RESISTANCE OF WINTER WHEAT VARIETIES TO HEAT AND COLD AT DIFFERENT STAGES OF GROWTH AND HARDINESS

by

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INTRODUCTION

Each year throughout the Great Plains wheat producing area yields are materially reduced by extremes in temperature at some period during the life of the crop. These reductions have resulted in lower profits and greater hardships to the producers of this commodity.

Such losses have stimulated investigations directed toward finding better and more efficient means of minimizing these hazards. Much progress has now been made in understanding the basic causes of winter injury and in developing varieties that are resistant to low winter temperatures.

It is realized that winter dormancy or hardening is important in protecting the crop during the winter months. In addition to winter losses, however, the Kansas wheat crop often suffers from high temperatures or late freezes after spring growth had begun. Research must be continued in an endeavor to develop varieties which are not only resistant to low winter temperatures but are also capable of surviving spring temperature fluctuations. In order to more nearly insure a satisfactory harvest from the nation's bread basket each year, greater protection must be afforded the crop from these adverse conditions.

Previous investigations have disclosed the fact that high temperature resistance as well as low temperature resistance is greater in plants that are hardened to winter conditions. It should be of interest to determine whether this correlation between high and low temperature resistance continues throughout the spring life cycle of the wheat plant. If so, the task of developing a variety that is resistant to injury from both high and low temperature in late spring would be simplified.

This investigation involved the study of resistance in wheat to high and low temperatures at different levels of hardiness and different stages of spring growth. The results of the tests are contained and discussed herein.

REVIEW OF LITERATURE

Previous research has provided a basic understanding of the effects that extremes in temperature have upon plants. Studies dealing with low temperature injury, high temperature injury, hardiness, and loss of hardiness have been included in the literature review for this paper. A section dealing with artificial temperature machines has also been added.

Low Temperature Injury

Numerous explanations have been devised to explain the cause of death by low temperature. One of the oldest and most commonly accepted is that advanced by Muller-Thurgau in 1886, quoted by Chandler (6). He decided, after careful study, that ice usually formed in the intercellular spaces and within the cells only in the case of rapid freezing or in exceptionally large cells. He also proved that in some cases the formation of ice was the cause of death, since plants when supercooled were not injured, but were killed if ice formed at higher temperatures. He held that death was due to the withdrawal of water from the cells.

Wiegand (38) believed that death from freezing is usually, if not always, caused by the drying out of protoplasm beyond its critical water content. Newton and Brown (23) explain the phenomena of freezing in plants in this manner:

> The sap adhering to the external surface of the cell walls is necessarily more dilute than the vacuolar sap, else plasmolysis would exist. When the cells are exposed to frost, the more dilute sap freezes first, and ice forms in the intercellular spaces. These abstract water from the cell walls in considerable force, disturbing the equilibrium of the whole system, to restore which there is set up a streaming of water out of the cells.

Wiegand (38) found that hardy tissue, upon thawing, draws water back into the cells while less hardy tissue is not capable of regaining the water lost and thus death results.

It may be, too, that the protoplasm is injured by the formation of ice. According to Maximov (20), there may be enough pressure produced by the ice to mechanically injure the protoplasm.

The rate of freezing has also received attention and the effects of different rates have been studied. Chandler (6) found the rate of temperature fall to be very important, especially for winter buds. He found, in the case of apples, that buds may be frozen rapidly enough with salt and ice so that nearly all will be killed at 0° F. while they are able to withstand a temperature of -20° to -30° F. if the fall in temperature is gradual.

Most literature reviews dealing with the effects of the rate of thawing are rather contradictory in nature. Levitt (17), after an extensive review of the literature, found that in the majority of the cases the rate of thawing failed to affect frost injury.

Other external factors are believed to enter into the results which low temperatures have on plants. Klages (12) grew wheat seedlings in different soil types and moisture contents and found that a low percent of moisture had a protective influence during the first part of the exposure. When killing on the low moisture soil set in, however, it progressed rapidly and almost completely. This phenomenon was explained on the basis of relative activity of the plants grown on soils differing in moisture content and also upon the relation of specific heat of water to that of soil particles. This latter factor would probably be especially important in early spring fluctuations in temperature.

High Temperature Injury

High temperature injury to plants has been found to be closely related to injury caused by drouth. Chi Chen (7) stated that injury due to either soil drought or to atmospheric drought, which usually involves high temperature, is through dessication and dehydration of the cells. For this reason, drouth studies might include information which is also applicable to high temperature situations.

It was found by Tumanov (34) in his work with drouth resistance of different species, that those plants survived whose protoplasm remained more stable and were more capable of enduring dehydration. When drying protoplasm is coagulated in such a manner the change is irreversible and death occurs.

Vassiliev (35) reported that work done in Russia with Canada wheats indicated that in drouth conditions wheat varieties unadapted to drought suffer more from a high intensity of atmospheric factors, including high temperature, which promote increased transpiration, than from a deficiency of water, as is generally accepted. Being highly depressed by the atmospheric factors the yields of the non-resistant wheat suffer but little or not at all from soil drought.

Carroll (5), in exposing 17 varieties of grasses to high air temperatures and a similar group to high soil temperatures, found that much less injury occurred in those treated with high air temperatures.

Berkley and Berkley (4) studied the maximum limit of high temperature under which plants could survive. They concluded that the normal death point, viz., that temperature which will kill protoplasm immediately at a given relative humidity, seemed to depend upon the age of the plant, the duration and the conditions of exposure. Carroll (5) also reported that the lethal temperatures varied with exposure.

Tumanov (34) found that different plant organs show a different dehydration resistance. Krasnosselsky-Maximov (13) subjected oats and barley in the stage of inflorescence to artificial dry hot winds and found that under these adverse conditions the leaves drew water from the flower. In connection with this work they found that plants suffer from hot dry winds differently at different stages of development; they are injured most at the time of flowering and least at the time of waxy ripeness.

Hardening

It has been pointed out that injury to plants by high temperatures is closely allied with injury due to atmospheric drought. Likewise, factors that increase the plants' resistance to one of those types of injury probably increase resistance to the other, as well. In addition, the plants will probably show an increased tolerance to low temperatures. For instance, Waldron (37) found that the order of drought resistance of some spring wheat varieties he was testing agreed well with their order of frost resistance.

Wiegand (38) assumed that the basis of frost resistance lies in the capacity of the protoplasm to withstand the dehydrating influence of a direct or indirect deprivation of water. A similar theory for high temperature resistance, suggested by Tumanov (34), has also been pointed out. It appears, then, that in order for a plant to become resistant, some mechanism is needed to absorb and retain within the cells as much water as possible. Numerous investigations have been conducted in connection with this point.

Aamodt and Johnson (2) discovered that drought resistant varieties of spring wheat possessed a more highly branched primary root system than susceptible varieties. The influence of other structural factors has been studied, too; however, a good summary of the situation has been made by Newton and Martin (24) in which they state that the structural or mechanical features of plants are not effective in controlling the absolute water loss but that these features may be regarded as safety devices protecting the plant against rapid dessication while the cells adjust themselves physiologically for drought resistance.

A plant is said to be hardened when its resistance to adverse conditions has been increased by external influences. According to MacDougal (18), plants may be hardened by exposure to cold, restricting the water supply, growing in poor soils for a period, by root pruning, or by watering with a weak salt solution. These conditions tend to create a stunted type of growth, cause a concentration of the cell sap, and a high proportion of dry matter in the plant.

MacDougal further reported that a notable feature of resistance is the large proportion of mucilage or pentosans present and emphasized the fact that these materials have a high temperature point before they break up and coagulate. Rosa (28) also found this to occur in cabbage and other vegetables during the hardening off process. Vassiliev and Vassiliev (36) noted that hemicellulose content of wheat plants increased under conditions of drought and felt that this accumulation represented a means of resistance and a natural reaction of wheat plants to drought. This increased carbohydrate accumulation probably has at least two important functions: it provides for an increased concentration of the cell sap and can be used as food when conditions become critical.

The importance of the osmotic concentration of the cell sap is somewhat arbitrary. Greathouse and Stuart (9) observed a higher osmotic pressure in the roots of a hardy clover throughout the winter than in those of a less hardy one.

Newton and Martin (24) also found the osmotic pressure to be higher in resistant plants but felt that this was mainly the result of environment and their relation to resistance arises merely from the fact that the leaves were collected in typical habitats. Schmidt, et. al. (31), concluded that osmotic pressure is no criterion of drought resistance, since the relation between the osmotic pressure of tender and hardy varieties fluctuates markedly with external conditions.

A reduced quantity of water was reportedly found by Vassiliev and Vassiliev (36) in wheat plants whose resistance had been increased by controlled wilting. Many other workers have corroborated these findings, both in drought and frost resistance. Hence, moisture content must be considered a factor in inducing a hardened condition, according to Levitt (17). He claims that this reduction may be passive--simply due to an excess of evaporation over uptake, controlled primarily by environment; or, more likely, this drop may be the result of cell activity because in many cases this phenomenon takes place when there is normally nothing to prevent the plant from absorbing as much water as it transpires.

In spite of their lower water content, a multitude of evidence has been accumulated indicating that hardy plants have a higher water-holding power within the cells. Newton and Martin (24) found it satisfactorily possible to classify wheat and grasses with respect to drought resistance on the basis of the bound water content of the fresh press-juice that was extracted by pressure. Newton (22) earlier had reported the same situation in relation to frost resistance. Imbibitional pressure due to the accumulation of hydrophylic colloids during hardening is the explanation given for this condition.

Salmon (30) summarizes hardening of winter grains as it occurs in this manner:

> It appears to be generally accepted that the important changes include (1) a slight though not always consistent decrease in moisture content, (2) a marked decrease in the amount of sap that can be extracted from living tissue by pressure, (3) an increase in the sugar content, and (4) a decrease in free water, that is, the water in the tissue from which ice will be formed at any given temperature.

The age or size at which plants are subjected to adverse conditions plays a role in the overall effect. Heyne and Laude (10) observed that young corn seedlings were resistant to high temperature, that the resistance decreased with age, and that by the twentieth day the plants had become extremely susceptible to injury. The cause of these results appear to be associated with the carbohydrate reserves found in the seed itself and the colloidal condition of the cell contents.

Kezer and Robertson (11) pointed out that drouths occurring during the booting stage of spring wheats greatly reduce the yields. As previously mentioned, Krasnosselsky-Maximov (13) found that hot winds occurring at the flowering stage are extremely detrimental to the cereals studied. Tippett (33) states that pollen may be killed either by low temperatures or high temperatures that do not destroy other portions of the plant. Apparently the boot and flowering stage of cereals is the most critical period for extremes in temperatures to occur.

Loss of Hardiness

It has long been known that plants in active growth are more easily killed than in a state of rest. Treviranus, cited by Levitt (17), suggested this fact. Chandler (6) noted that under artificial conditions of hardening, there was a retardation of growth regardless of the treatment used. Dexter (8) and numerous other investigators have established the fact that the survival of winter grains during cold weather depends largely on whether they have become hardened before winter sets in.

Laude (14) reported experiments in which winter hardened cereal plants were transplanted into warm greenhouses for a few days prior to freezing them artificially. The quality and intensity of the light, the atmospheric moisture and other conditions remained essentially the same—only the temperature was changed. The resulting loss of hardiness was therefore attributed to temperature differences. It was further found that the rate of change is associated with the amount of heat.

In another case Laude (15) compared the relative rank in cold hardiness of hardened and non-hardened plants. Certain varieties that possessed a marked degree of resistance when hardened were not superior, and in some cases were inferior, in this respect several days after spring growth had begun.

Nauheim (21) found that the loss of cold resistance of winter cereals in early spring is associated with an increase in moisture content and a decrease in solids. Dexter (8) believes that the retention of hardiness is dependent upon environmental conditions which favor the conservation of organic reserves, that is, which depress respiration and top growth and favor dormancy with continued periods of photosynthesis.

Artificial Temperature Tests

In recent years, particularly within the last 25 years, much investigation concerning the effects of temperature extremes on plants has been carried on by use of artificial freezing chambers and by high temperature drought machines. The effect of high temperatures, the main factor in atmospheric drought, would be difficult to study if restricted to normal conditions. Shirley and Meuli (32) list these advantages, among others, for machine drought testing: (1) free from biotic influences which often disturb tests in the field, (2) the machine is available for tests at any time, whereas field tests can only be made during certain periods, (3) the close control over environmental factors possible in the machine greatly reduces variability with consequent improvement in the reliability of the results.

Bayles, et. al. (3), tested reactions of eight varieties of spring wheat to heat by placing pots of each variety on a revolving table in a current of hot air. A close relationship between the performance in the field and under artificial hot winds was apparent. Hunter, Laude, and Brunson (10) reported similar success when they subjected corn seedlings to 140° F. temperature for 6.5 hours with a relative humidity of about 30 percent.

Aamodt (1) constructed a drought machine consisting of a glass enclosed tunnel through which heated air blows at a velocity of about six miles per hour. He noted a high correlation between the results obtained with this apparatus and the findings of field test plots.

Salmon (30) used a low temperature room in conducting his research and reported a close relation between the results of artificial freezing and winter injury in the field. Martin (19), likewise, was successful in obtaining a high correlation between field and refrigeration injury in comparing varietal differences in wheat, both in hardened and slightly hardened stages.

MATERIALS AND METHODS

Eight varieties of winter wheat, viz., Pawnee, Comanche, Ponca, Kiowa, Cheyenne, KanKing, C.I. 12406, and C.I. 12517, were used in studying resistance to high and low temperatures. The first six varieties are standard commercial strains for this area while C.I. 12406 is a cross of Marquillo-Oro x Oro-Tenmarq and C.I. 12517 is from a Comahche x Blackhull-Hard Federation cross.

Planting of these plots was done on the Agronomy farm on October 10, 1952. However, due to unusually dry fall weather conditions, germination did not begin until November 17 and emergence did not take place until early in January, 1953. Removal of plants for experimental purposes was done between February 18 and March 1. Quart sized tin cans, measuring about four inches in diameter and six inches in height, were used in the transplanting process. Both ends of the cans were removed and the resulting tin shell placed over the selected plants. The shell was then carefully pushed into the ground about the plants, producing potted specimens with practically no disturbance of the roots. The resulting potted plants were heeled in at the plot site in such a manner that they could be easily removed and brought into the greenhouse as needed.

Fortunately, rains occurred during this period facilitating the procedure. Success of this method is illustrated by the fact that nearly 1,400 pots were removed with no transplanting losses being observed. No noticeable difference could be seen in those plants transplanted and those remaining undisturbed in the field.

Enough pots were brought into the greenhouse each day in order that three stages of hardiness and growth could be tested. The first series of plants was tested while still in the hardened condition—immediately after being brought in from the field, while the second group was allowed to grow in the greenhouse for two weeks prior to treatment. The final comparison was made with plants in the boot stage.

This procedure was duplicated eight times in the second and third stages. Only six high temperature and seven low temperature repetitions of the first series were successful, however, as the treatment administered was too severe in the early tests.

The investigations included subjecting similar groups of plants to artificial freezing and to high temperatures. Probably the most difficult task of the experiment was that of determining the proper temperature and duration to which the plants of each series should be subjected in order to effect good differential injury. It was necessary to conduct many preliminary tests to obtain this situation. This difficulty accounted for the loss in the first stage of one repetition of low temperature and two repetitions of high temperature treatments, even after preliminary tests had been made. However, more success was obtained with the second and third series.

The plants were placed on tables in randomized fashion while growing so that possible light or temperature differences within the greenhouse would not present a variable factor. Soil moisture in the pots was maintained as near optimum as possible at all times. Greenhouse temperatures normally ranged from 65° to 85° F.

Low Temperature Tests

Before subjection to either high or low temperatures the plants were watered thoroughly, though not excessively. The advisability of this has been pointed out by Salmon (29) in which he indicated that this prevented undue variations in injury due to fluctuations in soil moisture content. He also points out that it takes nearly twelve hours for the temperature of the soil in four inch pots to approach the temperature of the freezing chamber.

Each repetition of this experiment included 24 pots. After the material was placed in the chamber it was possible to control the temperature fluctuation to a $\pm 1^\circ$ F. A lapse of about one hour after the material was put in was needed before the chamber temperature returned to its normal running level. All duplications received the same fluctuation, however, so this was not a major problem.

Twelve hour runs were used for the hardened plants, ending either at 8 a.m. or 8 p.m. The temperature found to give the best differential injury was 4° F. After the plants had been growing in the greenhouse for two weeks, however, it became necessary to raise this temperature to 22.5° F. The period of time was necessarily reduced, also, from 12 hours to 9 hours. Plants were then placed in the freezer at 8 a.m. or 11 p.m. and taken out at 5 p.m. or 8 a.m., respectively.

In acquiring differential injury with plants in the boot stage it was necessary once again to raise the temperature, this time to 25° F., but the period of time the plants were exposed was increased to 13 hours. In this group all plants were placed in the chamber in the morning and taken out again at night.

In all cases the plants were taken out of the freezer and allowed to thaw in the greenhouse at a temperature of about 70° F.

Plants were frozen in a cork-insulated room in which low temperature was introduced by means of a direct expansion refrigerator. The refrigeration plant was thermostatically controlled, so that temperatures could be regulated. An electric fan placed above the pots and near the center of the freezing chamber was effective in promoting uniform temperatures throughout.

High Temperature Tests

Equipment used for this phase of the experiment consisted of a closed chamber through which warm air was circulated and controlled thermostatically. A rotating table was located in the center of the room, on which were placed 24 pots each repetition. Light of low intensity was provided by light bulbs about six feet above the plants. A double glass window provided a means of observation without affecting the temperature within the room.

As was the case with the low temperature treatments, it was necessary to inflict more severe adverse conditions to the smaller hardened plants than in the later stages of growth. Humidity was a more important factor here and, unfortunately, could not be accurately controlled. However, the level of humidity remained fairly constant throughout each series of repetitions. Thorough saturation of the soil about an hour prior to treatment probably helped maintain a constant relative humidity, in addition to reducing the damage the plants might have suffered from an actual deficiency of water while they were subjected to high temperatures. In order to reduce this possible injury still further the pots were rewatered after they had cooled following treatment. With this technique it was believed that nearly all injury suffered was due to high temperature alone.

In all series the plants were placed in the machine in the morning about 9:00 and removed during the afternoon.

Hardened plants were subjected to temperatures of 135-142° F. for periods of approximately 8 hours. The temperature gradually increased each time as the last three hours approached. Observation of injury was made through a glass window and the plants were removed when injury appeared to be severe enough. For this reason, the actual number of hours varied slightly. The relative humidity in this series ranged from 32 to 42 percent, usually decreasing in the latter hours.

Essentially the same procedure was used for those plants subjected to high temperature after two weeks of spring growth. It was necessary to lower the temperature, however. At this stage 125-129° F. was found to give best results. The relative humidity increased in these tests to 46-56 percent. The period of subjection to high temperature was also necessarily reduced to approximately six hours.

Those plants treated while in the boot stage were subjected to temperatures ranging from 119-126° F. They could be left in the chamber for only about four hours, else injury was too severe. The relative humidity continued to show a tendency to increase with larger plants, in this case ranging from 50-60 percent.

Recording of Observations

The number of plants per pot varied in the first two stages tested. It was not possible to obtain exactly the same numbers of plants per pot while transplanting from the field; however, care was taken in trying to make as uniform field selection as possible. In addition, only those plants that were reasonably close to the center of the pots were included in the recorded results. All others were removed prior to treatment. In spite of this difficulty fairly uniform pots were effected, averaging 4 to 6 plants each.

Varieties in all repetitions and series were represented by three pot samples, both in the high and low temperature treatments. Results of these pots were averaged together for each individual reading. In the first two stages of growth, mortality was used as the basis for comparison. Estimation of percent injury was considered, but it was reasoned that the plants were too small at these stages for proper differentiation to be made. In addition, the three pots combined gave 12 to 18 plants per reading, an ample number for good representation of fatally injured plants. Martin (19) and Laude (14) compared both methods and found a remarkably close relation between them, with Martin reporting a correlation coefficient of .946.

Readings for the first two series were taken the morning of the sixth day after treatment for both high and low temperatures. All plants not showing life at this time were presumed dead.

In order to allow for proper development of plants to the boot stage it was necessary to reduce the number of plants to one per pot. Only the center-most plant in these pots was left growing, the remainder being removed about one week after transplanting. After subjection in the boot stage, injury was estimated and recorded as percentage of killed tissue in the three pot samples. Tissue kill, rather than mortality, was necessarily used because of the small number of plants which comprised each reading.

First estimates of damage caused by low temperature were made the seventh day after treatment. Readings were taken again the following day to determine the accuracy of the first estimates. The difference between readings was negligible. Readings of plants exposed to high temperature were taken 4 to 7 days after treatment.

A statistical analysis of the data was computed, using the individual readings contained in the tables for determining the standard error. The mean average for each variety was used in computing the correlation within each series. Formulae as outlined by Paterson (25) were used in the procedure.

A comparison of resistance was also made between plants of Pawnee, in which they differed only with respect to size and development. Plants were obtained from a plot which had enough moisture in the autumn for early November emergence. They were exposed to high and low temperatures in comparison with small plants such as were used in the previously described experiment, where emergence occurred during the winter. The larger plants were much more fully developed, having tillered rather profusely, averaging ten or more per plant. The crown was similarly more developed, and a rather extensive secondary root system was observed in these plants.

Table 1 denotes the maximum and minimum field temperatures from October 10, 1952, the day the wheat was planted, to February 28, 1953, the last day plants were brought into the greenhouse. It is possible that a slight amount of winter hardiness had been lost by the time all the plants had been removed. This was not

Table 1. Daily maximum and minimum temperatures for Manhattan, Kansas, October 10, 1952, to February 28, 1953.

Date	October Max	October Min	November Max	November Min	December Max	December Min	January Max	January Min	February Max	February Min
1			77	38	32	1	25	1	53	25
2			77	40	33	10	35	25	53	36
3			79	50	37	11	33	17	58	30
4			63	28	38	30	32	18	68	28
5			73	37	41	28	40	20	44	31
6			73	31	51	29	26	20	50	28
7			53	20	52	28	29	10	52	24
8			50	25	53	29	26	17	59	30
9			56	38	57	34	34	16	52	44
10	72	34	44	15	50	29	28	16	48	31
11	76	39	47	20	44	27	42	19	33	23
12	81	44	62	28	53	23	43	23	42	29
13	80	44	75	35	40	17	57	32	48	21
14	74	48	70	36	30	14	48	27	44	24
15	59	26	68	29	32	14	56	9	59	21
16	65	31	76	37	52	18	11	-3	31	17
17	77	39	67	52	60	27	21	-2	59	17
18	50	23	67	35	42	27	33	21	64	34
19	71	29	50	29	33	26	42	24	48	42
20	*	35	43	19	31	26	38	25	46	14
21	*	28	51	24	32	19	31	24	30	11
22	63	33	59	27	32	25	54	31	51	20
23	72	36	47	30	30	9	32	24	56	30
24	79	39	43	32	20	-4	39	25	41	33
25	83	43	35	32	30	13	44	24	43	28
26	86	49	34	21	29	4	46	25	62	27
27	84	51	25	4	27	-6	62	25	53	28
28	63	25	21	-6	38	-3	45	21	55	25
29	51	20	27	-5	39	17	51	24		
30	67	26	30	-1	32	4	52	27		
31	76	38			26	-1	52	30		

*Data not available

likely, however, because very little spring growth had yet occurred and the results obtained indicated that the plants were quite resistant.

EXPERIMENTAL RESULTS

Series I—Hardened Condition

Winter hardened varieties of wheat were brought in from the field and subjected to treatments of high and low temperatures. Results obtained from these treatments at this stage of development are given in this section of the report.

Data in Table 2 give the percent mortality of the individual repetitions in this group, having been measured in the manner previously described.

A temperature of 4° F. for a period of 12 hours was used in obtaining differential low temperature injury in this series. Mortality among the eight varieties averaged from 33.7 percent in KanKing, the most hardy, to 85.1 percent in C.I. 12517, the most susceptible at this stage. Statistical study of the data showed that a difference of 9.1 percent between the means was sufficient for significance at the five percent level.

Observation of these data indicated that the eight varieties could be tentatively grouped into four classifications: KanKing, Kiowa, and Comanche showed marked resistance; Cheyenne and Pawnee were intermediate; C.I. 12406 and Ponca were less hardy; and C.I. 12517 was found to be the least hardy of these varieties. All these varieties, however, are considered relatively hardy to

Table 2 Percent mortality of plants subjected to temperature treatments while in the winter hardened condition.

4° Fahrenheit for 12 hours

Variety	Trial Number 1	2	3	4	5	6	7	Mean Average
KanKing	40	37	33	60	12	44	10	33.7
Kiowa	54	43	25	73	12	45	23	39.3
Comanche	33	40	46	60	39	50	20	41.1
Cheyenne	53	46	36	89	19	62	24	47.0
Pawnee	33	54	67	77	27	50	27	47.9
C.I. 12406	46	62	69	93	56	71	23	60.0
Ponca	70	75	77	100	50	77	28	68.1
C.I. 12517	100	92	92	100	58	100	54	85.1

135°-142° Fahrenheit for 8 hours

Variety	Trial Number 31	32	33	34	35	36	Mean Average
KanKing	10	46	50	36	47	15	34.0
Comanche	18	50	30	47	50	9	34.0
Cheyenne	40	46	60	49	40	5	40.0
Kiowa	33	67	53	36	57	21	44.5
Pawnee	49	49	71	36	67	10	47.0
Ponca	21	59	90	46	90	13	53.2
C.I. 12406	62	77	100	73	27	35	62.3
C.I. 12517	57	39	100	72	81	63	68.7

normal winter conditions, so this classification should not be construed to mean that the less resistant varieties are actually susceptible to winter injury under ordinary circumstances.

KanKing was significantly more resistant than all other varieties except Kiowa and Comanche, whereas these two were only significantly more resistant than C.I. 12406, Ponca, and C.I. 12517, although they approached this level over Cheyenne and Pawnee. Cheyenne and Pawnee were nearly alike, both being ranked significantly above C.I. 12406, Ponca, and C.I. 12517. This last variety ranked decidedly below the other varieties under the conditions of these trials.

High temperature data were handled in the same manner as the low temperature data. The standard error obtained was 9.2 percent, causing a difference between the means of 18.4 percent to be necessary for significance at 5 percent. It is probable that had there been more than six successful repetitions within this group the statistical data would have provided a sharper distinction in resistance among the varieties at this stage. Actually, there was a spread of about 35 percent between the most resistant and most susceptible varieties, indicating that definite differences existed.

KanKing and Comanche ranked first in high temperature resistance at this stage, though they were statistically significant only over Ponca, C.I. 12406, and C.I. 12517. Cheyenne and Kiowa appeared semi-hardy while Pawnee and Ponca were comparatively more susceptible. C.I. 12406 and C.I. 12517 were the most susceptible under the conditions of these tests.

In order to compare the varieties with respect to both high temperature and low temperature resistance, a statistical correlation was made, using the mean averages obtained for each variety in both trials. The resulting figure was +.9022, a highly significant correlation. KanKing ranked highest, C.I. 12517 ranked the lowest, and Pawnee remained in the same position in both experiments. The other varieties varied slightly, although none of them differed more than two places at this stage. From these figures it may be assumed, at least according to the situation under which these tests were conducted, that physiological conditions occurring within the plant to give low temperature resistance also provide protection for the plant from abnormally high temperatures. This is a fact that has been corroborated by many investigators. It is not probable, of course, that temperatures during midwinter would ever rise to a point where the plants would be subject to injury by extremely high temperature.

Plants subjected at this stage were small. When they were first brought in from the field they were approximately 2 to 3 inches tall and only a few had formed crowns. It is possible that the comparative resistance might have differed somewhat had older or larger plants been used in the trials. Dexter (8) has pointed out the advantages of protective crowns under adverse conditions. These points will be discussed in a later section.

After treating this group of plants with low temperature, recovery from injury was slow. The more susceptible plants never revived, while those less susceptible began to show normal turgidity and green color at the base of the leaves after 36 hours. These plants grew slightly for about seven days and then died, too. It was believed, however, that death at this time may not have been entirely due to early injury, as mold began growing on the young plants after about a week. Salmon (29) reported similar difficulties. For this reason all readings used in the data for this stage were taken within six days after treatment.

These small hardened plants exhibited extreme resistance to high temperature injury. Temperatures that killed unhardened plants did not seem to cause more than severe wilting of these plants. In order to effect mortality it became necessary to raise the temperature and subject the plants to longer periods. Once the top growth was killed back to the crown of these small plants, however, very little regrowth occurred.

Series II—Unhardened Plants

Part of the plants brought in from the field in the winter hardened condition were allowed to grow in the greenhouse for two weeks prior to treatment. After this growth it was assumed that most, if not all, of the cold resistance had been lost. Laude (14) found that after about two weeks at greenhouse temperatures nearly all acquired cold hardiness had been lost.

This group of plants were subjected to the same type treatment as the preceding group, varying the time and temperature as earlier described. Results from tests in these conditions are shown in Table 3.

Table 3. Percent mortality of plants subjected to temperature treatments after dehardening in the greenhouse for two weeks.

22.5° Fahrenheit for 9 hours

Variety	Trial Number								Mean
	11	12	13	14	15	16	17	18	Average
KanKing	38	21	8	20	25	72	40	30	31.8
Cheyenne	94	6	25	36	46	86	40	70	50.4
C.I. 12517	71	31	27	70	33	81	31	85	53.6
Kiowa	50	14	26	80	67	100	35	67	54.9
Pawnee	52	77	56	100	30	79	33	89	55.8
Comanche	59	50	45	71	41	90	54	69	59.9
Ponca	85	12	31	100	50	95	42	87	62.2
C.I. 12406	63	36	44	100	88	93	73	80	72.1

135°-142° Fahrenheit for 6 hours

Variety	Trial Number								Mean
	41	42	43	44	45	46	47	48	Average
KanKing	25	19	54	56	7	38	19	0	27.3
Cheyenne	27	33	69	67	25	45	20	39	40.6
Ponca	43	85	75	90	18	58	35	16	52.5
Kiowa	42	85	81	89	7	64	36	28	54.0
C.I. 12406	43	62	85	84	46	54	65	16	56.9
C.I. 12517	50	70	100	78	36	63	58	44	62.4
Pawnee	56	100	92	86	33	55	55	44	65.1
Comanche	75	100	93	100	54	64	77	17	72.5

In low temperature tests KanKing was the most resistant, averaging 31.8 percent mortality among the eight repetitions, while C.I. 12406 was the most severely affected, averaging 72.1 percent. Standard error obtained from the statistical analysis was 4.85 percent, from which it was found that for these conditions a difference of 9.7 percent was needed for significance at 19:1 odds.

KanKing was found to be significantly higher in resistance than the other varieties tested. Cheyenne, C.I. 12517, Kiowa, Pawnee, Comanche, and Ponca were somewhat similar in resistance, differing only about 12 percent from the most resistant to the most susceptible within this group. Cheyenne was significantly more hardy than Ponca, however, and approached significance over Comanche. C.I. 12517 approached significance over Ponca. All varieties were significantly more resistant than C.I. 12406, except Ponca, which closely approximated that level.

In results obtained from high temperature exposures to plants in the same unhardened condition, KanKing again showed superior resistance with 27.3 percent mortality while Comanche was the most susceptible under these conditions, showing 72.5 percent mortality. A difference between the means of 11.2 percent was found to be necessary for significance. KanKing, highest in resistance, was significant over all other varieties, and Cheyenne, ranking second, was significant over all other varieties except KanKing. The remaining varieties were not so differentiated in mortality, showing only about 3 percent difference between each descending variety. However, Ponca and Kiowa were significant over Pawnee and Comanche; C.I. 12406 was also significant over last place Comanche.

The correlation coefficient obtained by comparing the mean varietal resistance to high and low temperatures for this series was +.7767. This was significant at the five percent level. It can be seen from Table 3 that KanKing, Cheyenne, and Kiowa ranked first, second, and fourth, respectively, in both treatments. The other varieties differed in comparative rank, Pawnee and Comanche ranking two places lower and C.I. 12517 ranking three places lower in the high temperature tests compared to their low temperature ranks. C.I. 12406 was three places higher, but the greatest variation occurred with Ponca, in which this variety ranked four places higher in the high temperature tests. Although these variations occurred, they were of small magnitude because the general hardiness or susceptibility of the varieties remained the same in both groups. It could be said, then, that low temperature and high temperature resistances were apparently closely related, even after the acquired winter hardiness had been lost.

These plants had been growing for two weeks in the greenhouse and had obtained a height of approximately seven inches. Growth had assumed normal spring-like characteristics. After treatment with low temperature many of the more susceptible plants failed to recover upon thawing. Injury to the surviving plants occurred primarily within the leaves while those plants that were killed appeared to suffer severe crown or basal injury. Almost no regrowth was noted in those plants dying early.

High temperature injury was also primarily leaf injury, most of those plants surviving showed no injury around the basal portion of the stems. More regrowth was noted in plants apparently killed by high temperature than was seen in plants that appeared to be killed by low temperature.

Series III--Boot Stage

After the untreated plants had been in the greenhouse about two months they had developed into the late boot stage. It was at this time that the final treatments were made. Results obtained are found in Table 4. Data recorded are based on percent injury in this series, as mentioned earlier.

Injury by low temperatures varied from 41.9 percent in Cheyenne, the most resistant, to 66.3 percent in Kiowa, the most susceptible. Although this was not quite as great a difference as was noted in the earlier series, only a difference between the varietal means of 6.6 percent was necessary for significance at the 5 percent level. Cheyenne was significantly more resistant to low temperature injury at this stage than all other varieties. C.I. 12517 was significantly resistant over all other varieties except Cheyenne, which ranked above it, and KanKing, which ranked just below it. KanKing and Pawnee showed significantly greater resistance over Ponca, Comanche, and Kiowa, while KanKing also reached that level over C.I. 12406. The varieties C.I. 12406,

Table 4. Percent injury of plants in the boot stage when subjected to temperature treatments.

25° Fahrenheit for 13 hours

Variety	Trial Number 21	22	23	24	25	26	27	28	Mean Average
Cheyenne	50	35	35	45	35	50	50	35	41.9
C.I.12517	35	35	40	45	45	70	55	65	48.8
KanKing	45	40	35	55	50	65	60	60	51.3
Pawnee	55	50	45	50	50	70	70	65	56.9
C.I.12406	75	45	55	70	50	65	60	65	60.6
Ponca	70	55	45	60	65	70	75	60	62.5
Comanche	60	50	60	80	55	85	70	65	65.6
Kiowa	60	60	65	75	60	75	65	70	66.3

119°-126° Fahrenheit for 4 hours

Variety	Trial Number 51	52	53	54	55	56	57	58	Mean Average
Cheyenne	50	60	45	50	50	55	40	40	48.9
KanKing	55	70	65	60	60	75	50	45	59.4
C.I.12517	60	70	60	60	75	65	60	55	63.1
Ponca	75	75	65	55	75	65	55	55	65.0
C.I.12406	60	80	75	65	65	75	55	60	66.9
Kiowa	70	85	85	75	70	60	45	70	70.0
Pawnee	70	75	75	70	80	70	60	65	70.6
Comanche	75	80	80	65	80	70	60	65	71.9

Ponca, Comanche, and Kiowa showed no significant differences between them.

High temperature tests at this stage also produced less injury between the most resistant and most susceptible varieties, when compared with the previous series. Cheyenne averaged 48.9 percent injury while Comanche showed 71.9 percent injury.

A difference between the means of 5.7 percent was found necessary for significance. Cheyenne was significant over the other varieties tested. KanKing, ranking second, was significant over C.I. 12406, Kiowa, Pawnee, and Comanche, and nearly reached that level over Ponca. C.I. 12517 achieved significance over Kiowa, Pawnee, and Comanche. The only other variety to exhibit significantly superior resistance at this stage was Ponca, which was significant over Comanche and closely approached this level over Pawnee. Insignificant differences were found among the varieties C.I. 12406, Kiowa, Pawnee, and Comanche.

When a correlation of mean averages between the trials was made, a highly significant coefficient of + .8701 was obtained. This figure further illustrates the apparent similarity between high temperature and low temperature resistance of plants, even after the plants had lost all previously acquired winter hardiness and had entered into a stage of rapid growth and elongation.

Cheyenne and C.I. 12406 ranked first and fifth, respectively, in both high and low temperature tests. The other varieties showed minor variations in comparative rank. The greatest individual variations occurred with the varieties Pawnee and Ponca. Pawnee, which was significantly more resistant to three other varieties in low temperature injury, was significant over no other variety in high temperature tests, and ranked seventh in those trials. Ponca, on the other hand, was not significantly more resistant over any other variety in low temperature tests, but was so over one variety in high temperature tests. It is of interest to note that these two varieties have similar pedigrees, Pawnee having been produced from a cross between Tenmarq and Kawvale, and this cross being used with Kawvale x Marquillo to produce Ponca.

Those plants in the boot stage, after removal from the low temperature chamber, were slow in developing noticeable injury, compared with the previous series. Lodging of the most severely injured culms generally occurred within 24 hours, and many of the younger leaves never fully recovered. Injury to the older leaves did not appear for 3 or 4 days following treatment, when they suddenly began to lose their color and died. Death started from the apex of the leaves and gradually included all of the most severely injured leaves.

Most of the plants were unsuccessful in completing their heading stage, although a few heads subjected to low temperature did appear from some of the plants which were well along in the boot stage when treated. Most of these heads were sterile, however. Tippett (33) reported that severe damage by high and low temperature could occur to the heads of wheat, even though the remainder of the plant might appear unaffected.

Injury by high temperature was apparent much earlier. This treatment apparently caused severe injury to the meristematic tissue of the culms, for no heading occurred following this treatment. The surviving leaves did not appear to grow; however, a great amount of regrowth occurred from the base of the plant about a week after treatment in all of the varieties.

Varietal Changes in Comparative Resistance

One of the most striking facts that became evident upon completion of each series was that the varieties were relatively alike in their resistance to adverse temperature conditions, whether cold or heat. It was necessary to exercise care in order to differentiate injuries from the two causes. Previous investigations conducted by individuals in the Agronomy department of Kansas State College revealed that these varieties were superior over most other varieties in surviving winter temperatures in the field as well as high temperatures in greenhouse trials. It was assumed, then, that the results obtained and reported herein were from varieties exhibiting above normal resistance.

Laude (15), Salmon (30), and other investigators have presented evidence that winter wheat can endure lower temperatures for longer periods of time while in the so called winter hardened or dormant condition than at other times in the life of the plant. The results obtained in the trials here reported are in accordance with their findings, since winter hardened plants could withstand temperatures of 4° F. while plants which had lost their winter hardiness could survive at 22.5° F. It was noted in these experiments that high temperature resistance was greater in winter hardened plants than in unhardened plants. Plants hardened to cold were capable of recovering from eight hours exposure to temperatures of 135-142° F., while in the unhardened state resulting from two weeks growth in the greenhouse they could not recover from exposures longer than six hours at temperatures of 125-129° F.

Laude (14) pointed out that as the stages of development neared maturity, the relative resistance among varieties to low temperatures narrowed. This situation was found to be true regarding resistance to high temperature, as well as to low temperature, under the conditions of these experiments. The difference between the top ranking and bottom ranking varieties in the first series of low temperature trials was 51.4 percent; this difference had diminished to 24.4 percent with plants in the boot stage. Similarly, the maximum difference between varieties in the high temperatures diminished from 34.7 percent in the hardened stage to 23 percent in the boot stage.

A study of the data contained in Table 5 revealed that the rank of the varieties between high and low temperature tests within each series were similar, as has been pointed out. Yet, this congruency in rank could not be found when making comparisons among the series, i.e., different hardiness stages, for the high and low ranking varieties within one series did not necessarily occupy similar positions in another series.

KanKing ranked first in both the first and second series, yet it was significantly below Cheyenne in both high and low temperature tests when treated in the boot stage. It was observed

Table 5. Relative rank of varieties in resistance to high and low temperatures at different stages of hardiness and growth.

Series I—Winter hardened plants

Low temperature			High temperature		
Rank	Variety	Average Mortality	Rank	Variety	Average Mortality
1	KanKing	33.7	1	KanKing	34.0
2	Kiowa	39.3	2	Comanche	34.0
3	Comanche	41.1	3	Cheyenne	40.0
4	Cheyenne	47.0	4	Kiowa	44.5
5	Pawnee	47.9	5	Pawnee	47.0
6	C.I. 12406	60.0	6	Ponca	53.2
7	Ponca	68.1	7	C.I. 12406	62.3
8	C.I. 12517	85.1	8	C.I. 12517	68.7

Series II—Unhardened plants

Low temperature			High temperature		
Rank	Variety	Average Mortality	Rank	Variety	Average Mortality
1	KanKing	31.8	1	KanKing	27.3
2	Cheyenne	50.4	2	Cheyenne	40.6
3	C.I. 12517	53.6	3	Ponca	52.5
4	Kiowa	54.9	4	Kiowa	54.0
5	Pawnee	55.8	5	C.I. 12406	56.9
6	Comanche	59.9	6	C.I. 12517	62.4
7	Ponca	62.8	7	Pawnee	65.1
8	C.I. 12406	72.1	8	Comanche	72.5

Series III—Boot stage

Low temperature			High temperature		
Rank	Variety	Average Mortality	Rank	Variety	Average Mortality
1	Cheyenne	41.9	1	Cheyenne	48.9
2	C.I. 12517	48.8	2	KanKing	59.4
3	KanKing	51.3	3	C.I. 12517	63.1
4	Pawnee	56.9	4	Ponca	65.0
5	C.I. 12406	60.6	5	C.I. 12406	66.9
6	Ponca	62.5	6	Kiowa	70.0
7	Comanche	65.6	7	Pawnee	70.6
8	Kiowa	66.3	8	Comanche	71.9

that Cheyenne was about four days behind the other varieties in heading in the greenhouse. Since it is known that the heading stage is the most critical period for injury by abnormal weather conditions, this may provide a partial explanation for this reversal.

C.I. 12517 represents an even more impressive change in relative resistance. This variety ranked below all other varieties when tested in the winter hardened condition. After two weeks growth, however, it had climbed from eighth to third place in resistance to low temperature. Although it climbed only two positions in high temperature treatments at this stage, it ranked significantly below only KanKing and Cheyenne. Tests in the boot stage indicated that C.I. 12517's resistance continued to rise, comparatively, for at this time it ranked second in low temperature tests and third in high temperature tests, a decided change from a few weeks earlier.

Comanche represents a variety which changed relative rank in the opposite direction, being highly resistant while in the hardened condition, but comparing unfavorably when tested at later stages. In the hardened series Comanche ranked significantly below no other variety in low temperature tests and tied with KanKing for first in high temperature tests. Yet, after two weeks growth, this variety had descended to sixth place in low temperature tests and was significant over only one other variety. In high temperature tests at this stage, Comanche ranked last. With tests in the boot stage, Comanche descended even more with respect to comparative low temperature resistance, and remained last in high temperature injury.

Kiowa is another variety which descended in comparative rank in much the same manner as did Comanche. Kiowa ranked with the more resistant varieties in the winter hardened condition and ranked intermediate among the varieties after two weeks greenhouse environment. However, its greatest loss occurred between this period and the boot stage, at which time it ranked last in low temperature tests and nearly that in high temperature tests.

Pawnee was somewhat unique in its characteristics of resistance to high and low temperatures. Pawnee ranked intermediate in all trials with low temperature but its resistance to high temperature decreased comparatively in the second and third series. Ponca represented the reverse of this situation, indicating less resistance to low temperature in all trials conducted, but showing an increase in comparative resistance to high temperature after the first series.

C.I. 12406 showed no definite trend of changes as did the other varieties, but remained rather low in comparative resistance to both high and low temperatures in all stages.

All varieties in these experiments were considered to be above average in resistance to high and low temperatures, at least when in the hardened conditions. For this reason it was quite difficult to achieve significant differential injury among some of the varieties, as was previously mentioned. However, these varieties served to illustrate quite well the fact that comparative resistance to adverse weather conditions may change as the plants grow and develop.

It was assumed that all winter hardiness had been lost by the plants after they had been in the greenhouse for two weeks. It may have been, however, that some varieties were capable of retaining a small amount of their acquired cold hardiness for a longer period than other varieties. This would account for the fact that Kiowa never lost its comparative resistance until sometime after two weeks growth. Comanche, on the other hand, apparently could have lost all winter induced hardiness in a much shorter time, thus causing its rapid decrease in comparative hardiness.

It may be that there are two distinct types of cold and heat resistance in plants. One might have to do with the hardening ability of the plant. Some plants, such as Kiowa and Comanche, might possess the peculiar physiological properties that would allow for a greater degree of induced resistance. Such plants would then be comparatively more capable of surviving adverse conditions while in this hardened condition.

In addition, there may be a type of resistance which is associated with vegetative growth. This would protect the plant at such critical stages as the jointing and heading stage. C.I. 12517 might possess this type of resistance, although showing less ability to attain the same degree of winter hardiness.

If this situation exists, as was pointed out by Laude (15), it is not unreasonable to assume that the genetic factors controlling these phenomena are separate and distinct, and that some varieties could possess both types of resistance. Such varieties as KanKing and Cheyenne might well fit into this group. And, if these conditions were desired in a new variety combining other favorable characteristics as well, it might be that successful crosses could be made to couple the two types of resistance within the new variety. The value of this type breeding program has been suggested by a committee dealing with research programs for improving hard red winter wheat (27).

High temperature, as well as low temperature injury, has been known to damage wheat in the later stages of development under field conditions. Added protection from this type of injury would be beneficial, especially in areas such as Kansas where both high and low spring temperature fluctuations are not uncommon. According to the results of these tests, high temperature resistance is closely correlated with low temperature resistance in all stages; it should therefore be possible to afford inherited protection to both conditions within the same variety.

Large Plants Versus Small Plants

Emergence of the plants used in the previously described experiments did not take place in the field until early in January, even though the crop had been planted in October and had begun to germinate in November. There was one plot of Pawnee wheat on the Agronomy farm, however, in which there was sufficient subsoil moisture so that emergence of some plants took place at about the normal time in autumn. Samples of these were taken and treated along with the first and second series of the previous experiments.

As described earlier, the late emerging plants were small, averaging only 2 to 3 inches in height. The larger plants, however, were well developed, having as many as fifteen tillers on some of the plants, and averaging five inches in height.

Mortality resulting from treatment to high and low temperatures is indicated in Tables 6 and 7. No statistical analysis was made of these data because the results obtained appeared obvious. In the first series of low temperature tests, only one of seven repetitions indicated more mortality in the larger plants compared with the recently emerged plants. The larger plants averaged 27.1 percent mortality per repetition compared with 47.9 percent in the smaller plants. In numbers, 9 out of 39 larger plants died compared with 38 of 72 younger plants.

Results from high temperature trials were even more evident, for none of the larger plants were killed while 37 of 78 smaller plants, or 47 percent, were killed.

Results of these trials conformed with those reported by Laude and Nauheim (16). This information indicated that plants emerging earlier in the autumn and showing greater size were more capable of withstanding adverse winter conditions than those which came up later. Pauli (26) demonstrated that extremely low temperatures seriously injured the crown tissue, perhaps severing the vascular connections between tops and roots of the plants.

Table 6. Percent mortality of winter hardened Pawnee wheat, differing in size, when subjected to temperature treatments.

4° Fahrenheit for 12 hours

Condition of plants	Trial Number 1	2	3	4	5	6	7	Mean Average
Small	33	54	67	77	27	50	27	47.9
Normal	20	0	0	50	0	0	100	27.1

135°-142° Fahrenheit for 8 hours

Condition of plants	Trial Number 31	32	33	34	35	36	Mean Average
Small	49	49	71	36	67	36	47.0
Normal	0	0	0	0	0	0	0.0

Table 7. Percent mortality of unhardened Pawnee wheat, differing in size, when subjected to temperature treatments.

22.5° Fahrenheit for 9 hours

Condition of plants	Trial Number 11	12	13	14	15	16	17	18	Mean Average
Small	52	7	56	100	30	79	33	89	55.8
Normal	0	0	0	0	0	25	0	16	5.1

125°-129° Fahrenheit for 6 hours

Condition of plants	41	42	43	44	45	46	47	48	Mean Average
Small	56	100	92	86	33	55	55	44	65.1
Normal	0	25	60	40	0	0	0	0	15.6

It would be plausible to assume that a plant with a larger crown could more nearly protect at least part of the tissue from injury, both from high temperature and low temperature.

Results obtained from the unhardened plants were similar, the plants with greater development of crown tissue showing a greater percentage of survival.

No trials were conducted with the two sizes of plants in the boot stage because it was not possible to maintain comparable growing conditions for the two groups. It is probable, however, that the problem of resistance in relation to size and age is important primarily during the winter or early spring. If spring weather conditions are favorable, the small plants will increase in size quickly so that the difference will not be important by the time the boot stage is reached. In addition, it seems improbable that high or low temperature injury under actual field conditions would be so severe as to effect notable differences at this stage, because the immature heads probably would be killed under much less adverse conditions than that necessary for injury to the crown tissue.

The results of this test serve to emphasize the importance of obtaining well established, strong plants in the fall whenever this is possible. This would better protect the crop from low winter temperatures and, perhaps, from drouth situations.

Although only one variety was used in this test, it is plausible to assume that correspondingly greater resistance would be found in larger plants of the other varieties as well. Laude and

Nauheim (16) reported similar results with several varieties. It is possible that had the previous trials been conducted with larger plants there might have been some changes in the comparative standings of the varieties. For this reason, the results obtained must be interpreted on the basis of the use of young plants only.

SUMMARY

Young plants of eight varieties of winter wheat were transplanted from their winter environment in the field to the greenhouse. The varieties included were Cheyenne, Kiowa, Comanche, Ponca, Pawnee, KanKing, C.I. 12517, and C.I. 12406. The purposes of the experiment were to determine the comparative resistance of these varieties to high temperature and to low temperature at different stages of hardening and growth, and to determine whether a correlation existed between high and low temperature resistance within the plants.

Low temperatures were provided by means of a thermostatically controlled refrigeration unit placed in a cork-insulated room. High temperature was provided by warm air which was circulated in a similarly insulated room.

As the plants were brought in from the field, some of them were subjected at that time to treatment in order to denote resistance of the plants to temperature extremes while they were in a winter hardened condition. Another group was allowed to become dehardened by growing in the greenhouse for two weeks prior to treatment, while a third group was treated after they had reached the boot stage of development.

Resistance of all the varieties to both high and low temperatures was found to be much higher when they were treated in the winter hardened condition. As they continued growth in the greenhouse, their resistance was considerably reduced. The most susceptible stage to both temperature conditions was found to be the boot stage.

A high correlation between cold resistance and heat resistance was found to exist within the varieties. Highly significant correlations of +.9022 and +.8701 were obtained in the winter hardened condition and the boot stage, respectively, while a significant correlation of +.7767 was found in the unhardened plants.

However, the comparative rank of the varieties was found to vary at different stages, indicating that varieties relatively resistant to high and low temperatures in one stage are not necessarily similarly resistant at a different stage. Under the conditions of this test, KanKing, Kiowa, and Comanche were most resistant in the winter hardened condition, followed closely by Cheyenne and Pawnee, while C.I. 12406, Ponca, and C.I. 12517 were found to be the most susceptible at that stage. In the boot stage, however, Cheyenne and C.I. 12517 were comparatively resistant to the point that they ranked with KanKing above the remainder of the varieties. Ponca and C.I. 12406 climbed somewhat, too, in comparative resistance in the later stages, although neither showed more than intermediate resistance at any time. Pawnee maintained nearly the same comparative position in low temperature tests throughout the series, but was found to be more susceptible to high temperatures at later stages.

Although it was possible to obtain differential injury among the varieties by diligent effort, it was obvious throughout the experiment that the varieties did not differ widely in their resistance.

To determine the effect that the size of the plant might have upon the resistance, Pawnee plants which were older and more developed due to earlier emergence were also treated in conjunction with the hardened and unhardened stages of the smaller plants. The older and larger plants displayed far more resistance to temperature extremes in both the hardened and unhardened stages.

CONCLUSIONS

Significant differences were obtained in the laboratory through careful control of the temperature and the length of time of exposure, although it would seem that each of these varieties would be capable of surviving winter temperatures under ordinary Kansas weather conditions.

Changes in the relative resistance of these varieties of wheat were found in the transition from the hardened to the unhardened stages. Comanche represented a variety which showed superior resistance to temperature extremes in the hardened condition, but was found to be inferior to most varieties in later stages. Under the conditions of these tests, C.I. 12517 had somewhat opposite reactions, having been found comparatively inferior while in the hardened state, but superior to most varieties in the spring stages of growth. Apparently, then, the superiority or inferiority of varieties to temperature extremes in the hardened condition cannot serve as an index to their temperature reactions in later stages of growth.

The results of these tests may serve as supporting evidence for the hypothesis that midwinter resistance to temperature extremes is not genetically linked with the plants' ability to survive high or low temperatures after spring growth is initiated. Certain varieties, such as Cheyenne and KanKing, which displayed superior resistance in all stages tested, demonstrate the fact that both midwinter hardiness and spring hardiness can be combined in the same variety.

It was interesting to note that resistance to high temperatures as well as to low temperatures could be induced by winter conditions. Accordingly, it would seem that those changes which occur within a plant to increase low temperature resistance are similar to changes which must occur in order to increase high temperature resistance. Of more practical importance to successful wheat production, however, is the fact that spring hardiness to low temperature was also found to be closely correlated with high temperature resistance. As injury from both high and low temperatures have been known to occur after spring growth has begun, the value of having resistance to both temperature extremes within the same variety is obvious. The high correlation obtained suggests at least two hypotheses: (1) the inheritance of spring hardiness to high and low temperatures is closely linked, and (2) the conditions protecting a wheat plant from low temperature are the same as those needed for protection from high temperatures.

Data from these experiments were somewhat inconsistent, but seemed to indicate that most of the changes in relative resistance which were to occur between the winter hardened stage and the boot stage had occurred within two weeks after spring growth had begun. Although there were some differences in the comparative rank of the varieties between the unhardened stage and the boot stage, it would seem that after the midwinter resistance has been lost by the plants, the relative hardiness of varieties will remain approximately the same up to the boot stage.

Significant differences in survival were obtained with plants tested in the boot stage. However, even in those varieties showing greater survival, there was a high degree of injury to the head within the boot, most of them never completing their emergence. From this fact, then, it cannot be inferred that greater survival of the plants from temperature injury at this stage will also result in greater yields.

The superiority in resistance found in large, well-tillered plants over small plants suggests the possibility that the size of the plants when tested might be a factor affecting the comparative resistance of varieties. This fact, however, definitely points out one of the values of obtaining well established stands in the fall of the year. Inherent resistance within the varieties to adverse weather conditions is only part of the answer to the problem of winter-kill and spring injury--well developed, strong plants will also increase the hardiness of the winter wheat crop.

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RESISTANCE OF WINTER WHEAT VARIETIES TO HEAT AND COLD AT DIFFERENT STAGES OF GROWTH AND HARDINESS

by

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Introduction

Winter wheat in the Great Plains area is subjected to adverse weather conditions throughout the life of the crop. Temperature extremes, both low temperature and high temperature, are primary among the factors which determine the success or failure of the crop. In response to this difficulty, research must be continued in an endeavor to develop varieties which are not only resistant to low winter temperatures but are also capable of surviving spring temperature fluctuations. Information concerning the relationship of midwinter hardiness to spring hardiness, and high temperature resistance to low temperature resistance is needed for this work. These investigations were conducted in an effort to obtain more information regarding this problem.

Materials and Methods

Eight varieties of winter wheat, viz., Comanche, Pawnee, Kiowa, Ponca, Cheyenne, KanKing, C.I. 12517, and C.I. 12406, were used in studying resistance to high and low temperatures. They were planted in the fall of 1952, but because of limited moisture supply, did not begin to germinate until in November and did not emerge until early January of 1953. Enough specimens of each variety were transplanted to the greenhouse during the latter part of February, 1953, so that plants could be tested for high and low temperature resistance while in three stages: (1) while in the winter hardened condition, (2) after two weeks growth in the greenhouse, and (3) when the boot stage of development had been reached. A thermostatically controlled refrigerator located in an insulated room provided cold temperature, and heated air circulated into a similar room provided warm temperature.

From 6 to 8 replications containing three pot samples of each variety were made. Each pot contained 4 to 6 plants, but in order for the plants to grow properly to the boot stage, the number in those pots was reduced to one. Percent mortality was used for recording the results in the first two stages, but percent injury provided the better means of differentiation in the boot stage.

Larger Pawnee plants which had received enough moisture for normal fall emergence also were treated and compared with the above plants in order to consider the effect of size of plants on resistance.

Results

Significant differences among the varieties were noted in all stages of growth. Proper differentiation of injury, however, was difficult because they did not differ widely in their resistance. Resistance of all the varieties to both high and low temperatures was found to be much greater when they were treated in the winter hardened condition. The most susceptible stage was found to be the boot stage.

A high correlation between cold resistance and heat resistance was found to exist within the varieties in each stage tested. However, the comparative rank of the varieties was found to vary at different stages, indicating that varieties relatively resistant to high and low temperatures in one stage are not necessarily similarly resistant at a different stage. KanKing, Kiowa, and Comanche were most resistant in the winter hardened condition, followed closely by Cheyenne and Pawnee, while C.I. 12406, Ponca, and C.I. 12517 were most susceptible at this stage. In the boot stage, however, Comanche and Kiowa had dropped to the bottom while C.I. 12517 and Cheyenne were resistant to the point that they ranked with KanKing above the remainder of the varieties. Apparently, then, the superiority or inferiority of varieties to temperature extremes in the hardened condition cannot serve as an index to their temperature reactions in later stages of growth. Most of the change in rank between the winter hardened and boot stage had occurred within two weeks after spring growth had begun.

Results of these tests may serve as supporting evidence for the hypothesis that midwinter resistance to temperature extremes is not genetically linked with the plants' ability to survive high or low temperature after spring growth is initiated. Such varieties as Cheyenne and KanKing, which displayed superior resistance in all stages tested, indicate that both midwinter hardiness and spring hardiness can be combined in the same variety. The high correlation found between high temperature and low temperature, however, suggests that the inheritance of resistance to both conditions is closely linked, or the conditions protecting the plant from both temperature extremes are nearly the same.

The superiority in resistance found in large, well-tillered Pawnee plants over young plants suggests the possibility that the size of the plant when tested might be a factor affecting the comparative resistance of varieties. It also serves to emphasize the importance of obtaining good stands in the fall of the year.