A STUDY OF HEAT AND ATMOSPHERIC DROUGHT RESISTANCE AND SOME RELATED CHARACTERISTICS IN WHEAT VARIETIES

by

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INTRODUCTION

Drought resistance, according to Maximov (36), is the "capacity of plants to endure drought and recover readily after permanent wilting, with the minimum of damage to the plant itself and to yield produced".

The drought condition in general is a problem of major importance in crop production in subhumid and especially in semiarid regions of the world. Most of the wheat growing areas are situated in these regions which are subjected every year to drought conditions of varying intensity.

There have been numerous crop failures due to severe drought and sometimes such disastrous harvests have been termed drought famine in some parts of the world. Such drought conditions caused a national calamity in Russia in 1921 when millions of human lives were lost by famine and accompanying diseases (48).

Drought may be classified as (a) atmospheric drought, (b) edaphic drought. The former is the result of high temperature and low humidity accompanied with dry-winds, while the latter is the condition of the soil moisture which is not sufficient for normal plant growth and development. The scope of this study is mainly limited to the former condition but both drought conditions are interrelated with each other. In great plains, (U.S.A.), wheat producing areas, the fluctuation in atmospheric temperature is not an uncommon feature. Extremes of high temperature sometimes result in heavy losses to wheat farmers. High temperatures are closely associated with soil drought. It is therefore necessary to develop strains resistant to higher temperature and deficient soil moisture to endure successful crop production in these semi arid regions.

The use of a drought chamber is becoming very popular for testing the relative resistance of plants. That equipment is of great help in plant research because drought and extremely high temperatures do not occur every year which makes it impossible for testing the strains for their tolerance to drought. Shirley and Meuli (56) stated the following three advantages of the drought machine:

1. It is free from biotic influence which often disturbs tests in the field.

2. The machine is available for test at anytime whereas field tests can be made only during certain periods.

3. Possible control over environmental factors in the machine reduces variability to a great extent and consequently it increases the reliability of the results.

Keeping in view the importance and need of parental material for breeding drought resistance and selecting better resistant wheat varieties, an endeavor has been made:

1. To study resistance to high temperature and atmospheric drought in wheat varieties.

2. To study the relation of the root to drought resistance.

3. To study the relation of rate of water loss from excised plants to heat resistance.

REVIEW OF LITERATURE

The use of yield trials as an index for drought resistance has not proved very satisfactory under dry conditions because early varieties may have high yield, but are drought escaping rather than drought resistant. Furthermore it is not possible to have desirable conditions every year for testing the strains for their tolerance to drought resistance. It is therefore desirable to determine the relative drought resistance under controlled laboratory conditions in the greenhouse. Maximov (36) and Newton and Martin (40) have suggested methods such as chemical analysis, rate of transpiration and physiological and anatomical analysis.

The Use of Drought Chamber for Measuring Resistance

Several investigators have emphasized the importance of artificial heat tests for studying varietal selection to determine relative drought resistance. Shirley (55) was probably the first who placed Picea Canadensis in an illuminated chamber in which the temperature was controlled by a thermo regulator and the air was passed over calcium chloride used as dehydrating agent. The duration of exposure was used as a criterion of its drought resistance. Shirley and Meuli (56) have pointed out many advantages of drought machines over field testing. Many of the workers have shown the possibility of using controlled high temperatures to select the strains which are drought resistant under field conditions. Hunter, et al (20) subjected corn seedling to 140° F temperature for 6.5 hours with a relative humidity of about 30 percent and found a close relationship between the results obtained by the drought machine and the performance of the same strains under field conditions. Bayles, et al (6) when testing eight spring wheat varieties in a drought machine reported similar success.

Aamodt (1) has described the construction of a drought chamber used in determining the relative resistance of several spring wheat varieties.

Aamodt and Johnston (2) reported the relative resistance of several spring wheat varieties as determined in the drought chamber. Krasnosel, et al (27) in Russia have reported the studies on the effect of drought at different stages of plant development by using a drought chamber with controlled temperature, humidity and air velocity. The injury of drought during the period from shooting to the end of flowering was most injurious to cereals.

Heyne and Laude (18) and Heyne and Brunson (17) while conducting a genetic study of drought resistance in inbred lines of corn reported that high temperature tests of seedling plants will be valuable aid in breeding of strains resistant to heat and drought. Heyne and Laude (18) reported that testing of seedlings for heat resistance can be relied upon for distinguishing genetic differences in the drought tolerance of larger plants of different strains of maize. Flat and Droch (46) stated that artificial drought tests would be very useful in eliminating low yielding lines of plants from hybrid population. Kinsey et al (23) could not establish any relation between the results obtained by the drought chamber and yield under field conditions.

The Effect of High Temperature in Relation to Drought Resistance

It has been observed by several workers that artificial high temperature tests are a valuable supplement to field studies of drought resistance. The nature and cause of drought is not yet fully understood. Heyne and Laude (18) and Jalander (22) were of the opinion that what is usually considered drought resistance may sometimes be heat resistance. Chi Chen (10) observed that in both cases of atmospheric drought and soil drought, the injury is due to dessication and dehydration of the sells. For this reason soil drought studies might include information which is applicable to high temperature situations. Tumanov (59) reported that in case of resistant strains, the protoplasm remained more stable and was more capable of enduring dehydration. Vassiliev (60) stated that the varieties unadapted to drought conditions suffer more from high atmospheric temperatures and other factors which promote increased transperation than from a deficiency of soil water as is generally accepted.

Carrol (9) found that much less injury occurred to varieties of grasses exposed to high air temperature in comparison with the treatment of high soil temperature to the same group of grasses.

Berkley and Berkley (7) concluded that lethal temperature which would kill protoplasm immediately at a given relative humidity depended upon the age of the plant, the duration and condition of exposure. Tumanov (59) stated that different plant organs showed a different dehydration resistance.

Krasnosselsky-Maximov (28) reported in case of oats and barley that plants suffer from hot, dry winds differently at different stages of development. They are injured most at the time of flowering and the least at the time of waxy ripening.

Root Development Studies in Relation to Drought Resistance

There are only limited studies on this aspect. Some of the workers attempted to establish a relation between root system and drought resistance. Talanov (57) and Aamodt and Johnston (2) reported a relation between root system and drought resistance while testing spring wheat varieties in an artificial drought chamber. They found that drought resistant varieties had more highly branched primary root systems than non resistant varieties. Chi Chen (10) found that plants which were resistant to atmospheric drought had larger root systems.

Hubbard (19) observed that Ceres spring wheat had a large number of roots, more root hairs and a greater weight of roots than Marquis and Hope spring wheats.

Ivanov (21) pointed out that plants with extensive root systems had higher suction power and consequently were in better position to resist atmospheric drought when a rapid moisture supply is necessary to prevent the wilting of the plant.

Miller and Coffman (37) observed that sorgum had twice as many secondary roots as corn. Collins (12) observed that drought resistant strains of maize lacked branches of secondary roots entirely and had deeper root system than non-resistant varieties.

Weaver et al. (63), Pavlychenko (45) and Albertson (3) have emphasized the importance of depth and extent of root system which enables the plants to grow under abnormal soil moisture conditions.

Noll (42) reported that wheat varieties with shallow root system died during drought period. Misra (38) found that hardy varieties of wheat had larger root systems than non-hardy varieties.

Alexander (4) found a correlation in oats between root and shoot length in seedling stage and drought resistance. The more drought resistant varieties produced a smaller proportion of root and shoot at all moisture content in comparison with less resistant varieties.

Relation of Water Loss from Excised
Plants to Drought Resistance

Bayles et al, while testing spring wheat varieties for atmospheric drought resistance, reported that drought resistant varieties lost lesser quantities of water than non-resistant varieties. Martin (35) obtained similar results between drought resistant sorgum and non-resistant corn leaves. On the other hand Newton and Martin (40) found no difference in rate of loss of water in timothy and western rye grasses even though the latter is more drought resistant. Michiporovich (41) found that xerophytes lose moisture less readily than other types.

The Effect of Hardened and Unhardened Conditions on Resistance in Plants

A plant is said to be hardened when its resistance to adverse condition has been increased by external influences. McDougal (34) reported that plants may be hardened by exposure to cold, restricting the water supply, growing in poor soil, by root pruning or by watering with a weak salt solution. He further reported that a notable feature of resistance in the large proportion of mucilage or pentosans present and pointed out that these materials have high temperature point before they break off and coagulate. Rosa (49) also confirmed the same in cabbage and other vegetables during the hardening process. Vassiliev and Vassiliev (61) believed that the accumulation of carbohydrates represented a means of resistance.

Laude (31) and Heyne and Laude (18) reported that the heat resistance was considerably increased in corn seedlings by exposure of one hour to light after having been kept in dark for 12 to 18 hours.

Tumanov (59), and Kondo (26) reported that wilting results in hardening. Aamodt and Johnston (2) observed a hardening process induced by limited period of atmospheric drought. The hardened plants of both resistant and non--resistant strains became more tolerant to drought.

Salmon and Fleming (52) and Harvey (16) reported that the plants when grown in a soil with different amounts of moisture became less succulent and hardened. Newton and Brown (39) stated that hardy varieties had less moisture content due to hardening process. These results were in line with the results obtained by Martin.

Laude (30) found that winter wheat, rye, barley and oats were hardened when grown outdoors under natural weather conditions and the effect of hardening decreased when the plants were brought into the greenhouse.

Jalander (22) observed that plants grown with deficient moisture required much longer heat exposure before they were killed than those plants grown with plenty of water.

Worf (66) reported that wheat varieties in the winter hardened conditions were much more resistant to high temperature than when in unhardened condition.

Dexter (14) was of the opinion that hardiness of plant was dependent upon environmental conditions which were favorable in maintaining organic reserves i.e. which depressed respiration and top growth and favored dormancy with continued period of photosynthesis.

Salmon summarised the hardening process as follows:

1. A decrease in moisture content to some extent.

2. Marked decrease in the amount of sap that can be extracted from living tissue.

3. Increase in the sugar content.

4. A decrease in the free water, i.e. the water in tissue from which ice will be formed at any given temperature.

Kezer and Robertson (24) reported that the shooting stage of spring wheat is a critical stage for drought. Krasnosselsky-Maximov (28) found that the flowering stage is extremely critical and susceptible to atmospheric drought in cereals. Tippet (58) also observed that pollen may be killed by high temperatures.

Studies on Physiological and Anatomical Characteristics in Relation to Drought Resistance

Alexander, Tulaikov, Kiesselbach, Richardson, and Dillman reported by Aamodt and Johnston (2) were of the opinion that the water requirement could not be used as a basis of selection for drought resistance. Miller and Coffman (37) found more dry matter, reducing sugar, non-reducing sugar and starch in sorghum than in corn. Vassiliev (61) observed that these sugars help protect the plants from desiccation.

Lvoff and Fichtenholz (33) stated that drought resistant plants had more hydrolysis of starch to monosacchrides than non-resistant plants.

Clements (11) was of the opinion that the cells and protoplasm of the leaves and stems had large amounts of hemicellulose.

Newton and Martin (40) stated that bound water is a good criterion for the selection of drought resistant strains. Maximov (36) reported that drought resistant wheat varieties had more bound water than non-resistant varieties as the soil moisture decreased. Calvert (8) found significant differences in bound water between the non-resistant and the most susceptible varieties. Whiteman (64) and Carrol (9) failed to establish this relationship between these phenomena.

Maximov (36) found that xerophytes are characterized with high osmotic pressure. Newton and Martin (40) noticed higher osmotic pressure in drought resistant strains of wheat and grasses, than in non-resistant strains. Bartell (5) found that resistance in plants increased with the increase in osmotic pressure. While Schmidt et al (53) concluded that osmotic pressure is no criterion of drought resistance.

Whiteside (65) observed that the cells of wheat plants grown under drought conditions were smaller in size. Lal and Malhotra (29) obtained similar results in a drought resistant variety of sugar cane, named Rheora. Maximov (36) has advocated the selection of resistant varieties on the basis of xeromorphic structures. Kolkunov (25) found that drought resistant wheat varieties had smaller stomata. He assumed that the transpiration is regulated by stomata and hence it is a good criterion for drought resistance.

Pool (47) found no relation between leaf anatomy and transpiration. Yakushina and Vanilov (67) found no relation between cell size and yield and drought resistance in wheat varieties. Haber (15) did not find any significant difference between the number of stomata in the leaves of resistant and non-resistant varieties of sweet corn and number of vascular bundle per square mm of stem even under severe drought condition. Vasiliev (61) found that the cell size and length of stomata in wheat varieties were not related to their drought resistance, but Pavlov (44) reported that, in general the more drought resistant and earlier varieties of winter wheat had smaller stomata but he could not find the same situation in the case of spring wheat and oat varieties.

Miller and Coffmann (37) observed that mesophyll cells of sorgum were smaller, more compact, and more numerous than in corn. Clements (11) found that the cells of leaves and stems were thickened with hydrophyllic hemi-celluloses in case of drought resistant varieties of soya beans.

MATERIALS AND METHODS

The materials and methods used in this investigation are described in the following sections.

Artificial Drought Chamber Tests

Two separate experiments were conducted in order to determine the relative heat resistance in a number of wheat varieties.

Experiment No. 1: The varieties used in this experiment were Kanking (C.I. 12719), Ponca (C.I. 12128), Concho (C.I. 12517), Kharkof (C.I. 1442), Pawnee (C.I. 11669), Yogo (C.I. 8033) and Sioux (C.I. 12142), (winter wheats) and Thatcher (C.I. 10003), Mida (C.I. 12008) and Baart (C.I. 11907) (spring wheats).

Planting was done in four inch unglazed clay pots. Seven seeds were sown per pot and later on, were thinned down to five plants per pot. Three pots were used for each variety in each of ten replications.

The pots were kept on a table in randomized fashion in the greenhouse so that the possible effect of differences of light and temperature within the greenhouse might be reduced to a minimum. Air dried soil used in all the pots was of one type and care was taken to use an equal quantity of soil in each pot. Soil moisture was kept as near the optimum as possible at all times during the growing period of the seedlings. Greenhouse temperature generally ranged from 65° to 85° F.

The equipment used for testing the relative hardiness of plants in this experiment was a drought chamber and unit-heater "Johnson automatic temperature and humidity control", installed recently. The drought chamber in which the plants were subjected to heat, was 5 x 5 x 8 feet. The temperature was controlled automatically, but unfortunately, relative humidity could not be controlled due to the reason that the plant could not be completed for want of certain parts. The relative humidity remained fairly constant during the course of each trial as shown in Plate I.

A constant stream of hot wind was passing over the plants placed on a revolving round table fixed in the center of the room. Light, of low intensity, was provided by light bulbs about six feet above the plants. A double glass window provided a means of observing the plants under treatment without affecting the room temperature in the course of heat exposure.

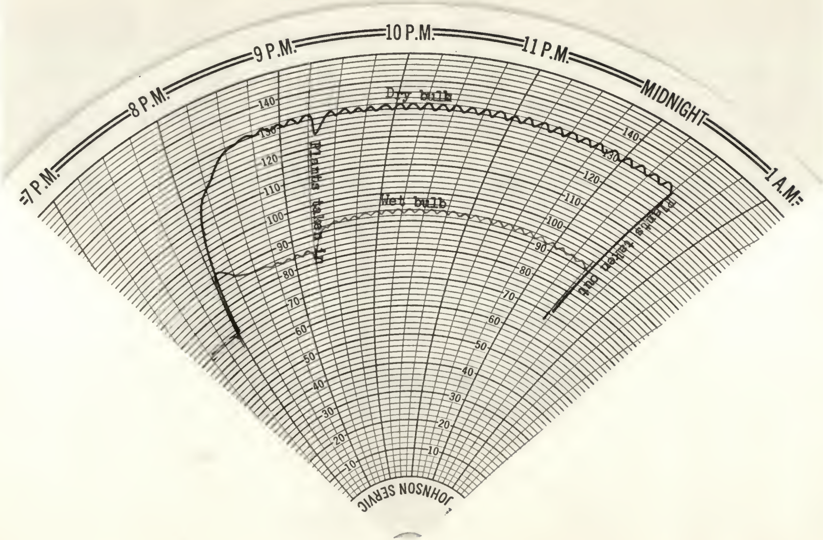
Before the actual testing of these strains for their relative heat resistance, it was considered necessary to find out the best and most suitable conditions and method of testing wheat seedlings with this newly installed unit heater. Several preliminary trials had to be conducted in order to know the suitable temperature and duration of exposure for effecting good differential injury. An experiment was especially designed for the purpose in which the temperature and duration of exposure were varied in case of each trial. It was observed that high temperature of 130° F and three to four hours exposure seemed to be most suitable.

Before taking the plants into a drought chamber, the plants were watered thoroughly, about one hour prior to the heat treatment as suggested by Salmon (50), who stated that this prevented undue variation in injury due to fluctuation in soil moisture content. It was assumed that this watering would reduce the possibility of the plants being injured from deficient soil moisture. In order to reduce this possible injury still further, the pots were rewatered after they had cooled following treatment. With the adaptation of this technique, it was believed that nearly all injury to plants was due to high temperature alone. It was suspected that the soil on the

EXPLANATION OF PLATE I

Dry bulb and wet bulb temperatures in one representative test out of ten tests.

PLATE I


7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
MIDNIGHT
1 A.M.
Dry bulb
Wet bulb
Plants taken in
Plants taken out
JOHNSON SERVIC

outerside, touching the surface of the pot, might get heated and thus might be at higher temperature than the temperature of the soil towards the center of the pot. But it was observed that there was no variation of temperature in any part of the pot, which suggested that any injury that might occur to the root system of the plants during the period of exposure to high temperature would be uniform throughout the pot. There were 30 pots in each replication. The pots were placed in random arrangement on the revolving table in the drought chamber in the morning about 9:00 and removed during afternoon everyday. In all the ten repetitions, the dry bulb was adjusted at 130° F. The relative humidity ranged from 25 to 30 percent. The duration of exposure was three to three one-half hours. An effort was made to take out the treated pots from the drought chamber as soon as good differential injury was inflicted to the plants. Care was also taken to remove the plants from the heat room before the surface soil in the pots first showed the slightest effect of drying up.

Experiment No. 2: Some of the wheats in the world collection showed marked differences in their resistance to cold weather conditions in the field and hence it was desired to test those strains for their resistance to high temperatures under controlled laboratory conditions. The varieties used were those given below.

Serial No.	Name of Variety or CI No.		Source
1	Kiowa	12133	Kansas
2	Pawnee	11669	Kansas
3	Beloglina	1667	U.S.S.R.
4	----	2029	Hungary
5	----	2608	Roumania
6	Ching Chow White	5086	China
7	Kanred	5146	Kansas
8	Egyptian	5286	Mexico
9	No 816	5489	U.S.S.R.
10	Barletta No.77	5998	Argentina
11	Touse	6017	Utah
12	Minturki	6155	Minnisota
13	Nebraska No.60	6250	Nebraska
14	Wisconsin Pedigree No.2	6683	Wisconsin
15	Ashkof	6698	Canada
16	Tulan No 390	6917	Russia
17	White Geneo-logical	6929	Japan
18	Red Geneo-logical	6930	Japan
19	Sandmirka	6932	Japan
20	Michikof	6990	Indiana
21	----	7285-7	India
22	----	7286-1	India
23	----	7308-7	India
24	----	9248	Russia
25	----	9370	China
26	----	9382	China
27	----	9398	China
28	----	9404	China
29	----	9452	China
30	----	9509	China
31	----	9511	China
32	----	9517	China

Essentially, the same procedure and methods were used for this experiment as described above, except that the dry bulb temperature used was 120° F. Comparatively low temperature was used in this case due to the reason that most of the varieties were spring wheats, which could be injured severely enough at this lower temperature.

Recording of Observations

In case of experiment No. 1, the varieties in all repetition were represented by three pot samples. The number of plants per pot were five and the total number of plants per sample was 15. The results of these three pots, i.e., 15 plants were averaged together for each individual reading. Estimation of top injury was considered but it was reasoned that the plants treated were small for proper differentiation to be made. Hence, mortality of plants and tillers was used as the basis for comparison in these tests. Martin (35) and Laude (30) compared the method of rating by top percent injury and plant mortality percentage and found close relationship between them, with Martin reporting correlation coefficient of .946.

Readings were taken after one week from the treatment. All plants and tillers not showing life, were presumed to be dead. In experiment No. 2, the same technique and method of recording observations were followed except that each variety was represented by two pots in a sample and total number of plants per sample was 10 to 14.

It was observed that there was a close relationship between plant and tillers with respect to percent of mortality of a variety. A correlation coefficient of .876 was obtained. A statistical analysis of the data was computed, using the individual reading contained in the tables for determing the standard error. The mean average for each variety was used in computing the correlation within each series. Formula as outlined by Paterson (43) were used in the procedure.

Study on Root Development in Relation to
Drought Resistance in Ten Wheat Varieties

Kanking, Ponca and Pawnee winter wheat varieties were used in preliminary studies on root development. Three plants of each variety were grown in six inch unglazed clay pots in vermiculite. Root systems of these three varieties were studied at three different stages of growth, i.e. two weeks, four weeks, and six weeks of age. When the differences between root top ratios of these varieties was established, ten varieties used in experiment No. 1 under artificial drought tests were planted in vermiculite and their root top ratios were studied at two stages of growth, i.e., three weeks and four weeks. The plants were grown to the desired stage and then they were uprooted for root study. The roots could be washed carefully without damaging them. Oven dry weight of roots and shoots were recorded and then the root top ratio was computed. The extensiveness of root system could not be used as the criterion for rating the varieties for drought resistance. It might be illustrated by citting an example of Kanking, which had demonstanted more heat resistance than Yogo, but in this present investigation, it had a decidedly smaller root system than Yogo. But it was interesting to note that Yogo had also comparatively larger top growth. Giving due consideration to this observation, it was argued that under these conditions the study of the root-top ratio might be more feasible and appropriate for comparing relative drought resistance of these varieties.

Study on Rate of Water Loss from Excised Plants in Relation to Drought Resistance in Ten Wheat Varieties

The above mentioned seven winter wheat varieties and three spring wheat varieties were taken for this study. The plants were grown under identical conditions in four inch unglazed clay pots, under the similar conditions simultaneously as grown for atmospheric drought tests. A sample of three plants representing each variety was taken. Efforts were made to weigh the sample as quickly as possible after pulling out the plants and removing roots and soil. In order to insure quick weighing, one individual was preparing a sample and the other was weighing simultaneously. It was assumed that this technique of weighing left little chance for loss of water from the sample and thus the green weight obtained included the total amount of water each sample contained. After weighing, the sample was placed on a frame covered with 1/4 inch wire mesh and kept in the greenhouse at a temperature of approximately 75° F. Three replication were used in this trial.

The samples of each replication were weighed at intervals and then the final oven-dry weight was determined. The percentages of water lost at different intervals were worked out.

Those ten varieties were also planted in one wooden flat under the same level of moisture and under similar conditions. When the plants reached the desired stage of growth, a representative sample of four plants of each variety was taken and the rate of loss of water was studied in the same manner as mentioned above.

EXPERIMENTAL RESULTS

Comparative Resistance to High Temperature and Atmospheric Drought Conditions in Wheat Varieties

Artificial Drought Chamber Tests: Two groups of wheat varieties were tested for their resistance to atmospheric drought. The first group of 10 varieties was composed of seven winter wheat varieties and three spring wheat varieties, and the second group contained 30 world collection varieties and two hard winter varieties, as described previously. Results obtained from these two groups are reported in this section.

Group I. The percent-plant mortality of the ten varieties is shown in Tables 1 and 2. Plant-mortality among the seven winter wheat varieties ranged from an average of 19.0 percent in Kanking, the most resistant, to 56.9 percent in Sioux, the most susceptible under these conditions. Statistical study of the data revealed that a difference of 15.2 percent between variety means was necessary for significance at 5 percent level. Sioux and Yogo stood out as significantly worse than all the other winter varieties. Pawnee had also significantly higher percentage mortality than Kanking. There was no significant difference among Kanking, Ponca, Concho and Kharkof.

The spring wheat varieties had sharp differences with respect to percentage plant mortality. Plant mortality averaged from 37.0 percent in Thatcher, the most resistant to 71.3 percent in Rusart, the most susceptible, under the conditions prevailed during the course of this experiment. There were significant differences between any two of the varieties and thus these spring varieties represented three distinct degrees of hardiness.

Similar results were obtained in case of percentage of dead tillers as shown in Tables 3 and 4. The percent mortality of tillers was 34.0 in Kanking,

Table 1. Percent mortality of plants of winter wheat varieties subjected to temperatures of 130° F for three one-half hours.

Variety	Tests Number 1	2	3	4	5	6	7	8	9	10	Mean Average
Nanking	0	0	7	50	20	13	20	33	7	40	19.0
Ponca	13	13	0	9	67	64	0	41	0	13	22.0
Concho	7	13	20	33	60	14	35	40	7	0	22.9
Kharkof	0	0	0	53	27	7	47	52	53	64	30.3
Pawnee	7	20	7	73	33	40	47	42	27	47	34.3
Yogo	47	53	40	60	40	53	73	45	53	53	51.7
Sioux	27	40	33	47	80	73	73	50	73	73	56.9

L.S.D.* = 15.2 between variety means.

Table 2. Percent mortality of plants of spring wheat varieties subjected to temperatures of 130° F for three and one-half hours.

Variety	Tests Number 1	2	3	4	5	6	7	8	9	10	Mean Average
Thatcher	20	47	7	13	53	47	68	22	33	60	37.0
Mida	47	20	33	43	60	87	65	24	73	87	53.9
Baart	73	47	60	87	87	80	95	24	93	67	71.3

L.S.D.* = 14.9 between variety means.

Table 3. Percent mortality of tillers of winter wheat varieties subjected to temperatures of 130° F for three and one-half hours.

Variety	Tests Number 1	2	3	4	5	6	7	8	9	10	Average
Nanking	2	0	6	49	52	38	50	27	51	65	34.0
Ponca	49	29	10	24	89	76	19	46	42	39	42.3
Concho	32	7	26	55	69	28	42	50	44	74	42.7
Kharkof	16	15	18	73	47	24	56	81	76	84	49.0
Pawnee	18	48	11	80	55	57	68	76	61	55	52.9
Yogo	73	55	69	77	52	67	74	71	70	82	68.4
Sioux	32	46	63	66	90	89	81	66	89	91	71.3

L.S.D.* = 15.0 between variety means.

Table 4. Percent mortality of tillers of spring wheat varieties subjected to temperatures of 130° F for three and one-half hours.

Variety	Tests Number 1	2	3	4	5	6	7	8	9	10	Average
Thatcher	40	63	9	19	65	69	68	68	41	67	50.9
Mida	52	26	39	56	71	91	65	75	82	85	64.2
Heart	86	71	83	92	95	87	95	79	97	78	86.3

L.S.D.* = 14.2 between variety means.

the most resistant, and 71.3 percent in Sioux, the most susceptible among winter wheat varieties. Sioux and Yogo showed significantly greater mortality than any of the other varieties. Pawnee and Kharkof were significantly worse than Kanking. There was no significant difference among Kanking, Ponca and Concho.

In case of spring wheat varieties, Thatcher had the lowest percentage of dead tillers and Baart had the highest. The percentage of dead tillers ranged from 50.9 to 86.3 percent. Baart was definitely highest in mortality. The greater mortality in Mida compared with Thatcher, was almost at the 5 percent level.

Comparison of percentages of dead plants and dead tillers showed that there was high correlation between these two characters as shown in Plate II and Tables 5 and 6. It appears that this method of testing may prove very useful in the study of atmospheric drought in young plants at stooling stage.

On the basis of the data presented on mortality of plants and tillers, these varieties can be tentatively classified as follows:

Winter Wheat Varieties

Resistant-Kanking, Ponca and Concho.

Moderately Resistant-Kharkof and Pawnee.

Least Resistant-Yogo and Sioux.

Spring Wheat Varieties

Resistant-Thatcher.

Moderately Resistant-Mida.

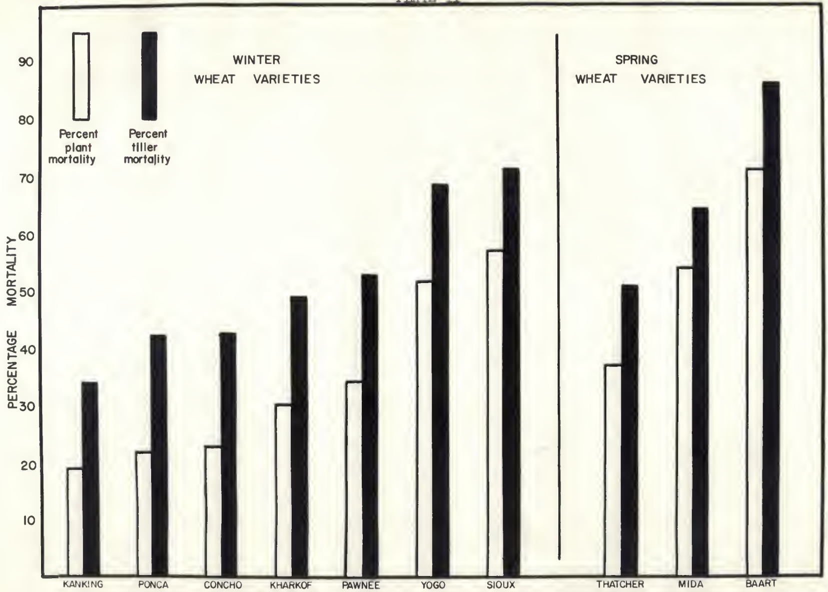
Least Resistant-Baart.

The reaction of these strains to heat exposure is illustrated in Plates III and IV.

EXPLANATION OF PLATE II

Comparison of resistance to high temperature in different wheat varieties as shown by percentages of dead plants and tillers.

PLATE II



HEAT TOLERANCE OF SEVEN WINTER AND THREE SPRING WHEAT VARIETIES AS INDICATED BY PERCENTAGE OF DEAD PLANTS AND PERCENTAGE OF DEAD TILLERS

EXPLANATION OF PLATE III

Comparison of the ability of winter wheat varieties to recover from heat exposure. 1. Nanking, 2. Ponca, 3. Concho, 4. Kharkof, 5. Pawnee, 6. Yogo, 7. Sioux.

PLATE III

EXPLANATION OF PLATE IV

Comparison of the ability of spring wheat varieties to recover from heat exposure. 1. Thatcher, 2. Mida, 3. Baart.

PLATE IV

Table 5. Relative rank of winter wheat varieties in resistance to high temperature.

Variety	Average Plant Mortality	Rank	Average Tillers Mortality	Rank
Kanking	19.0	1	34.0	1
Ponca	22.0	2	42.3	2
Concho	22.9	3	42.7	3
Kharkof	30.3	4	49.0	4
Pawnee	34.3	5	52.9	5
Yogo	51.7	6	68.4	6
Sioux	56.9	7	71.3	7

Table 6. Relative rank of spring wheats in resistance to high temperature.

Variety	Average Plant Mortality	Rank	Average Tillers Mortality	Rank
Thatcher	37.0	1	50.9	1
Mida	53.9	2	64.2	2
Baart	71.3	3	86.3	3

This classification should not be construed to mean that the least resistant of these varieties is actually highly susceptible to high temperature injury under ordinary atmospheric drought conditions, as all of these varieties may be considered reasonably resistant to normal spring conditions or ordinary atmospheric drought.

<u>Group II.</u> The second group of 32 varieties vis 30 world collection varieties and two local standard hard winter varieties were subjected to high temperature tests. The percentages of dead plants with respect to these 32 varieties are shown in Table 7. Tulan 390 showed the lowest plant mortality of 25 percent and Egyptian had the largest plant mortality of 97.2 percent and thus there was a spread of 72 percent among the varieties. A difference between the means of 28.8 percent was found to be necessary for significance. There were varietal differences but no significant "breaks" between adjoining varieties in the ordered array. Tulan 390 and Beloglina were significantly better than Cl 9511, No 82.6, Cl 9452 and Nebraska No. 60 and those shown lower in the list. Cl 7308-7 was significantly poorer than Cl 7236-1 and the varieties listed above. Similarly Egyptian was significantly poorer than Cl 7285-7 and the varieties shown above.

Varieties rating between Beloglina and Cl 9511 did not show any significant differences, but they differed in average plant mortality as well as the varieties between Cl 7236-1 and Cl 9509, had different varietal means but did not differ significantly. However it was interesting to note that some of the strains showed lesser plant mortality than some known hard varieties. Kiowa which had been observed previously to be one of the heat hardiest varieties, was placed sixth in rank in this test. Ten varieties showed lesser plant mortality than Wisconsin Pedigree No. 2. Pawnee and

Table 7. Percentage of dead plants subjected to temperature of 120° F and relative humidity 35 to 40 percent.

Sno	Variety or CI No	Name of Variety	Source of Seed	Test Number 1	2	3	4	5	Average
1	6917	Tulan 390	U.S.S.R.	15	45	40	17	8	25.0
2	1667	Beloglina	"	0	57	31	42	0	26.0
3	5086	Ching Chow White	China	30	83	10	23	15	32.1
4	6990	Michikof	Indiana	27	9	42	89	14	36.2
5	6155	Minturki	Minnisota	21	67	71	0	31	38.0
6	12133	Kiowa	Kansas	38	64	31	0	58	38.1
7	6698	Ashkof	Canada	44	92	33	33	23	45.0
8	2029	—	Hungary	15	77	70	23	42	45.4
9	6930	Red Geneological	Japan	38	25	67	64	46	48.0
10	6932	Sandmirka	Japan	36	71	43	29	64	48.6
11	6683	Wisconsin Pedigree No.2	Wisconsin	21	85	71	46	38	52.2
12	9511	—	China	92	20	42	64	58	55.2
13	5499	No. 816	U.S.S.R.	17	100	73	46	50	57.2
14	9452	—	China	44	100	100	0	42	57.2
15	6250	Nebraska No.60	Nebraska	58	71	91	62	8	58.0
16	7286-1	—	India	60	83	42	89	17	58.2
17	6929	White Geneol.	Japan	62	77	82	33	42	59.2
18	11669	Pawnee	Kansas	46	85	67	75	25	59.6
19	9370	—	China	75	100	58	42	29	60.8
20	5998	Barletta No.70	Argentina	73	58	85	23	79	63.6
21	5146	Kanred	Kansas	92	79	83	45	21	64.0
22	7285-7	—	India	27	91	63	70	77	65.6
23	9382	—	China	77	78	50	54	92	70.2
24	2608	—	Roumania	50	77	92	58	85	72.4
25	6017	Touse	Utah	79	90	46	75	73	72.6
26	9248	—	U.S.S.R.	75	75	92	79	42	72.6
27	9404	—	China	63	100	92	100	20	75.0
28	9517	—	"	77	86	38	100	82	77.8
29	9398	—	"	77	93	100	50	71	78.2
30	9509	—	"	64	92	100	67	79	80.4
31	7308-7	—	India	50	100	100	83	100	86.6
32	5286	Egyptian	Mexico	86	100	100	100	100	97.2

L.S.D.* = 28.8 between variety means.

Kenred ranked 18th and 21st among these 32 varieties which showed that there was a good number of varieties exhibiting low plant mortality.

The percentages of dead tillers observed in these varieties are shown in Table 8. The mean average of tiller mortality among the 32 varieties ranged from 51.6 percent in Beloglina and to 97.8 percent in Egyptian. A difference in tiller mortality of 21.5 percent is significant at 5 percent level. There were no significant "breaks" between adjoining varieties. Beloglina was significantly better than Cl 9370 and 7285-7 and those shown below in the list. The results obtained on the basis of tillers mortality are in agreement with the results obtained with respect to percent of plant mortality but the differences were more in the latter case.

Highly significant coefficient correlation of .876 was obtained between percentages of dead tillers and dead plants of a variety. Thus it indicates the apparent similarity between these two methods of comparing plant resistance to high temperature.

The reaction of world collection wheat varieties to cold tolerance in the field during early spring and an average of five laboratory high temperature tests with plants of 32 varieties are presented in Table 9. All these varieties were exposed to high temperature in an artificial drought chamber at the same time. The data in Table 9 showed a high relationship between the cold resistance of these varieties observed in the field and their heat tolerance under laboratory conditions. The varieties which were observed resistant to cold injury, were also found to be resistant to high temperature, and artificial atmospheric drought. The only varieties which did not come in line as expected from their field behavior to cold injury, were Cl 7286-1, 9370 and 2608.

Table 8. Percentage of dead tillers subjected to temperature of 120° F and relative humidity 35 to 40 percent.

Sno	Variety or Cl No	Name of Variety	Source of Seed	Test Number 1	2	3	4	5	Average
1	1667	Beloglina	U.S.S.R.	44	72	39	57	46	51.6
2	6990	Michikof	Indiana	67	20	51	95	43	55.2
3	9511	—	China	95	36	42	70	58	60.2
4	5086	Ching Chow White	China	52	93	42	51	65	60.3
5	6250	Nebraska No.60	Nebraska	67	87	50	73	25	60.4
6	6155	Minturki	Minnisota	49	76	87	24	67	60.6
7	12133	Kiowa	Kansas	55	76	59	42	84	63.2
8	6917	Tulan 390	U.S.S.R.	47	70	84	71	54	65.2
9	6698	Ashkof	Canada	56	97	69	50	59	66.2
10	6932	Sandmirka	Japan	68	52	62	56	84	70.4
11	6930	Red Geneological	Japan	62	50	87	74	82	71.0
12	2029	—	Hungary	56	86	85	64	71	72.4
13	5998	Barletta No.77	Argentina	77	67	92	36	91	72.4
14	9370	—	China	88	100	79	63	37	73.4
15	7285-7	—	India	53	94	54	86	89	75.2
16	6683	Wisconsin Pedigree No.2	Wisconsin	51	93	88	72	74	75.6
17	6017	Touse	Utah	89	95	71	38	86	75.8
18	5489	No. 816	U.S.S.R.	52	100	85	76	67	76.0
19	11669	Pawnee	Kansas	72	94	80	89	48	76.6
20	7286-1	—	India	74	93	67	93	59	77.2
21	9382	—	China	84	87	71	59	94	79.0
22	6929	White Geneological	Japan	79	88	90	72	70	79.8
23	9452	—	China	72	100	100	46	81	79.8
24	9509	—	China	78	95	100	67	63	80.6
25	9404	—	China	67	100	97	100	50	82.4
26	5146	Kanred	China	95	87	93	79	59	82.6
27	2608	—	Roumania	66	83	98	79	91	83.4
28	9517	—	China	92	93	60	100	87	86.4
29	9398	—	China	88	96	100	77	85	89.2
30	9248	—	U.S.S.R.	91	91	97	89	83	90.2
31	7308-7	—	India	64	100	100	91	100	91.0
32	5286	Egyptian	Mexico	89	100	100	100	100	97.8

L.S.D.* = 21.5 between variety mean.

Table 9. Reaction of world collection wheat varieties to cold injury in the field and to controlled high temperatures.

Serial No	Variety or C.I. No.	Plants 1954 % cold injury in spring	Seedling Plants Under Controlled high temp.% dead plants
1	6917	R	25.0
2	1667	R	26.0
3	5086	R	32.1
4	6990	MR	36.2
5	6155	R	38.0
6	Kiowa	R	38.1
7	6698	MR	45.0
8	2029	R	45.4
9	6930	MR	48.0
10	6932	MR	48.6
11	6863	R	52.2
12	9511	MS	55.2
13	5489	R	57.2
14	9452	MS	57.2
15	6250	R	58.0
16	7286-1	S	58.2
17	6929	MR	59.2
18	Pawnee	R	59.6
19	9370	S	60.8
20	5998	S	63.6
21	5146	R	64.0
22	7285-7	S	65.6
23	9382	MS	70.2
24	2608	MR	72.4
25	6017	S	72.6
26	9248	MS	72.6
27	9404	MS	75.0
28	9517	S	77.8
29	9398	MS	78.2
30	9509	S	80.4
31	7308-7	S	86.6
32	5286	S	97.2

R - Resistant
MR - Moderately Resistant
MS - Moderately susceptible
S - Susceptible

Relation of Root Development to Atmospheric Drought Resistance

Some of the workers have emphasized the importance of root study in relation to drought resistance in plants. In a few cases of spring wheat, it has been reported that drought resistant varieties possess greater weights of roots and have slightly deeper crown and shorter subcrown in some cases, than non-resistant varieties. However, the work of this nature is not available with respect to winter wheat varieties. It was, therefore, considered desirable to find the possible relationship of root development to drought resistance in winter wheat varieties.

For this purpose, the preliminary study was made on three winter wheat varieties, Kanking, Ponca and Pawnee. The first two varieties were found to be resistant and the third as moderately resistant in high temperature tests as described previously. The roots of normal plants of these three varieties were studied after two weeks of growth. The results obtained are shown in Table 10.

Table 10. Comparative root development in three winter wheat varieties after two weeks growth.

Variety	Total Root Length in cm.
Kanking	57.73
Ponca	56.50
Pawnee	49.50

Practically, there was no difference of root length between Kanking and Ponca which were also found to have very little difference in their resistance to high temperatures. However, Pawnee had lesser root length than the other two. Pawnee was found inferior in heat tests to Kanking and Ponca. It was observed that Kanking and Ponca, which were shown to be comparatively more resistant to high temperature and atmospheric drought, had larger numbers of roots on an average, than the less resistant variety, Pawnee.

A study of relationship between weight of roots and top growth of these three varieties was made at three different stages of growth as reported in Table 11. It was observed that the root-shoot ratio after two weeks growth, was lesser in case of the most resistant variety, Kanking, than in Ponca, which had a lower ratio than Pawnee. The trend of root-shoot ratio was in agreement with the results obtained in high temperature and artificial atmospheric drought tests. When the plants were four weeks old, there was almost no difference in root-shoot ratio. At the age of six weeks, more varietal differences were shown and the results obtained at this stage of growth were in general agreement with results obtained at the first two stages of growth.

Table 11. Ratio between weight of roots and shoots of three winter wheats at different stages of growth.

Age in weeks	Kanking Wt. in gms. Roots	Shoots	Ratio	Ponca Wt. in gms. Roots	Shoots	Ratio	Pawnee Wt. in gms. Roots	Shoots	Ratio
2	.37	.42	1.135	.25	.41	1.640	.25	.46	1.840
4	1.88	2.10	1.063	1.40	1.47	1.050	1.65	1.82	1.103
6	5.63	7.29	1.294	6.13	8.35	1.362	4.72	6.40	1.155

In order to explore further toward this situation, similar study was arranged with a group of ten varieties viz 7 winter wheat varieties and three spring wheat varieties. The results obtained have been presented in Table 12 and 13. A study of root-shoot ratio was made at two stages of growth at three weeks and four weeks. When the plants were three weeks old, no significant differences were found between ratios, but it was observed that varieties

Table 12. Ratio between dry weights of roots and shoots of seven winter wheat varieties at two stages of growth.

Variety	After 3 weeks Dry weight in gms. Roots	Shoots	Ratio	After 4 weeks Dry weight in gms. Roots	Shoots	Ratio
Kanking	.16	.29	1.81	.20	.36	1.80
Ponca	.09	.18	2.00	.12	.24	2.00
Concho	.07	.14	2.00	.11	.28	2.25
Kharkof	.11	.14	1.27	.13	.33	2.55
Pawnee	.07	.16	2.28	.09	.24	2.66
Yogo	.13	.28	2.15	.15	.45	3.00
Sioux	.07	.16	2.28	.10	.35	3.50

Table 13. Ratio between dry weights of roots and shoots of three spring wheat varieties at two stages of growth.

Variety	After 3 weeks Dry weight in gms. Roots	Shoots	Ratio	After 4 weeks Dry weight in gms. Roots	Shoots	Ratio
Thatcher	.09	.19	2.11	.10	.21	2.10
Mida	.15	.32	2.13	.18	.39	2.16
Baart	.18	.42	2.34	.20	.48	2.40

more hardy to atmospheric drought in general had lower root-shoot ratios than the less resistant varieties with the exception of Kharkof, which was found to have a high ratio even though it was resistant. At the age of four weeks, the results obtained were more clear, but still there were no appreciable differences. On the basis of root-shoot ratio these varieties could be tentatively classified as:

Resistant-Kanking, Ponca.

Moderately Resistant-Kharkof, Pawnee and Concho.

Less Resistant-Yogo and Sioux.

This classification is in close agreement with the tentative classification of these varieties made on the basis of the data obtained in heat tests with the exception that Concho was graded as resistant variety in high temperature tests instead of moderately resistant.

The data obtained with respect to three spring wheat varieties at both the stages, showed the same trend, but again no appreciable differences were obtained. But it was interesting to note that Thatcher, which showed marked resistance in high temperature tests, possessed the lowest root-top ratio and Baart, which exhibited the least resistance was found to have the greatest root-shoot ratio.

These data suggest that a smaller proportion of shoot to roots might be associated with the character of drought resistance in wheat plants.

Relation of Water Loss from Excised Plants to Drought Resistance

It is believed that many xerophytes lose moisture at slower rate than other types of plants due to some special morphologic or protoplasmic characteristics. It is argued, if there is any difference in the protoplasmic or morphologic characteristics of varieties which makes some more resistant to drought than others, it is probable that differences in rate of loss of moisture from the plant tissue, during drying, may be shown. Very little work has been done on comparative rate of water loss in spring wheat and practically no such work seems to have been reported with respect to winter wheats. In order to determine if there is any such difference in rate of water loss in the wheat varieties used in the high temperature tests, a study was made on comparative rate of water loss from excised leaves in seven winter wheats and three spring wheat varieties.

The percentages of water lost in different varieties are given in Tables 14 and 15. The results reported in these tables are the average of three tests. The observations were taken after 5, 23, 54 and 72 hours after removing the plants from the soil. It was seen that Kanking, Yogo and Pawnee lost almost the same amount of water during the first five hours of drying, but in subsequent intervals of 23, 54 and 72 hours, some differences were shown. Sioux, Kharkof, Concho and Ponca also did not show any appreciable differences in the amount of water lost during the first five hours but they showed some differences during later periods of drying.

The rate of water loss in these varieties were in the following order: Kanking, Yogo, Pawnee, Sioux, Kharkof, Concho and Ponca as illustrated in Fig. 1 and 2 of Plate V.

In case of spring wheat, Thatcher lost 35 percent of the total amount of water, while Baart and Mida lost 25.3 and 26.9 percent respectively during the first five hours. There was very little difference in loss of water in Baart and Mida during subsequent periods of drying, but Thatcher lost comparatively more water than these two varieties. It was observed that the rate of water loss in these varieties was in the following order: Baart, Mida, and Thatcher.

Observations of the data of winter and spring wheats revealed that spring varieties lost decidedly more water than winter wheats at every time interval after removal of plants from the soil.

In order to check that there might be some effect on the rate of loss of water from excised plants grown in four inch unglazed clay pots due to variation of moisture from pot to pot, wheat plants of these ten varieties were raised in an identical condition of soil moisture in a wooden flat. The excised

Table 14. Percentages of water lost in excised plants of seven winter wheat varieties after different periods of drying at room temperature of 75° F.

No. of hours after removal from soil	Percentage of water lost in different varieties							
	Kanking	Yogo	Pawnee	Sioux	Kharkof	Concho	Ponca	Average
5	21.2	21.2	21.1	26.8	26.3	27.7	25.5	24.3
23	53.6	52.4	59.7	61.7	61.1	60.1	66.2	59.3
54	76.4	79.1	83.2	85.0	84.5	87.1	87.8	83.3
72	85.9	85.6	90.8	91.6	90.7	93.6	93.9	90.3
Mean	59.3	59.6	63.7	66.3	65.7	67.1	68.4	

Table 15. Percentage of water lost in excised plants of three spring wheat varieties after different periods of drying at room temperature of 75° F.

No. of hours after removal from soil	Percentage of water lost in different varieties			
	Baart	Mida	Thatcher	Average
5	25.3	26.9	35.0	29.1
23	70.7	70.8	79.9	71.9
54	88.9	90.5	90.5	87.9
72	93.2	93.5	93.9	92.5
Mean	69.5	70.4	74.8	

EXPLANATION OF PLATE V

Rate of water loss from excised plants of wheat varieties at room temperature when grown in four inch unglazed clay pots.

PLATE V

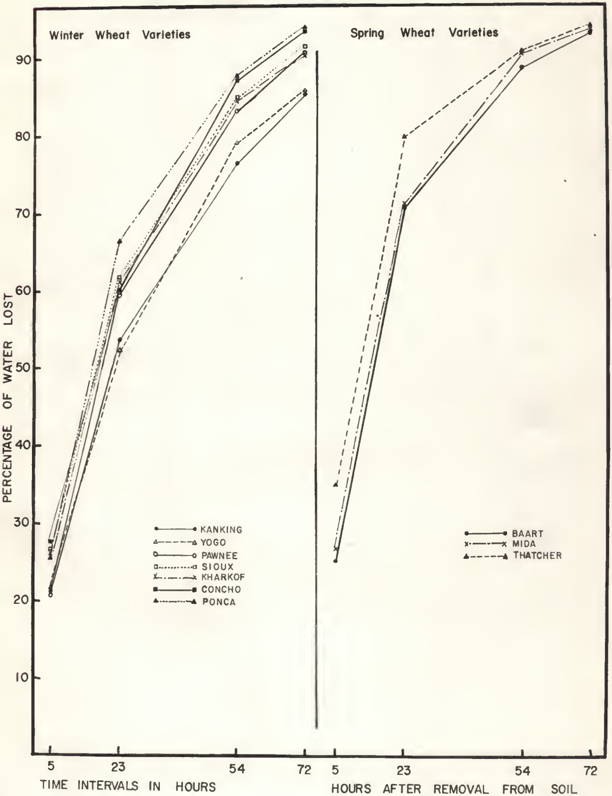


Fig. 1 Fig. 2

shoots of plants were dried at room temperature. The same technique and method was followed in both the experiments on rate of water loss. The observations were taken at shorter time intervals than in the previous experiment in order to detect the differences in rate of water loss during shorter intervals. The samples were weighed after 3, 6, 10, 23, 28 and 31 hours after the plants were removed from the soil. The results obtained are shown in Table 16. Kanking lost 48.8 percent of its total water which was significantly less than that lost by the other varieties which differed only little in water loss. Similar results were obtained in spring wheats in which Baart lost significantly less water than the other two varieties. Mida and Thatcher did not show significant differences. The results of this experiment are in close agreement with the results obtained in the previous experiment where the plants were grown in pots. The order of the varieties with respect to rate of loss of water, remained exactly the same as found previously. Comparative rate of water loss in winter and spring wheats illustrated graphically in Figs. 1 and 2 of Plate VI. Results of both the experiments showed that the spring types of wheat lost moisture more readily than the winter type at each individual time interval as shown in Tables 16 and 17.

Table 16. Percentage of water loss in excised plants of seven winter wheat varieties after different periods of drying at room temperature of 75° F.

No. of hours after removal from soil	Percentage of water lost in different varieties							
	Kanking	Yogo	Pawnee	Sioux	Kharkof	Concho	Ponca	Average
3	21.6	25.7	25.5	29.4	27.5	28.6	28.4	26.7
6	33.7	40.0	41.8	44.6	44.8	45.9	46.3	42.5
10	43.0	52.3	53.5	56.7	57.2	59.0	59.7	54.5
23	54.1	64.7	67.3	69.5	72.6	72.3	72.8	67.8
28	66.6	78.4	80.7	82.1	85.2	85.7	85.7	80.6
31	73.8	84.8	86.4	87.4	89.4	89.8	89.8	85.9
Mean	48.8	57.8	59.2	61.6	62.8	63.6	63.6	

L.S.D.* = 2.1

Table 17. Percentage of water loss in excised plants of three spring wheat varieties after different periods of drying at room temperature of 75° F.

No. of hours after removal from soil	Percentage of water lost in different varieties			
	Daart	Mida	Thatcher	Average
3	31.2	37.7	36.2	35.0
6	49.3	57.8	56.9	54.7
10	63.1	71.8	70.3	68.4
23	74.6	80.7	80.0	78.4
28	88.2	87.7	85.1	87.0
31	90.2	89.5	88.7	89.3
Mean	66.1	70.9	69.5	

L.S.D.* = 3.4 between variety means.

EXPLANATION OF PLATE VI

Rate of water loss from excised plants of wheat varieties when grown in wooden flat.

PLATE VI

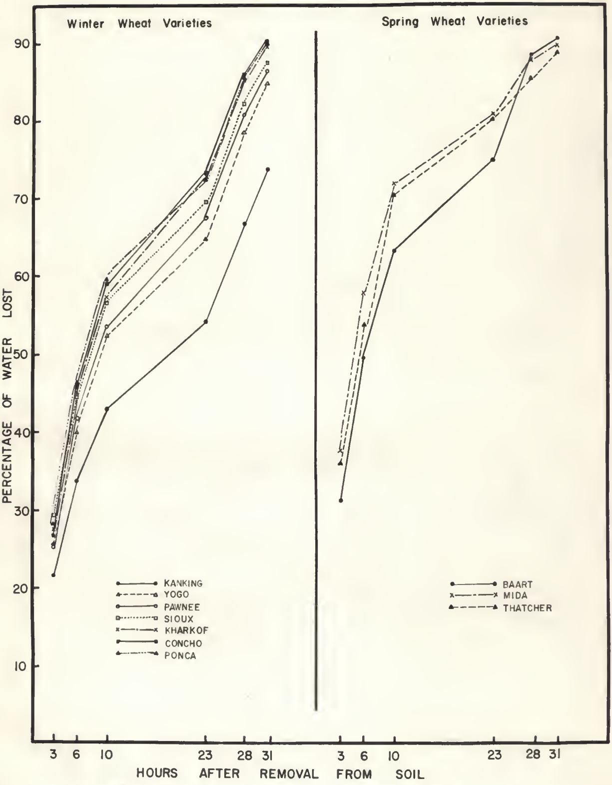


Fig. 1

Fig. 2

DISCUSSION

Kansas wheat crop often suffers from high temperature after spring growth has begun. It is, therefore, desirable to continue the research work to find and develop varieties which are not only resistant to low temperature but are also capable to withstand temperature fluctuation. As it is evident that drought and extremely high temperatures do not occur every year, it is not practicable to depend on selecting varieties in the field that are superior in drought resistance. The use of an artifical drought chamber is, therefore, of immense value to supplement field studies.

The results obtained by Heyne and Laude (18), Shirley and Meuli (56) Hunter et al. (20), Schults and Hayes (54), Plat and Droch (46), Bayles et al. (6), Aamodt (1), Aamodt and Johnston (2), in drought chamber machines were found to be a good supplement to field studies.

The reaction of seven winter wheat varieties and three spring wheat varieties to high temperature in a drought chamber was in close agreement with the results previously obtained by the staff of Kansas State College and the U.S.D.A. Kanking which showed the maximum heat resistance in a greenhouse test, was also observed to behave similarly to adverse weather conditions of spring 1954 in a field test at Kansas State College Branch Experiment Station at Garden City. A letter to this effect was received from Mr. A. E. Lowe, Assoc. Agron. Branch Experiment Station Garden City. Worf (66) also obtained similar results with Kanking, Ponca and Pawnee in his high temperature tests with unhardened plants of these varieties during the period of spring growth.

The results obtained in case of a group of world collection wheats, tested showed high relationship between their reaction to high temperature and atmospheric drought and field behavior to adverse weather conditions. Most of the varieties which were resistant to cold in the field were found to be resistant to high temperature and artificial atmospheric drought.

Worf (66) obtained high coefficient correlation of .7767 between mean varietal resistance to high and low temperature. Levitt (32), and Waldron (62) also reported high relationship between frost and drought resistance.

In view of the author's findings and with support of the results obtained by several other investigators, it could be suggested that testing of young plants for heat and atmospheric resistance in a drought chamber can be a useful and handy means for supplementing field studies.

Most of the workers have laid special emphasis on the point that the drought hardy variety generally has greater and deeper root system but they have failed to take into consideration the relationship of the root and shoot development. In the present investigation, it was observed that certain wheat varieties such as Yogo, had larger roots than the other heat and atmospheric drought resistant varieties but at the same time, it too, had larger shoot development. Furthermore, it was observed that Mida and Baart out of the three spring wheat varieties demonstrated the same tendency of having proportionally larger root and top growth as compared to winter wheat varieties under test. So in such cases, root and shoot ratio seems to be better associated with drought resistance than size of shoot or root. In general, the drought resistant varieties had the larger proportion of roots to top growth than the other resistant varieties. Although the differences between varieties were not significant, there was a clear tendency of this character being associated with drought resistance. This finding is in conformity with the results obtained by Alexander (4), Cook (13) and Misra (38).

The study of rate of loss of moisture from excised plants of ten varieties in both the experiments revealed that the spring varieties lost water more rapidly during every time interval than the winter varieties. The results obtained are in line with Misra (38) who found similar results while comparing two winter wheats and two spring wheats. The results of this investigation gave the evidence that Kanking, which was the most resistant to heat and atmospheric drought in the artificial drought test, was also observed to lose water at much slower rate than all other varieties. The results obtained in the remaining six winter varieties and three spring varieties did not show any significant differences.

Levitt (32) in his review on heat resistance, states that heat resistance primarily depends on specific protoplasmic properties and secondarily on water content. Ilgin reported by Maximov (36) found that the protoplasm can withstand desication but it is killed due to mechanical injury caused by shrinkage due to rapid loss of water in the vacuole. The plants which lack vacuole and which are filled with various substances such as starch, fats, and proteins, can withstand mechanical rupture of protoplasm and consequently can endure drought conditions. Further more, it may be stated that under the condition of high temperature tests the temperature is so high and relative humidity is so low that high transpiration takes place. The plants which are capable of withstanding such a condition, necessarily may have larger root system as compared to total transpiring area. It has also been observed when the temperature is extremely high, the stomata open widely and lose the ability to close. So in such cases, the total number of stomata in a unit area of the leaf and total leaf surface may become the determining factor of water loss provided other characters are similar.

It is believed that some of the morphological and physiological characters contribute towards the ability of plants to endure drought. It may be assumed that certain characters may be predominant over the others under a certain set of conditions.

It is therefore, argued that the differences in results obtained with drying of the excised plants of wheat varieties and their reaction in drought chamber, may be due to certain predominating factors over others under different conditions.

In the absence of sufficient data on the rate of loss of water from excised plants of wheat, it is not possible to state the relation of rate of water loss to heat and atmospheric drought resistance. Further investigations are needed before any conclusion may be drawn in this connection.

SUMMARY AND CONCLUSION

A study of heat and atmospheric drought resistance and some related characteristics in wheat was made in the greenhouse from fall of 1953 to spring of 1954. Two groups of wheats were exposed to high temperature of 130° F in a drought chamber. In case of the first group of wheats, there were seven winter wheat varieties viz Kanking, Ponca, Concho, Kharkof, Pawnee, Yogo and Sioux and three spring wheats namely Thatcher, Mida and Baart. Differences in the amount of injury among varieties were clearly demonstrated. The rating of the varieties was done on the basis of plant and tiller mortality. Exactly the same order in rank was obtained with both of these methods of observation. In the order of increasing injury the winter wheats ranked as listed below: Kanking, Ponca, Concho, Kharkof, Pawnee, Yogo and Sioux and the spring varieties were in the following order: Thatcher, Mida and Baart.

Kanking was found significantly superior to Pawnee, Yogo and Sioux. Ponca and Concho were very close to Kanking in heat and atmospheric drought resistance. Thatcher, Mida and Baart were found to be in three distinct hardiness groups.

Although significant differences were obtained in laboratory through careful control of temperature and time of exposure, yet it did not mean that all of these varieties could not withstand usual, ordinary weather conditions.

The second group of 32 varieties was also similarly treated. Some of the world collection varieties compared well with our well known varieties of Minturki, Nebraska, Yogo, Pawnee, Kiowa, Kanred and Wisconsin Pedigree No. 2. Further repetition of these tests on these varieties should make it possible to select some best heat resistant varieties out of this world collection lot. In this large group of varieties, also, high coefficient correlation of .876 was obtained between plant mortality and tiller mortality of a variety. Hence, it is suggested that both of these methods of recording plant injury can be safely adopted in such studies but however, a little wider range of differences was obtained in plant mortality than tiller mortality. These high temperature tests gave evidence that the varieties which were observed to be resistant to cold weather in the field were also found to be resistant to high temperature under laboratory conditions.

The results indicate that the high temperature test is a valuable supplement to field studies of drought resistance.

A study on root and shoot development was made with the first group of ten varieties. It was found that the hardier varieties had lesser root-shoot ratio than less hardy varieties.

It was also observed that the varieties having larger root development alone were not necessarily hardier, but a variety having comparatively more roots than top growth was found more resistant to drought. It is suggested, therefore, that a study of root development alone in case of wheat may not be a right method for rating the wheat varieties for their drought resistance.

The rate of loss of water from excised plants of these ten varieties grown in pots and in a wooden flat in an identical condition showed that the spring varieties lost water decidedly more readily at every time interval than winter wheat varieties. There were some varietal differences among both types of wheats, but no relation could be established between their ability to lose water and heat and atmospheric drought resistance found in high temperature tests. But Kanking proved to be an exception to this as its excised plants lost water at much slower rate than all other varieties.

Kanking was found all round best in all the studies made in this present investigation. It is assumed that further studies may possibly place the Kanking variety as one of the best varieties in the hands of plant breeders for breeding drought resistant varieties.

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A STUDY OF HEAT AND ATMOSPHERIC DROUGHT RESISTANCE
AND SOME RELATED CHARACTERISTICS IN
WHEAT VARIETIES.

by

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Importance of drought needs no special emphasis in crop production in semiarid regions of the world which are subjected every year to drought conditions of varying intensity. Sometimes drought conditions create serious situation and thus disturb the agricultural economy of that particular area. It is therefore very essential on the part of research workers to continue their efforts to develop drought resistant varieties and improve cultural practices.

During this present investigation, an attempt has been made (a) to study the comparative heat and atmospheric drought resistance in a number of wheat varieties (b) to study root development of some wheat varieties and its relation to atmospheric drought resistance, (c) to study the rate of water loss from excised plants of wheat and its relation to atmospheric drought resistance.

Two groups of wheats were tested for their relative resistance to high temperatures in a drought chamber under controlled laboratory conditions. The first group was composed of seven hard winter wheat varieties and three spring wheat varieties and the second group of 32 wheat varieties included a number of world collection wheats and some varieties developed in the U.S.A.

The young wheat plants were grown for this purpose in a greenhouse in four inch unglazed clay pots, each of which generally included five plants of each variety. A sample for each test consisted of three pots in the first group of wheat and two pots in the second group. Ten tests were run in case of the former group and five tests in case of the latter. Percent plant and tiller mortality were used as bases of rating the varieties.

For root study, the young plants of ten varieties were raised in vermiculite in six inch unglazed clay pots having a drainage hole at the bottom. The weights of roots and top growth were taken and the root-top ratio was computed.

Rate of water loss from excised plants grown in four inch unglazed clay pots and in a wooden flat was studied. The plants were weighed immediately after extracting them from the soil and removing the roots. Subsequent weights were taken after certain time intervals of drying the excised shoots on wooden frames covered with 1/4 inch wire mesh. Finally dry weights were taken and the percent of water lost at different time intervals was computed.

The results of high temperature tests indicated that Yogo and Sioux were significantly less hardy than any of the other five winter wheat varieties in the first group. Kanking was found significantly better than Pawnee, Yogo, and Sioux. Ponca and Concho followed Kanking very closely. Three spring wheat varieties represented three distinct degrees of hardiness. In case of the second group, Tulan No.390, Beloglina and Chingchow White, were found most resistant, closely followed by Michikof, Mintunki and Kiowa.

In general the varieties which were observed to be resistant to cold injury in the field were also found resistant to heat and high atmospheric drought resistance.

The root study showed that a smaller proportion of shoots to roots might be associated with the character of drought resistance in plants. It was also observed that the extensiveness or largeness of roots alone was not the criterion of hardiness, but lesser root-shoot ratio was the character of hardier varieties. Yogo, less resistant, had comparatively more roots but its root-shoot ratio was greater than resistant varieties.

The rate of water loss from excised plants indicated that the spring wheats lost water more readily during each time interval than winter wheat varieties. No significant differences in rate of water loss were found among winter wheats except in case of Nanking which lost water at slow rate. In case of spring wheats, Thatcher lost water more readily than Baart and Mida which did not show any appreciable difference.