CONDITIONS INDUCING HEAT RESISTANCE IN SEEDLING PLANTS OF CORN, WHEAT, AND SORGHUM

by

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INTRODUCTION

Severe droughts in the Midwest during the last decade have created an increased interest in investigation of drought-resistant crops. In 1934 and in 1936 the Great Plains region was scourged with drought from end to end. Thereafter, in every year until the end of the decade some part of the region was affected by serious drought. Westbrook (1934) estimated that the total loss from the 1934 drought in the United States was $5,000,000,000. The drought extended over 75 percent of the area and affected 27 states. Estimates by Thornthwaite (1941) based on past meteorological data were that drought periods of 35 or more consecutive days may be expected annually and periods between 60 and 70 days once in 10 years. Less frequently a drought period may reach 90 days in the northern Great Plains and 120 days in the southern Plains.

Drought is a condition of the soil or atmosphere, or of both, that prevents or hinders the plant in obtaining sufficient water for its functions. Drought resistance includes either resistance to heat, to a water deficit, or to the association of both of these conditions. Resistance to either condition tends to increase drought hardiness.

That problems relative to drought resistance in plants are receiving much attention among scientific investigators is evidenced by the volume of the literature appearing on the subject. Newton and Martin (1930) stated that the ability of certain plants to resist drought has long interested scientific observers. The economic importance of this quality has furnished an incentive to its investigation. In the semi-arid plains of western America where moisture is a limiting factor in plant growth, plant breeders are giving much attention to the production of drought-hardy varieties of forage and cereal crops. For the identification of such varieties, reliance is commonly placed upon field observation of their behavior under drought conditions. Selection of drought-resistant varieties of crops has probably been delayed by the indefiniteness of the concept of drought. A greater knowledge of the fundamental nature of drought resistance would point the way to increased progress in breeding for this quality. Heat resistance is the temperature phase of drought resistance. A study of the resistance of plants to high temperatures is a means of studying the adaptability of plants to drought conditions.

The purpose of this study is to consider factors which apparently induce resistance in plants to the high temperature phase of drought. Consideration is given the relationship between these factors and the physiological changes within plants which may cause greater resistance to heat.

REVIEW OF LITERATURE

One of the chief obstacles to plant growth is the deficiency of water, which in its extreme manifestation is designated as "drought." According to Tumanov (1926) a distinction should be made between "atmospheric" and "soil or edaphic" drought. Atmospheric drought may produce rapid wilting or desiccation of the plant through the action of hot dry winds while ample supplies of moisture are available. Atmospheric drought, states Maximov (1938), is characterized by a high temperature and a low relative humidity ranging from 10 to 20 percent in the air. Under these conditions transpiration of the plant is greatly increased disturbing the coordination between the rate of water absorption and expenditure. Then the plant begins to wilt. Soil or edaphic drought occurs when the amount of water secured by plants is insufficient to replace the water lost by transpiration. Soil drought usually occurs toward the end of the summer when moisture reserves are exhausted and precipitation has been insufficient to replenish them. The dry soil ceases to yield water to the plant. When the tissues become dehydrated and growth is retarded or entirely stopped the plant becomes permanently wilted.

In a study of the relationship between soil moisture and drought resistance Shantz (1927) proposed that true drought occurs only when the available soil water has been exhausted. In summary he states that plants which succeed in a country subject to drought (1) escape by a short rapid growth period; (2) evade drought by conserving moisture supply because of small size, restricted growth, wide spacing, or low water requirement; (3) endure drought by storing up a supply of water in the plant;

(4) resist drought by passing into a dormant condition.

Caldwell (1913) and Tumanov (1926) believed that the ability of a plant to resist drought depends upon many morphological and physiological characteristics which investigators have failed to separate into their component parts. Studies of drought resistance must not be considered only from the standpoint of a plant's reaction to high temperature, low humidity, and other atmospheric factors but also from the standpoint of soil factors and the plant's own physiological and morphological adaptation to adverse conditions. The means that a plant uses to avoid intensive loss of water are different for the various species.

Resistance of seedling plants to high temperature is so closely associated with atmospheric drought that it would be well to review some facts and studies regarding temperature. Temperature is one of the most important external factors that affects plant growth. Hildreth, Magness, and Mitchell (1941) maintained that temperature influences in one way or another every chemical and physical process which occurs in plants, including solubility of minerals, absorption of water, gases, and mineral nutrients, diffusion, and synthesis as well as vital processes such as growth and reproduction. The greater number of both higher and lower plants are capable of carrying on growth only within a comparatively narrow range of temperature from about 0° to 50° C.

For each species and variety of plant there is a maximum temperature above which growth ceases. Likewise, there is a minimum temperature below which growth is not possible. Between these limits is an optimum temperature at which growth proceeds with greatest rapidity. These three points, called cardinal growth temperatures, may very considerably with the stages of plant development such as germination, seedling stage, and maturity.

General effects of high temperature include defoliation, premature dropping of fruit and, in extreme cases, death. Beyond the optimum temperature, when physiological processes reach their highest rate, there follows a decrease up to the maximum temperature when they cease entirely. The sharp decrease in the rate of the separate physiological functions at temperatures above the optimum is explained by the fact that beginning from certain temperatures pathological processes begin to prevail in the plant which suppress the normal physiological functions and cause the death of cells. Death is preceded by a disturbance in the coordination of the biochemical processes taking place in the cell and by an accumulation of poisonous substances of the types of toxins which poison the protoplasm. At high temperatures of about 50° C. and above the toxic effect aggrevated by coagulation of the protoplasm leads to rapid death of cells.

Lehenbauer (1914) made a comprehensive study on the growth of corn seedlings in relation to temperature. He observed that the optimum temperature for growth in a 12-hour period was 32° C., but that this was not the optimum when the length of the exposure was altered. At a temperature above 31° C. the initial rate of growth was not maintained and there was a marked falling off of the rate during prolonged periods of exposure. He believed that optimum temperature should be defined as the temperature which for a specified time period of exposure produces the greatest growth. A definition of maximum temperature for growth must also involve a consideration of time. Maximum temperature might be defined as the highest temperature at which growth ceases after a specific time exposure. 43° C. can be considered the maximum temperature for growth of these seedlings for an exposure period of 15 hours and 42° C. for an 18-hour period. Leitsch (1916) made similar observations with Pisum sativum.

That light is a factor in developing heat resistance in plants has been suggested in a limited number of research studies. Kreizinger (1938) discovered that alfalfa plants tested in the heat room for heat resistance during the forenoon were injured more than plants tested in the afternoon. Conditions for the test and the materials used were the same for both trials.

A diurnal cycle of heat resistance was found by Laude (1939) in sorghum, wheat, corn, barley, and alfalfa. In these studies, the daily maximum resistance was attained by plants at mid-day and continued during the afternoon. Minimum resistance prevailed early in the morning.

Heyne and Laude (1940) observed that light has a marked influence on the resistance of seedling plants to high temperatures. Lack or deficiency of sunlight decreases the tolerance to heat in wheat and corn.

According to Schultz and Hays (1938), Peto found that a diurnal effect was found when artificial drought injury was tested during early and late stages of plant growth. The diurnal condition was primarily the result of period variations in sunlight.

It would be impractical to present all of the literature in this paper regarding the effect of light on plant growth. Miller (1938) compiled a comprehensive bibliography and thoroughly reviewed the general subject of light. Many explanations have been offered as to the specific role which sunlight plays in plant growth. The major effect of light is in the process of photosynthesis. However, it affects the plant in several ways.

Spoehr (1915) noted that light increases respiration which may be caused by the higher oxidative power of the air during hours of illumination.

In their studies of photoperiodism, Garner, Bacon, and Allard (1924) suggested that a light period influences the acidity relations, the form of carbohydrates present in the plant, and probably the water content of the tissues.

Andrews (1925) concluded that quality and intensity of light are extremely important in starch formation.

Priestley (1925) observed the effect of brief light exposures upon etiolated plants. He believed that light has a photocatalytic action upon fatty or lipoid substances which either releases them from the surface of the protoplast into the wall or sets them free from combination with the wall. As a result they slowly diffuse through the aqueous substratum of the cellulose wall and accumulate at the surface of the shoot in the cuticle.

Shirley (1928) showed that the curve of increase in dry weight with increasing light intensity was almost a straight line for sunflowers during the winter. In summer the slope of the curve fell off at higher intensities there being little increase in dry weight at intensities above 50 percent of sunlight. For the experiments plants were grown under a series of shades located in and outside of the greenhouse. Plants grown under artificial light gave similar results.

Reid (1929) studied the effect of light on seedlings in relation to available nitrogen in carbon. Light does not favor the growth of seedlings from low protein, starchy seed unless extra nitrogen is supplied. Light favors assimilation of nitrates and favors the process of thickening of cell walls in all types of seedlings.

Vickery (1937) worked with tobacco leaves in dark and light, and observed a synthesis of organic solids of considerable amount in light. In the dark he found a decomposition of organic solids into volatile products.

Light, according to Miller (1938), was found by several workers to greatly increase the absorption of certain ions especially in the case of Nitella.

Drought resistance of plants is sometimes considered analogous to frost resistance. Literature on this relationship will be briefly reviewed because of its significance in this study.

Schroder (1909), Kreutz (1930), Savage and Jacobson (1935), and Vassiliev and Vassiliev (1936) reported that apparently plants resistant to drought have the same general characteristics as those resistant to cold.

Tumanov (1929) working with sunflowers, Kondo (1931) with soybeans, and Tysdal (1933) with alfalfa found that plants kept severely wilted for several days were more resistant to low temperatures than those which had been watered regularly.

In a study involving five varieties of wheat under semi-arid conditions Waldron (1931) found a positive relationship between frost resistance and drought resistance.

Maximov (1929) studied the processes taking place during the hardening of the plant to frost and drought. A comparison was made of the chemical composition and physical properities of plants closely allied systematically but differing sharply in their drought or frost resistance. Better results have been obtained in frost resistance but both methods have given conformable results. A greater endurance is obtained by the accumulation of sugars and other soluble carbohydrates in the cell and by means of an increase of the water retaining power of the cells in consequence of the accumulation of hydrophilic colloids.

Newton and Martin (1930) stated that investigations in drought resistance naturally grew out of earlier invesitgations of frost resistance. Any factor within the cell which opposes the abstraction of water will act as a resisting agent against drought. The imbibition pressure of hydrophilic colloids was regarded by them to be the most significant of such factors.

MATERIAL AND METHODS

Equipment

A heat room was used in this study to simulate the temperature phase of drought conditions in the field. Krassnosselsky-Maximov and Kondo (1933), Shirley (1934), Aamodt (1935), Bayles, Taylor, and Bartel (1937), and Shirley and Meuli (1939) were among the few investigators using artificially controlled rooms to study the drought resistance of plants. In their experiments, varieties of certain crops known to be most drought resistant in the field showed less injury than varieties known to be non-drought resistant. A close relationship between performance in the field and artificial drought in the heat room was apparent.

Hunter, Laude, and Brunson (1936), by treating 14-day old seedlings of inbred lines of corn in a heat room at 140° F. and with a relative humidity of about 30 percent for six hours, found that the injury of the tested plants was parallel to the injury from drought in the field. Since the relative order of resistance of the seedlings was the same as the plants in the field it was possible to distinguish the drought resistance between different strains by means of the heat room treatment.

Heyne and Laude (1940) subjected several strains of 20-day-old corn seedlings to heat for five hours at 130° F. and a relative humidity of from 20 to 30 percent. Reaction of strains to artificial drought correlated very well with behavior of the strains under drought conditions in the field.

The heat room used in these studies consisted of an insulated room 6' x 5'4" x 9'. Heat was produced by blowing air through a steam radiator and into the heat room through vents in the wall. Relative humidity was increased by the escape of steam from a nozzle into the air stream and decreased by fresh air drawn in from the outside. Temperature was increased by introducing steam into a radiator, located in the path of the air stream. A series of baffles and dampers controlled the path of air and were regulated by thermostat and humidistat thus controlling the temperature and relative humidity. A turntable five feet in diameter was located in the center of the room and driven by an electric motor at a velocity reduced to about 1.2 revolutions per minute. The room could be lighted by four 250-watt bulbs.

To study the effect of varying intensities of light on the heat resistance of plants two small rooms were used. One of the rooms was divided into three compartments. The first compartment was lighted by two 150-watt bulbs; the second by four 150-watt bulbs, and the third by eight 150-watt bulbs. In all cases Mazda reflector bulbs were used. Light bulbs, suspended from cross arms supported by standards, were approximately 22 inches above the plants. A fan kept the air in circulation to maintain a fairly even temperature throughout the three compartments. The other room was used as a "dark" room. An electric plate helped to keep the temperature about equal to that in the lighted compartments of the other room. In experiments involving low temperatures, an unlighted electric refrigerator was used.

Material

Seedling plants of sorghum, wheat, and corn were used. Varieties selected were Atlas, a forage sorgo; Kanred, a hard red winter wheat; and Pride of Saline, a white open-pollinated corn. All are standard, well established varieties in Kansas.

The soil used was a good, uniform, bottom land soil from the Agronomy Farm. Eight kernels were planted in each four-inch, unglazed, clay pot and the seedlings later thinned to five per pot. Plants were grown at about optimum conditions in the greenhouse at a temperature of 70° to 75° F. In the tests, 14-day-old seedlings of wheat and corn and 21 to 28-day-old seedlings of sorghum were used. In the tests on the heat resistance of plants dehardened to cold, pots were planted in the greenhouse and thinned, after which they were placed outside and packed firmly in sand, the tops of the pots being at ground level. Whenever necessary they were watered. The plants thus hardened to cold through exposure to natural winter conditions. They were protected by screen against rabbit injury.

Experimental Methods

A study was made of the conditions that might influence heat hardiness in seedling plants of corn, wheat, and sorghum. Plants were conditioned with certain pre-treatments and tested for heat resistance by being subjected to final treatments at high temperatures. The amount of heat hardiness developed in the seedlings by the pre-treatments was determined by their resistance to heat injury.

In one phase of the work, seedling plants were given pre-treatments of varying intensities of light for three hours and then were tested for resistance to high temperatures. In another set of experiments, plants were subjected to moderately high temperatures of either 100° or 110° F. in the heat room on each of one, two, three, or more consecutive days and one day after pre-treatment they were tested for heat resistance. The rate of inducing heat resistance in plants by a pre-treatment of heat at 110° F. and the rate of the loss of this artificially induced heat resistance were also determined. In similar experiments, plants were subjected to moderately low temperatures of from 34° to 40° F. for three hours on one day and some of the wheat seedlings were pre-treated on two and some on three days.

One day after pre-treatment, they were tested for heat resistance. Other wheat seedlings hardened to cold under natural winter conditions were dehardened varying amounts in the greenhouse and then tested for heat resistance. In other experiments, plants, after being given pre-treatments of drought, were tested for their resistance to heat. A detailed plan for each experiment will be found under experimental results.

Plants were watered thoroughly but not excessively before transfer to the heat room for pre-treatment or final heat treatment. In all experiments, temperature and length of final treatment depended upon the crop being tested. After the final treatment in the heat room, the plants were transferred to the greenhouse and placed under normal conditions. As soon as the soil in the pots had cooled to nearly normal, the plants were watered. The third day after treatment the percent of injury was determined. This measure, an estimate of the observer, was based upon the percent of leaf area injured and desiccated by the heat treatment. Each pot of five plants was considered a unit and no attempt was made to record the injury of individual plants.

Data in these experiments were treated statistically. Analysis of variance was used as it has proved to be the best method of analysis of data from experiments involving two or more variables. Analysis of variance was computed on percentage data. The differences recorded among the pots having received the same treatment were considered as error because replications of the treatment should have the same readings except for uncontrolled variations and chance. All second and third order interactions involving pots were considered as error. The mean square of the interaction between treatments and trials was used as the error term when observing the general effect of the various treatments in an experiment. In all experiments, variations due to treatments were highly significant as their calculated F values exceeded the level of significance for the one percent point. In most cases, variations due to trials were significant; their calculated F values exceeding the level of significance for the five percent point.

The least significant differences within a trial and the least significant differences between treatment means were also calculated from the tables on analysis of variance.

EXPERIMENTAL RESULTS

Effect of Varying Intensities of Light upon the Resistance of Corn, Wheat, and Sorghum Seedlings to High Temperature

A positive correlation between length of exposure to light and the resistance of seedling plants to high temperatures was found by Laude (1939), Heyne and Laude (1940), and Finkner (1940). This experiment was made not only to verify the fact that light is a major factor in developing heat resistance in plants but principally to determine how different intensities of light for the same length of exposure affect the ability of plants to resist high temperatures.

Plants were given treatments of varying intensities of light and then were tested for resistance to heat. Each afternoon at 5:00 P.M. plants for the experiment were placed in the dark room and left there until 10:00 A.M. the next forenoon. At that time the plants were removed from the dark room to these places of varying intensities of light:

D = left in dark room

NL = north light in basement window of plant research laboratory

G = direct sunlight in greenhouse

NG = north light in greenhouse

2 = artificial light from 2-150 watt bulbs, 22 inches above plants

4 = artificial light from 4-150 watt bulbs, 22 inches above plants

8 = artificial light from 8-150 watt bulbs, 22 inches above plants

The plants were treated by exposure to these various light conditions for three hours, removed at 1:00 P.M., watered, and placed immediately in the dark heat room for five hours at a temperature of 126° to 132° F.

The data obtained show clearly that the resistance of plants to high temperatures was affected by varying intensities of light. The average percentages of heat injury for corn, wheat, and sorghum are shown in Tables 1, 2, and 3, respectively.

Table 1. Percentage heat injury of corn tested five hours at 128° -- 130° F. immediately following pre-treatments of varying light intensities.

Trial	N[1]	D Dark	NL North light basement	NG North light greenhouse	G Direct sun greenhouse	No. of 150-watt bulbs 2	4	8
		Light pre-treatments (3 hrs.)[2]						
1	2	55.0	45.0	17.5	17.5	45.0	35.0	20.0
2	4	85.0	80.0	8.8	6.3	51.3	40.0	13.8
3	4	85.0	76.3	15.0	12.5	52.5	40.0	20.0
4	4	88.8	67.5	23.8	13.8	52.5	35.0	11.3
5	4	77.5	45.0	21.3	15.0	37.5	28.8	20.0
6	6	90.0	20.0	14.2	10.0	45.0	45.8	31.7
7	6	90.8	29.2	22.5	11.7	47.5	42.5	32.5
8	6	90.8	20.0	17.5	9.2	44.2	40.8	45.0
9	8	84.4	51.3	25.0	6.3	42.5	43.1	36.9
10	8	83.1	30.0	18.1	8.1	41.9	39.4	37.5
Mean[3]		83.04	46.43	18.37	11.04	45.99	39.04	26.87
Av. temp. of each pre-treatment, °F.		73	78	69	69	77	81	85

[1]Number of pots in each group.

[2]Least significant differences within trials:

	(N = 2)	(N = 4)	(N = 6)	(N = 8)
At the five percent point ...	12.01	8.49	6.94	6.00
At the one percent point ...	15.82	11.19	9.13	7.91

[3]Least significant differences between treatment means:

At the five percent point ... 9.46
At the one percent point ... 12.55

Table 2. Percentage heat injury of wheat tested five hours at 126° -- 128° F. immediately following pre-treatments of varying light intensities.

Trial	N[1]	Light pre-treatments (3 hrs.)[2] D Dark	NL North light basement	NG North light greenhouse	G Direct sun greenhouse	No. of 150-watt bulbs 2	4	8
1	4	90.0	16.3	15.0	6.3	18.8	13.8	5.0
2	4	86.3	18.8	17.5	8.8	20.0	13.8	6.3
3	4	85.0	21.5	17.5	6.3	23.8	22.5	26.3
4	4	88.8	20.0	17.5	5.0	22.5	15.0	5.0
5	4	87.5	20.0	15.0	8.8	21.3	13.8	8.8
6	4	86.3	18.8	15.0	11.3	23.8	16.3	11.3
7	4	83.8	17.5	16.3	12.5	25.0	17.5	13.8
8	4	98.8	42.5	71.3	26.3	73.8	56.3	42.5
9	4	96.3	87.5	81.3	16.3	51.3	38.8	17.5
10	4	92.5	51.3	36.3	12.5	58.8	40.0	20.0
11	4	100.0	80.0	25.0	25.0	80.0	67.5	27.5
Mean[3]		90.48	35.84	29.79	12.64	38.10	28.66	16.73
Av. temp. of each pre-treatment, °F.		69	72	72	72	75	79	83

[1]Number of pots in each group.

[2]Least significant differences within trials:

At the five percent point ... 7.06
At the one percent point ... 9.31

[3]Least significant differences between treatment means:

At the five percent point ... 10.11
At the one percent point ... 13.45

Table 3. Percentage heat injury of sorghum tested five hours at 130° -- 132° F. immediately following pre-treatments of varying light intensities.

Trial	N[1]	Light pre-treatments (3 hrs.)[2]						
		D Dark	NL North light base-ment	NG North light green-house	G Direct sun green-house	No. of 150-watt bulbs 2	4	8
1	4	85.0	30.0	16.3	8.8	80.0	53.8	42.5
2	4	86.3	31.3	22.5	10.0	77.5	60.0	37.5
3	4	83.8	28.8	20.0	10.0	83.8	56.3	40.0
4	4	88.8	33.8	17.5	7.5	81.3	47.5	42.5
5	4	95.0	82.5	33.8	30.0	77.5	56.3	31.3
6	4	92.5	28.8	18.8	7.5	50.0	18.8	11.3
7	4	96.3	65.0	41.3	30.0	67.5	52.5	41.3
8	4	96.3	70.0	40.0	31.3	45.0	37.5	28.8
Mean		90.50	46.28	26.28	16.89	70.33	47.84	34.40
Av. temp. of each pre-treatment, °F.		78	78	72	72	76	79	84

[1]Number of pots in each group.

[2]Least significant differences within trials:

At the five percent point ... 6.79
At the one percent point ... 8.95

[3]Least significant differences between treatment means:

At the five percent point ... 12.48
At the one percent point ... 16.69

These data are the average of two, four, six or eight pots for each pre-treatment as indicated in the tables. The grand means for each pre-treatment along with other data are given for the 29 trials.

Least significant differences within trials were calculated statistically from analysis of variance tables for corn, wheat, and sorghum and are found in Tables 1, 2, and 3, respectively. Calculations are for the five percent and the one percent levels of significance. Plants receiving pre-treatments of varying intensities of light developed more heat hardiness than plants receiving no light. With few exceptions, differences were highly significant. A north light in the greenhouse induced more heat resistance in corn and sorghum plants than a north light in the basement of the plant research laboratory. Differences were highly significant. In general, however, non-significant differences were observed between these two pre-treatments within the wheat trials. Likewise, pre-treatments of a north light in the basement of the plant research laboratory were more effective in inducing heat resistance in corn and sorghum than pre-treatments of light from two, 150-watt bulbs. Non-significant differences were also found within the wheat trials. Differences within trials in comparing heat hardiness developed by a north light in the greenhouse and by direct sunlight in the greenhouse ranged from non-significant to highly significant figures. Much variation was, likewise, found in all trials between pre-treatments of direct sunlight in the greenhouse and pre-treatments of light from eight, 150-watt bulbs. However, direct sunlight in the greenhouse induced more heat resistance in corn, wheat, and sorghum plants than light from four, 150-watt bulbs. In a majority of cases, the differences were highly significant. Light from four, 150-watt bulbs induced more heat resistance in sorghum than light from two, 150-watt bulbs. Differences between the two pre-treatments were highly significant in all but one of the sorghum trials. However, differences between these two pre-treatments ranged from non-significance to high significance within the corn and wheat trials. Pre-treatments of light from four 150-watt bulbs and pre-treatments of light from eight 150-watt bulbs showed differences ranging from non-significance to high significance. Pre-treatments of light from eight, 150-watt bulbs induced more heat resistance in corn, wheat, and sorghum than pre-treatments of light from two, 150-watt bulbs. In general, the differences were highly significant.

Least significant differences between pre-treatment means or the "over-all" effect of the different pre-treatments of light were calculated for corn, wheat, and sorghum and are found in Tables 1, 2, and 3, respectively. Calculations are for the five percent and the one percent levels of significance. Plants receiving pre-treatments of varying intensities of light developed more heat resistance than plants receiving no light. In all cases, the differences were highly significant. Pre-treatments of a north light in the greenhouse induced more heat resistance in corn and sorghum than pre-treatments of a north light in the basement of the plant research laboratory. The differences were highly significant. However, differences between these two pre-treatments were non-significant in their "over-all" effect in the wheat trials. A north light in the basement of the plant research laboratory induced more heat resistance in sorghum than light from two, 150-watt bulbs. The differences between the two pre-treatments were of high significance. However, non-significant differences between the two pre-treatments were found in corn and wheat. Direct sunlight in the greenhouse developed more heat hardiness in wheat than a north light in the greenhouse. The differences were observed to be highly significant. Non-significant differences were found between these two pre-treatments in their "over-all" effect on corn and sorghum. Direct sunlight in the greenhouse also induced more heat resistance in corn, wheat, and sorghum than light from four, 150-watt bulbs. In all cases, the differences were of high significance. In comparison of direct sunlight in the greenhouse and light from eight, 150-watt bulbs, high significance was observed in corn and sorghum, the natural light in the greenhouse being more effective than the artificial light. However, non-significance was found in wheat. Light from four, 150-watt bulbs induced more heat resistance in sorghum than light from two, 150-watt bulbs, differences being of high significance. Non-significant differences were found between these two pre-treatments in corn and wheat. Light from eight, 150-watt bulbs induced more heat resistance in corn, wheat, and sorghum than light from four, 150-watt bulbs. In all cases, the differences were significant. High significant differences were obtained in all seedlings between pre-treatments of light from two, 150-watt bulbs and pre-treatments of light from eight, 150-watt bulbs, the light from eight, 150-watt bulbs being more effective.

In Tables 1, 2, and 3, the average temperature is given for each pre-treatment of varying intensity of light. The temperatures were not consistent for any specific pre-treatment and there does not appear to be any definite correlation between temperature and the amount of heat hardiness developed in plants. High temperature does not necessarily follow with a lower percentage of heat injury.

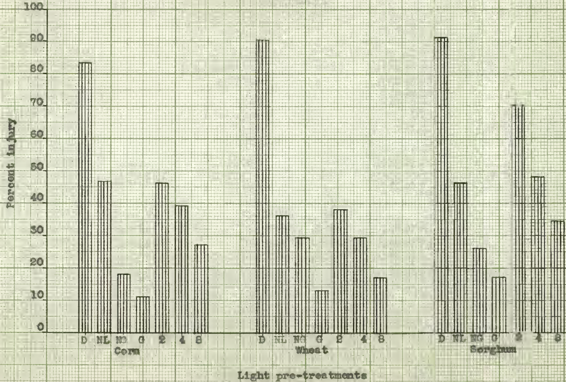
Plate I is a histogram showing the amount of heat resistance developed in corn, wheat, and sorghum seedlings by the varying intensities of light. For corn, wheat, and sorghum the decline in percentage heat injury is from the pre-treatment of no light to direct greenhouse light. Likewise, when using artificial light from Mazda reflector bulbs the percentage injury decreases as more 150-watt bulbs are used in the pre-treatment.

Differences in the amount of heat resistance developed by the various pre-treatments of light occur and are probably due to different physiological reactions of corn, wheat, and sorghum to light. However, the results appear to be very similar. The

EXPLANATION OF PLATE I

Histogram of percentage heat injury of plant seedlings tested immediately following pre-treatments for three hours at varying light intensities. Temperature of test treatment for corn was 128° -- 130° F., for wheat 126° -- 128° F., and for sorghum 130° -- 132° F.

PLATE I



Percent injury
100
90
80
70
60
50
40
30
20
10
0
D NL NG G 2 4 8
Corn
D NL NG G 2 4 8
Wheat
D NL NG G 2 4 8
Sorghum
Light pre-treatments

heat resistance developed in the seedlings was apparently proportional to the intensities of the pre-treatments of light.

Effect of Moderately High Temperatures upon the Resistance of Corn, Wheat, and Sorghum Seedlings to High Temperature

This experiment was made to study the effect of moderately high temperatures in developing heat resistance in plants. Seedling plants of corn, wheat, and sorghum were subjected to a temperature of either 100° or 110° F. in the heat room for three hours, usually from 9:00 A.M. to 12 o'clock, on each of one, two, or three or more consecutive days. One day after pre-treatment, the plants were placed along with untreated (control) plants in the heat room at a temperature of 126° to 132° F. for five hours usually beginning at 1:00 P.M. The data obtained show that plants subjected to a temperature of either 100° or 110° F. develop heat hardiness. Percentage heat injury for corn, wheat, and sorghum when pre-treated at 110° F. are shown in Tables 4, 5, and 6, respectively. These data are the average of four, eight, 10, or 15 pots for each treatment as indicated in the tables. The grand means for each pre-treatment along with other data are given for the 28 trials. A three-hour pre-treatment of 110° F. for one day developed an increase of from 20 to 65 percent in the resistance of the seedlings to high temperatures. Added resistance was induced when pre-treatments were repeated for two and three days. Pre-treatments apparently

Table 4. Percentage heat injury of corn tested five hours at 128° -- 130° F. after pre-treatment to heat at 110° F.

Trial	N[1]	Not pre-treated	No. of days of pre-treatment[2] (3 hrs. per day) 1	2	3
1	4	82.5	45.3	47.5	61.3
2	10	75.0	37.0	16.5	8.0
3	10	73.5	32.0	22.0	12.5
4	10	78.5	29.5	14.0	10.5
5	10	81.0	28.0	14.5	13.0
6	10	82.5	36.5	15.5	11.0
7	10	88.5	42.0	20.5	8.0
8	10	91.0	26.0	12.0	17.5
Mean[3]		81.56	34.66	20.31	17.73

[1]Number of pots in each group.

[2]Least significant differences within trials:

	(N = 4)	(N = 10)
At the five percent point ...	8.52	5.39
At the one percent point ...	11.23	7.11

[3]Least significant differences between treatment means:

At the five percent point ... 8.98
At the one percent point ... 12.23

Table 5. Percentage heat injury of wheat tested five hours at 126° -- 128° F. after pre-treatment to heat at 110° F.

Trial	N[1]	Not pre-treated	No. of days of pre-treatment[2] (3 hrs. per day) 1	2	3
1	4	88.8	46.3	26.3	16.3
2	4	86.3	45.0	8.8	5.0
3	4	88.8	61.3	52.5	12.5
4	4	83.8	57.5	25.0	18.8
5	4	88.8	63.8	15.0	12.5
6	8	94.4	15.6	12.5	12.5
7	8	66.9	8.8	7.5	7.5
8	15	91.0	70.3	54.3	22.7
Mean[3]		86.10	46.08	25.24	13.48

[1]Number of pots in each group.

[2]Least significant differences within trials:

	(N = 4)	(N = 8)	(N = 15)
At the five percent point ...	9.09	6.55	4.78
At the one percent point ...	11.99	8.64	6.31

[3]Least significant differences between treatment means:

At the five percent point ... 12.94
At the one percent point ... 17.61

Table 6. Percentage heat injury of sorghum tested five hours at 130° -- 132° F. after pre-treatment to heat at 110° F.

Trial	N[1]	Not pre-treated	No. of days of pre-treatment[2] (3 hrs. per day) 1	2	3
1	4	75.0	20.0	17.5	10.0
2	4	63.8	28.8	16.3	10.0
3	4	78.8	12.5	6.3	8.8
4	4	57.5	20.0	11.3	6.3
5	4	61.3	22.5	12.5	10.0
6	8	92.5	8.5	7.0	2.5
7	8	64.4	27.5	13.1	8.8
8	8	63.8	18.1	16.9	9.4
9	8	65.0	26.3	15.0	7.5
10	8	90.0	18.8	11.9	9.4
11	8	92.5	24.4	13.1	7.5
12	8	90.6	28.1	17.5	13.8
Mean[3]		74.60	21.29	13.20	8.67

[1]Number of pots in each group.

[2]Least significant differences within trials:

	(N = 4)	(N = 8)
At the five percent point ...	7.82	5.53
At the one percent point ...	10.30	7.28

[3]Least significant differences between treatment means:

At the five percent point ... 6.80
At the one percent point ... 9.13

developed more heat resistance in sorghum than in corn and wheat seedlings.

Least significant differences within trials and between treatment means were statistically calculated from analysis of variance tables. Calculations are for the five percent and the one percent levels of significance and are found in Tables 4, 5, and 6. Plants receiving a pre-treatment at 110° F. for three hours on one day developed more heat resistance than plants receiving no pre-treatment. Differences were highly significant within all trials of corn, wheat, and sorghum.

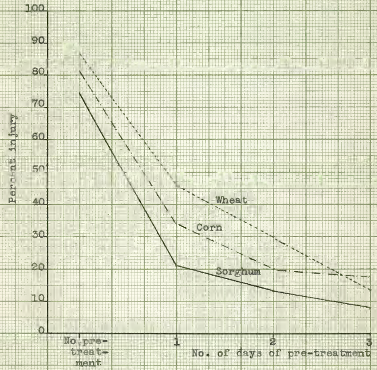
Differences between one, two, and three days of pre-treatment ranged from non-significance within some trials to high significance in others. In calculations of the least significant differences between treatment means, high significance in heat resistance was found between untreated plants and those given a pre-treatment of 110° F. for three hours on one day. High significance was also found between one and two days of pre-treatment, the two days of pre-treatment being the more effective in developing heat hardiness. Although heat resistance was added by three days of pre-treatment, non-significance was found between the means of the two and three days of pre-treatment.

Plate II is a line graph showing the decrease in percentage heat injury as hardiness was developed by one, two, and three days of pre-treatment at 110° F. for three hours per day. In this graph, a direct comparison of the position of the curves

EXPLANATION OF PLATE II

Line graph showing the percentage heat injury to crops tested after pre-treatment in the heat room at 110° F. for three hours on each of three consecutive days. Temperature of test treatment for corn was 128° -- 130° F., for wheat 126° -- 128° F., and for sorghum 130° -- 132° F.

PLATE II


100
90
80
70
60
50
40
30
20
10
0
Per cent injury
Wheat
Corn
Sorghum
No pre-treatment
1
2
3
No. of days of pre-treatment

for the different crops should not be made. Instead, the characters of the curves should be compared. As will be noted, the curves agree very well as to their general trend.

Sorghum seedlings were treated for three hours per day at 110° F. on each of one, two, three, four, and five consecutive days to determine the length of time necessary to artificially develop the maximum amount of heat resistance in plants. Table 7 gives the percentage heat injury which is the average of eight pots for each pre-treatment. The grand mean for each pre-treatment along with other data are given for the seven trials. Least significant differences within trials and between treatment means were calculated for the five percent and one percent levels of significance. Plants receiving a pre-treatment at 110° F. for three hours on one day developed more heat resistance than plants receiving no pre-treatment. Differences were highly significant within all trials. However, differences between one and two, and two and three days of pre-treatments were variable ranging from non-significance to high significance. Differences between three and four and four and five days of pre-treatment were mostly non-significant.

The least significant differences between treatment means indicate that highly significant differences were found between untreated plants and those given a pre-treatment for one day. The difference between one and two days was barely significant while differences between two and three, three and four, and

Table 7. Percentage heat injury of sorghum tested five hours at 130° -- 132° F. after pre-treatment to heat at 110° F.

Trial	N[1]	Not pre-treated	No. of days of pre-treatment[2] (3 hrs. per day)				
			1	2	3	4	5
1	8	64.4	27.5	13.1	8.8	6.9	6.3
2	8	63.8	18.1	16.9	9.4	6.9	3.8
3	8	65.0	26.3	15.0	7.5	10.6	5.6
4	8	92.5	8.1	6.9	3.1	3.8	2.5
5	8	90.0	18.8	11.9	9.4	10.0	6.3
6	8	92.5	24.4	13.1	7.5	8.8	13.1
7	8	90.6	28.1	17.5	13.8	12.5	6.9
Mean[3]		79.83	21.61	13.49	8.50	8.50	6.36

[1] Number of pots in each group.

[2] Least significant differences within trials:

At the five percent point ... 4.69
At the one percent point ... 6.18

[3] Least significant differences between treatment means:

At the five percent point ... 7.47
At the one percent point ... 10.06

four and five days of pre-treatment were non-significant. Apparently some heat hardiness was developed artificially in plants after three days of pre-treatment, however, the most resistance was induced during the first three days.

The percentage heat injury for corn, wheat, and sorghum seedlings when subjected to a pre-treatment of 100° instead of 110° F. is shown in Table 8. These data are the average of four, 10, 15, or 16 pots for each pre-treatment as indicated in the table. The grand means for each pre-treatment along with other data are given for the 15 trials. A pre-treatment at 100° F. induced heat resistance. In comparison of the average of the means in Table 8 with those in Tables 4, 5, and 6 it appears that pre-hardening at 100° F. was slightly less effective than pre-treatment at 110° F.

A direct comparison of percentage heat injury of sorghum seedlings pre-treated to heat at 100° and at 110° F. is given in Table 9. These data are the average of four or eight pots in each pre-treatment as indicated in the tables. The grand mean for each pre-treatment along with other data are given for the five trials. In these trials, a pre-treatment at 100° was less effective than one at 110° F.

To determine the rate of inducing heat resistance in plants by pre-treating with heat, plants were treated at 110° F. for three hours, from 9:00 A.M. to 12 o'clock, and left in the heat room while the temperature was raised from 110° to 126° or

Table 8. Percentage heat injury of seedling plants tested five hours after pre-treatment to heat at 100° F.[2]

Trial	N[1]	Not pre-treated	No. of days of pre-treatment (3 hrs. per day) 1	2	3
Corn					
1	4	77.5	52.5	25.0	20.0
2	4	70.0	42.5	31.3	17.5
3	4	78.8	38.8	27.5	21.3
4	4	75.0	37.5	25.0	27.5
5	4	81.3	48.8	33.8	28.8
Mean		76.52	44.02	28.52	23.02
Wheat					
1	10	89.5	50.5	21.5	10.0
2	10	91.0	53.0	40.0	15.5
3	15	92.6	59.6	48.3	24.6
4	15	56.5	16.3	10.0	6.5
5	16	88.4	48.7	22.5	7.1
Mean		83.60	45.62	28.46	12.74
Sorghum					
1	4	57.5	17.5	11.3	15.0
2	4	56.3	16.3	6.3	8.8
3	10	49.5	10.5	4.5	3.0
4	10	82.5	29.0	22.0	17.0
5	10	84.5	26.0	20.5	16.5
Mean		66.06	19.86	12.92	12.06

[1]Number of pots in each group.

[2]Temperature of test treatment for corn was 128° -- 130° F., for wheat 126° -- 128° F., and for sorghum 130° -- 132° F.

Table 9. Comparison of percentage heat injury of sorghum tested five hours at 130° -- 132° F. after pre-treatment to heat at 100° and at 110° F.

Trial	N[1]	Not pre-treated	Temperature of pre-treatment (3 hrs. on one day) 100° F.	110° F.
1	4	92.5	20.0	13.8
2	4	40.0	8.8	10.0
3	4	65.0	15.0	11.9
4	8	92.5	25.0	8.5
5	8	90.0	26.9	18.8
Mean		76.00	19.14	12.60

[1]Number of pots in each group.

132° F. Untreated plants were placed in the heat room at the time the temperature was raised. At the time the temperature was raised, untreated plants (controls) were placed in the room and the plants already in the heat room were well watered.

Table 10 gives data on the rate of induction of heat resistance in corn, wheat, and sorghum. These data are the average of four, eight, or ten pots in each pre-treatment as indicated in the table. The grand means for each pre-treatment along with other data are given for the 15 trials. Data indicate that in all trials a three-hour pre-treatment at 110° F. induced heat resistance in plants which protected them against injury when exposed to higher temperatures immediately following the pre-treatment. Percentage heat injury was reduced by pre-treatment from 71.28 to 41.64 in corn trials, 64.76 to 30.78 in wheat, and 46.48 to 15.76 in sorghum.

To find the rate of loss of artificially induced heat resistance in wheat and sorghum, plants were pre-hardened to heat by subjecting them to a temperature of 110° F. for three hours, 9:00 A.M. to 12 o'clock, on each of three successive days. The plants were then placed in the greenhouse and left there with untreated plants until the final heat treatment was made at a temperature of 126° -- 128° F. or 130° -- 132° F. for five hours, from 1:00 P.M. to 6:00 P.M. The interval between the pre-treatment and the final test ranged from one to 13 days in sorghum and from two to 14 days in wheat. Thus, the rapidity

Table 10. Percentage heat injury in a study of the rate of induction of heat resistance in seedling plants tested five hours immediately following a pre-treatment to heat at 110° F.[2]

Trial	N[1]	Not pre-treated	3 hrs. at 110° F. immediately before raising of temperature
Corn			
1	4	71.3	46.3
2	4	75.0	42.6
3	4	73.8	40.0
4	4	66.3	41.3
5	10	70.0	38.0
Mean		71.28	41.64
Wheat			
1	4	57.5	27.5
2	4	61.3	26.3
3	4	67.5	28.8
4	4	65.0	31.3
5	4	72.5	40.0
Mean		64.76	30.78
Sorghum			
1	4	72.5	27.5
2	4	52.5	20.0
3	4	40.0	8.8
4	8	28.1	12.5
5	8	39.3	10.0
Mean		46.48	15.76

[1]Number of pots in each group.

[2]Temperature of test treatment for corn was 128° -- 130° F., for wheat 126° -- 128° F., and for sorghum 130° -- 132° F.

of loss of heat hardiness which had been developed in plants by the pre-treatment of heat was determined. Data on the rate of the loss of artificially induced heat resistance in wheat and sorghum are found in Tables 11 and 12, respectively. These data are the average of four, eight, or 10 pots in each pre-treatment as indicated in the tables. The grand means for each pre-treatment along with other data are given for the four trials.

Plate III is a line graph showing rate of loss or artificially induced heat resistance. The induced heat resistance in both wheat and sorghum was gradually lost. Rates of loss were essentially equal for the entire period. However, in sorghum, the rate of loss was most rapid after the sixth day while in wheat the rate was increased after the eighth day. Very little, if any, induced heat resistance remained 12 to 14 days after the last pre-treatment.

Effect of Moderately Low Temperatures upon the Resistance of Corn, Wheat, and Sorghum Seedlings to High Temperature

In this experiment, a study was made of the effect of moderately low temperatures in developing heat resistance in plants. To study the development of heat resistance in plants by pre-hardening them with a cold treatment, seedlings of corn, wheat, and sorghum were subjected to a temperature of from 34° to 40° F. in an unlighted refrigerator for three hours, 9:00 A.M. to 12:00 o'clock on one day. Some of the wheat seedlings were exposed to pre-treatment of cold on two and some on three con-

Table 11. Rate of loss of artificially induced heat resistance in wheat; percentage heat injury.[2]

Trial	N[1]	No. of days lapse before testing at 126° -- 128° F. for 5 hrs.													Untreated plants
		2	3	4	5	6	7	8	9	10	11	12	13	14	
1	4	7.5	13.8	21.3	30.0	27.5	40.0	42.5	62.5	68.8	70.0	70.0	73.8	91.3	77.5
2	10	10.0	17.5	20.5	28.5	35.0	42.5	46.0	60.0	69.0	72.5	73.0	79.5	86.0	84.5
Mean		8.8	15.7	20.9	29.3	31.3	41.3	44.3	61.3	68.9	71.3	71.5	76.7	88.7	81.0

[1]Number of pots in each group.
[2]Heat resistance developed by pre-treatment at 110° F. for three hours on each of three consecutive days.

Table 12. Rate of loss of artificially induced heat resistance in sorghum; percentage heat injury.[2]

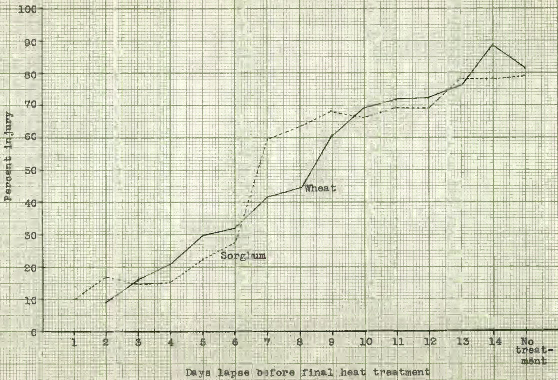
Trial	N[1]	No. of days lapse before testing at 130° -- 132° F. for 5 hrs. 1	2	3	4	5	6	7	8	9	10	11	12	13	Untreated plants
1	8	9.4	17.5	14.4	15.6	21.3	23.1	61.9	64.4	65.0	66.3	68.8	66.3	81.3	82.5
2	10	10.0	16.0	15.5	15.0	23.0	32.0	57.5	62.0	71.0	67.5	69.5	71.5	85.0	87.0
Mean		9.7	16.8	15.0	15.3	22.2	27.6	59.7	63.2	68.0	66.9	69.2	68.9	83.2	84.8

[1] Number of pots in each group.
[2] Heat resistance developed by pre-treatment at 110° F. for three hours on each of three consecutive days.

EXPLANATION OF PLATE III

Line graph showing the rate of loss of heat resistance artificially induced by pre-treatment at 110° F. for three hours on each of three consecutive days. Temperature of test treatment for wheat was 126° -- 128° F., and for sorghum 130° -- 132° F.

PLATE III


Percent injury
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
No treat-ment
Wheat
Sorghum
Days lapse before final heat treatment

secutive days. A day after pre-treatment these plants along with untreated plants were placed in the heat room for five hours at a temperature of from 126° to 132° F. to determine the affect of pre-treatments of cold on heat resistance.

The data obtained indicate that plants subjected to a temperature of from 34° to 40° F. develop heat hardiness. Percentage heat injury for corn, wheat, and sorghum when pre-treated at 34° to 40° F. for three hours are shown in Table 13. These data are the average of four pots for each pre-treatment. The grand means for each pre-treatment along with other data are given for the 24 trials. A pre-treatment for three hours developed an average increase of from 10 to 65 percent in the resistance of the seedlings to high temperatures.

Table 14 gives the percentage heat injury to wheat when pretreated at 34° to 40° F. for three hours on each of one, two, and three consecutive days.

These data are the average of four pots for each pretreatment. The grand mean for each pre-treatment along with other data are given for the five trials. Added heat resistance was induced in wheat seedlings when a pre-treatment to cold was repeated for two and three days. A comparison was made of the heat resistance developed in the plants by a pre-treatment of cold with that developed by a pre-treatment of heat. Plants were placed in the refrigerator for three hours, 9:00 A.M. to 12 o'clock. Other plants were given a three hour treatment at 110° F. in the heat room at the same time. These treated plants

Table 13. Percentage heat injury in corn, wheat, and sorghum tested five hours after pre-treatment to cold at 34° -- 40° F.[2]

Trial	N[1]	Not pre-treated	Pre-treated (3 hrs. for one day)
Corn			
1	4	68.8	22.5
2	4	62.5	25.0
3	4	72.5	40.0
4	4	71.3	31.3
5	4	72.5	37.5
6	4	76.3	26.3
7	4	71.3	35.0
8	4	70.0	41.3
Mean		70.65	32.36
Wheat			
1	4	88.9	78.8
2	4	86.3	28.8
3	4	72.5	15.0
4	4	81.3	18.8
5	4	75.5	23.8
6	4	81.3	27.5
7	4	71.3	37.5
8	4	72.5	30.0
Mean		78.70	32.52
Sorghum			
1	4	82.5	31.3
2	4	86.3	21.3
3	4	76.3	37.5
4	4	75.0	43.8
5	4	78.8	41.3
6	4	81.3	48.8
7	4	87.5	46.3
8	4	89.9	40.5
Mean		82.20	38.85

[1]Number of pots in each group.
[2]Temperature of test treatment for corn was 128° -- 130° F., for wheat 126° -- 128° F., and for sorghum 130° -- 132° F.

Table 14. Percentage heat injury of wheat tested five hours at 126° -- 128° F. after pre-treatment to cold at 34° -- 40° F.

Trial	N[1]	Not pre-treated	No. of days of pre-treatment (3 hrs. for one day) 1	2	3
1	4	88.9	78.8	16.3	18.9
2	4	86.3	28.8	22.5	13.8
3	4	72.5	15.0	15.0	8.8
4	4	81.3	18.8	17.5	13.8
5	4	71.3	30.0	20.0	17.5
Mean		80.06	34.28	18.26	14.56

[1]Number of pots in each group.

along with untreated plants were the following day given a final treatment of five hours at a temperature of 126° to 132° F.

In Table 15, is shown the percentage heat injury to corn, wheat, and sorghum seedlings after a pre-treatment for three hours at 110° F. compared with a pre-treatment for three hours at from 34° to 40° F. These data are the average of four pots for each pre-treatment. The grand means for each pre-treatment along with other data are given for the 20 trials. Both pre-treatments developed heat hardiness. However, the pre-treatment of heat was apparently more effective in developing heat resistance than the pre-treatment of cold.

A study was made of the heat resistance of wheat when dehardened to cold in varying degrees. To test the heat resistance of plants dehardened to cold, pots of wheat were exposed to natural winter conditions. These winter-hardened plants were brought into the greenhouse at 8:00 A.M. each day. In three or four hours, the soil was thawed and had reached greenhouse temperature. The plants were then watered. The dead tissues of the wheat plants were removed, thus facilitating the determination of percentage injury after treatments. Plants were brought into the greenhouse for several successive days and then subjected to a temperature of 126° to 132° F. for from six to eight hours in the heat room.

A complete summary of the data is found in Table 16. These data are the average of four pots for each pre-treatment. The

Table 15. Percentage heat injury in corn, wheat, and sorghum tested five hours after pre-treatment to cold at 34° -- 40° F. compared with pre-treatment to heat at 110° F.[2]

Trial	N[1]	Not pre-treated	Pre-treatment: Cold 3 hrs. at 34° -- 40° F.	Pre-treatment: Heat 3 hrs. at 110° F.
Corn				
1	4	62.5	25.0	22.5
2	4	72.5	40.0	21.3
3	4	71.3	31.3	26.3
4	4	72.5	37.5	16.3
5	4	71.3	35.0	25.0
6	4	70.0	41.3	31.3
7	4	76.3	26.3	33.8
Mean		70.91	33.77	25.21
Wheat				
1	4	77.5	23.8	7.5
2	4	71.3	30.0	27.5
3	4	80.0	36.3	23.8
4	4	85.0	32.5	25.0
5	4	65.0	37.5	27.5
Mean		75.76	32.02	22.26
Sorghum				
1	4	87.5	31.3	8.8
2	4	82.5	31.3	26.3
3	4	86.3	21.3	22.5
4	4	76.3	37.5	35.0
5	4	75.0	43.8	32.5
6	4	78.8	41.3	33.8
7	4	81.3	48.8	41.3
8	4	87.5	46.3	43.8
Mean		81.90	37.70	30.60

[1]Number of pots in each group.
[2]Temperature of test treatment for corn was 128° -- 130° F., for wheat 126° -- 128° F., and for sorghum 130° -- 132° F.

Table 16. Percentage heat injury of wheat tested six to eight hours at 126° -- 132° F. after dehardening to cold.

Trial	N[1]	No. of days dehardened in greenhouse[3] 0 (4 hrs.)	1	2	3	4	5	6	7	8	9	10	11	12	13
1[2]	4	6.3	10.0	21.3	22.5	22.5	80.0								
2	4	7.5	6.3	17.5	23.8	25.0	30.0	43.8					70.0		
3	4	17.5	18.8	28.8	50.0	92.5	88.8	100.0	95.0						
4	4	11.3	12.5	13.8	33.8	57.5	82.5	98.8	86.3						
5	4	3.8	11.3	41.3	57.5	72.5	96.3	92.5	87.5	71.3	97.5	98.8	96.3		
6	4	7.5	18.8		83.8		93.8		90.0		95.0		96.3		
Mean of 5 comparative trials[4]		9.3	11.8	24.5	37.5	54.0	75.5								

[1] Number of pots in each group.
[2] First five trials have comparative results and were used in statistical analysis.
[3] Least significant differences within trials:

At the five percent point ... 13.07
At the one percent point ... 17.31

[4] Least significant differences within trials:

At the five percent point ... 18.47
At the one percent point ... 25.18

grand means for each pre-treatment along with other data are given for the six trials. The first five trials have comparative data for six days in the greenhouse and are used in calculating the least significant differences within trials and the least significant differences between treatment means. Calculations are for the one percent and the five percent levels of significance. Differences within trials vary from non-significance to high significance. Differences between no day and one day in the greenhouse are, in all cases, non-significant. With the exception of one trial, differences between one day and two days in the greenhouse are non-significant. Differences between the two, three, four, and five days of pre-treatment in the greenhouse range from non-significance to high significance. Cold-hardened wheat plants dehardened to heat very rapidly after the first day and very little resistance remained after five days in the greenhouse. Laude (1937) has shown that cold-hardened wheat plants when exposed to greenhouse temperatures dehardened to cold in about the same way as the plants in these experiments dehardened to heat.

Effect of Drought Treatments upon the Resistance of Corn, Wheat, and Sorghum Seedlings to High Temperature

This experiment was conducted to determine the effect of soil drought on the resistance of plants to high temperatures. To pre-harden with a drought treatment, seedling plants of corn, wheat, and sorghum were subjected to conditions of continuous drought for from five to 14 days. Length of pre-treatment depended upon the environmental conditions in the greenhouse and on the age of the plants. Plants were pre-treated until the morning that they showed signs of continuous wilting. At that time, on the day of the final heat treatment, the plants were thoroughly watered at 8:00 A.M. At 1:00 P.M. of the same day the treated plants, along with the untreated plants, were given a final treatment in the heat room for five hours at 126° to 132° F. Untreated plants had been watered daily along with the other plants in the greenhouse. The data obtained indicate that deficient soil moisture caused the plants to become more heat resistant. Table 17 gives the average percent heat injury for corn, wheat, and sorghum seedlings. These data are the average of four, eight, 10, 20, or 40 pots as indicated in the table. The grand means for each pre-treatment along with other data are given for the 24 trials. As is observed in the table, plants given a moderate drought treatment were, in all cases, more resistant to heat than those which were watered regularly. Percent injury for untreated corn seedlings was 59.39 compared to 11.99 for treated plants; in wheat, 77.55 in comparison with 25.99; in sorghum, 73.80 in comparison with 17.24.

DISCUSSION

That artificial light from Mazda bulbs induced heat resistance in sorghum, wheat, corn, barley, and alfalfa was found by Laude (1939). Heyne and Laude (1940) noted that light greatly

Table 17. Percentage heat injury in corn, wheat, and sorghum tested five hours after pre-treatment to drought.[2]

Trial	N[1]	No. days pre-treatment of drought	Not pre-treated	Pre-treatment of drought
Corn				
1	4	5	68.8	6.3
2	4	5	88.8	10.0
3	4	5	27.5	5.0
4	4	8	52.5	1.3
5	10	6	47.0	15.5
6	10	7	56.0	21.0
7	10	8	63.5	24.0
8	20	6	71.0	12.8
Mean		6	59.39	11.99
Wheat				
1	8	11	93.1	18.8
2	8	5	96.9	63.1
3	10	6	74.0	18.5
4	10	5	68.0	20.0
5	10	7	79.0	25.5
6	10	6	74.5	27.5
7	10	8	59.0	24.5
8	40	5	75.9	10.0
Mean		7	77.55	25.99
Sorghum				
1	4	9	60.0	5.0
2	8	8	91.3	30.0
3	8	9	86.9	2.5
4	8	15	61.9	6.9
5	10	15	69.0	13.5
6	10	8	75.5	30.5
7	10	8	78.5	26.0
8	20	15	67.3	23.5
Mean		11	73.80	17.24

[1] Number of pots in each group.
[2] Temperature of test treatment for corn was 128° -- 130° F., for wheat 126° -- 128° F., and for sorghum 130° -- 132° F.

hardens corn seedlings to high temperature. Heat resistance was considerably increased by exposures to sunlight for as short a period as one hour. This indicated that a lack or deficiency of sunlight decreases the tolerance of plants to heat.

Data in this problem also indicate that light increased heat resistance in seedlings of corn, wheat, and sorghum. In all cases, the differences between treatment means of no light and any of the other pre-treatments of varying intensities of light were highly significant, exceeding the calculated one percent level of minimum significant differences. On the strength of data by past investigators and data presented in this paper it may be concluded that light is advantageous to the plant in resisting high temperature.

In these experiments it was shown, furthermore, that varying intensities of light apparently were responsible for differences in resistance of the plants to high temperatures. (Plate IV). Calculated least significant differences between treatment means were in a majority of cases significant or highly significant for the pre-treatment of varying intensities of light in this problem. Light being the source of energy for photosynthesis it would seem logical that with increased intensity of light the process also goes on at a higher rate. This, however, would not hold true for high light intensity. If beginning with low values the intensity of light is augmented by steps representing equal energy increases, assimilation will increase by almost uniform steps until a certain intensity of light is

EXPLANATION OF PLATE IV

Development of Heat Resistance in Sorghum by Varying Intensities of Light

The plants were all placed in a dark room at 5:00 P.M. the day preceding the trial. During the three hours immediately preceding the heat test the plants were exposed to different light conditions as follows:

Pot 1. Plants were left in the dark room.

Pot 2. Placed in north light in basement of plant research laboratory for three hours.

Pot 3. Placed in direct sunlight in greenhouse for three hours.

Pot 4. Received light from two 150-watt Mazda reflector bulbs for three hours.

Pot 5. Received light from four 150-watt Mazda reflector bulbs for three hours.

Pot 6. Received light from eight 150-watt Mazda reflector bulbs for three hours.

Immediately following these pre-treatments the plants were placed in the heat room at a temperature of 130° -- 132° F. for a period of five hours. The photograph was taken four days after the test treatment.

PLATE IV

reached.

Blackman and Matthaei (1905) investigated the influence of light intensity upon the photosynthetic rate with a full realization of the importance of other factors and under well controlled conditions. They concluded that if the temperature and carbon dioxide are in excess the rate of photosynthesis is proportional to the intensity of the incident light.

Adams (1925) emphasized that temperature must be considered in experiments dealing with the reaction of plants to light. Plants showed as good a growth under exposure to 569 hours of daylight at a mean temperature of 60.8° F. as they did with an exposure to light of 500 hours at a temperature of 68.2° F. Apparently no definite correlation between temperature and percentage heat injury to plants could be observed in this problem. Although temperature variations may have had an effect, light is considered the major factor in developing resistance to high temperatures in these tests.

Finkner (1940) concluded from his studies that light and carbon dioxide have a marked effect upon the resistance of seedling wheat plants to high temperature. Results indicate that the products of photosynthesis are instrumental in causing plants to be resistant to high temperatures. There seems to be little doubt but that photosynthesis is a partial cause of resistance although other mechanisms are probably involved. Hardening ability probably depends upon the amount of photosynthetic products manufactured under the different light intensities.

Research workers including Harvey (1930), Dunn (1933), Dexter (1935a), and Suneson and Peltier (1938) increased the cold resistance of plants by gradually lowering the temperature. In this experiment, heat resistance was developed by exposing seedling plants to moderately high temperatures of 100° and 110° F. (Plate V, Figures 1 and 2).

The changes occurring within the plants to make them more resistant to heat when given a pre-treatment at 110° F. apparently had the following characteristics: The rate of induction of this change was rapid as a three-hour pre-treatment immediately before the final treatment was effective. The pre-treatment on the first day was more effective in developing heat resistance than those on the succeeding days. After the third day very little resistance was developed in the plants by pre-treatments. Hardening was induced at 100° and at 110° F., however, a pre-treatment at 110° F. was the more effective. The induced heat resistance was not permanent as it was lost in a period of from six to eight days lapse after a pre-treatment. However, exposure of plants to 110° F. for three hours on each of three consecutive days induced heat resistance that was apparent for about a week. (Plate VI)

There are several possibilities as to the changes occurring within the plants to make them more resistant to high temperatures. The rapid and marked effect of so short an exposure as three hours at 110° F. suggests that a shock response not correlated with the product of time and temperature of exposure

EXPLANATION OF PLATE V

Fig. 1. Hardening to heat by exposure to heat.

Two pots of wheat seedlings were placed in the heat room at a temperature of 126° -- 128° F. for a period of five hours. Previous treatment was as follows:

Pots on left. Plants were not pre-treated.

Pots on right. Plants were exposed to 110° F. for three hours, the day preceding the test treatment.

Plants were photographed 32 days after the final test treatment.

Fig. 2. Hardening to heat by exposure to heat.

Two pots of sorghum seedlings were placed in the heat room at a temperature of 130° -- 132° F. for a period of five hours. Previous treatment was as follows:

Pot on left. Plants were exposed to 110° F. for three hours, the day preceding the test treatment.

Pot on right. Plants were not pre-treated.

Plants were photographed 13 days after the final test treatment.

PLATE V

Fig. 1

Fig. 2

EXPLANATION OF PLATE VI

Rate of loss of artificially induced heat resistance in plants.

All nine pots of sorghum were placed in the heat room at a temperature of 130° -- 132° F. for a period of five hours. Previous treatment preceding trial was as follows:

Pots, number one through eight, were pre-treated with heat three hours per day for three days at 110° F.

Pot	1	2	3	4	5	6	7	8
No. days lapse before final treatment	8	7	6	5	4	3	2	1

Pot 9. Plants were not pre-treated.

Plants were photographed nine days after the final test treatment.

PLATE VI

might have induced the resistance. Changes within the plants similar to those inducing drought resistance reported by Newton and Martin (1930) might have increased resistance to high temperatures. Factors suggested include an increase in the amount of bound water, a change in the osmotic pressure of the plant cells, or the reaction of unidentified physico-chemical properties.

A temperature of 110° F. is approximately 35 degrees above the temperature at which plants are normally grown in the greenhouse. The thermal death point of most plant cells lies between 113 and 131° F. According to Maximov (1938) as a temperature of 110° F. is approached there is a disturbance in the coordination of the biochemical processes taking place in the cell and poisonous substances of the types of toxin accumulate for death usually begins at temperatures slightly above 110° F. Coagulation of the protein substances of the protoplasm might also begin at this temperature. A by-product of one of these breakdown processes might induce heat resistance, at 100° and 110° F. and yet the temperature would not be high enough to kill the cells.

The exact nature of physiological adaptation to cold is still unknown. Many correlations have been noted between cold resistance and certain plant characteristics such as structure and the chemical and physical properties of the cells. The general effect of low temperatures on plant tissue has been thoroughly reviewed and investigated by many investigators.

The quantity of hydrophilic colloids contained in pressed juice of hardened leaves was found by Newton (1924) and Dunn (1933) to be proportional to winter hardiness.

In summary, Martin (1927) stated that hardy plants are characterized by low moisture content of tissues, high percentage of total solids in juice, high freezing point depression or osmotic concentration of juice when plants are actively growing, high percentage of bound water in juice, low rate of respiration at low temperatures, and frequently by a long period of vegetative growth.

Dexter, Tottingham, and Graber (1930), within limits of their investigation showed that there exists a correlation between know hardiness of alfalfa roots and the degree of retention of electrolytes by the tissues after freezing.

Schaffnit and Lüdthe (1932) in their studies conducted with winter wheat, winter vetch, and cabbage found that the entire relationship of the nitrogen compounds was altered by low temperature.

According to Dexter (1935b) more water is left unfrozen in hardened plants than in unhardened ones, and the concentration of minerals is lower in the unfrozen water in hardened than in unhardened plants.

Scarth and Levitt (1937) summarized a linked series of changes associated with hardiness.

1. Complicated hydrolytic breakdown of carbohydrates 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. Due to similar changes in the protoplasmic colloids the whole cytoplasm, probably, and the plasmic membranes, almost certainly become more hydrated.
3. As a consequence of this change the viscosity of the protoplasm is lowered.
4. Because of the change in the membranes in particular, cell permeability is increased.

The exact nature of cold resistance must await a better knowledge of the structure and the physiology of the plant protoplasm. Perhaps, the same factor or factors causing cold hardiness also make plants more resistant to heat as plants given a pre-treatment to cold were decidedly more resistant to heat than untreated ones. (Plate VII)

The close analogy between cold resistance and resistance to high temperatures is further strengthened by the studies made on the heat resistance of wheat dehardened to cold. Several research workers have given consideration to the loss of cold hardiness in plants when exposed to conditions for normal growth.

Suneson (1930) noted that loss of hardiness under constant greenhouse temperatures was readily discernible in from 24 to 48 hours. According to Salmon (1928), this was previously observed by Bayles.

Tumanov (1931) worked with hardened wheat plants and found

EXPLANATION OF PLATE VII

Hardening to heat by exposure to pre-treatments of heat and cold

Three pots of wheat were placed in the heat room at a temperature of 126° -- 128° F. for a period of five hours. Treatments preceding trial were as follows:

Pot 1. Plants were not pre-treated.

Pot 2. Pre-treatment of cold at 34° -- 40° F. for three hours on the previous day.

Pot 3. Pre-treatment of heat at 110° F. for three hours on the previous day.

Plants were photographed eight days after the final test treatment.

PLATE VII

a definite loss of hardiness in a single day with plants maintained at greenhouse temperature.

According to Anderson and Kiesselbach (1934) wheat plants may decrease in cold resistance following a few warm days in winter. As the crop loses its hardiness with the approach of early spring, its cold resistance is reduced. Data in this problem indicate that plants dehardened to cold in the greenhouse gradually lost their heat resistance. (Plate VIII) An explanation of the loss of cold hardiness might explain the loss of resistance to heat if it is assumed that the same factor or factors are responsible for cold and heat resistance in plants.

Dexter (1933) in his study of the loss of cold resistance believed 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 or elongation of new leaves is stimulated there is a rapid decrease in hardiness, presumably because of the labilization and use of organic food.

Laude (1937) studied the changes in cold resistance during transition from dormancy to active growth in winter cereals including wheat, rye, barley, and oats. Water content and amount of expressed sap increased as active growth began after dormancy. The total solids in the sap decreased. Cold resistance changes were negatively associated with H_2O content, refraction of sap, and expressed juice during the first half of the transition

EXPLANATION OF PLATE VIII

Heat resistance of plants dehardened to cold.

All seven pots of wheat were placed in the heat room at a temperature of 126° -- 132° F. for a period of eight hours. Treatment before trial was as follows:

Plants were hardened outside to natural winter conditions and then brought into the greenhouse.

Pot	1	2	3	4	5	6	7
No. of days in greenhouse before final treatment	0 (4 hrs.)	1	2	3	4	5	6

Plants were photographed 15 days after the final test treatment.

PLATE VIII

period and similarly associated with pressed juice during the last half of the period.

Aamodt and Johnston (1936), Kondo (1931), Krassnosselsky-Maximov and Kondo (1933), and Shirley and Meuli (1939) have either observed or suggested that hardening of plants by soil drought or by limited exposures to atmospheric drought increased resistance to exposures of severe atmospheric drought.

Drought resistance in plants is considered a result of the interaction between many complex physiological processes and physiological and anatomical responses. Newton and Martin (1930) summarized diagrammatically the principal factors affecting drought resistance. They outlined in detail absorption and transpiration but did not attempt to elaborate wilt endurance which is still an obscure physiological adaptation enabling plants to maintain life when the moisture content of the tissues becomes abnormally low. Certain physico-chemical properties of the leaf tissue fluids agreed closely with the drought resistance of various crops. Bound-water content served as a reliable index to use in classifying crops relative to their ability to resist drought.

Vassiliev and Vassiliev (1936), in their study of all the factors causing drought resistance in wheat found that carbohydrates aid markedly in regulating the osmotic pressure of the plant cell. Carbohydrates also play the role of a protector in preventing coagulation of protoplasm when influenced by harmful factors. They believed that the accumulation of hemicellulose during the stage of water loss is a means of resistance and a natural reaction of a wheat plant towards drought. Accumulation of soluble carbohydrates by a plant is a means of increasing its drought resistance.

In this problem, drought treatments contributed to a less vigorous development of the vegetative organs and definitely hardened the plants to high temperatures. (Plate IX) Hardening of the treated plants may have been caused by one or by a combination of several factors including the accumulation of soluble carbohydrates or hemicellulose, an increase in the amount of bound water, a change in the osmotic pressure of the plant cells, and the reaction of certain unidentified physico-chemical properties. To this may be added anatomical changes induced by drought conditions which might interfere with the plant processes of absorption and transpiration. Periods of drought for as short a time as five days gave a marked difference in the resistance of plants to high temperatures in certain tests. Although complex physiological changes may have occurred within the plant in that length of time it is very probable that some factor or group of factors, either those already suggested, or variations of them, induced heat resistance in the plants. Hardening may also have been caused by some factor as yet not studied or understood when the plant entered a stage of temporary dormancy because of the drought treatment.

EXPLANATION OF PLATE IX

Two pots of corn seedlings were placed in the heat room at a temperature of 130° -- 132° F. for a period of five hours. Treatment preceding trial was as follows:

Pot on left. Plants were not watered for six days preceding final heat treatment. Plants were watered thoroughly on the morning of the final heat treatment.

Pot on right. Plants were not pre-treated. Plants were growing under normal conditions in the greenhouse; watered daily.

Plants were photographed seven days after the final test treatment.

PLATE IX

SUMMARY AND CONCLUSIONS

1. The effect of certain environmental conditions on the resistance of corn, wheat, and sorghum seedlings to high temperature was studied. Four main tests were made: (1) the effect of varying intensities of light upon the resistance of seedling plants to high temperatures; (2) the effect of moderately high temperatures upon the resistance of seedling plants to high temperatures; (3) the effect of moderately low temperatures upon the resistance of seedling plants to high temperatures; and (4) the effect of drought treatment upon the resistance of seedling plants to high temperatures.

2. Results of the experiments with varying intensities of light indicate that light is a major factor for developing heat resistance in seedling plants. Although temperature may have had an effect, light was considered the major factor in developing resistance to high temperature. Heat resistance was directly correlated with increasing intensities of the light pre-treatments.

3. Plants subjected to pre-treatments of moderately high temperatures of 100° and 110° F. for three hours developed heat hardiness. Although some heat resistance was developed in plants after three successive days of pre-treatment, marked influence occurred in the first three days, especially the first day. A pre-treatment at 100° was slightly less effective than one at 110° F. Rate of induction of heat resistance by pre-

treatment at 110° F. was rapid as a pre-treatment of three hours immediately before the final test to determine percentage heat injury increased the resistance of the plants to high temperature. Artificially induced heat resistance was gradually lost. Very little, if any, artificially induced heat resistance remained 12 to 14 days after the last pre-treatment.

4. Plants subjected to pre-treatments of moderately low temperatures of from 34° to 40° F. for three hours developed heat resistance. Added heat resistance was induced in wheat by two and three days of pre-treatment. Pre-treatments to heat at 100° or 110° F. were apparently more effective than pre-treatments to cold at 34° to 40° F. in developing heat hardiness in seedling plants.

5. Wheat plants were hardened to cold through exposure to natural winter conditions. Heat resistance of the plants decreased rapidly after the first day and little resistance remained after five days of dehardening to cold under normal growth conditions in the greenhouse.

6. Pre-treatments of drought induced heat resistance in seedling plants. Plants not watered for from five to 15 days until the day of the final test treatment to determine percentage heat injury were more resistant to heat than plants watered daily.

7. It may be concluded from these studies that conditions such as varying intensities of light, moderately high temperatures, moderately low temperatures, and drought have a marked

effect upon the resistance of corn, wheat, and sorghum seedlings to high temperatures. A close similarity was observed between heat resistance and cold resistance. Apparently the same factor or factors inducing cold resistance in plants may also induce heat resistance. The resistance to high temperature artificially developed in the seedlings by various pre-treatments is considered a result of the interaction between many simple or complex physiological processes and physiological and anatomical responses. No factor or factors studied so far serve as a reliable index to use in classifying crops relative to their ability to resist drought.

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