THE EFFECT OF TIME OF PLANTING VARIETIES OF WINTER WHEAT ON RESISTANCE TO LOW TEMPERATURES

by

CLEMENT HENRY AULT

B. S., UNIVERSITY OF IDAHO, 1930

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1932

TABLE OF CONTENTS

INTRODUCTION

The results of several investigations indicate that the time of planting may be a factor in the cold resistance of varieties of winter wheat. Interest was stimulated in the question particularly by the hypothesis of Suneson (32) which suggests that hardiness is a function of the time of year at which the plants emerge rather than the age of the plants.

The experiments herein reported were conducted to obtain specific information as to the effect of time of planting varieties of winter wheat on their resistance to low temperatures. The study was so outlined as to detect differential response of varieties in various stages of hardening during the fall and early part of the winter and after they acquired the fully hardened condition in midwinter.

REVIEW OF LITERATURE

There are differences of opinion as to how low temperatures affect plant tissue. The theory of early Greek philosophers was that ice formed within the cell and expansion due to freezing ruptured the cell wall.

Salmon (26) states that winterkilling may be due to heaving, smothering, physiological drouth or direct effect of low temperature on the plant tissue.

The latter is considered to be the most important factor in the southern portion of the Great Plains area. Heaving and smothering may be factors of considerable importance in the more humid eastern and northern areas.

According to Weigand (35) Sachs and Nageli 1860 and 1861 respectively, showed that the freezing expansion of all the water in the cell would not be sufficient to rupture the wall. Goeppert 1830 seems to be the first to point out that ice forms in the intercellular spaces instead of within the cell. Weigand (35) contends that death is due to the actual withdrawal of water to form ice, not to the cold itself.

The earlier workers on winterhardiness in cereals tried to tie up hardiness with some anatomical or morphological character. However, this idea has been abandoned by most present day workers. Martin (17) states that any relation between hardiness and all morphological characters could be disproved by proper selection of a limited number of varieties. Govorov (8 and 9) and Baroulina (3) found no strict correlation between any morphological character and hardiness.

According to Hill (11) the theory of anabiosis of Stebut, in which varieties characterized by prostrate growth habit are able to pass the winter in an anabiotical state, and that the more erect type of seedlings perish under severe conditions, has not been confirmed. Govorov (9), Baroulina (3) and others also take exception to this rule.

Many other methods of measuring hardiness have been attempted. The increased sugar content of hardy varieties has been noted by many workers. Newton (23) suggests that hardy cereals maintain sugar reserves better than non-hardy ones, because of their lower rate of respiration. This has also been shown by Govorov (8) to be the case.

Akerman (1) found a clear parallelism between sugar content and cold resistance and in a later study (2) obtained close agreement between results from field tests, refrigerator experiments and sugar analysis. Akerman (2), Newton (25), and Maximov (19) maintain that sugar content exerts a protective influence.

Govorov (8 and 9) found that the more hardy forms had a higher glucose content at low temperatures, but there was not a complete parallelism between the intensity of this character and the resistance of different forms. Maximov (20) states that the endurance increases more rapidly than the accumulation of sugars, and appears therefore to be a consequence of some other changes in the cell.

Most physiologists seem to be of the opinion that injury is due principly to the precipitation of proteins.

Their theory is that proteins stay in solution only at a certain pH value and as freezing withdraws water from the cell the concentration of the cell sap is increased to the point at which the proteins are precipitated, after which they will not go back into solution.

Newton made a study of the causes (22) and nature of winterkilling and developed the hydrophilic colloid theory (23) in which he found that the quantity of hydrophilic colloids contained in the press juice of hardened tissues is directly proportional to hardiness and that imbibitional pressures of fresh hardened leaves in most cases were found to be directly related to hardiness (24). In his later study (25) he states that the adaptation of plants to resist frost appears to depend on seasonal changes which give the protoplasm stability. One of the most important changes is the reduction of moisture content, which takes place to a greater degree in hardy varieties, and results in increased concentration of colloids and sugars in the cell fluids and a corresponding increase in the resistance to freezing.

Along the same line Tysdal (34) found the viscosity of the sap was the most consistent index of hardiness. He ranked the varieties according to hardiness in field trials, also according to the viscosity of the extracted cell sap, and obtained a rank correlation of $.9000 \pm .0386$ between hardiness and viscosity. This proved to be a more consistent index of hardiness than the moisture content. The quantity of press juice proved to be the least reliable of the three methods in determining the degree of hardiness. Steinmetz (31) in determining relative hardiness of alfalfa varieties, also found the quantity of press juice to be a poor indicator of hardiness, and that there was no absolute correlation between the freezing point depression of the tissue and hardiness. This is in harmony with Newton's results (22) and with those of Tumanov and Borodin (33).

Martin (17) states that the freezing point of sap may differ materially from the freezing point of tissue. He characterizes hardy wheats as having low moisture content of tissue, high per cent of total solids in juice, a high freezing point depression, a high per cent of bound water in the juice, a low respiration at low temperatures and frequently a long period of vegetative growth.

Tumanov and Borodin (33) found that determination of per cent dry matter in expressed sap gave in many cases a correct estimate of hardiness. These determinations were made by use of the refractometer.

Klages (16) in his work on relation of moisture control of soil to hardiness, found that a low soil moisture content had a protective influence at first, but that injury was rapid after once setting in. Plants grown on a wet soil were last to completely kill. With wheat seedlings his results show a gradual loss of hardiness up to four weeks of age.

Much of the more recent work on hardiness is being done by the use of artificial refrigeration. Akerman was the pioneer in this method of determination, and obtained accurate results. He states (2) that direct refrigerator experiments might be the most practical and reliable method for supplementary observations in the field, whereas other methods should be used more as a control and supplement. Since this time Hill and Salmon (12), Tumanov and Borodin (33), Suneson (32) and others have used this method quite extensively and have found high correlation between their results and those from field studies. The use of artificial refrigeration is considered of special value in selecting hardy strains from segregating generations of crosses. This eliminates the slowness and uncertainty of natural freezing in the field.

Recently special studies have been made to determine the relation of several specific factors to hardiness. One of these is the effect or relation of "hardening" to resistance to low temperatures. Harvey (10) suggests that hardening is a cold shock response and is not correlated with temperature and time exposure.

Hill and Salmon (12) grouped wheats into three classes: Varieties which were relatively hardy when thoroughly hardened, varieties which were relatively hardy whether hardened or unhardened, and those which were non-hardy regardless. Suneson (32) found a difference in varietal response to hardening and that this is of special importance in a hardiness test. Salmon believes hardening to be essential in order to get results that are comparable to those obtained in field varietal tests.

According to Maximov (21) Harvey 1918, Rosa 1921 and Newton 1924 attempt to explain the endurance of frost by plants on a phenomenon of "hardening" and changes of colloids in the cell accompanying this process. Martin (17) states that the most important character influencing hardiness is the ability to build up a high imbibition pressure of the cell colloids during hardening. Harvey (10) believes that hardened plants have protein in a form less easily precipitated. Tumanov 1927 working with sunflowers states "that repeated wilting results in a hardening process analogous to that observed at low temperatures."

Another phase of the winterhardiness problem that is beginning to receive considerable attention is the relation of time of planting to hardiness. Janssen (15) states that "the date at which winter wheat is sown in the fall greatly affects the winter mortality of the plant as well as the resumption of active growth in the spring." He also states (14) that plants from the most favorable dates of seeding have a greater capacity of changing protein nitrogen from precipitable to a non-precipitable form; also that there seems to be a positive correlation between soluble carbohydrate compounds and better dates of seeding or winter-hardiness.

According to Suneson (32) changes in varietal relationships and abnormal expressions of relative cold resistance sometimes observed in varietal comparisons are believed to result primarily from differences in time of seeding. The relation appears to be a function of time of year rather than age of plant. Spring survival of potted plants was not in complete accord with artificial freezing results which suggests a continuous adjustment of varietal relationships throughout the winter.

MATERIAL AND METHODS

The artificial refrigeration experiments reported herein were conducted at the Kansas Agricultural Experiment Station during the winters of 1930-31 and 1931-32.

The refrigeration equipment consists of a cooling chamber which has a capacity of 43 cubic feet within the coils. The thick walls of the chamber are made up of layers of sheet cork coated on the outside with a layer of concrete. Refrigeration was produced by means of a direct expansion carbon dioxide refrigeration plant, thermostatically controlled. A minimum temperature of about -30 degrees F may be attained within the chamber. An electric fan aided materially in maintaining a uniform temperature throughout the chamber, and made it possible to control the temperature within a range of about 3 degrees F.

Five varieties of winter wheat, Minhardi C.I. 5149, Minturki C.I. 6156, Kanred C.I. 5146, Blackhull C.I. 6251, and Prelude x Kanred C.I. 8886 were included in the experiment. These varieties were selected because they are known to differ in regard to hardiness, forming a range from the so called hardy group to the non-hardy group of hard winter wheats. They are also of particular interest in this study because of the peculiar manner in which Minturki, Minhardi and Blackhull have reacted in former tests as reported by Bower (4) and Suneson (32). Prelude x Kanred which will be referred to hereafter in this report as P x K, was selected because of the interest in it as a promising early wheat. It is an attempt to combine desirable characters including winterhardiness and earliness.

This work was carried on over a period of two years but the major portion was done during the winter of 1931-32.

The experiments conducted in 1930-31 included 960 pots. Each of five varieties was planted in 192 pots, one-fourth of which were planted at each date of planting. One half of this material was placed outside the greenhouse to harden under natural weather conditions until frozen. The remaining half was grown in the greenhouse.

The work for the year of 1931-32 included 2400 pots. This number was made up of 120 pots of each variety for each of four planting dates. These were ten days apart, extending from September 23 to October 23.

The 4 inch clay pots in which the varieties were planted were filled with soil early in August. Filling the pots early enough to give the soil time to become firmly settled is advisable as it tends to eliminate much of the pot variability encountered in this work.

Plantings were made September 23, October 3, October 14 and October 23. Eight to ten kernels were planted per pot. Plants were thinned to five per pot soon after emergence, those remaining being evenly distributed in the pot, about 1 inch from the edge.

About two weeks after emergence the plants were moved outside to undergo natural hardening. The pots were arranged in freezing lots of 80 pots each including the varieties and ages that were to be frozen as a unit. Thus all the plants to be frozen at one time were under the same conditions since they were in a small compact group. The location of each freezing lot in the outside enclosure was mapped so that the proper pots could easily be located in case of a heavy snow cover. The plants were watered uniformly at times when there was not sufficient rain for good growing conditions.

When the first six lots were frozen all but the last planting had tillered and had assumed a prostrate position. By the time the next lots were frozen these plants while smaller, were exhibiting the prostrate position, although to a lesser degree. The varieties did not differ materially in the extent to which they assumed this prostrate growth habit.

Each freezing lot consisted of 80 pots which included four pots of each variety, from each date of planting. The varieties for each date of planting were arranged systematically in the boxes which were also located in a systematic manner in the machine during the winter of 1930-31 at which time a study was made of the effect of location of the pots in the freezing chamber. The use of a fan apparently eliminated significant differences due to location, hence this matter did not receive special attention in 1931-32.

Freezing periods were 12 hours in length, each one ending at six o'clock. Temperature regulations were made as seemed justified by the condition of plants frozen previously and existing conditions. It was not always possible to judge accurately the desired temperature in advance. However, it was possible in every case to set the machine so that differential injury resulted. The machine could be accurately adjusted to the desired temperature by watching it carefully for a few hours after changing the thermostat.

Injury notes were based on the estimated percentage of injured tissue. These estimates were made four to five days after freezing. Survival notes were taken from two to four weeks later and were based on the actual percentage of plants living.

A new system of making readings was worked out in which the value obtained is termed the index number. This will be discussed in detail later.

The probable error was calculated for each group of four pots which were directly comparable in each freezing lot, using Bessel's formula.

$$\text{Probable error of mean} = \pm .6745\sqrt{\frac{\Sigma d^2}{N(n-1)}}$$

where Σ = summation

d = deviation from the mean

and N = number of variates

The average probable error was obtained by averaging the probable errors for all of the four pot groups. This probable error was used in determining the generalized error for any grouping of the data as to variety or time of planting by using the formula: $E_m = \frac{E_s}{\sqrt{N}}$

Temperature records for the year 1930-31 are given in Tables I and II. The outside temperatures to which the plants were exposed before being placed in the refrigeration chamber are recorded in Table I. The greenhouse temperatures in which the plants were started and were kept after freezing are given in Table II. This table gives average maximum and minimum temperatures at weekly intervals. Similar temperature data for 1931-32 are given in Tables III and IV respectively.

The data presented have been analyzed for the varieties from the standpoints of time of planting and age of plants.

EXPERIMENTAL RESULTS

The experiments were carried on through the winter seasons of 1930-31 and 1931-32. Although the method was a little different, the purpose was the same both seasons.

Table I. Daily Maximum and Minimum Temperatures for Manhattan, Kansas. 1930

Day	October		November	
	Maximum	Minimum	Maximum	Minimum
1	84	50	68	33
2	85	62	67	30
3	81	59	69	26
4	82	59	71	29
5	70	58	57	29
6	61	56	52	19
7	76	57	61	23
8	83	52	68	41
9	91	61	71	47
10	88	64	72	37
11	87	56	72	43
12	76	65	72	41
13	65	53	71	46
14	65	54	65	55
15	73	57	70	52
16	69	40	54	29
17	55	28	68	31
18	50	28	74	39
19	45	34	70	54
20	37	25	63	37
21	39	30	45	30
22	43	36	50	28
23	61	26	52	29
24	70	27	40	29
25	74	35	55	27
26	67	50	36	20
27	71	37	39	22
28	59	42	43	20
29	59	32	48	35
30	47	28	49	30
31	57	17		
Mean	66.8	44.5	59.7	33.7

Table II. Greenhouse Temperatures November 21, 1930 to January 30, 1931

Week ending	Mean Maximum	Mean Minimum	Mean
November 21	62.5	47.6	55
28	60.6	45.9	53
December 5	59.1	42.7	51
12	62.1	47.0	55
19	58.1	44.7	51
26	57.4	37.3	47
January 2	45.3	38.0	42
9	60.1	44.9	53
16	58.1	41.1	50
23	60.9	48.1	55
30	66.1	48.6	57

Table III. Daily Maximum and Minimum Temperatures for Manhattan, Kansas. October 1931 through January 1932

Day	October		November		December		January	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	73	62	58	22	47	23	32	28
2	87	52	72	36	51	21	37	18
3	88	68	74	37	43	26	29	15
4	90	61	68	30	37	26	34	27
5	81	58	65	29	38	26	34	25
6	91	68	70	24	48	24	34	11
7	79	59	80	48	51	21	28	12
8	74	47	83	48	46	33	31	9
9	76	47	77	46	44	32	36	1
10	92	66	58	42	54	42	39	23
11	82	51	68	47	53	35	32	25
12	56	53	67	45	41	27	55	30
13	68	53	55	35	38	26	45	25
14	71	46	66	52	45	18	26	17
15	73	42	73	45	51	19	33	10
16	70	42	70	57	52	24	36	28
17	69	33	64	41	54	21	44	26
18	73	41	60	32	58	27	43	22
19	77	48	57	40	64	40	54	29
20	82	57	53	44	54	31	60	39
21	69	57	50	36	51	46	42	28
22	70	58	55	42	47	38	30	23
23	73	57	48	35	59	36	36	26
24	84	52	38	24	54	34	43	14
25	76	42	51	20	62	26	44	27
26	83	48	37	32	58	43	38	29
27	77	46	37	32	52	34	47	12
28	64	33	42	34	59	26	35	21
29	48	37	41	33	62	34	29	9
30	46	39	38	25	58	39	19	1
31	49	36			46	32	24	7
Mean	73.9	50.6	59.2	37.1	50.9	30.0	37.1	19.9

Table IV. Greenhouse Temperatures November 13, 1931 to February 29, 1932

Week ending	Mean Maximum	Mean Minimum	Mean
November 19	72	57	65
26	70	55	63
December 3	68	55	62
10	72	54	63
17	74	55	65
24	69	51	60
31	67	51	59
January 7	60	47	54
14	77	56	66
21	69	52	60
28	62	49	56
February 4	67	47	57
11	68	50	59
18	62	44	53
25	72	47	59

Freezing Data for the Year 1930-31

Data and information were obtained from readings on 960 pots of wheat which included 48 pots of each variety for each of four dates of planting. One half of this material was grown in the greenhouse, the other half being placed outside to harden under natural conditions.

Hardened Plants. The results of the freezing tests in which hardened plants were included are given in Table V. This gives the average per cent injury for each variety at each planting date, the average of all varieties for each date and the average of each variety for all planting dates.

The probable error for any single four pot unit was found to be ±3.04 per cent. The error for any variety for all dates is therefore ±.72 $(3.04 \div \sqrt{18})$ and for any variety at any one date is ±1.24 $(.72 \times \sqrt{3})$. The error of the difference between any two varieties for one date of planting is therefore $1.24.\sqrt{2}$ or ±1.75 and the least significant difference is 5.25 per cent (3x1.75).

For the experiment as a whole there is very little difference between the September 20 and September 30 plantings. Minhardi shows distinctly the greatest resistance in the September 30 planting. P x K evidenced greatest resistance when planted September 20. Minturki, Kanred and Blackhull

Table V. Comparative Injury of Hardened Plants for Different Dates of Planting

	September 20	September 30	October 13	Average
Minhardi	51.5±2.70	44.4±2.70	68.8±1.82	54.9±1.39
Minturki	60.0± .84	59.0±1.41	86.5± .76	68.5± .58
Kanred	59.4± .84	62.1± .98	75.2±1.45	65.6± .63
Blackhull	71.3±1.10	68.1± .76	94.4± .35	77.9± .43
P x K	56.5±1.53	75.0±1.18	85.6± .43	72.3± .61
Average	59.7± .63	61.7± .63	82.1± .43	67.8± .32

do not show significant differences for these two dates. All varieties were less resistant when planted October 13 than for either of the earlier dates. Kanred was considerably more resistant than Blackhull at all dates and P x K was more resistant than Blackhull when planted September 20 and October 13. P x K was as hardy as Kanred when planted September 20 but less hardy for the two later dates.

With the exception of Minturki which on the average was injured more than Kanred the varieties rank in the expected order, as shown by previous studies. Although Kanred was injured 2.9 per cent less than Minturki as an average of all dates of planting, this is hardly a significant difference in favor of Kanred.

There are only three dates of planting reported, since the last planting was made so late that it could not be put outside to harden because of cold weather. All of the hardened plants were frozen December 10 to 12, 1930.

Unhardened Plants. A summary of the results of the freezing trials with greenhouse grown plants is included in Table VI. This gives the percentage injury of the varieties for each of the different dates of planting, the average injury for each variety for all dates, and the average for all varieties for each date of planting, with probable errors for each.

Table VI. Comparative Injury of Unhardened Plants for Different Dates of Planting.

	September 20	September 30	October 13	Average
Minhardi	47.7±2.82	26.6±2.10	67.7±1.41	47.0±1.22
Minturki	56.7±1.96	53.8±3.35	92.6±1.14	67.7±1.25
Kanred	56.1±2.53	45.2±2.78	81.7±1.88	61.0±1.39
Blackhull	84.2±1.49	66.7±2.31	97.5± .43	82.8± .82
P x K	85.9±1.88	67.7±1.84	96.0± .65	83.2± .88
Average	66.1± .96	52.0±1.10	87.1± .51	68.4± .50

The average probable error for any single four pot unit is ±4.75. The average probable error of each variety for all dates was found to be ±1.12. The error for any variety at any one date is ±1.94.

The error of the difference for any two varieties is ±2.74 ($1.94 \times \sqrt{2}$). The least significant difference between varieties would be 8.22 per cent.

It is very noticeable that there is greater variability in the experiment with unhardened plants than was evident with plants in the hardened condition. It is impossible at present to explain just why this relationship should exist.

Here as with the hardened plants only three dates of planting are reported in the table. The plants from the November 8 planting were all killed therefore the data are not tabulated. These plants were only 17 to 19 days old when frozen. All varieties were killed completely. The unhardened plants were frozen November 25 to 28, 1930.

The results with the unhardened plants show less fluctuation between varieties at the various dates of planting than those of the hardened plants. All of the varieties showed greatest resistance when planted September 30 and were more resistant when planted September 20 than October 13. Plants of the October 13 planting were more resistant than those planted November 8, which were completely killed.

Here again Kanred seems to be as resistant as Minturki when planted September 20 and more resistant when planted September 30 and October 13. Blackhull and P x K show about the same degree of resistance in the unhardened condition. The varietal response was essentially the same whether hardened or unhardened plants were frozen.

The data presented this season show Kanred to be slightly more resistant than Minturki, but in previous experiments Minturki has been more hardy. Blackhull and P x K exhibited about the same degree of hardiness in this experiment. Minhardi in all dates of planting and in both hardened and unhardened conditions was the most hardy of the varieties tested.

Freezing Data for the Year 1931-32

The experiments conducted during this season included 2400 pots which were made up of 120 pots of each of the five varieties at four dates of planting. All of the plants tested were in the hardened condition. Data as to the time of day and the temperature at which each lot was frozen are presented in Table VII.

Injury to Leaves and Stems. The average per cent of injury to the leaves and stems for each four pot unit in each freezing lot, and the average injury for all varieties

Table VII. Date, Time of Day and Temperature at which each Lot was Frozen

Lot No.	Date Frozen	Time of day taken from refrigerator	Temperature frozen. Degrees F.
1	November 24	P.M.	5
2	25	A.M.	9
3	25	P.M.	9
4	26	A.M.	9
5	26	P.M.	9
6	27	A.M.	9
7	December 3	P.M.	10
8	4	A.M.	9
9	4	P.M.	9
10	5	A.M.	8
11	5	P.M.	7
12	6	A.M.	8
13	16	A.M.	5
14	16	P.M.	5
15	17	A.M.	5
16	17	P.M.	7
17	18	A.M.	7
18	18	P.M.	3
19	January 6	P.M.	-3
20	7	P.M.	-8
21	8	A.M.	-10
22	8	P.M.	-11
23	9	A.M.	-14
24	9	P.M.	-14
25	27	A.M.	-14
26	27	P.M.	-12
27	28	A.M.	-11
28	28	P.M.	-12
29	29	A.M.	-11
30	29	P.M.	-13

for each date of planting together with probable errors are given in Table VIII. The probable errors were calculated by Bessel's formula. The table also includes the average probable error of each variety for each date of planting. This is the probable error of the mean on the basis of 30 four-pot units. A probable error for all varieties for each date of planting is also given.

The probable error for any single four-pot unit was found to be ±2.185. The average error for any one variety for all dates of planting is ±.20 ($2.185 \div \sqrt{120}$) and for any one date of planting is ±.40 ($.20\sqrt{4}$). The error of the difference between any two varieties for one date of planting is therefore .57 ($.40\sqrt{2}$). The least significant difference is 1.71 (.57 x 3) per cent. This applies for any two varieties for the same date of planting or for any one variety at different dates of planting.

Table IX includes a summary of the percentage injury for each variety for all dates of planting, and for all varieties for each planting date. It may be observed from this table than Kanred and P x K for the September 23 planting are the only varieties which do not show a significant difference in injury for any planting date, Kanred being injured 48.8 as compared to 49.9 per cent for P x K.

Table VIII. Varietal Comparison in Percentage of Injury as Influenced by Time of Planting.

Lot No.	September 23 Minhardi	Minturki	Kanred	Blackhull	P x K
1	93.8± 0.8	98.8± 0.8	100.0± 0.1	100.0± 0.0	95.0± 0.0
2	2.5± 1.0	2.5± 1.0	5.0± 0.0	77.5± 4.2	42.5± 8.0
3	47.5± 1.7	52.5± 4.2	70.0± 3.9	82.5± 3.2	35.0± 6.5
4	57.5± 6.4	70.0± 6.2	82.5± 1.7	87.5± 4.2	67.5± 5.1
5	90.0± 0.0	92.5± 3.2	95.0± 1.9	95.0± 1.9	42.5± 1.7
6	65.0± 4.4	65.0± 4.4	77.5± 4.2	85.0± 5.8	30.0± 2.8
7	10.0± 0.0	7.5± 1.0	10.0± 0.0	57.5± 3.2	7.5± 3.2
8	12.5± 1.7	12.5± 1.7	10.0± 0.0	52.5± 1.7	20.0± 4.8
9	25.0± 1.9	35.0± 1.9	25.0± 5.8	75.0± 1.9	57.5± 5.1
10	32.5± 4.2	15.0± 3.4	15.0± 1.9	45.0±10.1	22.5± 6.4
11	45.0± 4.4	42.5± 3.2	30.0± 4.8	75.0± 1.9	42.5± 5.1
12	15.0± 1.9	25.0± 1.9	40.0± 0.0	75.0± 1.9	25.0± 4.4
13	60.0± 0.0	45.0± 4.4	35.0± 4.4	67.5± 1.7	50.0± 4.8
14	12.5± 1.7	12.5± 1.7	60.0± 2.8	67.5± 1.7	52.5± 1.7
15	52.5± 3.2	60.0± 4.8	55.0± 1.9	67.5± 1.7	47.5± 3.2
16	45.0± 4.4	52.5± 3.2	57.5± 1.7	72.5± 1.7	57.5± 3.2
17	35.0± 4.4	37.5± 5.8	47.5± 1.7	67.5± 3.2	52.5± 3.2
18	55.0± 1.9	40.0± 2.8	50.0± 3.9	62.5± 3.2	57.5± 1.7
19	25.0± 1.9	32.5± 1.7	27.5± 3.2	62.5± 1.7	30.0± 4.8
20	27.5± 1.7	45.0± 4.4	27.5± 1.7	60.0± 4.8	50.0± 2.8
21	52.5± 1.7	60.0± 0.0	60.0± 0.0	85.0± 1.9	65.0± 1.9
22	42.5± 1.7	62.5± 3.2	50.0± 2.8	82.5± 3.2	60.0± 2.8
23	55.0± 1.9	55.0± 1.9	60.0± 2.8	77.5± 1.7	60.0± 0.0
24	50.0± 0.0	70.0± 2.8	62.5± 3.2	77.5± 1.7	60.0± 0.0
25	67.5± 1.7	80.0± 0.0	82.5± 1.7	97.5± 1.7	80.0± 2.8
26	50.0± 0.0	50.0± 0.0	50.0± 0.0	62.5± 1.7	60.0± 0.0
27	47.5± 1.7	40.0± 0.0	45.0± 1.9	70.0± 2.8	65.0± 4.4
28	30.0± 0.0	40.0± 0.0	40.0± 0.0	55.0± 1.9	60.0± 0.0
29	65.0± 1.9	60.0± 0.0	55.0± 1.9	60.0± 0.0	57.5± 1.7
30	30.0± 2.8	32.5± 2.9	37.5± 1.7	60.0± 0.0	45.0± 1.9
Av.	43.3± .37	46.6± .44	48.8± .37	72.1± .46	49.9± .57

Average of all pots planted September 23= 52.1± .20

Table VIII continued

Lot No.	October 3 Minhardi	Minturki	Kanred	Blackhull	P x K
1	57.5± 1.7	77.5± 3.2	75.0± 4.4	95.0± 1.9	90.0± 3.9
2	12.5± 3.2	36.3± 7.2	30.0± 6.2	80.0± 2.8	55.0± 6.5
3	6.3± 0.8	37.5± 9.0	27.5± 3.2	85.0± 3.4	45.0± 1.9
4	17.5± 2.9	20.0± 0.0	22.5± 3.2	70.5± 0.0	57.5± 3.2
5	12.5± 1.9	35.0± 4.4	37.5± 3.2	75.0± 3.4	65.0± 4.4
6	10.0± 0.0	10.0± 0.0	12.5± 1.7	50.0± 6.2	11.3± 2.2
7	5.0± 1.9	10.0± 0.0	12.5± 1.7	67.5± 7.5	20.0± 2.8
8	7.5± 1.7	5.0± 1.9	10.0± 0.0	70.0± 0.0	27.5± 7.5
9	17.5± 1.7	17.5± 1.7	17.5± 3.2	72.5± 1.7	50.0± 3.9
10	10.0± 0.0	22.5± 5.1	22.5± 3.2	47.5± 7.5	22.5± 3.2
11	35.0± 4.4	35.0± 5.8	30.0± 4.8	77.5± 1.7	32.5± 5.1
12	15.0± 1.9	17.5± 3.2	30.0± 2.8	55.0± 1.9	12.5± 1.7
13	35.0± 4.4	45.0± 1.9	52.5± 3.2	60.0± 2.8	50.0± 2.8
14	45.0± 1.9	47.5± 4.2	52.5± 1.7	57.5± 1.7	57.5± 3.2
15	35.0± 6.5	35.0± 4.4	52.5± 3.2	57.5± 4.3	40.0± 7.3
16	57.5± 1.7	55.0± 1.9	57.5± 1.7	70.0± 0.0	62.5± 1.7
17	52.5± 1.7	40.0± 2.8	45.0± 5.8	55.0± 1.9	30.0± 2.8
18	55.0± 1.9	47.5± 3.2	52.5± 3.2	62.5± 3.2	35.0± 1.9
19	22.5± 1.7	22.5± 1.7	50.0± 2.8	50.0± 2.8	25.0± 1.9
20	37.5± 1.7	37.5± 1.7	42.5± 1.7	57.5± 3.2	50.0± 3.9
21	42.5± 1.7	57.5± 1.7	60.0± 0.0	75.0± 1.9	70.0± 0.0
22	42.5± 1.7	47.5± 1.7	60.0± 0.0	70.0± 2.8	60.0± 0.0
23	50.0± 0.0	55.0± 1.9	60.0± 0.0	80.0± 2.8	60.0± 0.0
24	50.0± 0.0	57.5± 1.7	55.0± 1.9	80.0± 5.5	55.0± 1.9
25	57.5± 1.7	72.5± 1.7	77.5± 1.7	90.0± 0.0	80.0± 0.0
26	37.5± 1.7	42.5± 1.7	50.0± 0.0	70.0± 2.8	60.0± 0.0
27	32.5± 1.7	40.0± 0.0	55.0± 3.4	82.5± 3.2	72.5± 3.2
28	40.0± 0.0	50.0± 0.0	42.5± 1.7	67.5± 1.7	57.5± 1.7
29	40.0± 0.0	42.5± 1.7	42.5± 1.7	77.5± 3.2	70.0± 0.0
30	30.0± 0.0	35.0± 1.9	45.0± 1.9	62.5± 1.7	47.5± 1.7
Av.	32.3± .32	38.5± .47	43.3± .45	69.0± .51	49.0± .49

Average of all pots planted October 3= 46.4± .20

Table VIII continued

Lot No.	Minhardi	Minturki	Kanred	Blackhull	P x K
	October 14				
1	57.5± 5.8	85.0± 1.9	92.5± 1.7	97.5± 1.7	100.0± 0.0
2	22.5± 6.4	37.5± 9.3	81.3± 5.2	90.0± 0.0	85.0± 1.9
3	12.5± 1.7	47.5± 1.7	62.5± 3.2	82.5± 1.7	82.5± 3.2
4	12.5± 1.7	67.5± 3.2	67.5± 1.7	90.0± 0.0	82.5± 3.2
5	42.5± 5.8	72.5± 1.7	45.0± 1.9	60.0± 2.8	62.5± 1.7
6	6.3± 2.1	17.5± 1.7	17.5± 1.7	20.0± 0.0	12.5± 1.7
7	5.0± 1.9	15.0± 3.4	7.5± 3.2	27.5± 5.1	10.0± 4.8
8	10.0± 0.0	15.0± 1.9	27.5± 5.8	47.5± 5.1	25.0± 8.0
9	40.0± 2.8	42.5± 4.2	20.0± 2.8	52.5± 3.2	40.0± 4.8
10	12.5± 1.7	20.0± 0.0	15.0± 1.9	30.0± 4.8	20.0± 0.0
11	17.5± 3.2	37.5± 4.2	37.5± 4.2	77.5± 1.7	50.0± 2.8
12	5.0± 1.9	10.0± 0.0	12.5± 1.7	37.5± 3.2	15.0± 1.9
13	40.0± 7.8	52.5± 1.7	70.0± 0.0	85.0± 1.9	70.0± 2.8
14	52.5± 1.7	47.5± 1.7	50.0± 3.9	60.0± 3.9	60.0± 2.8
15	47.5± 4.2	55.0± 1.9	52.5± 3.2	62.5± 1.7	50.0± 2.8
16	50.0± 0.0	55.0± 1.9	52.5± 1.7	65.0± 1.9	60.0± 0.0
17	30.0± 3.9	32.5± 3.2	32.5± 4.2	50.0± 2.8	55.0± 1.9
18	45.0± 1.9	47.5± 1.7	40.0± 2.8	60.0± 0.0	57.5± 1.7
19	10.0± 0.0	12.5± 1.7	10.0± 0.0	17.5± 1.7	12.5± 1.7
20	35.0± 1.9	45.0± 1.9	47.5± 1.7	65.0± 4.4	52.5± 1.7
21	45.0± 1.9	70.0± 0.0	70.0± 0.0	75.0± 1.9	72.5± 1.7
22	40.0± 0.0	50.0± 0.0	50.0± 0.0	60.0± 0.0	57.5± 1.7
23	45.0± 1.9	52.5± 1.7	60.0± 0.0	75.0± 1.9	65.0± 1.9
24	40.0± 0.0	50.0± 0.0	52.5± 1.7	65.0± 1.9	60.0± 0.0
25	55.0± 1.9	62.5± 1.7	65.0± 1.9	85.0± 1.9	80.0± 2.8
26	40.0± 0.0	40.0± 0.0	45.0± 1.9	55.0± 4.4	50.0± 0.0
27	40.0± 0.0	60.0± 2.8	62.5± 1.7	75.0± 3.4	70.0± 2.8
28	40.0± 0.0	47.5± 1.7	50.0± 0.0	65.0± 3.4	60.0± 0.0
29	40.0± 0.0	50.0± 0.0	52.5± 1.7	77.5± 1.7	70.0± 0.0
30	22.5± 1.7	30.0± 0.0	37.5± 1.7	55.0± 1.9	40.0± 0.0
Av.	32.0± .38	44.2± .35	46.2± .38	62.2± .43	54.3± .37

Average of all pots planted October 14= 47.8± .17

Table VIII continued

Lot No.	October 23 Minhardi	Minturki	Kanred	Blackhull	P x K
1	85.0± 1.9	92.5± 1.7	100.0± 0.0	100.0± 0.0	100.0± 0.0
2	47.5± 1.7	80.0± 0.0	97.5± 1.7	100.0± 0.0	100.0± 0.0
3	65.0± 4.4	80.0± 2.8	85.0± 1.9	95.0± 1.9	75.0± 5.8
4	70.0± 0.0	67.5± 3.2	77.5± 3.2	77.5± 3.2	67.5± 3.2
5	57.5± 1.7	62.5± 1.7	80.0± 0.0	92.5± 3.2	85.0± 4.4
6	10.0± 0.0	15.0± 3.4	37.5± 1.7	50.0± 6.2	35.0± 4.4
7	10.0± 0.0	10.0± 0.0	12.5± 1.7	20.0± 0.0	20.0± 2.8
8	20.0± 4.8	10.0± 0.0	12.5± 1.7	35.0± 1.9	40.0± 0.0
9	27.5± 3.2	37.5± 4.2	40.0± 2.8	47.5± 3.2	42.5± 3.2
10	37.5± 3.2	32.5± 1.7	20.0± 0.0	52.5± 1.7	20.0± 0.0
11	47.5± 1.7	47.5± 1.7	47.5± 1.7	65.0± 1.9	42.5± 1.7
12	20.0± 2.8	15.0± 1.9	30.0± 7.3	50.0± 4.8	20.0± 0.0
13	55.0± 3.4	55.0± 4.4	57.5± 3.2	72.5± 3.2	57.5± 1.7
14	50.0± 6.2	57.5± 1.7	70.0± 0.0	80.0± 2.8	72.5± 1.7
15	42.5± 4.2	60.0± 0.0	57.5± 1.7	65.0± 1.9	50.0± 3.9
16	52.5± 1.7	62.5± 1.7	60.0± 0.0	67.5± 1.7	57.5± 1.7
17	40.0± 2.8	17.5± 3.2	37.5± 5.1	52.5± 1.7	50.0± 0.0
18	47.5± 1.7	42.5± 1.7	47.5± 3.2	60.0± 0.0	57.5± 1.7
19	10.0± 0.0	10.0± 0.0	10.0± 0.0	15.0± 1.9	10.0± 0.0
20	27.5± 1.7	32.5± 1.7	32.5± 1.7	55.0± 1.9	50.0± 2.8
21	47.5± 1.7	72.5± 3.2	60.0± 0.0	70.0± 0.0	60.0± 0.0
22	30.0± 0.0	40.0± 0.0	50.0± 0.0	60.0± 0.0	50.0± 0.0
23	50.0± 0.0	60.0± 0.0	65.0± 1.9	70.0± 0.0	67.5± 1.7
24	50.0± 0.0	50.0± 0.0	55.0± 1.9	70.0± 0.0	55.0± 1.9
25	60.0± 0.0	67.5± 5.1	70.0± 0.0	87.5± 1.7	77.5± 3.2
26	40.0± 0.0	40.0± 0.0	45.0± 1.9	55.0± 4.4	45.0± 1.9
27	50.0± 0.0	70.0± 2.8	70.0± 0.0	75.0± 1.9	60.0± 0.0
28	50.0± 0.0	60.0± 0.0	50.0± 0.0	50.0± 0.0	50.0± 0.0
29	52.5± 1.7	67.5± 1.7	62.5± 1.7	67.5± 3.2	80.0± 2.8
30	15.0± 1.9	22.5± 1.7	35.0± 5.8	47.5± 3.2	42.5± 1.7
Av.	42.2± .32	47.9± .31	52.1± .32	63.5± .35	54.7± .32

Average of all pots planted October 23= 52.1± .14

Table IX. Average Per cent of Injury for all Varieties for Each Date of Planting, and Each Variety for all Planting Dates

Date of planting	Minhardi	Minturki	Kanred	Blackhull	P x K	Average
September 23	43.3±.37	46.6±.44	48.8±.37	72.1±.46	49.9±.57	52.1±.20
October 3	32.3±.32	38.5±.47	43.3±.45	69.0±.51	49.0±.49	46.4±.20
October 14	32.0±.38	44.2±.35	46.2±.38	62.2±.43	54.3±.37	47.8±.17
October 23	42.2±.32	47.9±.31	52.1±.32	63.5±.35	54.7±.32	52.1±.15
Average	37.5±.17	44.3±.20	47.6±.19	66.7±.22	52.0±.22	49.6±.089

It may also be seen from the lower line in Table IX that there is very little difference between varieties so far as variability is concerned.

One of the outstanding points in connection with the experiment is the fact that the varieties arrange themselves in the same order in regard to their relative hardiness, that is Minhardi, Minturki, Kanred, P x K and Blackhull regardless of time of planting.

From the results of this experiment the early part of October could be considered the optimum planting date for these varieties with the exception of Blackhull. This is shown clearly in figure 1. Blackhull on the average evidences its greatest resistance when planted the middle of October.

Bower (4) in his study of several winter wheat varieties found that Minturki showed its greatest resistance when planted early in October, which checks closely with the results of this experiment.

Survival of Plants. In addition to data on injury to leaves and stems notes were taken also on the percentage of plants which actually survived after freezing. These data tell much the same story as those based on the estimated percentage of injury and therefore are not presented in

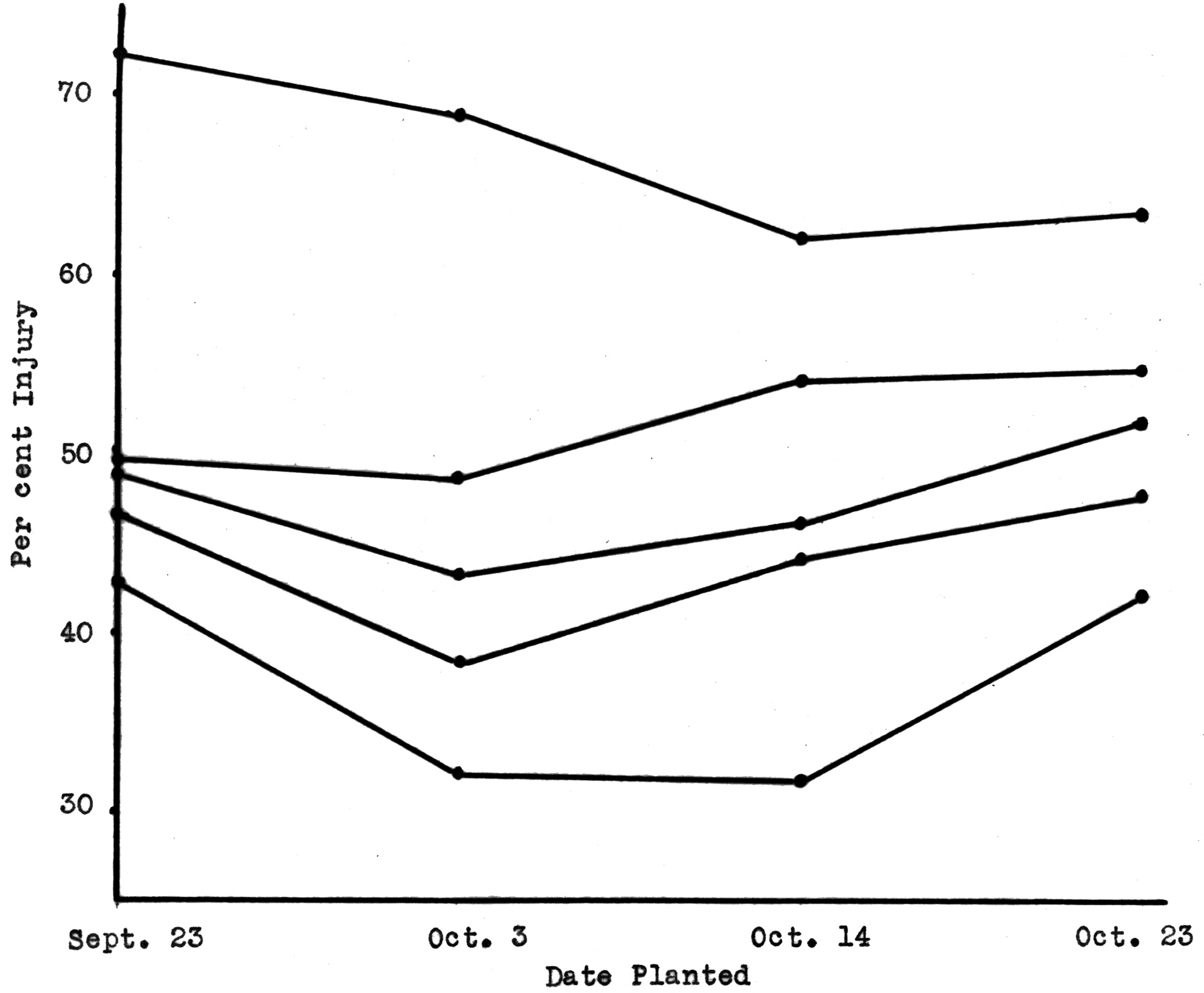

Fig. 1. Average per cent of injury of each variety for each planting date

detailed tabular form. It should be noted that the survival of plants in the last six lots that were frozen was practically zero which was relatively low as compared to the estimated injury for these plants. The high mortality was probably due to some factor other than frost injury, therefore the data from these lots are not considered in the study.

A negative correlation of .681±.085 was found between the estimated injury of plants and the percentage survival for the first 24 freezing lots.

Index Values as a Measure of Resistance. Previous work at this station and the relationship just reported shows the close agreement between the injury and survival notes, when fairly large numbers are considered. Some variation was noticed, however, between the injury and survival readings in several pots in each freezing lot.

A plan using an "index value" was devised to narrow these obvious differences, without changing the values of those pots in which the injury and survival notes were in agreement.

The "index value" was obtained by getting a summation of the percentage of injury and the per cent of plants killed. Thus the value is a representation of two readings, one taken soon after freezing and one two to four weeks after.

It was thought that this system might give a more accurate value for each pot, and in this way reduce the variability in the experiment.

Since this value includes the summation of two readings the range of the values is from 0 to 200 or twice as large as for that of injury, therefore a probable error just twice as large as one for an injury value would be comparable.

Table X includes a varietal comparison expressed in index values as influenced by time of planting.

The probable error for any single four-pot unit is ±4.71. The error for any variety for any planting date was found to be ±.86 ($4.71 \div \sqrt{30}$). The error of the difference between any two varieties is ±1.21 ($.86\sqrt{2}$). The least significant difference for any one variety for any planting date or between any two varieties for a date of planting is 3.63 (1.21 x 3).

Comparing these values with those obtained for injury it is obvious that the variability is not reduced by this method since a difference of 3.63 is equal to 1.82 per cent, whereas the least significant difference for injury to leaves and stems was 1.71 per cent. Thus statistical measurements show slightly more variability in index values.

Table X. Varietal Comparisons Expressed by Index Values as Influenced by Time of Planting

Date of planting	Minhardi	Minturki	Kanred	Blackhull	P x K	Average
September 23	74.1±.78	90.3±.81	97.3±.72	140.0±1.1	104.7±1.1	101.2±.40
October 3	60.0±.74	76.3±.63	89.3±.90	129.5±1.2	102.1±0.93	91.4±.39
October 14	53.7±.61	82.7±.73	94.9±.82	124.3±1.0	106.7±0.73	92.5±.35
October 23	73.8±.88	93.6±.60	100.3±.72	126.5±1.1	109.7±0.97	100.8±.38
Average	65.4±.38	85.7±.35	95.5±.40	130.1±0.55	105.7±0.47	96.5±.19

The index values agree with the injury readings in showing a significant difference between varieties for every date of planting.

A summary of the per cent of injury, survival and the index values for the entire experiment is given in Table XI.

Table XI. Summary of Percentage Injury, Survival and Index Value for the Varieties for the Entire Experiment

	Injury	Survival	Index Value
Minhardi	37.5	67.6	82.0
Minturki	44.3	49.1	97.8
Kanred	47.6	42.9	107.5
P x K	52.0	37.6	118.6
Blackhull	66.7	28.9	138.8

This shows a close relationship between the three methods of measuring resistance. It also points out the fact that the differences in hardiness among the varieties are highly significant since the least significant difference between any two varieties as indicated by the injury readings is .85 and in terms of index value is 1.82.

Age of Plants in Relation to Resistance to Low Temperatures. In connection with a study of age of plants being conducted at this station, it was decided to analyze these data from that standpoint. Table XII gives a summary of the varieties on the basis of percentage injury, survival and the index values.

Under each of these headings are given the average values for five different groups of plants arranged according to variety and the age range in which the plants fell at the time they were frozen. Each group of plants is a summary of six freezing lots of plants. An average for all ages is also given for the varieties under each particular division of the table.

Because of the bulkiness of Table XII probable errors for each of the values are not given. A statistical analysis of the injury data was made, however. Since the values presented in this are the same as in the time of planting study the same error for a single four-pot unit ±2.185 can be applied here. The probable error for any variety at any particular age is ±.89 ($2.185 \div \sqrt{6}$). The error of the difference is therefore 1.26 ($.89\sqrt{2}$) per cent and the least significant difference is 3.78 (1.26 x 3).

These data show again the same consistent ranking of the varieties according to their relative hardiness, that is

Table XII. Varietal Comparisons of Injury Survival and Index Values as Influenced by Age of Plants

Freezing	30 - 39 days					40 - 49 days				
lots	Min-hardi	Min-turki	Kan-red	Black-hull	P x K	Min-hardi	Min-turki	Kan-red	Black-hull	P x K
					Injury					
1- 6	55.8	66.3	77.8	85.8	77.1	25.6	54.6	61.1	73.3	70.8
7-12						27.1	25.4	27.1	45.0	30.8
13-18										
19-24										
25-30										
Av.	55.8	66.3	77.8	85.8	77.1	26.4	40.1	44.4	58.7	50.8
					Survival					
1- 6	80.0	60.8	52.1	24.2	38.8	98.3	84.2	57.5	52.1	57.5
7-12						95.0	98.3	97.5	86.2	100.0
13-18										
19-24										
25-30										
Av.	80.0	60.8	52.1	24.2	38.8	96.7	91.3	77.5	69.2	78.8
					Index Values					
1- 6	181.3	105.4	126.7	161.7	140.0	27.3	70.4	99.4	121.3	113.8
7-12						32.1	27.1	29.6	57.9	31.0
13-18										
19-24										
25-30										
Av.	181.3	105.4	126.7	161.7	140.0	29.7	48.8	64.5	89.1	72.4

Freezing	50 - 59 days					60 - 69 days				
lots	Min-hardi	Min-turki	Kan-red	Black-hull	P x K	Min-hardi	Min-turki	Kan-red	Black-hull	P x K
					Injury					
1- 6	19.4	36.1	37.5	75.8	54.0	59.4	63.6	71.7	87.9	52.1
7-12	15.0	23.3	20.0	45.4	26.7	15.0	17.9	20.4	65.0	27.5
13-18	47.9	49.1	55.0	66.3	57.5	44.2	48.3	49.6	63.8	58.8
19-24										
25-30										
Av.	27.5	36.2	37.5	62.5	46.1	40.9	43.2	47.2	72.2	46.1
					Survival					
1- 6	98.3	92.9	91.7	65.8	75.8	76.7	73.5	57.5	32.1	75.0
7-12	100.0	100.0	100.0	81.6	99.2	100.0	100.0	100.0	72.5	95.0
13-18	85.8	76.7	70.8	45.8	58.8	100.0	92.5	75.8	41.2	57.5
19-24										
25-30										
Av.	94.7	89.9	87.5	64.4	77.9	92.2	88.7	77.8	48.3	75.8
					Index Values					
1- 6	21.5	40.0	45.8	110.0	83.1	81.1	90.2	114.2	157.5	80.0
7-12	15.0	24.2	20.0	63.8	25.8	15.0	17.9	20.4	92.5	32.5
13-18	62.1	72.5	84.2	116.1	98.8	44.2	55.8	73.8	117.1	97.1
19-24										
25-30										
Av.	32.9	45.5	50.0	96.6	69.2	43.4	54.6	69.5	122.4	69.9

Freezing	70 - 79 days					80 - 89 days				
lots	Min-hardi	Min-turki	Kan-red	Black-hull	P x K	Min-hardi	Min-turki	Kan-red	Black-hull	P x K
					Injury					
1- 6										
7-12	23.3	22.9	21.7	63.3	29.2					
13-18	46.7	45.0	52.1	60.4	45.8	43.3	41.3	50.8	67.5	52.9
19-24	35.8	44.2	45.4	56.7	48.8	35.8	46.7	48.3	59.6	53.3
25-30										
Av.	35.3	37.3	39.7	60.1	41.3	39.6	44.0	49.6	63.6	53.1
					Survival					
1- 6										
7-12	100.0	100.0	100.0	73.3	98.3					
13-18	97.5	94.2	68.3	50.8	62.5	99.2	90.8	86.7	51.7	48.3
19-24	60.8	34.2	40.0	23.3	27.1	62.5	28.3	19.2	8.3	18.3
25-30										
Av.	86.1	76.1	69.4	49.1	62.6	80.9	59.6	53.0	27.9	33.3
					Index Values					
1- 6										
7-12	23.3	22.9	21.7	88.3	30.8					
13-18	49.2	50.8	83.8	108.8	83.3	44.2	50.4	64.2	115.8	104.6
19-24	75.0	110.0	105.4	133.3	121.7	73.3	118.3	129.2	151.3	135.0
25-30										
Av.	49.2	61.2	70.3	110.1	78.6	58.8	84.4	96.7	133.6	119.8

Freezing	90 - 99 days					100 - 109 days				
lots	Min-hardi	Min-turki	Kan-red	Black-hull	P x K	Min-hardi	Min-turki	Kan-red	Black-hull	P x K
					Injury					
1- 6										
7-12										
13-18										
19-24	40.8	46.3	54.6	68.8	53.3	42.1	55.0	47.9	74.2	54.2
25-30	44.6	54.6	55.4	63.8	59.2	39.6	48.3	52.1	68.8	61.7
Av.	42.7	50.5	55.0	66.3	56.3	40.9	51.7	50.0	71.5	58.0
					Survival					
1- 6										
7-12										
13-18										
19-24	39.2	20.8	10.0	7.5	6.7	45.0	19.1	13.3	3.3	9.2
25-30	25.0	1.7	0	0	0	38.3	3.3	0	.8	0
Av.	32.1	11.3	5.0	3.8	3.4	41.7	11.2	6.7	2.1	4.6
					Index Values					
1- 6										
7-12										
13-18										
19-24	101.7	125.4	144.6	161.3	146.7	97.1	138.3	134.6	170.8	145.0
25-30	119.6	152.9	155.4	163.8	167.5	101.3	145.0	152.1	167.9	161.7
Av.	110.7	139.2	150.0	162.6	157.1	99.2	141.7	143.4	169.4	153.4

Freezing	110 - 119 days					120 - 129 days				
lots	Min-hardi	Min-turki	Kan-red	Black-hull	P x K	Min-hardi	Min-turki	Kan-red	Black-hull	P x K
					Injury					
1- 6										
7-12										
13-18										
19-24										
25-30	39.6	47.1	52.1	75.0	64.6	48.3	50.4	51.7	67.5	61.3
Av.	39.6	47.1	52.1	75.0	64.6	48.3	50.4	51.7	67.5	61.3
					Survival					
1- 6										
7-12										
13-18										
19-24										
25-30	48.3	0	0	0	0	23.3	2.5	0	0	.8
Av.	48.3	0	0	0	0	23.3	2.5	0	0	.8
					Index Values					
1- 6										
7-12										
13-18										
19-24										
25-30	91.3	147.1	152.1	175.0	165.0	125.0	149.6	151.7	167.5	160.4
Av.	91.3	147.1	152.1	175.0	165.0	125.0	149.6	151.7	167.5	160.4

Minhardi, Minturki, Kanred, P x K and Blackhull, regardless of age. It seems, however, that Blackhull is the only variety which shows a consistent significant difference at the various ages from the variety next to it in rank.

There was no consistent evidence which indicated that in earlier freezings Blackhull was equal to Kanred in cold resistance, as suggested by Suneson (32). His results show Blackhull to be inferior to Kanred in later freezings. These results check with the findings of Hill (11) who reports a constant inferior relationship.

It seems that all varieties must reach the stage of development to have tillered and become prostrate in position before being capable of hardening to the greatest extent.

Since the relationship between varieties appears to be the same regardless of age, the injury data from each age of the separate groups regardless of variety are averaged and presented in Table XIII.

The lower division of the table has a comparable set of data in which the average of each group of six freezing lots is used as 100 per cent. These values were obtained to eliminate the differences among the groups due to more severe injury in one group than in another, thereby obtaining as nearly as possible differences due to age alone. The

Table XIII. Injury of all Varieties at Different Ages

Freezing lots	Age in Days									
	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110-119	120-129
					Actual percentage injury					
1- 6	72.5	57.1	44.6	66.9						
7-12		31.1	26.1	29.2	32.1					
13-18			55.2	52.9	50.0	51.2				
19-24					46.2	48.7	52.8	54.7		
25-30							55.5	54.1	55.7	55.8
					Values in which the average of each group of six freezing lots is used as 100 per cent					
1- 6	120.2	94.7	74.0	110.9						
7-12		105.1	88.2	98.6	108.4					
13-18			105.5	101.1	95.6	97.9				
19-24					91.3	96.2	104.3	108.1		
25-30							100.4	97.8	100.7	100.9
Av.	120.2	99.9	89.2	103.5	98.4	97.1	102.3	102.5	100.7	100.9

average in the lower line of Table XIII gives a relative measure of injury as influenced by age.

With the exception of the value for the 60-69 day age range which is somewhat out of line, these data agree closely with the results of the age of plant experiment which is being conducted at this station. This relationship is again shown in figure 2 which pictures graphically the effect of age of plants on resistance to low temperatures. It is made up from the average values in Table XIII.

Other freezing work in which Kanred planted at weekly intervals indicates the most hardy age of plants to be between seven and eight weeks. In most of the freezing lots the most hardy plants fell within the 50 to 90 day age range. Both older and younger plants tend to be less hardy.

Other Studies

Comparison of Day and Night Freezing. Davis (5) and Hubbard (13) observed in their experiments that plants frozen during the day were injured more severely than when frozen at the same temperatures at night. Davis' explanation is that photosynthetic activity within the plant during the day builds up the cell sap concentration, thereby increasing its resistance to low temperatures, whereas at night this concentration is lowered.

Martin (18) also found a consistent relationship in

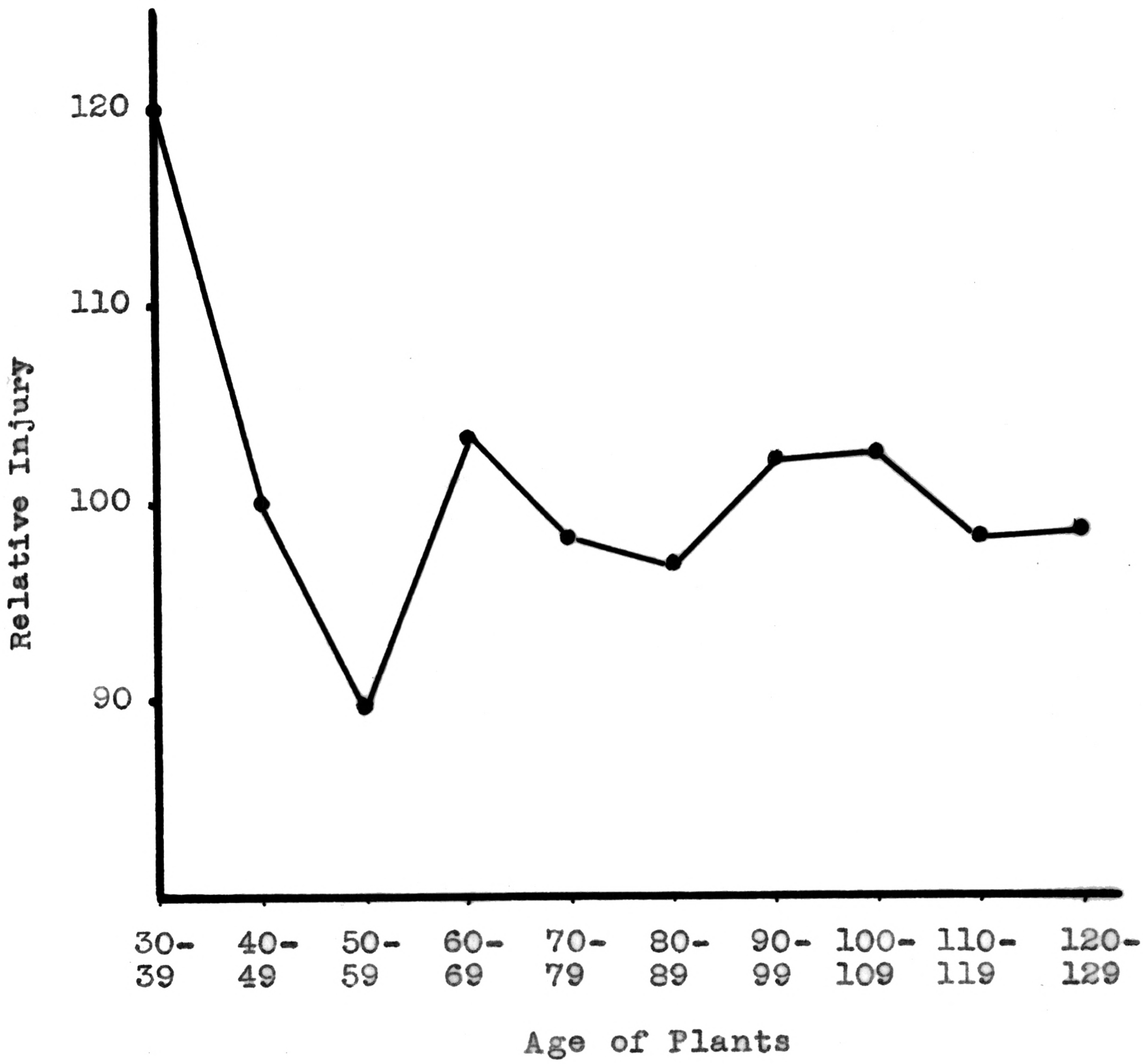

Fig. 2. Relative injury of all varieties at different ages.

favor of plants frozen at night. He obtained a correlation coefficient of .750±.089 between varietal rankings from day and night freezing. This was based on percentage of plants killed in which the difference was not as pronounced as when based on the per cent of injured tissue.

Suneson (32) found no consistent relationship between time of day plants were frozen and the extent of injury.

A study was made in 1930-31 of 750 pots of hardened and unhardened material which were comparable as to temperature frozen and treatment. It is shown in Table XIV, that there was no consistent relationship in either the hardened or unhardened material between the time plants were frozen and the extent of injury.

Table XIV. Comparison of Leaf Injury from Day and Night Freezing

	Unhardened Plants Per cent Injury		Hardened Plants Per cent Injury	
	Day	Night	Day	Night
Minhardi	54.4	51.3	63.9	45.7
Minturki	65.4	67.6	71.3	65.7
Kanred	62.2	61.1	64.6	68.2
Blackhull	88.3	77.1	80.4	75.4
P x K	78.6	86.3	69.4	75.3
Average	69.8	68.7	69.9	66.1

The average percentage injury is slightly higher in both hardened and unhardened plants for the day than for the night freezing. This relationship is by no means consistent, and the differences observed in favor of the day freezing may have been due entirely to chance fluctuation between pots.

The Effect of Location in the Freezing Chamber on Freezing Injury. In some of the early tests during the season of 1930-31 a marked difference in injury was observed apparently due to location in the freezing chamber. Special observations were made with both hardened and unhardened material to determine more accurately this relation.

A record was made of the location of the pots in the freezing chamber. These were arranged in such a way that comparisons could be made between pots of the same variety next to the coils and those in the center of the chamber.

The results of this study are given in Table XV in which is indicated the percentage injury for pots next to the coils, for those in the center of the chamber, the difference, the number of pots included in each case, and the ratio of the difference to the probable error calculated by the point binomial method as suggested by Salmon (27).

A marked difference was recorded between the pots adjacent to the coils and those located in the center of the chamber in every case except the last group of hardened plants reported in Table XV. An electric fan was located in one end of the freezing chamber when the last group of plants were frozen, which kept a free circulation of air throughout the chamber, thereby eliminating much of the border effect which was previously so noticeable.

Table XV. Effect of Location in the Freezing Chamber on Freezing Injury

Treatment	Average percentage injury			Number of pots	D/E
	Next to coils	Center of chamber	Difference		
Unhardened	77.1	60.6	16.5	80	9.78
	69.8	58.2	11.6	81	5.66
Hardened	71.9	57.8	14.1	80	8.78
	70.1	58.7	11.4	83	9.00
Unhardened	83.2	63.8	19.4	104	11.40
	88.9	70.5	18.4	102	13.90
Hardened*	61.1	58.0	3.1	83	3.00
	63.4	61.0	2.4	82	1.33

* Fan was used

Highly significant differences are shown for the first three groups when the fan was not used, the ratios of D/E ranging from 5.66 to 13.9. The use of the fan reduced the difference to within three times the probable error thus indicating that a significant difference due to location probably does not exist when the air is circulated.

SUMMARY AND CONCLUSIONS

The effect of time of planting varieties of winter wheat on their resistance to low temperatures was studied in 1930-31 and 1931-32. The work was so outlined as to detect differential response of varieties in various stages of hardening during the fall and early part of the winter, and after they acquired the fully hardened condition in mid-winter.

Both hardened and unhardened plants were tested during the winter of 1930-31. All of the plants tested during the season of 1931-32 were in the hardened condition.

The following varieties of wheat, in order of their hardiness in these experiments were tested: Minhardi, Minturki, Kanred, P x K and Blackhull. Plantings were made at four different dates each season.

The relative varietal response the first season was essentially the same whether hardened or unhardened plants were frozen. Kanred and Minturki were about equally resistant, but in previous experiments Minturki had been more hardy.

September 30 proved to be a more favorable date of planting for all varieties except P x K than either September 20, October 13 or November 8. P x K showed the greatest resistance in the hardened condition when planted September 20.

In the second season the varieties consistently arranged themselves in order of their known hardiness throughout the experiment, regardless of time of planting.

All varieties but Blackhull exhibited greater cold resistance when planted October 3 than when planted September 23, October 14, or October 23. Blackhull showed greatest resistance when planted October 14.

A positive correlation of $.681 \pm .085$ was obtained between the values based on estimated per cent of injury of leaves and stems and the per cent of plants killed.

In an attempt to reduce variability a new method of measuring resistance was tried in which the readings obtained were termed "index values". The extent of the variability in these experiments was no lower for index values than for injury to leaves and stems.

Plants in the age range of 50-90 days were more cold resistant than either younger or older plants. The varietal relationship remained the same regardless of age.

A study of the data obtained in 1930-31 indicated no consistent relationship between time of day plants were frozen and the extent of injury.

A pronounced "border effect" due to location in the freezing chamber was found to exist unless a fan was used to keep up a good circulation of air.

ACKNOWLEDGMENTS

The author wishes to express his gratitude for the help of Mr. S. C. Salmon, formerly Professor of Farm Crops, in planning and executing these experiments during the first year, and for instruction given in estimating freezing injury. The advice and guidance of Professor H. H. Laude in conducting the experiments, analyzing the data, and writing the manuscript is gratefully acknowledged. Thanks are due Mr. C. O. Johnston, Associate Pathologist, Bureau of Plant Industry, U.S.D.A. for his helpful suggestions on greenhouse technique.

REFERENCES

1. Akerman, A.
   1923. Undersokingar Rorande vora Hostsadessortess. Vinterhardighet (Nordish, Jordbrugsforsking). Investigations on winterhardiness of our varieties of winter cereals. (Translated by Prof. L. Bonander of Lindsborg and A. F. Swanson of Hays)

2. ----------
   1927. Studien uber den Kaltetod und die Kalterestenz- der pflanzen nibst untersuch uber die winter- festigheit des weisens Lund. (Eng. Rev. by Nilsson-Leisner, G. 1929. Death from low temperatures and resistance of plants to cold. Quart. Rev. of Biol. 4:113-117.)

3. Baroulina, E. E.
   1923. The resistance of winter cereals to winter cold. Ann. Inst. Agron. Saratov 1:42-57. (Abstracted in Bot. Abst. 13:7678.)

4. Bower, C. W.
   1928. Winterkilling in winter wheat. Thesis, Iowa State College.

5. Davis, L. L.
   1930. Inheritance of cold resistance and other characters in the backcross, Kanred x Kanmarq. Thesis K.S.A.C.

6. Dexter, S.T., Tottingham, W.E. and Graber, L.F.
   1930. Preliminary results in measuring hardiness of plants. Plant Physiol. 5:215-223.

7. ----------
   1932. Investigations of the hardiness of plants by measurements of electrical conductivity. Plant Physiol. 7:63-79.

8. Govorov, L.E.
   1923. The diverse characters of winter and spring forms of cereals in connection with the problem of hardiness in winter crops. Bul. Appl. Bot. and Plant Breed. 13:575-61 (Russian with Eng. Abs.)

9. ----------
1926. The difference of characters in the winter and spring forms of cereals in relation to the resistance of winter crops. Int. Rev. Sci. and Pract. Agr. 4:949-950.

10. Harvey, H. B.
1918. Hardening process in plants and developments from frost injury. Jour. Agr. Res. 15:83-112.

11. Hill, D. D.
1927. The resistance of winter varieties of wheat to low temperature. Thesis, K.S.A.C.

12. Hill, D. D. and Salmon, S. C.
1927. The resistance of certain varieties of winter wheat to artificially produced low temperatures. Jour. Agr. Res. 35:933-937.

13. Hubbard, V. C.
1929. A study of the inheritance of cold resistance and other characters in the cross, Kanred x Blackhull. Thesis, K.S.A.C.

14. Janssen, George.
1929. Effect of date of seeding winter wheat upon some physiological changes of the plant during the winter season. Jour. Amer. Soc. Agron. 21:168-200.

15. ----------
1929. Effects of date of seeding on plant development and its relation to the winter hardiness. Jour. Amer. Soc. Agron. 21:444-446.

16. Klages, K. H.
1926. Relation of soil moisture content to resistance of wheat seedlings to low temperatures. Jour. Amer. Soc. Agron. 18:184-193.

17. Martin, J. H.
1927. Comparative studies of winter hardiness in wheat. Jour. Agr. Res. 35:493-535.

18. Martin, J. F.
1931. Artificial refrigeration as a means of determining resistance of certain spring wheats to frost. Thesis, K.S.C.A.A.S.

19. Maximov, N. A.
1929. Internal factors of frost and drowth resistance in plants. Protoplasma 7:259-291.

20. ----------
1929. The role of Hydrophylic colloids.

21. ----------
1929. The plant in relation to water. Trans. and edited by R. H. Yapp. London: George Allen and Unwin.

22. Newton, R.
1922. A comparative study of winter wheat varieties with special reference to winter killing. Jour. Agr. Sci. 12:1-19.

23. ----------
1924. The nature and practical measurement of frost resistance in winter wheat. Univ. of Alberta Res. Bul. 1.

24. ----------
1924. Colloidal properties of winter wheat plants in relation to frost resistance. Jour. Ag. Sci. 14:178-191.

25. ---------- and Brown, W. R.
1926. Seasonal changes in composition of winter wheat plants in relation to frost resistance. Jour. Agr. Sci. 16:522-538.

26. Salmon, S. C.
1917. Why cereals winterkill. Jour. Amer. Soc. Agron. 9:353-380.

27. ----------
1930. The point binomial formula for evaluating agronomic experiments. Jour. Amer. Soc. Agron. 22:77-81.

28. -----------
1932. Resistance of plants to low temperature in relation to winterhardiness and the adaptation of crop varieties. Thesis. PhD. Univ. of Minnesota.

29. ----------- and Fleming, F. S.
1918. Relation of density of cell sap to winterhardiness in small grain. Jour. Agr. Res. 13:497-506.

30. Stebut, A.
1911. Influence of low temperature and snow covering on the winterkilling of cereals. Russian Jour. Exp. Landw. Vol. 12, No. 1.

31. Steinmetz, F. H.
1926. Winterhardiness in alfalfa varieties. Minn. Agr. Exp. Sta. Tech. Bul. 38.

32. Suneson, C. A.
1930. The effect of hardening on relative cold resistance of winter wheat varieties. Thesis, K.S.A.C.

33. Tumanov, I. I. and Borodin, I.
1929. Investigations on frost resistance of winter crops by means of direct freezing and indirect methods. Bul. Appl. Bot. of Gen. and Plant Breed. 22:395-440. (In Russian, Eng. Abs. pp. 438-440.)

34. Tysdal, H. M.
1926. A study of hardiness in winter cereals. Thesis, K.S.A.C.

35. Weigand, K. M.
1906. The occurrence of ice in the plant tissue. Plant World 9:25-39.