to Kanred	Resemblance doubtful	Total number of families
Kanred		18		18
Blackhull	13			13
F_3 hybrids	24	42	17	83

F_4 Greenhouse Cultures, 1928-1929

On November 5, 1928, ten kernels of each of eighty-four F_4 hybrid families and five each of twenty-seven F_4 hybrid families, were planted in clay pots in the greenhouse. On the same date, 100 kernels of Kanred and of Blackhull were sown. The parental plants were used as checks for the F_4 hybrids. Up to the time of freezing, the F_4 hybrids received the same treatment as to watering and

temperatures as did the second F_3 greenhouse planting.

Nine lots of plants were frozen for six-hour periods at a mean minimum temperature of -11° C. Half of the pots from each family were frozen in the morning and early afternoon from 8 a.m. to 2 p.m. The others were frozen in the afternoon and early evening from 2 p.m. to 8.p.m. As in the F_3 greenhouse freezing studies, it was noticed that the F_4 plants frozen in a dry soil were more severely injured than were plants that were frozen in a wet soil. Treatment after freezing was the same as on the F_3 generation previously described. Notes on amount of freezing injury were taken as on the F_3 plants.

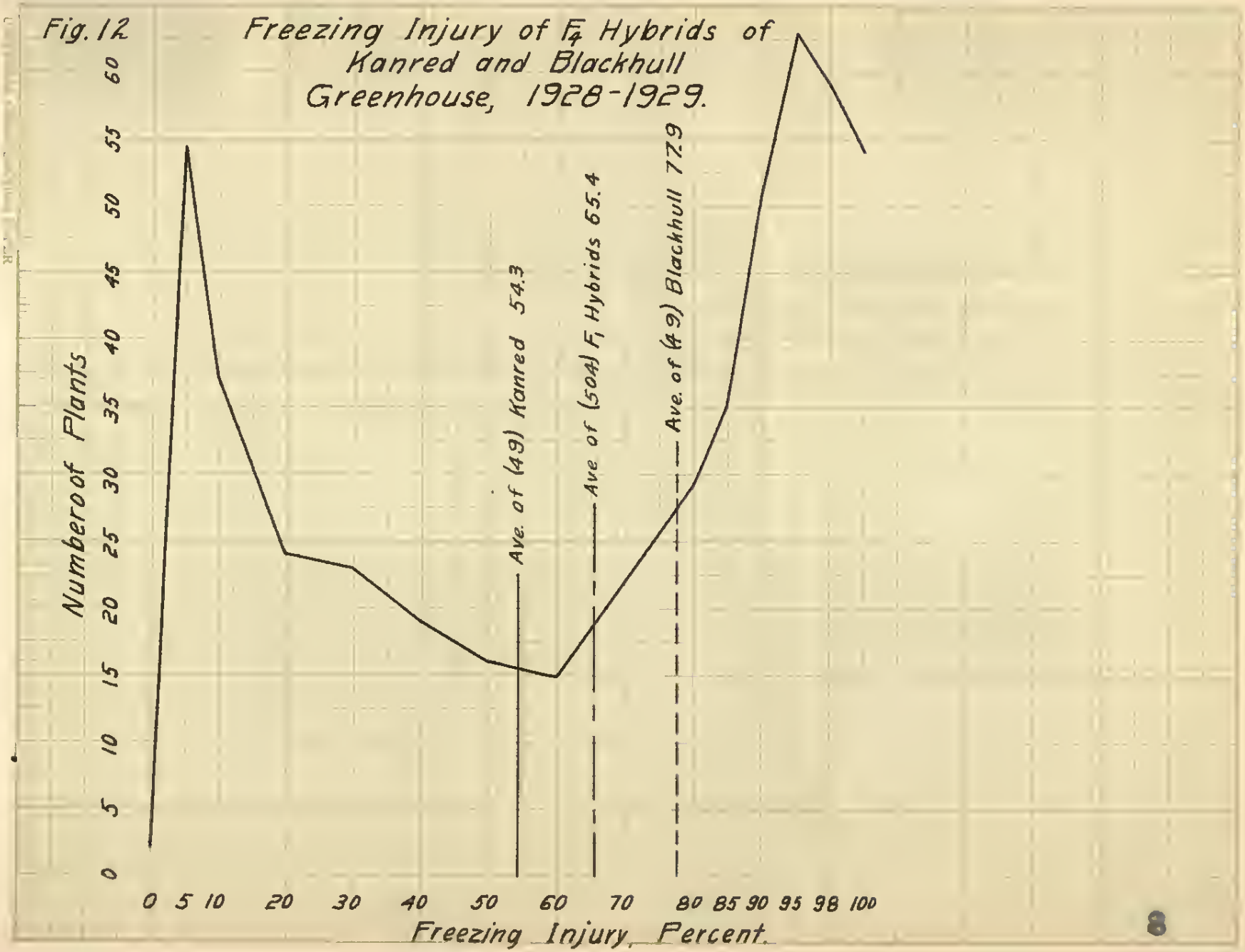
The average per cent freezing injury of 504 F_4 plants was 65.4 as shown in Table XIX. and Figure 12. Forty-nine Kanred plants had an average freezing injury note of 54.3 per cent as compared with forty-nine Blackhull plants that averaged 77.9 per cent. The F_4 hybrids were clearly intermediate in cold resistance, compared with Kanred and Blackhull. A similar bimodal curve was evident in the F_4 generation as in the F_3 generation. The lower mode was at 5 per cent freezing injury. Plants in this class excelled Kanred in cold resistance. Those plants less hardy than Blackhull made up the second mode, located at the 98 per cent point on the curve.

Table 19 Freezing injury of Kanred, Blackhull and F_4 hybrids, Agronomy Greenhouse, Manhattan, Kansas, 1928-1929.

	Freezing injury, percent (0 = no injury) (100 = killed)																Total No. of plants	Ave. % injury
	0	5	10	20	30	40	50	60	70	75	80	85	90	95	98	99	100	
Kanred		3	6	1	2	6	1	5	4	2	6	1	6	4			2	49	54.3
Blackhull		1	3	1	1	3	1	3	2	1	1	3	3	5	7		14	49	77.9
F_4 hybrids	2	54	37	24	23	19	16	15	22	1	29	35	51	63	59		54	504	65.4

Fig. 12

Freezing Injury of F_4 Hybrids of Kanred and Blackhull Greenhouse, 1928-1929.



Individual plants in the F_4 generation ranged from zero, no freezing injury, to 100 per cent or complete killing.

Estimates of freezing injury to individual plants of Kanred and Blackhull are presented graphically in Figure 13. Kanred had more plants than Blackhull that had a low freezing injury. Kanred also had many less plants than Blackhull with a high degree of freezing injury.

Comparative Injury to Plants Frozen in the Morning and in the Afternoon. As in the studies of F_3 plants made during the winter of 1927-1928, plants frozen in the afternoon, after a daylight period of active growth, showed less freezing injury than did plants that were frozen in the morning, after a night period of darkness. In Table XX. a comparison is shown of the freezing injury to Kanred, Blackhull and F_4 hybrids frozen in the morning and in the afternoon. The average freezing injury percentages are 67.0 for Kanred, 85.5 for Blackhull and 72.3 for the F_4 plants frozen during the morning. For lots frozen in the afternoon, an average advantage; i.e., less severe freezing injury, of 7.4 per cent for Kanred, 6.0 per cent for Blackhull and 3.8 per cent for the F_4 hybrids is shown. The differences are not so great as were those of the F_3 lots

Fig. 13

Freezing Injury of Kanred and Blackhull Greenhouse, 1928-1929.

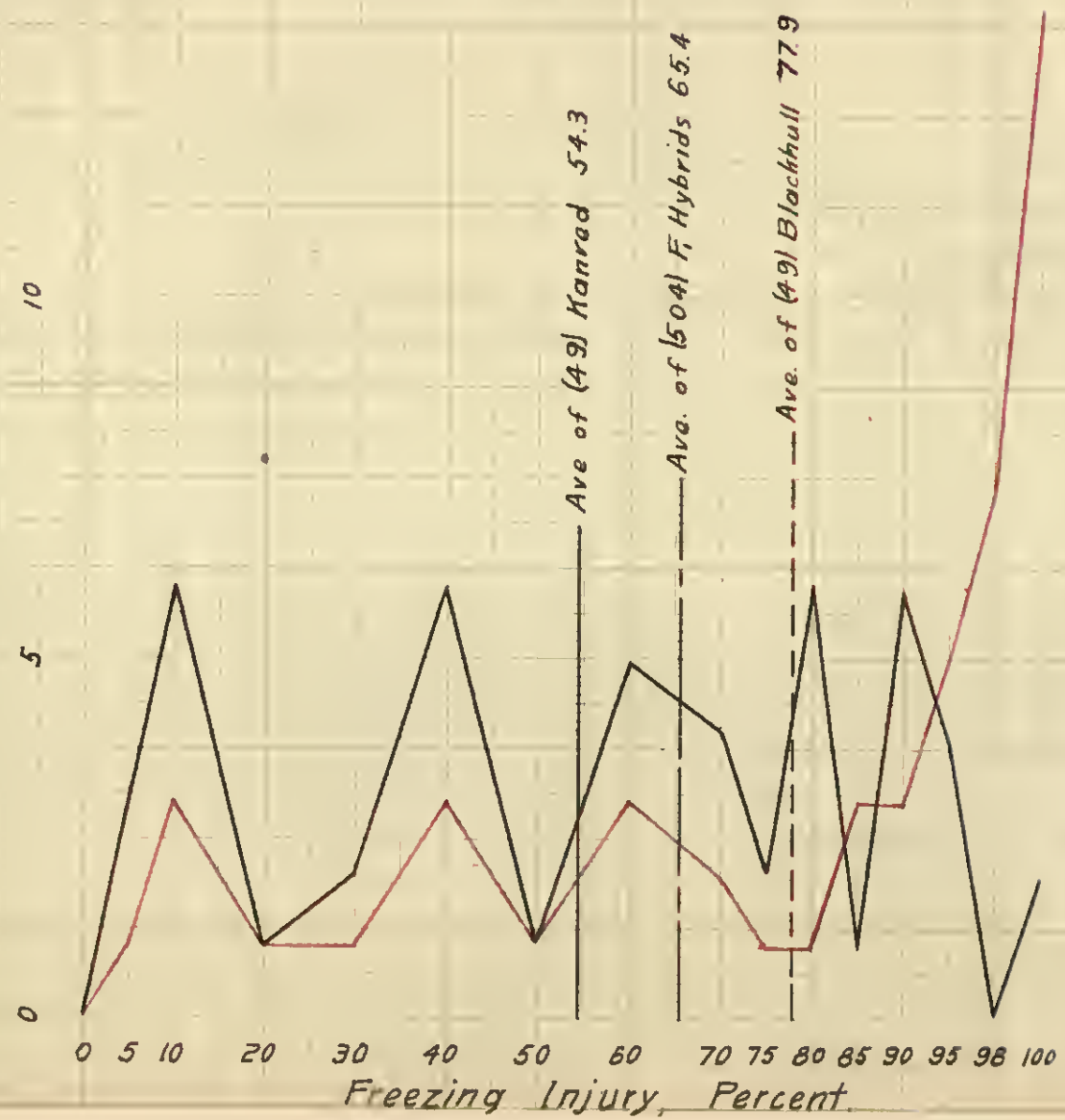


Table 20 Comparison of injury to Kanred, Blackhull and F_4 Hybrids frozen in the morning and in the afternoon.

Agronomy Greenhouse, Manhattan, Kansas, 1928-1929.

Frozen 8 A.M. to 2 P.M.			Frozen 2 P.M. to 8 P.M.		
Lot No.	No. of plants	% injury	Lot No.	No. of plants	% injury
Kanred					
1	8	22.5	2	8	37.5
3	9	86.1	4	6	48.2
5	6	75.0			
6	8	60.6	7	7	72.6
8	8	91.0	9	11	63.0
Totals and Averages	39	67.0		32	59.6
Blackhull					
1	8	41.9	2	8	70.7
3	9	88.4	4	7	64.3
5	6	100.0			
6	7	97.3	7	7	82.9
8	8	100.0	9	12	100.0
Totals and Averages	38	85.5		34	79.5
F_4 Hybrids					
1	108	51.73	2	109	65.51
3	103	69.28	4	107	62.74
5	77	83.53			
6	78	65.07	7	78	54.54
8	80	91.72	9	77	91.14
Totals and Averages	446	72.3		371	68.5

frozen during the night and during the day. Lower temperatures were used on the F_4 plants to obtain the same relative amount of killing, but they were frozen only half as many hours as the F_3 plants. The smaller differences between morning and afternoon freezing injury percentages are to be expected since only half as many hours were allowed for the manufacture of plant foods as were available to the F_3 plants frozen during the night periods.

Habit of Growth. Variation in growth habit in the F_4 generation was similar to that of the F_3 hybrids. The majority of the F_4 hybrids were semi-erect, similar to the Blackhull parent. However, individuals as prostrate as any of the Kanred plants and others more erect than Blackhull were noted.

Date of Heading. The average date of first heading of the F_4 hybrids was April 22, or one day later than the average of Kanred and four days later than Blackhull. A 43-day range in date of heading was found in the F_4 population. The earliest date of heading was on April 15 and the latest was on May 27. Part of the variation in date of heading was due to the injury of the young plants by exposure to low temperatures in the freezing chamber.

Height of Plants. All of the F_4 plants grown in the greenhouse in 1928-1929 were measured. On the average, they

were taller than either of the parents. Kanred averaged 23.3 inches, Blackhull 25.2 inches and the F_4 hybrids averaged 25.5 inches in height. The average difference between Blackhull and the F_4 hybrids is very slight. It is considerably less than the difference in the F_2 generation and slightly less than the difference between the F_3 hybrids and the average height of Blackhull. The gradual decrease in height with each successive generation seems to indicate that the difference in height probably was due to hybrid vigor and that the hybrid vigor is gradually being lost with each successive generation.

Number of Culms and Heads per Plant. Kanred produced an average of 4.8 culms and 4.2 heads per plant, Blackhull averaged 5.3 culms and 4.4 heads per plant, and the F_4 hybrids produced 5.7 culms and 4.1 heads per plant. As in the F_3 generation, there was considerable variation in the number of culms and heads produced per plant. Individual plantr showed wide variations. The largest number of culms and heads produced by an individual F_4 plant was 11 and the least number produced per plant was 1 culm and 0 heads. The F_4 hybrids had a slightly higher average number of culms per plant than Blackhull, but the average number of heads per plant was slightly lower than Kanred and Blackhull.

Glume Color. Black glume color was developed in a part of the Blackhull and F_4 hybrid plants. Table XXI. shows the Kanred, Blackhull and F_4 hybrids arranged according to glume color.

TABLE XXI. GLUME COLOR IN KANRED, BLACKHULL AND F_4 HYBRIDS AGRONOMY GREENHOUSE, 1928-1929

Variety	Number of Plants				Total number of plants
	White	Trace of black	Medium black	Black	
Kanred	53				53
Blackhull	27	1	9		37
F_4 hybrids	432	39	19	4	492

Greenhouse conditions were evidently not optimum for the expression of black glume color, as 27 of the 37 Blackhull plants produced white glumes, and 432 of the 492 F_4 hybrids produced white glumes. No Blackhull plants having black glumes were found although 4 of the hybrid plants produced black glumes.

Winter Wheat Nursery

Seventy families were sown in eight-foot rows, space planted, in the winter wheat nursery in September, 1928. These plants were not harvested until the end of June,

1929, and could not be threshed in time to be described in this thesis.

SUMMARY AND CONCLUSIONS

A cross between Kanred and Blackhull was made in 1922 by B. B. Bayles. The characters of Kanred and Blackhull seemed to indicate that a fairly promising new variety for Kansas might be obtained from this cross.

Both varieties have a number of desirable characters. Kanred, a pure line selection from Crimean wheat, is winter-hardy, has good grain quality, is resistant to eleven physiologic forms of stem rust and is partially resistant to some of the forms of leaf rust. Weak straw and susceptibility to Hessian fly are two of its chief defects. Blackhull has a somewhat stiffer straw than Kanred, is partially resistant or tolerant to Hessian fly, produces high yields and has grain of high test weight. Blackhull is inferior to Kanred in winterhardiness and in baking quality.

Clark, Martin and Parker; Martin; Klages; Newton and others have reported on various phases of the physical resistance of plants to low temperatures and of the physiolog cal resistance of plants to low temperatures, specific gravity, dry matter content, hydrogen ion con-

centration, etc.

The F_3 and F_4 generations of the cross Kanred x Blackhull were studied. Duplicate plantings, ten pots of each of eighty-two F_3 families were made in October, 1927, in the Agronomy Greenhouse. One of these lots was placed out-of-doors a few days after planting. Two rather severe cold spells on December 7 to 11, inclusive, when a minimum of 3° F. was reached, and on December 15 to 17, inclusive, when a minimum of 4° F. was reached, resulted in a total loss of both hybrids and parents. The second lot was kept in the greenhouse and frozen in a carbon dioxide direct expansion refrigeration machine. Plants were frozen for twelve hours at a temperature ranging between -7° C. and -10° C. The average per cent freezing injury for the F_3 hybrids was 76.6 as compared with 96.2 per cent for Blackhull and 78.5 per cent for Kanred.

Transgressive segregation, on the cold resistant tail of the curve, was evident. Eight families showed less average freezing injury than Kanred. No F_3 family was injured as much as the average of Blackhull.

Plants frozen in the morning or during the day are injured more than are plants frozen during the afternoon or at night. Plants frozen during the day had an average per cent freezing injury note of 94.2 for Kanred, 98.7 for

Blackhull and 86.6 for the F_3 hybrids, compared with the lower average freezing injury percentages of 65.7 for Kanred, 92.2 for Blackhull and 62.4 for the F_3 hybrids, when the plants were frozen at night.

Plants frozen in dry soil were more severely injured than those frozen in a wet soil.

A third planting was made in eight-foot rows, space planted, in the winter wheat nursery, in September, 1927.

In both field and greenhouse phantings, notes were taken on growth habit of young plants, date of heading, height, number of culms, number of heads, beak length, glume color and plumpness of grain. The semi-erect growth habit similar to that of Blackhull appeared to be dominant in the F_3 and F_4 generations.

The average date of heading in the F_3 and F_4 generations, both in the greenhouse and in the field, was later than the average heading dates of Kanred and Blackhull. Heading dates were altered to some extent by the freezing injury to young plants.

Plants of the F_2, F_3 and F_4 generations were taller than Blackhull, the taller parent. With each successive generation the height of the hybrids decreased slightly.

This gradual reduction in height is in accord with expectation, assuming that the extra height of the hybrids is due to heterosis.

Leaf rust notes on the F_3 hybrids indicated that some of them were more resistant than Kanred.

The average number of culms produced per plant was 5.1 for Kanred, 6.0 for Blackhull and 5.9 for the F_3 hybrids. The average number of heads produced was 3.2 for Kanred, 5.0 for Blackhull and 4.5 for the F_3 hybrids.

The F_3 and F_4 hybrids showed clear-cut segregation as regards length of beaks on the outer glumes. Beaks of Kanred averaged 10.4 mm., those of Blackhull averaged 4.2 mm. and the beaks of the F_3 hybrids averaged 7.3 mm.

Blackhull produced glumes ranging from white to black in color; i.e., growing conditions were not such as to favor the full development of the black glume color. Most of the hybrid plants had colorless glumes.

Many of the F_3 hybrid plants produced grain that resembled the rather plump, dull, semi-hard kernels of Blackhull. The average plumpness note of kernels produced by 641 F_3 plants was 89.6 per cent, compared with average plumpness of Kanred kernels, 86.9 per cent, and 86.5 per cent for Blackhull.

The general appearance of the data obtained from the F_2, F_3 and F_4 generations seem to indicate that a new

variety with the grain quality and winterhardiness of Kanred and with the stiff straw, high yield and heavy test weight of Blackhull may be obtained from this cross. It is not likely, however, that one will be obtained which will equal Tenmarq, Kawvale or certain selections from the crosses, Kanred x Marquis, Kanred x Hard Federation, Prelude x Kanred in earliness, stiff straw and other desirable characters.

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LITERATURE CITED

1.	1921	Clark, J. Allen and Salmon, S. C.	Kanred wheat. U.S.D.A. Circular 194.
2.	1927	Salmon, S. C., Swanson, C. O. and Laude, H. H.	Blackhull wheat in Kansas. Kan. Agri. Exp. Sta. Bul. 241.
3.	1926	Clark, J. Allen, Martin, J. H. and Parker, John H.	Comparative hardiness of winter wheat varieties. U.S.D.A. Circular 378.
4.	1927	Martin, J. H.	Comparative studies of winter hardiness in wheat. Journ. Agr. Res. 35:493-535.
5.	1926	Klages, K. H.	Relation of soil moisture content to resistance of wheat seedlings to low temperatures. Journ. Amer. Soc. Agron. 18:184-193.
6.	1922	Newton, R.	A comparative study of winter wheat varieties with special reference to winterkilling. Journ. Agr. Sci. 12:1-19.
7.	1924	Newton R.	Colloidal properties of winter wheat plants in relation to frost resistance. Journ. Agr. Sci. 14:178-191.
8.	1927	Davis. L. L.	Kanred x Blackhull. An unpublished report on the F_1 and F_2 generations of the cross, Kanred x Blackhull. Agronomy Dept., K. S. A. C.