RESISTANCE OF VARIETIES OF OATS TO HEAT AND COLD AT DIFFERENT STAGES OF GROWTH

by

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INTRODUCTION

Temperature is one of the major factors in determining the economic area of adaptation for a crop. Average temperature, in general, may determine the areas of adaptation; but within such an area extremes in temperature in specific years are important because they may cause extensive damage to crop plants. Winter-killing of winter cereal crops has been studied extensively by many investigators. The study of resistance to heat has shown that generally those factors influencing heat resistance of plants also influence resistance to low temperature.

In the studies of resistance to drought and resistance to high temperatures, a correlation was found between these two factors. The question arises, is there any relationship between resistance to low temperature and to high temperature in the various stages of growth of a specific crop.

In the spring-sown small grain area of Kansas, the crop may be exposed to extremes in temperature during any part of the growing season. During early spring, the crop may be exposed to temperatures so low as to cause damage, and occasionally to relatively high temperatures. In later stages the crop may be subjected to extremely high temperatures, and occasionally freezing temperatures occur then also.

This study was conducted to ascertain the relative hardiness of varieties of oats to heat and cold. The experiment was designed to determine if there is any correlation between heat and cold hardiness of the various oat varieties.

Those crops or varieties which have a greater resistance to extremes of temperature in the different stages of growth, in certain years, may return larger yields than other crops which possess less resistance.

REVIEW OF LITERATURE

The cause of injury to plants from exposure to cold has been studied extensively by many investigators. DuHamel and Buffon (8) were among the first to present a theory of cause of death from cold based on a partial knowledge of the cell structure. They believed killing to be a rupturing of the cell walls due to the expansion accompanying ice formation. Goeppert (9) was among the first to make a careful study of killing from cold. He observed the formation of ice within the cells and also in the intercellular spaces. Sachs (39) confirmed the work of Goeppert. Muller-Thurgau (31) considered that ice formation within the tissue is necessary for freezing to death of plant tissue. When ice crystals are found within the cells, it was due to very rapid freezing. When the temperature was lowered very slowly, ice crystals were seldom found within the cell. In his investigations, when plant tissues were supercooled to 4-5° centigrade below the freezing point without forming ice, if the temperature was raised without ice formation, killing never occured. Death is attributed to the denaturing of protoplasm that is caused by the exosmosis of water to the intercellular spaces where it forms ice masses. Molisch (29) considered death from low temperature due to an injurious concentration of the cell sap caused by the removal of water in ice formation. Gorke (10), in his study of freezing plants, found certain proteids may be precipitated out and apparently these plants that are more easily killed by freezing have their proteids precipitated out at a higher temperature. He accounts for this precipitation by the greater concentration of salts in the sap as water is removed to form ice crystals.

Maximow (26) believed that death from low temperatures is due to the rupturing of the protoplasm by masses of ice crystals that are formed in it. That part of the cell which is injured when exposed to low temperature is the plasma membrane, and that as long as a film of water was kept in contact with this membrane, death was not likely to occur. Chandler and Hildreth (3) believed this theory to be correct.

Stiles (49) attributed the death of a plant by freezing to be caused by the formation of ice crystals in the protoplasm, which produces a disturbance in the relations between the dispersed and continuous phases of the protoplasm, with an aggregation of the dispersed phase. Such changes are usually irreversible, so that, upon thawing, the original colloidal system of the living protoplasm is not reformed and is thus no longer living.

Schaffnit and Ludtke (46) concluded the death of a plant from frost or heat is a problem of metabolism. The entire process of metabolism need not be suspended. The cessation of activing of only one enzyme may be sufficient to cause death. Dexter, Tottingham and Graber (7) believed the injury or killing of tissue by cold or by any other means, involves the disorganization of the substances essential for carrying on the processes of life. With such disorganization it is recognized that the cell loses its capacity to regulate the diffusion of its soluble contents.

In summarizing the methods of killing of tissue by cold, Miller (28) believes death in some cases depends upon ice formation rather than on the direct effect of low temperature. The withdrawal of water from the cell by freezing may bring about death by the following causes: (1) the desiccation of the protoplasm, (2) the mechanical injury to the protoplasmic membrane, and (3) the precipitation of proteins by salting out due to the greater concentration of salts in the sap or to its increase in acidity as water is withdrawn. Lutz (23), working with the rate of thawing of frozen tissue, found no measurable influence upon injury resulting from exposure to freezing temperature by the rate of thawing. He summarized the method of killing by cold. His conclusions, how withdrawal of water from the cell by low temperature may bring about the death of cells, are similar to Miller. His work has further shown that death, in some cases, depends upon ice formation, but may be the direct effect of low temperature.

Molisch (30), Sellschop and Salmon (47), and Salmon (41) found plants continuously exposed to a temperature too low for normal metabolism, but above the freezing point, will eventually die. Under these conditions, death ensues more slowly than where plants are killed by a sudden freeze.

Salmon (41) summarized the causes of winterkilling. How the plants die is not fully determined. Physiological drought is any habit of growth or structure which enables a variety to reduce transpiration in proportion to water obtained from soil or any character or quality which permits it to survive with less water and presumably prolong its life in comparison with those varieties which lack this ability. The direct effects of temperature are (1) mechanical injury, (2) desiccation of the protoplast, (3) chemical effects, and (4) suspension of metabolism. Any one or two or more may occur at the same time. Mechanical injury is due to rupture of the cell wall, separation of tissue, and/or evaporation of water frozen in intercellular spaces before it can be absorbed by the cells. Disiccation of protoplasm is brought about when water is withdrawn and frozen in the intercellular spaces. The chemical effects of cold are the precipitation of proteids when plants are frozen. Those plants are most easily killed at low temperature whose proteids are precipitated at the highest temperature. Also the acidity of the cell sap increases with cooling.

Lidforss (21), working with winter green plants in South Sweden, found that with most of them at least during cold weather, the starch is almost entirely changed to sugar. On return of warm weather starch may again be deposited in the cell. He assumes that sugar is formed during cold weather as a means of protecting the plant against freezing by lowering the freezing point of its sap. Kneen and Blish (18) found a positive correlation between cold hardiness and sucrose content of wheat plants. Dexter (6) determined the conditions which favor hardening to cold are those which tend toward the accumulation or conservation of carbohydrates or other food reserves. Greathouse and Stuart (11), working with red clover, found winter hardiness associated with a high concentration of total sugars and total nitrogen. Newton and Martin (34), working with wheat plants, show an increase of amino nitrogen content during the hardening process and that high carbohydrate and nitrogen content are necessary for cold resistance.

Harvey (12), in his study on hardening process in plants and developments from frost injury, found the factors which produce protein precipitation on freezing of plant juice are principally the increase in the hydrogen ion concentration and an increase in the concentration of salts. The effects of desiccation, freezing, and plasmolysis were considered to be similar in that all these processes cause changes in the hydrogen ion and salt concentration. He concluded splitting proteins into less easily precipitated forms is a method of adaptation of plants to cold. In working with wheat crowns, Dexter (5) determined that the withdrawal of water by ice formation was not a fully reversible process, but that in hardier plants it was more nearly so. When plants are frozen beyond recovery, the water that has been removed by ice formation is not reabsorbed sufficiently to give previous condition of turgidity.

Scarth and Levitt (44) studying the changes of the cell associated with hardiness, found (1) complicated hydrolytic breakdown of carbohydrates which increases the osmotic pressure of the cells and also in hardier plants, the non-solvent space in the vacuole at the expense of starch and other reserves held in the cytoplasm; (2) the plasmic-membranes become hydrated due to similar changes in the protoplasmic colloids; (3) as a consequence of this change, the viscosity of the protoplasm is lowered; (4) cell permeability is increased, because of the change in the membranes. Martin (24) considered hardy wheats to be characterized by low moisture content of the tissues, a high percentage of total solids in the cell sap, a high osmotic concentration of the cell sap, a high percentage of bound water, and a low rate of respiration at a low temperature. During the hardening of wheat, there is a decrease in the moisture content, increase in the total solids in the sap, and an increased osmotic pressure and imbibition pressure of colloids as measured by the ability of the tissues to hold the sap against the forces of freezing and pressure. Joslyn and Marsh (17), working with fruits and vegetables found the physical changes which occur during freezing depend chiefly upon ice formation and osmotic relations. The chemical changes are those concerned with the hydrolysis of pectins and sucrose.

Hooker (15) determined pentosan content of fruit trees in relation to winter hardiness and found hardened plants possess a larger amount of hydrophilic colloids, probably pentosans, than unhardened plants. Jassen (16) found the more cold resistant winter wheat plants contained more sugar. He also found a correlation between total nitrogen and winter hardiness.

Hardening is favored by conditions which tend toward the accumulation or conservation of carbohydrates and other reserve foods which favor photosynthesis, and which reduce the respiratory rate and the extension of vegetative parts, Dexter (4). He considered that the retention of hardiness is dependent upon the preservation of an adequate supply and concentration of organic food. This supply is ordinarily depleted by respiration. If production of elongation of new leaves is stimulated, there is a rapid decrease in hardiness presumably because of the labilization and use of organic food. Laude (19) studied changes in cold resistance during transition from dormancy to active growth in winter cereals. The water content and amount of expressed sap increased as active growth began after dormancy. The total solids in the sap decreased. Change in cold resistance was negatively associated with water content; refraction of sap and expressed juice during the first half of the transition period and similarly associated with pressed juice during the last half of the period.

Peltier and Kiesselbach (37) found the seedling plants of oats, barley, and wheat were more cold resistant when just emerging from the soil or in the one-leaf stage that in the two or three leaf stage. The seedlings manifest the least cold endurance when the food reserves of the endosperm become exhausted.

Strausbaugh (50), studying the dormancy and hardiness in the plum, found the dormant condition reached by hardy forms of plum to involve fundamental changes in the colloidal condition of the protoplasm, whereby there was a marked retention of water against the force of dehydration. Rosa (38) found hardened plants lose less moisture by transpiration per unit of leaf surface than do tender plants.

Newton and Brown (32) measured hardiness of winter wheat in relation to frost resistance and seasonal changes by determining bound water. The hydrophilic colloids bind water and increase the concentration of aqueous solutions. The factors affecting drought and cold resistance include those concerned in absorption, transpiration and wilt endurance. Van Doren (54) found a direct correlation between bound water content of crown of winter wheat and cold resistance. There was an indirect correlation between bound water in the leaves and cold resistance. The leaves of hardened winter wheat plants were less cold resistant than the crown. Newton, Brown and Anderson (33) found moisture content of plant tissue less in hardy varieties than in non-hardy varieties. The resulting concentration of colloids and sugars in all fluids increases the resistance to freezing.

Salmon and Fleming (42) studied the density of the cell sap to winter hardiness in small grains. They found no correlation between total sap solids and cold resistance. The turgidity of the tissue as influenced by physiological drought appeared to have more influence than the amount of sap solids on the concentration of the cell sap. Steinmetz (48), studying winterkilling of alfalfa, found no correlation between freezing point of root tissue, freezing point depression of the expressed sap of roots, the quantity of press juice, the total solids in the sap, the viscosity of cell sap of roots, and the sugar, pentosan and amino acid content of the roots and cold resistance.

Schaffnit (45) found he could prevent the precipitation of proteids from the sap of greenhouse rye by adding to it small quantities of sugar. He concluded that the formation of sugar in winter green plants may be a means of protecting the plants against precipitation of proteids.

Suneson and Peltier (51), Dexter (4), and Metcalfe (27) found light was a factor in hardening cereal crops. Dexter pointed out that under light deficiency conditions the plant does not accumulate sugars.

Maximow (26) was among the first to recognize that the factors limiting cold resistance also condition drought resistance. He states:

> The ability to endure permanent wilting, then one can establish a pretty close analogy between the capacity of plants to resist frost and drought. We may observe the protective influence of the accumulation of water soluble substances in the cell sap; a greater accumulation of hydrophilic colloids is also a factor in drought resistant plants.

In a study of chemical composition of drought injured corn plants, Loomis (22) found starch is not formed in the vegetative parts. This is common in most grasses. Amylodextrin, a close equivalent of starch, is found to be only a minor constituent of the plant. Sucrose is the characteristic carbohydrate of the vegetative plant and accounts for nearly one-half of the total carbohydrates of the stalk. The carbohydrate accumulation above that of a normal plant as the result of drought injury was equally distributed between dextrin and sucrose with the other fractions playing a minor role. There was a 5 - 15 per cent increase of carbohydrates in the healthy stalks of drought injured plants, but no increase of carbohydrates of leaves. The totalcrude protein increased due to drought injury. This is made up of an increase of nitrates and highly soluble nitrogen.

Waldron (56), in a study of wheat varieties under semi-arid conditions, found a positive relationship between frost resistance and drought resistance. Tysdal (53), working with alfalfa, found a positive correlation between severe wilting and hardening to cold. The hardier varieties of alfalfa hardened more rapidly under short days than under normal days than did the less hardy ones. The short days reduced growth, a process that is conducive to hardening.

Vasiliev and Vasiliev (55) investigated changes in carbohydrate content of wheat plants during the process of hardening for drought and found, following wilting, there is an increase in the hydrolysis of starch and an increase in sugars. With the gradual drying of the soil in which wheat was raised, the water content of plants decreased nearly 35 per cent at the time of wilting. The total sugar content had increased, in all cases, the hemicelluloses decreased with monosaccharides, sucrose, and total carbohydrates increased. As result of irrigation of plants subjected to low moisture growth conditions, the moisture content, total carbohydrates and hemicelluloses increased while sucrose and total sugars decreased. Also there was a decided reduction of monosaccharides. During the period of water shortage, the plant is creating an internal state best suited for resistance to drought. Generally there is an increase of the suction tension of the cells and the water holding capacity of the tissues. During the period of gradual loss of moisture, the plants exhibited the following changes in their sugar content. First, a decrease in both forms of sugars, which is evidently due to decrease in photosynthesis. This change took place before the appearance of the first external signs of a shortage of water. The next step was the accumulation of sucrose and consequent decrease in monosaccharides. The plants had begun to wilt. This was followed by increase in monosaccharides and a simultaneous decrease in sucrose. Finally, there was a gradual disappearance of the monosaccharides and the loss of sugar by the tissues. This stage began when the wheat suffered greatly from loss of water and ended with the drying up and the death of certain parts of the plant. In general, the most conspicuous feature by which a wheat plant, hardened to resist drought, differs from a normal one is the greater accumulation of hemicellulose and sugars, chiefly sucrose. Sayre, Morris and Richey (43) found sucrose composed 51 per cent of the total sugars of barren drought injured corn stalks. This was 36 per cent higher sucrose content than adjacent normal stalks.

Newton and Martin (34) found the factors affecting drought resistance include those concerned in absorption, transpiration and wilt endurance. The colloidal properties of leaf tissue fluids were believed to be important in water retention under droughty conditions. Hydrophilic colloids bind water and increase the concentration of aqueous solutions as shown by freezing point determinations. Sucrose is more effective than dextrose in these determinations. Concentration, quality, and state of dispersion or coagulation of colloids are factors affecting the degree of water binding. The osmotic pressure of tissue fluids of crop plants has been found to vary with physiological scarcity of water, but is not a reliable index of drought resistance. Bound water content has been found a more dependable index. The cultivated wheats and several grasses, on this basis, have been satisfactorily arranged in the order of their drought resistance.

Aamodt and Johnston (1), in their studies on drought resistance in spring wheats, found prehardened plants were more hardy when subjected to drought and more hardy when subjected to hot winds 110° Farenheit of 16 per cent relative humidity and six miles per hour. Metcalfe (27), studying conditions inducing heat resistance in seedling plants of corn, wheat and sorghum, found that plants grown under low moisture conditions for a period of time were more resistant to heat treatments than plants grown under abundant moisture supply. The role of photosynthesis was studied and found those plants receiving light during the days prior to treatment were more resistant to heat treatments than plants receiving no light, light of low intensity, or short periods of light. Heyne and Laude (13), working with corn, found the heat resistance of corn seedlings exposed to light for longer time greater than seedlings exposed to light for short periods or no light.

Patterson (36), in his Brome grass studies, concluded the ability of a plant to resist both heat and drought is apparently due to a large degree to the nature of its protoplasm. When the proteins in the protoplasm are made up of hydrophilic colloids that can hold water against severe external conditions and prevent the precipitation of proteins, the plant prevents death which would otherwise ensue because of the physical and chemical conditions brought about by this precipitation.

Hill and Salmon (14), Timmons and Salmon (52), Martin (25) found a good correlation between greenhouse treatments reading the injury in per cent of leaf area damaged and field results for cold treatments. Aamodt and Johnston (1) found a good correlation between greenhouse heat treatments reading the injury in per cent leaf damage and field results.

Kneen and Blish (18) concluded cold resistance of neither the roots nor the leaf blades is a reliable index of the cold resistance of the plant. Survival seems to be entirely dependent upon the crown to resist frost injury. Jassen (16) considered the crown of winter wheat to be the seat of cold resistance.

MATERIAL AND METHODS

The heat room in the Plant Research Laboratory was used in testing the plants in this study. That room is insulated and is 6 x 5.3 x 9 feet in size. Heat was produced by blowing air through a steam radiator and into the room through vents in the wall. Relative humidity was increased by the escape of steam from a nozzle into the air steam, and decreased by fresh air drawn from the outside. The temperature was increased by introducing steam into a radiator located in the path of the air stream. A series of baffles and dampers determined the path of the air and thus aided in controlling the temperature and relative humidity. The instruments were operated by thermostat and humidistat. A turntable five feet in diameter was located in the center of the room and driven by an electric motor at reduced speed. The room was dark during the treatments.

The cold chamber used in these studies consisted of an insulated room 10 x 8 x 9 feet. The low temperature was produced by a mechanical refrigeration unit. The temperature was controlled by a mercury thermostat, and was held at the desired temperature with 2° F. flucuation. The relative humidity was not controlled, however, it was within the range of normal atmospheric conditions. A fan within the chamber maintained a constant flow of air. The plants were placed in a circle in front of the refrigeration unit, allowing a space between plants for the circulation of air. The room was dark during the treatments.

The varieties of oats treated in the seedling stage were: Osage, Neosho, Fulton, Tama, Clinton, Bond, Victoria, Richland, Markton, Stanton, Wintok, and Kanota. The seed was pure and was obtained from various sources. The results in each case are considered as being representative of the variety.

The same varieties, as used in the seedling stage, were used for the joint stage treatments.

In the boot and head stage treatments, Osage, Neosho, Clinton, Tama, Fulton and Kanota were used.

In order to determine the degree of correlation of hardiness of the several varieties of oats to extremes in temperature, one replication of a series was treated in the high temperature chamber, and during the same time another replication of the same series was treated in the low temperature chamber. Thus the plants subjected to the heat and cold treatments were grown under identical conditions.

The length of treatments within a series varied; the degree of injury was the determining factor for the length of treatment. In the treatments, injury to all plants was desired, but killing was avoided. In this way a relative degree of resistance of the various varieties to extremes in temperature could be ascertained. Soil conditions, including moisture content and most other factors, were fairly similar from day to day. However light intensity depended upon the weather conditions as the length of day varied with the season. This work was done during the winter months, continuing until spring and during the following fall. The length of time the plant was in the sunlight prior to treatment and the amount of sunshine received during several preceding days appeared to influence the resistance to extremes in temperature. However no readings as to the specific degree of hardening of a plant treated during sunshiny days compared with cloudy days or of plants treated during long days of late spring and fall compared with winter days were taken.

The degree of injury was read in per cent of leaf area damaged as compared to the entire leaf surface of that variety in a single pot. A good correlation between injury estimated in this manner and the actual injury under field conditions was obtained by Martin (25), Timmons and Salmon (52), Hill and Salmon (14) for cold, and by Aamodt and Johnston (1) for heat.

A study was conducted by Salmon (41) to determine the personal error of judgment in estimating the per cent of damage to plants injured by freezing. It was found that a probable error of difference of not to exceed five per cent may be expected due to the random variation in making estimates.

The plants for seedling stage treatments were grown in four-inch pots in the greenhouse. Five plants of the variety to be treated were planted in one side of the pot, and five plants of Kanota, a uniform check, were planted in the other side of the pot. A pot stake place lengthwise across the pot separated the two varieties. The plants were allowed to grow until they were from four to six inches high before they were treated. The pots were watered every day during the growing period and just prior to treatment, allowing all excess water to drain before treating.

The method of growing the plants for the joint stage treatments was the same as for the seedling stage treatments.

In the boot and head stage treatments, five plants of a variety were grown in one side of a 10-inch pot and five plants of the Kanota check in the other side. These were allowed to grow in the greenhouse until the desired stage was attained for treatment.

Following treatment in either the heat chamber or cold chamber, the plants were taken into the greenhouse. Here they were allowed to grow under normal conditions. From three to five days following treatment, the injured portions turned yellow, and at that time the reading of per cent damage was taken.

Two readings were obtained for each pot, one for the variety tested, the other for the Kanota check. To reduce the two readings of each pot to one for the statistical analysis, the per cent damage of Kanota was subtracted algebraically from the per cent damage of the variety grown in the same pot.

The entire plant was subjected to the extremes in temperature. There may have been damage to the roots, crown, or above ground portions. It is believed that the sum of this damage will be reflected in the amount of damage to the leaves, as the investigations of Martin (25), and Timmons and Salmon (52) showed a high correlation between per cent of leaf injury caused by freezing as compared with cold hardiness in the field.

The level of significance was determined by analysis of variance. The covariance and correlation were determined by the usual method, Paterson (35).

EXPERIMENTAL RESULTS

Seedling Stage

The plants tested for heat resistance in the seedling stage were subjected to a temperature of $128^{\circ} \pm 5^{\circ}$ F. The length of treatment for different replications varied from 3 hours to 5.5 hours. The degree of injury to the plants was the determining factor for the length of treatment.

The temperature in the cold chamber was 23° ±2° F. The length of treatment varied from 4 hours to 7.5 hours.

The data in Tables 1 and 2 were obtained by subtracting the mean per cent damage for the five plants of Kanota in a pot from the mean per cent damage for the other variety in the same pot. This difference was used as the basic data for analysis of variance and correlation determinations.

The data will denote the relative order of hardiness for the varieties of oats to heat and cold in the seedling stage. No summation was made of Tables 1 and 2 for hardiness of the varieties of oats, as the level of significance of hardiness was calculated for the average per cent damage of a variety. The average per cent damage and the order of hardiness of the oats varieties are shown in Table 3.

In these two tables, the same replications are comparable; i.e. Replication 1 of Table 1 was planted the same day as Replication 1 of Table 2, and these replications were treated the same day, one was tested for heat resistance and the other for cold resistance.

The data in Table 3 are the mean per cent damage of above ground vegetative portion for all plants of a variety within the seedling treatments for heat and for cold hardiness. The relative order or hardiness of the varieties of oats to heat and cold is shown in average per cent damage. The level of significance was determined from the difference of damage, varietal damage minus Kanota damage within the same pot (Tables

Table 1. Resistance of varieties of oats to heat in the seedling stage.

Experiment	Varietal damage compared to Kanota										
	Osage	Neosho	Fulton	Tama	Clinton	Bond	Victoria	Stanton	Richland	Markton	Wintok
1	-15	40	-5	15	10	10	5	-5	15	-5	-15
2	10	55	-5	25	0	10	10	-10	15	5	0
3	10	45	-25	50	10	0	-20	-15	50	10	-10
4	45	25	0	10	15	20	-5	-10	55	15	-10
5	10	10	-5	25	10	-5	10	15	20	10	0
6	5	35	0	30	20	5	20	30	10	10	0
7	15	20	35	40	-20	20	70	35	35	0	5
8	15	20	-5	15	50	10	25	-5	30	40	-15
9	15	40	0	5	15	25	15	10	25	20	0
10	35	20	0	15	20	25	0	30	20	15	0
11	30	55	0	50	35	30	5	15	55	10	-5
12	15	35	0	25	45	10	15	0	55	15	-15
13	25	20	45	-5	0	10	15	-10	10	15	-15
14	15	25	10	15	10	20	0	-5	20	40	-5
15	20	45	10	40	15	25	-5	-10	25	35	-10
16	25	15	10	15	10	15	0	5	15	20	-5

Table 2. Resistance of varieties of oats to cold in the seedling stage.

Experiment	Varietal damage compared to Kanota										
	Osage	Neosho	Fulton	Tama	Clinton	Bond	Victoria	Stanton	Richland	Markton	Wintok
1	25	45	15	20	30	10	5	-5	20	40	10
2	10	10	40	35	50	25	40	20	20	10	0
3	5	25	40	20	35	15	-5	0	20	-5	0
4	10	20	30	-5	15	40	0	-15	30	25	-15
5	0	15	0	15	20	-5	-5	-10	15	5	-15
6	10	35	-5	-10	15	15	25	0	25	30	-5
7	55	20	-5	-5	15	30	15	0	0	10	-20
8	0	10	0	0	35	5	5	-5	5	30	-5
9	30	65	10	20	5	20	25	-10	55	25	-15
10	0	10	5	-5	20	-5	5	0	20	10	0
11	60	50	15	5	20	35	30	-5	0	10	0
12	0	0	45	60	70	0	5	5	40	5	5
13	5	25	25	35	50	10	-60	0	5	45	-70
14	10	25	10	15	0	35	-5	-20	15	45	-20
15	25	15	10	10	30	0	25	0	0	-10	0
16	45	5	10	45	60	10	10	15	10	25	-15

1 and 2), and the least significant difference is in terms of average percent damage.

Table 3. Effect of heat and cold on varieties of oats in the seedling stage.

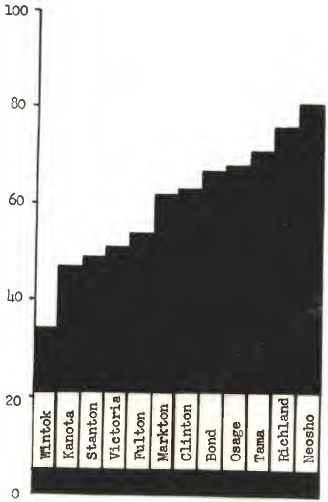
Variety	Heat: Av. Per cent Damage*	Heat: Rank	Cold: Rank	Cold: Av. Per cent Damage*
Wintok	34.3	1	1	17.1
Kanota**	47.6	2	3	27.4
Stanton	49.3	3	2	20.3
Victoria	51.5	4	4	30.6
Fulton	54.5	5	5	40.6
Markton	62.8	6	7	45.0
Clinton	63.1	7	12	57.5
Bond	67.8	8	11	52.5
Osage	68.1	9	6	40.9
Tama	71.8	10	10	52.1
Richland	76.5	11	8	46.2
Neosho	80.9	12	9	49.0

Least significant difference heat 10.3 per cent
Least significant differenct cold 12.1 per cent

* Data are average per cent damage.
**Data are the average damage to Kanota grown in all pots within the series of treatments.

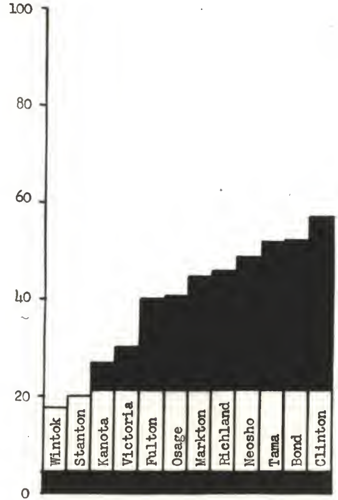
In Table 3, it is shown that Wintok was significantly more hardy to heat in the seedling stage than any of the other varieties. Kanota, Stanton and Victoria were significantly more hardy than Markton, Clinton, Bond, Osage, Tama, Richland, and Neosho. Fulton and Markton were significantly more hardy than Bond, Osage, Tama, Richland and Neosho. Clinton was significantly more hardy than Richland and Neosho, and Bond and Osage significantly more hardy than Neosho.

In treatments to extremes of cold in the seedling stage, Wintok was significantly more hardy than Victoria, Fulton,



Seedling Heat Treatment
mean percent damage

Fig. 1.



Seedling Cold Treatment
mean percent damage

Fig. 2.

Markton, Clinton, Bond, Osage, Tama, Richland, and Neosho. Stanton and Kanota were significantly more hardy than Fulton, Markton, Clinton, Bond, Osage, Tama, Richland and Neosho. Victoria, Fulton and Osage were significantly more hardy than Tama, Bond and Clinton. Markton was significantly more hardy than Clinton.

The average per cent damage of the above ground vegetative portion of the several varieties of oats in the seedling stage heat treatments is shown in graph form, Fig. 1. Figure 2 is the mean per cent damage of all plants of the various varieties in seedling stage cold treatments. These graphs show the degree of damage to each variety within a treatment and the relative hardiness of any variety to any other variety within the same treatment.

The correlation between varieties for resistant or hardiness to extremes in temperature both heat and cold is 0.752. This is above the one per cent level and shows there is a highly significant correlation between hardiness to extremes of both cold and heat of the various varieties in the seedling stage.

Joint Stage

The treatments of the several oat varieties in the joint stage were similar to those in the seedling stage. The temperature of the heat chamber was 128° ±5° F. and the length of treatment varied from 2.5 hours to 4.5 hours for different series. The temperature of the cold chamber was 23° ±2° F. and

Table 4. Resistance of varieties of oats to heat in the joint stage.

Experiment	Varietal damage compared to Kanota										
	Osage	Neosho	Fulton	Tama	Clinton	Bond	Victoria	Stanton	Richland	Markton	Wintok
1	45	50	30	15	60	40	65	25	5	10	-20
2	15	90	60	10	50	35	40	25	45	50	-25
3	25	50	0	60	40	40	50	-10	50	25	-20
4	35	60	-5	35	55	45	25	20	55	35	-20
5	25	35	15	40	35	30	40	0	30	25	-30
6	10	20	-45	35	30	30	25	20	30	25	0

Table 5. Resistance of varieties of oats to cold in the joint stage.

Experiment	Varietal damage compared to Kanota										
	Osage	Neosho	Fulton	Tama	Clinton	Bond	Victoria	Stanton	Richland	Markton	Wintok
1	35	75	20	5	5	10	5	5	40	40	-10
2	5	30	-5	0	10	0	-10	20	40	20	0
3	0	80	50	15	0	25	5	5	0	40	-5
4	5	5	10	0	45	25	-10	0	35	-5	-40
5	5	40	0	15	45	35	30	5	10	0	-20
6	20	10	5	5	45	50	-10	50	0	35	-20

the length of treatments varied from 6 hours to 6.5 hours. Here again the degree of injury was the determining factor for the length of treatment.

The plants were allowed to grow until they were in the proper stage for testing. This stage was characterized by jointing and elongation of the stem prior to the formation of the boot and was attained 30 to 35 days after planting. The varieties came into this stage on nearly the same date, but at the later stages there was a greater variation among the varieties.

The data in Tables 4 and 5 were obtained by subtracting the mean per cent damage for the five plants of Kanota in a pot from the mean per cent damage for the other variety in the same pot. This difference was used as the basic data for analysis of variance and correlation determinations. The replications within the two tables are comparable.

The data in Tables 4 and 5 denote the relative order of hardiness for the varieties of oats to heat and cold in the joint stage. No summation was made of Tables 4 and 5 for hardiness of the varieties of oats as the level of significance of hardiness was calculated for the average per cent damage of a variety. The average per cent damage and the order of hardiness of the oats varieties is shown in Table 6.

The data in Table 6 are the mean per cent damage of above ground vegetative portion for all plants of a variety within the joint treatments for heat and for cold hardiness. The relative order of hardiness of the varieties of oats to heat and cold is shown in average per cent damage. The level of significance was determined from the difference of damage, varietal damage minus Kanota damage within the same pot (Tables 4 and 5), and the least significant difference is in terms of average per cent damage.

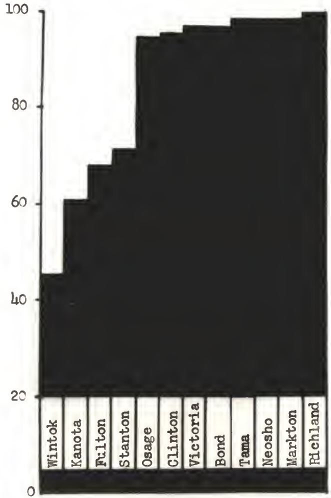
Table 6. Effect of heat and cold on varieties of oats in the joint stage.

Variety	Heat		Cold	
	Av. Per cent Damage*	Rank	Rank	Av. Per Cent Damage*
Wintok	45.8	1	1	8.3
Kanota**	60.9	2	4	22.9
Fulton	68.3	3	5	25.8
Stanton	71.6	4	7	37.5
Osage	95.0	5	3	21.6
Clinton	95.8	6	8	46.6
Victoria	97.5	7-8	6	33.3
Bond	97.5	7-8	12	62.5
Tama	99.1	9-11	2	17.5
Neosho	99.1	9-11	10	54.1
Markton	99.1	9-11	11	57.5
Richland	100.0	12	9	50.8

Least significant difference heat 20.0 per cent
Least significant difference cold 22.1 per cent

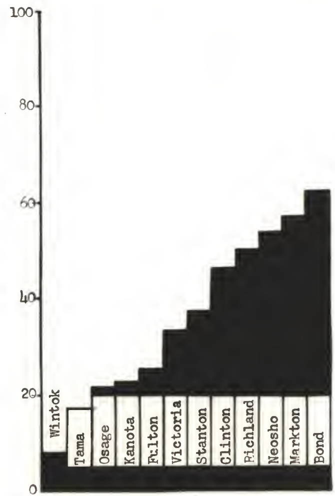
* Data are average per cent damage.
**Data are the average damage to Kanota grown in all pots within the series of treatments.

From Table 6 in the joint stage treatments to extreme heat it may be noted that Wintok was significantly more hardy than Fulton, Stanton, Osage, Clinton, Victoria, Bond, Tama, Neosho, Markton and Richland. Kanota, Fulton and Stanton were significantly more hardy than Osage, Clinton, Victoria, Bond, Tama,



Joint Heat Treatment
mean percent damage

Fig. 3.



Joint Cold Treatment
mean percent damage

Fig. 4.

Neosho, Markton and Richland. In the heat treatments Wintok, Kanota, Fulton and Stanton were damaged less than the other varieties. The other varieties were damaged 95 per cent or above. This is too severe a treatment to show an accurate relative degree of hardiness of those varieties.

When exposed to cold in the joint state, Wintok was significantly more hardy than Victoria, Stanton, Clinton, Richland, Neosho, Markton and Bond. Tama, Osage and Kanota were significantly more hardy than Clinton, Richland, Neosho, Markton and Bond. Fulton was significantly more hardy than Richland, Neosho, Markton and Bond. Victoria was significantly more hardy than Markton and Bond. Stanton was significantly more hardy than Bond.

The average per cent damage of the above ground vegetative portion of the several varieties of oats in the joint stage heat treatments is shown in graph form, Fig. 3. Figure 4 is the mean per cent damage of all plants of the various varieties in joint stage cold treatments. These graphs show the degree of damage to each variety within a treatment and the relative hardiness of any variety to any other variety within the same treatment.

The correlation between varieties for resistance or hardiness to extremes in temperature to both heat and cold is 0.753. This is above the one per cent level and shows there is a highly significant correlation between hardiness to extremes of both heat and cold of the various varieties tested in the joint stage.

Boot Stage

For the boot stage treatments, the varieties Fulton, Osage, Tama, Neosho, Clinton and Kanota were grown in 10-inch pots in the greenhouse. Five plants of the variety to be tested were grown in one side of the pot, with five plants of Kanota check grown in the other side of the pot. The plants were grown in the greenhouse until they were in the proper stage for treatment.

The various varieties did not come into the boot stage at the same time. In this series of treatments, each variety was in the boot stage, however, the earlier varieties were in the late boot stage just prior to emergence, while those later varieties were in the early boot stage. The effect of extremes in temperature upon the fertility of the different plants was not used in determining damage. The results were recorded in per cent damage of the above ground vegetative portion.

The plants were treated in the heat chamber at a temperature of 123° ±5° F. for a period of 2.33 hours to 3.58 hours. The plants in the cold treatment series were treated in the cold chamber chamber at a temperature of 23° ±2° F. for a period of 3 hours to 5 hours. The degree of injury was the determining factor for length of treatment.

The data in Tables 7 and 8 were obtained by subtracting the mean per cent damage for the five plants of Kanota in a pot from the mean per cent damage for the variety in the same pot. This difference was used as the basic data for analysis

Table 7. Resistance of varieties of oats to heat in the boot stage.

Experiment	Varietal damage compared to Kanota				
	Osage	Neosho	Fulton	Tama	Clinton
1	35	60	35	45	50
2	30	50	35	55	40
3	0	10	20	35	35
4	30	20	35	35	10
5	20	65	35	40	35
6	50	30	30	40	15
7	40	35	35	40	20
8	20	35	20	30	30
9	20	25	30	35	25
10	25	20	20	35	5
11	25	35	10	25	5
12	35	45	30	30	10

Table 8. Resistance of varieties of oats to cold in the boot stage.

Experiment	Varietal damage compared to Kanota				
	Osage	Neosho	Fulton	Tama	Clinton
1	40	95	-75	30	65
2	10	55	80	35	45
3	45	70	5	60	0
4	50	40	50	40	40
5	60	40	5	0	5
6	0	15	35	40	5
7	10	20	30	15	25
8	5	65	30	35	40
9	0	15	50	20	40
10	5	15	15	35	40
11	5	0	0	55	-20
12	10	25	25	60	40

of variance and correlation determinations. Similar replications within the two tables are comparable.

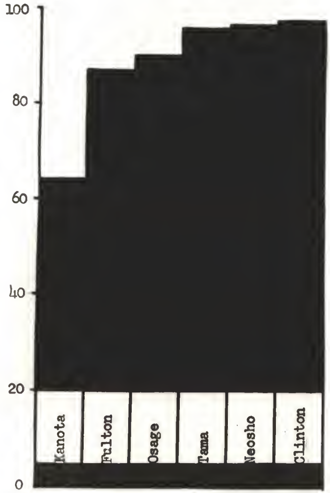
The data will denote the relative order of hardiness for the varieties of oats to heat and cold in the boot stage. No summation was made of Tables 7 and 8 for hardiness of the varieties of oats as the level of significance of hardiness was calculated for the average per cent damage of a variety. The average per cent damage and the order of hardiness of the oats varieties are shown in Table 9.

Table 9. Effect of heat and cold on varieties of oats in the boot stage.

Variety	Heat		Cold	
	Av. Per cent Damage*	Rank	Rank	Av. Per Cent Damage*
Kanota**	64.2	1	1	36.5
Fulton	87.5	2	3	63.7
Osage	90.3	3	2	51.8
Tama	96.0	4	5-6	70.4
Neosho	96.8	5	5-6	70.4
Clinton	97.3	6	4	68.7
Least significant difference heat 8.4 per cent				
Least significant difference cold 22.4 per cent				

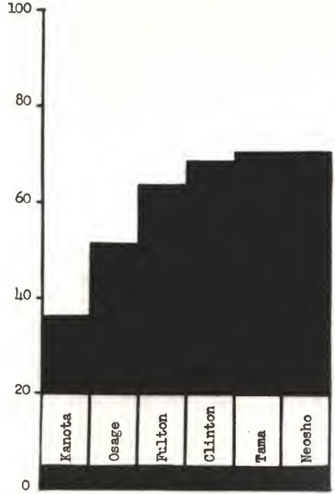
* Data are average per cent damage.
** Data are the average damage to Kanota grown in all pots within the series of treatments.

The data in Table 9 are the mean per cent damage of above ground vegetative portion for all plants of a variety within the boot treatments for heat and for cold hardiness. The relative order of hardiness of the varieties of oats to heat and cold is shown in average per cent damage. The level of significance was determined from the difference of damage, varietal



Boot Heat Treatment
mean percent damage

Fig. 5.



Boot Cold Treatment
mean percent damage

Fig. 6.

damage minus Kanota damage within the same pot (Tables 7 and 8), and the least significant difference is in terms of average per cent damage.

From Table 9 in the boot stage treatments to extreme heat, it will be noted, Kanota was significantly more hardy than Fulton, Osage, Tama, Neosho and Clinton. Fulton was significantly more hardy than Tama, Neosho and Clinton.

In the boot stage treatments to extreme cold, Kanota was significantly more hardy than Fulton, Clinton, Tama and Neosho.

The average per cent damage of the above ground vegetative portion of the several varieties of oats in the boot stage heat treatments is shown in graph form, Fig. 5. Figure 6 is the mean per cent damage of all plants of the various varieties in boot stage cold treatments. These graphs show the degree of damage to each variety within a treatment and the relative hardiness of any variety to any other variety within the same treatment.

The correlation between varieties for resistance or hardiness to extremes in temperature both heat and cold is 0.781. This is above the one per cent level and denotes there is a highly significant correlation between hardiness to extremes of both heat and cold of the varieties tested in the boot stage.

Head Stage

For the head stage treatments, the plants were grown in 10-inch pots in the greenhouse. Five plants of the variety to be tested were grown in one side of the pot, with five plants of Kanota grown in the other side of the pot. The varieties tested in these treatments were Osage, Kanota, Neosho, Fulton, Tama and Clinton.

The plants were treated in the heat chamber at a temperature of 123° ±5° F. for a period of 2 hours to 3.25 hours. The cold treatments were at a temperature of 23° ±2° F. for a period of 3 to 6 hours. The degree of injury was the determining factor for the length of treatment.

The injury was recorded as the per cent damage of the above ground vegetative portion. The several varieties varied considerably in heading dates. Temperature treatments affected seed set in many ways depending upon the stage of development of the head, temperature, and length of exposure. When the plant was treated following fertilization, a more severe treatment was necessary to prevent development of seed, as compared with plants treated prior to or at the time of fertilization. The amount of seed produced was small and the per cent seed set low. The seed produced was shriveled and small. A wide inconsistant variation in seed set and seed development was noted within a variety and within a series of varieties. For these reasons the seed set and seed produced were not used as measures of hardiness.

The data in Tables 10 and 11 were obtained by subtracting the mean per cent damage for the five plants of Kanota in a pot from the mean per cent damage for the variety in the same pot. This difference was used as the basic data for analysis of variance and correlation determinations. Similar replications within the two tables are comparable.

Table 10. Resistance of varieties of oats to heat in the head stage.

Experi-ment	Varietal damage compared to Kanota				
	Osage	Neosho	Fulton	Tama	Clinton
1	5	40	15	40	15
2	15	40	0	30	20
3	10	15	-15	10	15
4	0	10	10	25	15
5	0	5	-20	20	20
6	10	5	0	15	0
7	10	10	5	70	10
8	-5	10	-5	0	5
9	0	10	5	5	5
10	15	5	5	5	10
11	20	0	10	15	-5
12	-5	0	5	5	10
13	5	20	0	5	10

Table 11. Resistance of varieties of oats to cold in the head stage.

Experi-ment	Varietal damage compared to Kanota				
	Osage	Neosho	Fulton	Tama	Clinton
1	5	0	0	25	40
2	40	15	5	5	55
3	15	-15	15	15	15
4	15	5	5	-5	30
5	10	-5	0	15	0
6	45	-5	-5	-15	0
7	-5	10	-5	15	0
8	40	50	5	60	75
9	5	-25	10	80	-40
10	0	0	0	70	40
11	55	5	5	15	10
12	40	5	30	15	30
13	35	10	10	15	5

The data in Tables 10 and 11 will denote the relative order of hardiness for the varieties of oats to heat and cold in the head stage. No summation was made of Tables 10 and 11 for hardiness of the varieties of oats, as the level of significance of hardiness was calculated for the average per cent damage of a variety. The average per cent damage and the order of hardiness of the oats varieties are shown in Table 12.

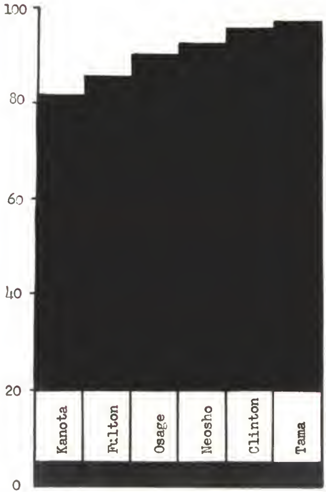
Table 12. Effect of heat and cold on varieties of oats in the head stage.

Variety	Heat: Av. Per cent Damage*	Heat: Rank	Cold: Rank	Cold: Av. Per cent Damage*
Kanota**	81.9	1	1	18.3
Fulton	86.6	2	3	28.4
Osage	90.3	3	6	39.6
Neosho	92.6	4	2	25.8
Clinton	95.6	5	5	38.8
Tama	97.0	6	4	37.3

Least significant difference heat 8.7 per cent.
Least significant difference cold 16.4 per cent.

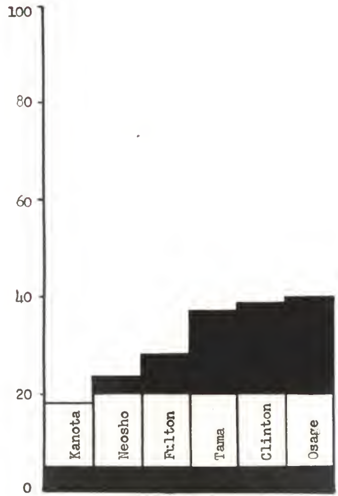
* Data are average per cent damage.
**Data are average damage to Kanota grown in all pots within the series of treatments.

The data in Table 12 are the mean per cent damage of above ground vegetative portion for all plants of a variety within the head treatments for heat and for cold hardiness. The relative order of hardiness of the varieties of oats to heat and cold is shown in average per cent damage. The level of significance was determined from the difference of damage, varietal damage minus Kanota damage within the same pot (Tables 10 and 11), and



Head Heat Treatment
mean percent damage

Fig. 7.



Head Cold Treatment
mean percent damage

Fig. 8.

the least significant difference is in terms of average per cent damage.

From Table 12 in the head stage treatments, Kanota was significantly more hardy than Neosho, Clinton and Tama. Fulton was significantly more hardy than Clinton and Tama.

In the head stage treatments to extreme cold, Kanota was significantly more hardy than Tama, Clinton and Osage.

The average per cent damage of the above ground vegetative portion of the several varieties of oats in the head stage heat treatments is shown in graph form, Fig. 7. Figure 8 is the mean per cent damage of all plants of the various varieties in head stage cold treatments. These graphs show the degree of damage to each variety within a treatment and the relative hardiness of any variety to any other variety within the same treatment.

The correlation between varieties for resistance or hardiness to extremes in temperature to both heat and cold is 0.362. This is above the one per cent level and denotes there is a highly significant correlation between hardiness to extremes of both heat and cold for the varieties tested in the head stage.

CONCLUSIONS

A highly significant correlation between hardiness to heat and hardiness to cold was found in the seedling, joint, boot and head stages of the varieties of oats tested.

In the seedling stage, Wintok, Kanota, Stanton, Victoria and Fulton ranked in order of heat hardiness and were the first five in resistance to cold. The order was essentially the same in both heat and cold treatments. The remaining seven varieties in these tests did not fall as nearly in the same order in the heat and cold treatments as the first five, but there was a highly significant correlation between hardiness to extremes of heat and cold.

In the joint stage, Wintok was the most hardy variety in both heat and cold treatments. Kanota, Fulton, Stanton and Osage were essentially more hardy than the other varieties when exposed to both cold and heat. However, Tama was relatively low in heat hardiness but ranked second in cold resistance. In these experiments, there was a highly significant correlation between hardiness to heat and to cold.

In the boot stage, Kanota was the most hardy in both heat and cold tests. Wintok was not included in these tests. Fulton and Osage fell below Kanota and were above the other varieties in both the heat and cold tests. There was a highly significant correlation between hardiness to extremes of both heat and cold.

In the head stage treatments, Kanota was relatively more hardy both to heat and to cold than the other varieties. Fulton ranked second in hardiness in the heat treatments and third in cold treatments. The other varieties did not fall in the same relative rank in hardiness to both heat and cold, but they show a highly significant correlation for resistance to extremes of both heat and cold.

The relative hardiness of varieties may be more readily and accurately ascertained in the seedling and joint stages than in the later stages when hardiness is reflected over a narrower range.

A highly significant correlation between hardiness to extremes of both heat and cold in seedling, joint, boot and head stages was found in this investigation.

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LITERATURE CITED

(1) Aamodt, O. S. and W. H. Johnston.
Studies on drought resistance in spring wheats. Canad. Jour. Res. Sec. C. Bot. Sci. 14(3):122-152. 1936.

(2) Chandler, W. H.
The killing of plant tissue by low temperatures. Mo. Agr. Expt. Sta. Bul. 8. 1913.

(3) Chandler, W. H. and A. C. Hildreth.
Evidence as to how freezing kills plant tissue. Proc. Am. Soc. Hort. Sci. 33:27-35. 1935.

(4) Dexter, S. T.
Effect of several environmental factors on the hardening of plants. Plant Physiol. 8:123-129. 1933.

(5) Dexter, S. T.
Salt concentration and reversibility of ice formation as related to the hardiness of winter wheat. Plant Physiol. 9:601-618. 1934.

(6) Dexter, S. T.
Effects of periods of warm weather upon the winter hardened condition of a plant. Plant Physiol. 16: 181-188. 1941.

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

(8) DuHamel and Buffon.
Observations de differents effets que produisent sur les vegeteux les grandes gelees d'hiver er petites gelees du printemps. Mem. d. l'Acad. Roy. Sci. Paris. pp. 273-298. 1737.

(9) Goeppert.
Uber die Warmeentwickelung in dem Pflanzen; deren Gefrieren und die Schntzmittel gegen dasselbe. Book. 1830.

(10) Gorke, H.
Uber chenischo Vorgange beim Erfrieren der Pflanzen. Landw. Versuchs-Stat. 65:149-160. 1906.

(11) Greathouse, G. A. and N. W. Stuart.
The relation of physical properties and chemical composition of red clover plants to winterhardiness. Me. Agr. Expt. Sta. Bul. 391. 1936.

(12) Harvey, R. B.
Hardening process in plants and developments from frost injury. Jour. Agr. Res. 15:83-113. 1918.

(13) Heyne, E. G. and H. H. Laude.
Resistance of corn seedlings to high temperatures in laboratory tests. Amer. Soc. Agron., Jour. 32:116-127. 1940.

(14) Hill, D. D. and S. C. Salmon.
The resistance of certain varieties of winter wheat to artifically produced low temperatures. Jour. Agr. Res. 35:933-939. 1927.

(15) Hooker, H. D.
Pentosan content in relation to winterhardiness. Am. Soc. Hort. Sci. Proc. 17:204-207. 1920.

(16) Jassen, George.
Effect of date of seeding of winter wheat on plant development and its relationship to winter hardiness. Amer. Soc. Agron., Jour. 21:444-466. 1929.

(17) Joslyn, M. A. and G. L. Marsh.
Changes occurring during freezing and storage and thawing of fruits and vegetables. Calif. Sta. Bul. 551. 1933.

(18) Kneen, E. and M. J. Blish.
Carbohydrate metabolism and winter hardiness of wheat. Jour. Agr. Res. 62:1-26. 1941.

(19) Laude, Hilmer H.
Cold resistance of winter wheat, rye, barley, and oats in transition from dormancy to active growth. Jour. Agr. Res. 54:799-817. 1937.

(20) Laude, Hilmer H.
Diurnal cycle of heat resistance in plants. Science. 89:556-557. 1939.

(21) Lidforss, B.
Zur Physiologie und Biologie Wintergrune Flora. Bot. Centlb. Vol. 68. No. 2. p. 33.

(22) Loomis, W. E.
The chemical composition of drought injured corn plants. Amer. Soc. Agron., Jour. 29:697-702. 1937.

(23) Lutz, J. M.
The influence of rate of thawing on freezing injury of apples, potatoes and onions. Amer. Soc. Hort. Sci. Proc. 33:227-233. 1935.

(24) Martin, J. H.
Comparative studies of winter hardiness in wheat. Jour. Agr. Res. 35:493-537. 1927.

(25) Martin, James F.
The cold resistance of Pacific Coast spring wheats at various stages of growth as determined by artificial refrigeration. Amer. Soc. Agron., Jour. 24:871-880. 1932.

(26) Maximow, N. A.
Internal factors of frost and drought resistance in plants. Protoplasma. 7:259-291. 1929.

(27) Metcalfe, Darrell S.
Conditions inducing heat resistance in seedling plants of corn, wheat and sorghum. Unpublished thesis. Kans. Stage Col. Agr. and Appl. Sci. 72 p. 1942.

(28) Miller, Edwin C.
Plant Physiology. New York. McGraw-Hill. 2nd ed. 1201 p. 1938. 3rd impression.

(29) Molisch, H.
Uber das Gefrieren and Erfrieren der Pflanzen. Jena. 1897.

(30) Molisch, H.
Untersuchung uber das Erfrieren etc. Book. 1897.

(31) Muller-Thurgau, H.
Uber das Gefrieren und Erfrieren der Pflanzen. Landw. Jahrb. 9:133-189. 1880: 15:453-610. 1886.

(32) Newton, R. and W. R. Brown.
Seasonal changes in the composition of winter wheat plants in relation to frost resistance. Jour. Agr. Sci. (England) 16:522-536. 1926.

(33) Newton, R., W. R. Brown, and J. A. Anderson.
Chemical changes in nitrogen fractions of plant juice on exposure to frost. Canad. Jour. Res. 5:327-332. 1931.

(34) Newton, R., and W. M. Martin.
Physio chemical studies on the nature of drought resistance in crop plants. Canad. Jour. Res. 3:336-427. 1930.

(35) Paterson, D. D.
Stastical technique in agricultural research. New York. McGraw-Hill. 263 p. 1935.

(36) Patterson, John K.
Variability in the resistance of brome grass strains to high temperature. Unpublished thesis. Kans. State Col. Agr. and Appl. Sci. 58 p. 1942.

(37) Peltier, G. L. and T. A. Kiesselbach.
The comparative cold resistance of spring small grains. Amer. Soc. Agron., Jour. 26:681-687. 1934.

(38) Rosa, J. T.
Investigation on the hardening process in vegetable plants. Mo. Sta. Res. Bul. 48. 1921.

(39) Sachs, J.
Krystallbildungen bei dem Gefrieren und Veranderung der Zellhaute bei dem Aufthauen saftiger Pflanzentheile. Landw. Versuche. p. 167. Heft 5. 1860.

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

(41) Salmon, S. C.
Resistance of varieties of winter wheat and rye to low temperature in relation to winter hardiness and adaptation. Kans. Sta. Tech. Bul. 35. 1933.

(42) Salmon, S. C. and F. L. Fleming.
Relation of the density of cell sap to winter hardiness in small grains. Jour. Agr. Res. 13:497-506. 1918.

(43) Sayre, J. D., V. H. Morris, and F. D. Richey.
The effect of preventing fruiting and of reducing the leaf area on the accumulation of sugars in the corn stem. Amer. Soc. Agron., Jour. 23:751-753. 1931.

(44) Scarth, G. W. and J. Levitt.
The frost-hardening mechanism of plant cells. Plant Physiol. 12:51-78. 1937.

(45) Schaffnit, E.
Uber den Einfluss nieder Temperaturen auf die Pflanz. Zell. Zeits. f. Allg. Phys. 12:323-336. 1912.

(46) Schaffnit, E. and M. Ludtke.
The effect of cold on plant cells. II, Metabolism of cultivated plants at different temperatures and with changing nutrition. Phytopath. Z. 4:329: Chem. Abst. 27:2473. 1932.

(47) Sellschop, J. P. F. and S. C. Salmon.
The influence of chilling above the freezing point on certain crop plants. Jour. Agr. Res. 37:315-339. 1928.

(48) Steinmetz, F. H.
Winterkilling of alfalfa. Minn. Agr. Expt. Sta. Tech. Bul. 38. 1926.

(49) Stiles, W.
On the cause of cold death of plants. Protoplasm. 9:459-468. 1930.

(50) Strausbaugh, P. D.
Dormancy and hardiness in the plum. Bot. Gaz. 71:337-358. 1921.

(51) Suneson, C. A. and G. L. Peltier.
Effect of defoliation upon the cold resistance of winter wheat. Amer. Soc. Agron., Jour. 28:807-809. 1936.

(52) Timmons, F. L. and S. C. Salmon.
The resistance of certain varieties and regional strains of alfalfa to controlled low temperatures. Amer. Soc. Agron., Jour. 24:642-655. 1932.

(53) Tysdal, H. M.
Influence of light, temperature and soil moisture on the hardening process in alfalfa. Jour. Agr. Res. 46:483-513. 1933.

(54) Van Doren, C. A.
Bound water and electrical conductivity as measures of cold resistance in winter wheat. Amer. Soc. Agron., Jour. 29:392-402. 1937.

(55) Vasiliev, I. M. and M. G. Vasiliev.
Changes in carbohydrate content of wheat plants during the process of hardening for drought resistance. Plant Physiol. 11:115-125. 1936.

(56) Waldron, L. R.
Frost injury to spring wheat with a consideration of drought resistance. Amer. Soc. Agron., Jour. 23:625-638. 1931.

(57) Waldron, L. R.
Differences of injury by frost to wheat plants grown comparably. Amer. Soc. Agron., Jour. 24:494-500. 1932.