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Inheritance of Cold Tolerance, Plant Height, Maturity and Other Characters in a Spring-Winter Barley Cross

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Summary

Cold tolerance, leaf damage by low temperatures and growth habit were studied in the F_1, F_2 and F_3 populations of a cross between Will (winter) x Aim (spring) barley varieties. On a group of 85 random F_2 plants and their F_3 progeny families, the above cold tolerance related characters were correlated with seven agronomic and morphologic characters.

Inheritance studies indicated that in this cross, growth habit and height were conditioned by three genes, maturity by two and greenbug reaction by one, with modifying factors. Correlation analysis showed that ascorbic acid content of leaves was related to cold tolerance and growth habit, but the correlations were small. Survival was correlated significantly with leaf damage but not with growth habit, indicating that cold tolerance could be combined with more erect types.

Leaf damage by low temperatures was correlated significantly with plant height and growth habit, but many exceptions were recorded. Ascorbic acid content of leaves was correlated moderately with leaf damage, leaf rust and greenbug reaction and may be worthy of further study. Neither plant height nor maturity was related closely to leaf damage, indicating that there will be no problem of combining the types desired.

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Inheritance of Cold Tolerance, Plant Height, Maturity and Other Characters in a Spring - Winter Barley Cross

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WINTERHARDINESS or tolerance to low temperatures is a complex character which is understood poorly. Some degree of cold tolerance is important for all the barley growing areas of Texas. Selection for cold tolerance under natural conditions is difficult because of the unpredictable degree of cold to which plants may be subjected in a given location or season. Artificial freezing equipment is expensive and has been used little on barley. Ascorbic acid content of seedling leaves has been used in wheat to some extent to predict cold tolerance but has not been reported in barley.

All plant breeders frequently find it desirable or necessary to use parents differing widely from the adapted cultivated type in order to obtain certain desired characteristics. In the present study, Will, the winter-type adapted variety, was greenbug resistant and adapted to most of the Texas barley-growing areas. Aim, the other parent, was a spring-type variety poorly adapted to Texas and lacking in cold tolerance but resistant to leaf rust and of desirable short stature. Major objectives were to combine the good characteristics of the two parents to provide a better barley for high production levels and determine the manner of inheritance of characters to improve the efficiency of breeding methods.

REVIEW OF LITERATURE

Low temperature hardiness is of three types: (a) resistance to low temperatures, (b) resistance to chilling or sudden freezes and (c) resistance to frost injury. Reid (16) reported on hardiness in 13 winter x spring crosses. Varieties differed in their ability to contribute to hardiness of progeny. Kearney and Dicktoo (winter-type) contributed more hardiness in crosses than other hardy varieties tested. Minsturdi and C.I. 5890[1] (spring-type) contributed more to hardiness of progeny than any other spring variety. Transgressive segregation was not reported. None of the 13 crosses gave lines which averaged as hardy as the winter parent, although individual F_4 lines from each cross were within the range of the hardy parent.

Rhode and Pulham (17) studied hardiness in 18 barley varieties, crossed in a diallel series. The phenotypic expression of winter-hardiness varied from complete dominance of a high degree of cold tolerance to complete dominance of susceptibility to cold injury. The effect of the major genes appeared to be additive. They obtained high correla-

[1]C. I. refers to the accession number of the Cereal Crops Research Branch, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture.

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tion values between leaf damage and winter survival, indicating that leaf damage notes may be valuable to the breeder even when no actual differential winterkilling occurs. High correlations also were obtained between artificial freezing tests and survival under natural conditions in the field. The heritability estimate was 85 percent when calculated from all data, but it was lower, 49 percent, when calculated from only the hardy progenies. Dantuma (6) reported transgressive segregation for winterhardiness.

Smith (19) cites several workers who found spring growth habit dominant and controlled by one gene. Nilan (14) cites the work of Takahashi and others who report three genes, one recessive and two dominant, controlling spring habit. These were influenced also by length of day. Reid (15) studied growth habit in 59 crosses involving 12 spring and 5 winter-type varieties. On the basis of one recessive factor pair (aa) and an unrelated dominant pair (BB), either of which conditioned spring growth habit, he grouped the spring varieties into three classes aaBB, AABB and aabb. The winter varieties were all of the AAbb genotype. Several other interpretations of growth habit were found in the literature. Several workers obtained winter-type segregates from crosses between spring varieties and several interpretations of this were found in literature.

Moseman (12) found some relationship of growth habit and cold tolerance, but Schiemann (18) stated that winterhardiness is independent of the genes controlling growth habit.

Futrell and Pilgrim (8) found that when plants were hardened by exposure to cold, winter-type varieties of wheat had higher concentrations of ascorbic acid than spring types; however, when the plants were growing rapidly, the differences between the types were not significant. Andrews and Roberts (3) reported similar results and were able to increase cold tolerance in seedlings by supplying them with an aqueous solution of ascorbic acid.

Plant height has been reported as controlled by one, two or more genes. In most instances, tallness was dominant. Neatby (13) reported that four genes govern the difference between the short "guy mayee" variety and Canadian Thorpe. The "Uzu" type has been used in attempts to obtain short, strong-strawed barleys. Barker (4) studied height inheritance in five barley crosses involving the "Uzu" type and found two or three genes for height in addition to the "Uzu" type. Tallness was dominant, and additive gene action was indicated with continuous variation from the short to tall parent plus transgressive segregation for height. Most heritability estimates for height were low or medium because of the influence of environment.

Maturity in barley likewise is greatly influenced by environment. Heritability values reported for maturity were usually high. For example, Fiuzat and Atkins (7) report values of 90 to 92 percent. They report one major gene pair plus modifying factors. Neatby (13) reported three pairs of genes for maturity and Barker (4) reports a minimum of three or four major pairs with dominance, additive gene action and epistasis apparent. In the material he worked with, there was a significant positive correlation between height and heading dates.

Gardenhire and Chada (9) found greenbug resistance was conditioned by a single gene. Moseman and Roane (12) reported that the variety Aim was resistant to all cultures of leaf rust and may possess a gene not found in other varieties.

MATERIALS AND METHODS

The parent varieties used in this study were Aim, (C.I. 3737) and Rogers x Kearney (C.I. 10880), a strain which was later bulked with a sister strain C.I. 10879 to make up the variety Will (10). The characteristics of the parents follow.

CHARACTER	VARIETY	
Growth habit	Aim, P_1	C.I. 10880, P_2
Height	Short	Tall
Winterhardiness	Tender	Hardy
Maturity	Early	Midseason
Leaf-rust reaction	Resistant	Susceptible
Greenbug reaction	Susceptible	Resistant

The cross of Aim x C.I. 10880 was made in the spring of 1962. The F_1 plants were grown in a controlled temperature greenhouse during the summer of 1962. Data were recorded for the F_1, F_2 and F_3 and parents. During the 1962-63 crop season, the F_2 and parents were grown in 4-inch spaced seedings, part at College Station and part at the USDA Southwestern Great Plains Research Center, Bushland, Texas. The winter was so severe that only two F_2 plants survived at Bushland. At College Station, the Aim parent winterkilled but most plants of the other populations survived.

The cross was remade in the spring of 1963. During the 1963-64 crop season, 30 F_1 plants, the parents and 385 F_3 rows were space-seeded in 10-foot rows at College Station while the parents, the check varieties Goliad and Cordova, for measuring the range cold tolerance, and 358 F_3 rows were grown at Bushland. Winter weather conditions were favorable for rating hardiness at Bushland, but no low temperature injury occurred at College Station.

Data on growth habit, plant height, maturity, survival, leaf damage ratings and leaf rust reaction under field conditions were taken on the F_2 plants and parents at College Station in 1963. Growth habit, maturity and plant height data were taken on a group of random F_3 rows at College Station in 1964.

Plants were classified for growth habit from 1-7, type 1 being similar to the Will parent and type 7 being similar to the Aim parent. An average rating was made of F_3 rows on the same scale, then plants

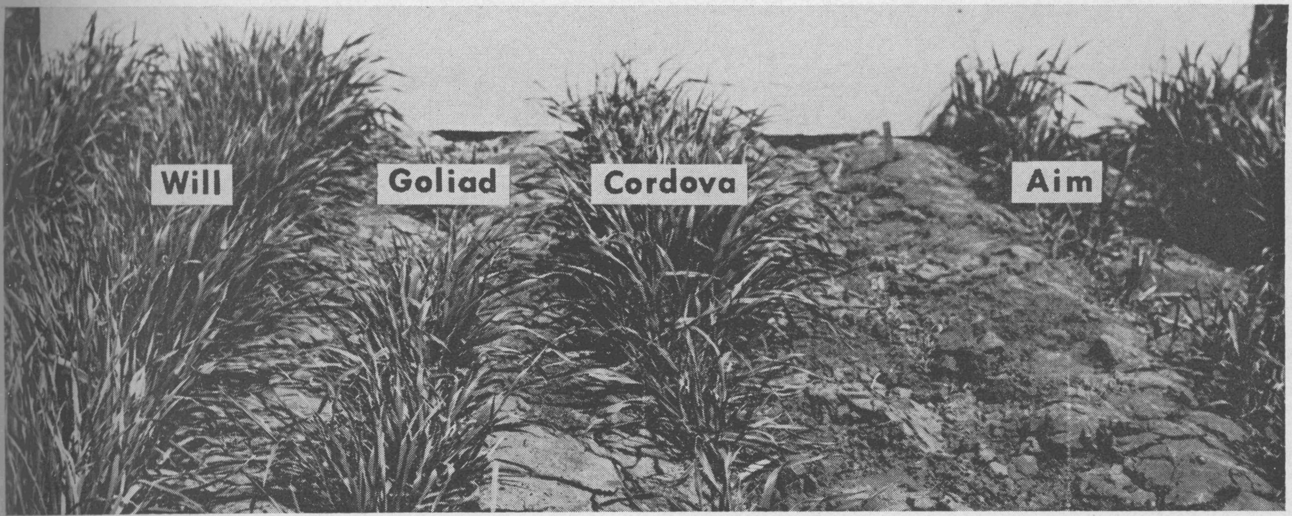

Figure 1. Survival of Will, Goliad, Cordova and Aim barley varieties at Bushland, Texas, 1964.

in 101 random F_3 rows were classified in detail. Height of the tallest spike of each F_2 plant, parents and of all plants in 35 F_3 rows was measured in inches. Heading date was recorded for the earliest spike of each F_2 plant and parent. A base date of March 1 was used for all plants and parents. Dates of heading of the earliest and latest plant in each F_3 row were recorded.

Leaf damage ratings were made February 2 on F_2 plants at College Station after a temperature of 13° F. had occurred a few days before. The Aim parent and a few plants of other populations were killed. Damage ratings were made on a scale of 1 to 6, the Will parent was rated 1 and the Aim parent rated 6. This same freeze killed all but two F_2 plants at Bushland. During the 1963-64 season, no freeze damage occurred at College Station. The Aim parent was killed at Bushland, but the tender variety Goliad partially survived and Cordova was damaged only slightly. Differential injury among F_3 rows was evident; therefore, the rows were classified. Recovery was such, however, that no analysis of killing was attempted.

Three readings of ascorbic acid content in each of 85 random juvenile F_2 plants and plants of the Will parent were made at College Station on March 4 and 5, 1963, when the temperature was near 45° F. The Aim parent was killed before this. The method used was that of Loeffler and Pouting as described by Pilgrim.[2]

Greenbug resistance tests were made on F_2 plants grown at Denton in 1963. Since the ratio obtained was abnormal, the F_3 families were tested in 1964. The methods and procedures were those described by Chada (5). Leaf rust readings were made on F_2 plants and parents growing in the field in 1963.

[2]Pilgrim, A. J. The ascordic acid content of stem rust susceptible and resistant wheat. PhD thesis Texas A&M University (unpublished), 1955.

Statistics such as the mean, variance and tests of significance were calculated by the methods outlined by Snedecor (21) and Steel and Torrie (22). Observed genetic ratios were compared with theoretical ratios by the X^2 (Chi-square) tests for goodness of fit. The inheritance of plant height was studied by the method suggested by Mather (11) for partitioning the F_2 variance, using F_3 data. Heritability estimates on growth habit, winterhardiness, maturity and plant height were calculated by the method of parent/progeny regression as described by Smith and Kinman (20). Simple correlations and multiple regression analysis for the data were made using the methods outlined by Steel and Torrie (22).

EXPERIMENTAL RESULTS

Winterhardiness

The parents differed widely in cold tolerance. At College Station in 1963, Aim was killed but Will was damaged only slightly. At Bushland in 1964, Aim was killed and Will survived. Goliad was damaged moderately, but Cordova was damaged only slightly in this test. A near normal distribution for leaf damage of plants at College Station in 1963 is presented in Table 1. Twenty-five F_2 plants and the Will parent were classed 1, while 20 plants and the Aim parent were winterkilled. Leaf damage ratings of F_3 were obtained at Bushland in 1964,

TABLE 1. FREQUENCY DISTRIBUTION OF LEAF DAMAGE OF F_2 PLANTS OF AIM X WILL BARLEY GROWN AT COLLEGE STATION, TEXAS, 1962-63

	Classes[1]						
Population	1	2	3	4	5	6	Total
P_1						40	40
P_2	40						40
F_2	25	63	115	182	27	20	432

[1]Scale ranges from 1 (no damage) to 6 (winterkilled).

TABLE 2. MEAN ASCORBIC ACID CONTENT OF LEAVES OF F_2 PLANTS OF AIM X WILL BARLEYS GROUPED BY LEAF DAMAGE CLASSES, COLLEGE STATION, TEXAS, 1963

Winter-hardiness class	Number of samples	Ascorbic acid content (Mgs)[1]	MR[2]
1	36	81.22	
2	27	76.52	
3	51	65.83	
4	126	61.36	
5	15	45.57	

[1]Milligrams of ascorbic acid per 100 grams of fresh leaf tissue.

[2]Multiple range — means not connected by the same line are significantly different at the 5% level.

and heritability of F_2 with F_3 was calculated to be 85 percent.

Ascorbic Acid Content of Leaves

The ascorbic acid content of seedling leaves by winterhardiness classes 1-5 is given in Table 2. Multiple range tests of these classes show that hardy, intermediate and tender classes differed significantly in ascorbic acid content, suggesting that this test could be used to roughly classify early generation plants for hardiness.

Growth Habit

Growth habit distribution of F_2 plants and parents in 1963 and of the F_1 grown in 1964 are given in Table 3. The parents are distinctly different; the F_1 is approximately intermediate. The F_2 plants were classified throughout the range but with a large majority similar to that of the Aim parent. The F_2 and F_3 distributions conform to a three gene hypothesis, and the gene action appears to be additive and cumulative. No transgressive segregation was found. Heritability for growth habit was 40 percent. These results differ from those of Reid (15) who found growth habit controlled by one recessive pair and an unrelated dominant pair. Takahashi (23) reported three major pairs of genes, one recessive and two dominant. He found that the effect of the three major genes was not cumulative, and epistasis and incomplete dominance were reported.

Heading Date

The frequency distributions for days to heading of the parents in 1963 and 1964, the F_2 grown in

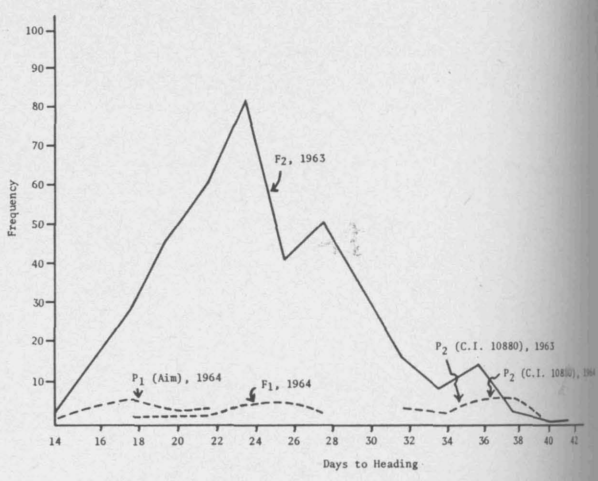

Figure 2. Frequency distribution for days to heading for P_1, P_2, F_1 and F_2 plants of the cross Aim x C.I. 10880 grown at College Station, Texas.

1963 and the F_1 grown in 1964 are shown in Figure 2. No data for the Aim parent are available in 1963, because it was winterkilled. The means of the parents, F_1 and F_2 were shown by Duncan's Multiple range test to be significantly different. Both the mean of the F_1 and F_2 are to the left of the mid-parent value. Partial dominance of early maturity is indicated in this cross, and transgressive segregation beyond the late parent Will was observed in the F_2 grown in 1963. It is suggested that at least two major factors, and perhaps modifying factors, are operating in this cross, which agrees with results of other workers. Heritability for maturity was relatively low – only 34 percent.

Plant Height

The tall parent Will ranged from 29 to 33 inches while Aim measured 13 to 21 inches. The F_2 ranged from 11 inches to plants equally as tall as the tallest plants of Will. Distribution is shown in Figure 3, and some of the F_2 and parent plants are shown in Figure 4. Both dominant and additive gene actions were indicated. Dominance, heritability, number of effective factors and possible selective advance are given in Table 4. The low heritability estimate is expected in cases where a number of genes are

TABLE 3. DISTRIBUTION OF GROWTH HABIT OF THE PARENTS, F_1 AND F_2 POPULATION OF AIM X WILL BARLEYS GROWN AT COLLEGE STATION, TEXAS, 1963-64

Population and year grown	Growth habit[1] 1	2	3	4	5	6	7	Total
Aim, 1963, 1964							40	40
Will, 1963, 1964	40							40
F_1 1964				23	4			27
F_2 1963	8	11	11	40	17	35	314	436

[1]Scale ranges from 1 = (winter-type) to 7 (spring-type).

TABLE 4. DOMINANCE, HERITABILITY, NUMBER OF EFFECTIVE FACTORS K_1 AND K_2 AND POSSIBLE SELECTIVE ADVANCE FOR PLANT HEIGHT IN THE WILL X AIM CROSS

Statistics	Estimated value	
(H/D) ½	3-9 (over-dominance)	
Heritability	9%[1]	33%[2]
Effective factors K_1	3.70	
K_2	6.02	
(K_2D) ½	3.75	

[1]Calculated as $\frac{VF_2}{\frac{1}{2} D} \times 100$.

[2]Calculated by the parent/progeny regression method as described by Smith and Kinman (20).

found. The difference between the two estimates of number of effective factor pairs could be due in part to unequal gene effects or non-isodirectional accumulation of allelomorphs. The immediate selective limit was found to be ± 3.8 inches from the midparent value of 35.0 inches. Since the parents depart from their mid-value by 2.9 inches, it appears unlikely that any plant markedly transgressing the parents can be selected. The shortest F_3 mean of those measured was 33.0 inches and the tallest was 40.4 inches, departures of 4.6 and 2.0 from the mid-point value. As only 85 F_3 families were measured, it is improbable that any with all the height genes would be recovered in this number.

Greenbug Reaction

Seed from six F_1 plants were used to test separately the greenbug reaction of F_2 families. Five of the F_2 populations gave ratios of three resistant plants to one susceptible, in agreement with work of Chada and Gardenhire (9). In one family, there was an abnormally high population of susceptible plants so that the ratio was abnormal. Two other families also had somewhat abnormally high proportions of susceptible plants so that Chi-square values were borderline. The total for all six families gave 1,453 resistant to 547 susceptible which also deviates considerably from a 3:1 ratio with a Chi-square value of 5.87 and a P value of 0.025-0.01.

Because of the variability of F_2 results and variations from data on greenbug tests obtained by other

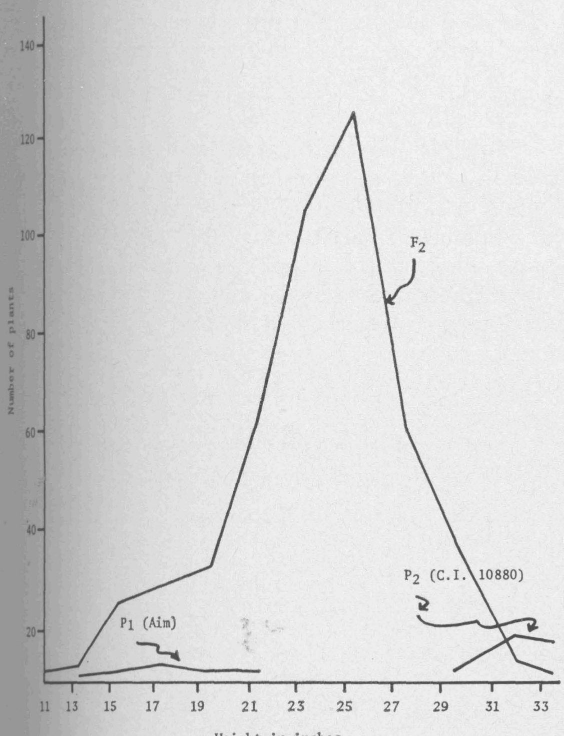

Figure 3. Frequently distribution of plant height for P_1, P_2 and F_2 plants of the cross Aim x C.I. 10880 grown at College Station, Texas, 1963.

Figure 4. Will, left, and Aim, right, parents with selected Will x Aim F_2 plants representing the height range of the parents.

workers, seed from the 352 F_2 plants grown at College in 1963 were tested as F_3 lines in 1964. Results did not fit well either the 1:2:1 ratio or a 3:1 ratio. The observed reaction was 152 resistant: 148 segregating: 52 susceptible whereas the expected was 88: 176:88. The Chi-square value was 61.4. The F_3 population tested was not completely random as some F_2 plants were killed by low temperature and some by yellow dwarf virus. No completely adequate explanation of the behavior of these populations is known, unless there are unknown modifying factors for greenbug reaction.

Interrelationship of Characters

Simple and partial correlation coefficients were determined for survival, leaf damage and growth habit in 1963, Table 5. More complete comparisons were made, using the 85 strains on which ascorbic

TABLE 5. SIMPLE AND PARTIAL CORRELATION COEFFICIENTS FOR SURVIVAL, LEAF DAMAGE AND GROWTH HABIT IN THE F_2 POPULATION OF AIM X WILL, COLLEGE STATION, TEXAS, 1963

	r		Partial r	
	2	3	2	3
1 Survival	−0.34**	−0.06	0.49**	0.25
2 Leaf damage		0.62**		
3 Growth habit				

**Significant at the 1% level.

TABLE 6. SIMPLE CORRELATION COEFFICIENTS AMONG 11 CHARACTERS IN THE CROSS OF WILL X AIM BARLEYS

Character	Simple correlation coefficients									
	2	3	4	5	6	7	8	9	10	11
1 Leaf damage in F_2	.69**	—.46**	.84**	.61**	—.39**	—.17	—.70**	—.63**	—.28*	—.02
2 Leaf damage in F_3		—.28*	.69**	.49**	—.34**	—.16	—.61**	—.56**	—.22	—.28*
3 Ascorbic acid in F_2			—.41**	—.19	.35**	—.12	.43**	.42**	.44**	.27*
4 Growth habit in F_2				.72**	—.29*	—.22	—.86**	—.76**	—.37**	—.02
5 Growth habit in F_3					—.24	—.24	—.73**	—.63**	—.27*	.15
6 Plant height in F_2						.32*	.18	.40**	.01	.15
7 Plant height in F_3							.13	.06	—.48**	.03
8 Heading date in F_2								.77**	.50**	.03
9 Heading date in F_3									.49**	.09
10. Leaf rust in F_2										.01
11 Greenbug reaction in F_3										

*Significant at the 5% level.
**Significant at the 1% level.

acid tests were made. Simple and partial correlations for all characters in 1963 and 1964 are given in Tables 6 and 7.

Characters related to low temperature reaction: Leaf damage in F_2 and F_3, ascorbic acid content of seedling leaves, growth habit and survival are all concerned with reaction to low temperature. Fortunately, the winter of 1962-63 was severe and valuable for evaluating this material and these methods of measuring cold tolerance. Because the correlation of survival and estimated leaf damage was highly significant but low (—0.34**), it would be of limited value in predicting hardiness. The relation to growth habit was near zero, indicating that type of plant did not influence the killing this season. However, it should be pointed out that only a few plants in the population at College Station were killed; therefore, the range of survival notes probably was not adequate for a good measure of correlation. The correlation of leaf damage and growth habit, a better measure of hardiness in this instance, was highly significant (0.62**) and indicates, as would be expected, that the more upright types were injured more by the freeze.

No data were obtained on cold tolerance at College Station in 1964. Although the 1964 season at Bushland was severe, the crop was so well hardened that most lines and even Goliad, a near-spring type, survived, Figure 1. The differential killing among lines is shown in Figure 5. Some interesting differences among F_3 lines were observed. The correlation of F_2 leaf damage and growth habit was 0.84**, Table 6, and between F_3 leaf damage and growth habit was 0.49**; yet there were striking differences in cold tolerance among lines of the same growth habit. Figure 6 shows strains 164 and 165 which before the freeze were approximately the same in growth habit; yet 165 was uninjured while 164 was reduced to a very thin stand. Figure 7 shows on the left an erect, broad-leaf F_3 line which survived equally as well as the narrow-leaf, more prostrate line on the right. From this, it would appear that progress can be made in selecting higher forage producing strains of barley with a considerable degree of hardiness. The survival and leaf damage in both F_2 and F_3 in the two seasons did not appear to transgress the range of the parents; therefore, there was no evidence that the Aim parent was contributing to cold tolerance in any way.

Multiple regression analysis was calculated to determine the relationship between the agronomic characters studied and cold tolerance as measured by leaf damage. Partitioning the regression sum of square among the variables studied showed that growth habit and ascorbic content were the variables contributing most to leaf damage. These measures then appear to be the best measures used in this study

TABLE 7. PARTIAL CORRELATION COEFFICIENTS AMONG 11 CHARACTERS IN A CROSS OF WILL X AIM BARLEYS

Character	Simple correlation coefficients									
	2	3	4	5	6	7	8	9	10	11
1 Leaf damage in F_2	.33**	—.27*	.53**	.06	—.16	.06	.07	.11	.07	.20
2 Leaf damage in F_3		.25*	.13	.01	—.14	.07	—.12	.01	—.03	—.41**
3 Ascorbic acid in F_2			—.05	.13	—.38**	—.30*	.18	—.13	.36**	.32*
4 Growth habit in F_2				.78**	.18	.23	—.41**	.32*	.12	.05
5 Growth habit in F_3					.06	—.11	—.35**	.14	.10	.23
6 Plant height in F_2						.43**	.75**	.45**	—.25*	—.02
7 Plant height in F_3							.05	—.31	.11	.07
8 Heading date in F_2								.24	.20	.02
9 Heading date in F_3									.32*	.10
10 Leaf rust in F_2										—.15
11 Greenbug reaction in F_3										

*Significant at the 5% level.
**Significant at the 1% level.

Figure 5. Differential winterkilling of Aim x Will F_3 lines and parents at Bushland, 1964.

for selecting hardy plants in F_2 and F_3, yet the partial correlations among these characters in F_3 were low and only that of the leaf damage and growth habit of F_2 were significant. Examples of exceptions to the general trend were shown also.

Correlation coefficients of growth and hardiness factors among 85 random lines: The more extensive comparison, using 85 random plants used for ascorbic acid tests, also gave some interesting data. Leaf damage of F_2 plants in 1963 was correlated (0.69**) with leaf damage of F_3 rows in 1964. Partial correlation coefficient for these characters was 0.33**. Leaf damage ratings of F_2 and F_3 plants were correlated significantly with plant height and growth habit and negatively correlated with heading dates in F_2 and F_3 and ascorbic acid content of leaves.

Ascorbic acid content was negatively correlated with leaf damage in both F_2 and F_3, growth habit in F_2 and with both plant height and heading dates in F_2 and F_3. It is of interest to note also that it was correlated significantly with leaf rust and greenbug reaction. No studies are known of the relationship of leaf rust reaction and ascorbic acid, but Pilgrim[3] found that the ascorbic acid of a stem rust susceptible, infected isogenic line of wheat was lower than its sister resistant line.

Growth habit in F_2 was highly correlated with growth habit in F_3 (r = 72**, and partial r = 0.78**) indicating that growth habit can be accurately selected in early generations. Growth habit was closely correlated with heading dates in F_2 and F_3 but was not correlated significantly with plant height. Therefore, it should be possible to select short stature plants in all *growth habit classes* of this cross.

[3]Pilgrim, A. J. The ascorbic acid content of stem rust susceptible and resistant wheat. PhD thesis Texas A&M University (unpublished), 1955.

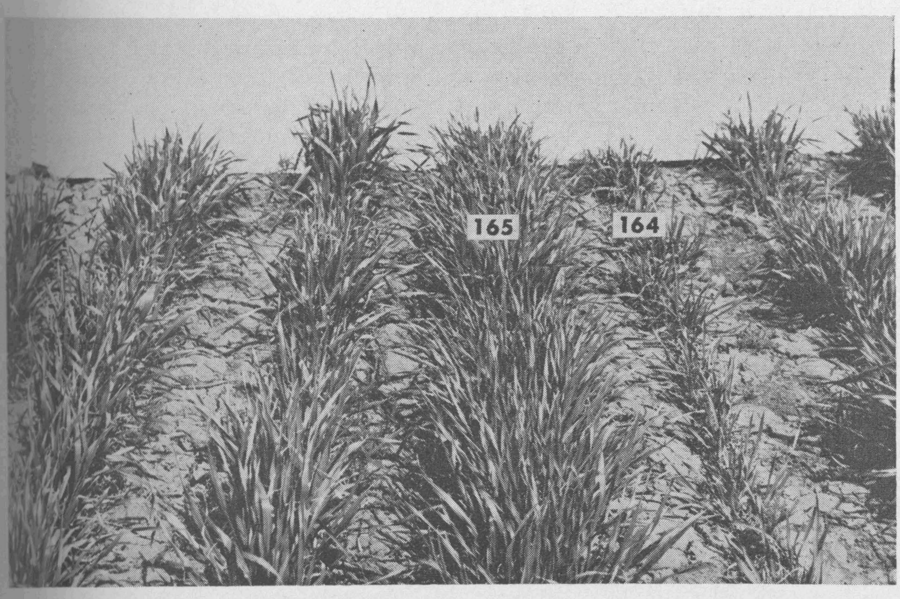

Figure 6. Aim x Will F_3 lines, which before the freeze were approximately of the same growth habit, showed striking differences in cold tolerance at Bushland, Texas, 1964.

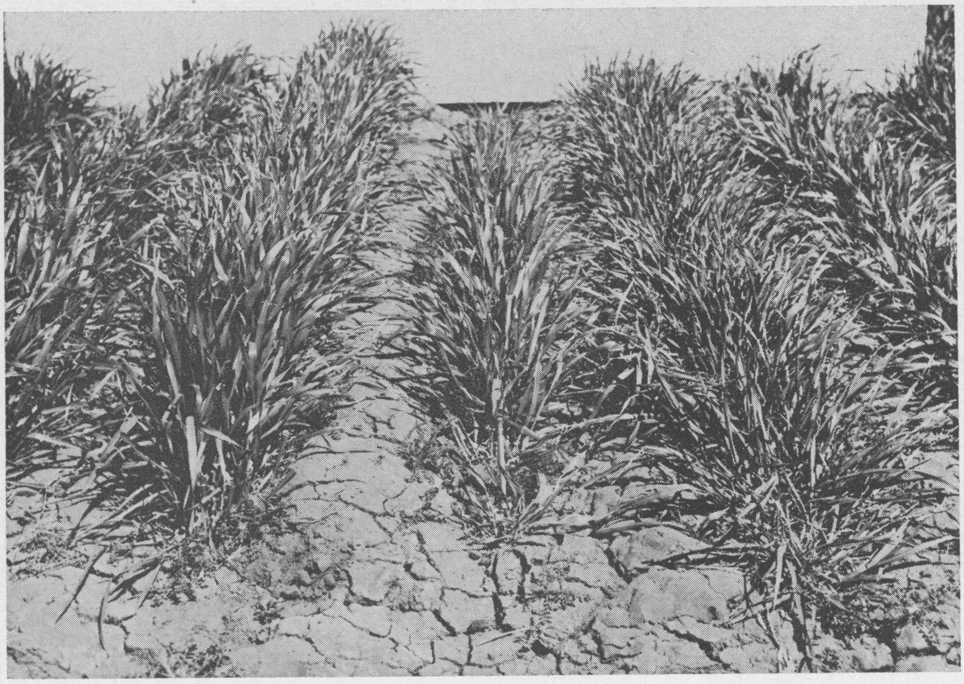

Figure 7. Erect, broad-leaf Aim x Will F_3 line at left survived equally as well as the narrow-leaf, prostrate-growing line on the right, Bushland, Texas, 1964.

Greenbug reaction: Simple correlation coefficients for greenbug reaction and other characters were usually low and nonsignificant. The correlations between greenbug reaction and low temperature freeze damage in F_3 was significant at the 0.05 percent level, but not high (0.28*). However, an r value of 0.41** was obtained in partial correlation analysis.

Leaf rust reaction: Simple correlation coefficients between leaf rust reaction and other characters were relatively small (less than 0.50). Those of leaf rust with heading dates and ascorbic acid content of leaves were positive and highly significant. Percent leaf rust infection was correlated negatively with plant height and growth habit. The partial correlation coefficients of leaf rust with other characters were low, and only that with ascorbic acid content of F_2 leaves was highly significant. As leaf rust reaction was recorded only from field infection, it appears that seasonal development of the plant probably influenced these factors.

Heading date: The correlation between F_2 plant heading date and mean of the F_3 row was high (0.77**), but the partial correlation coefficient was only 0.24 and nonsignificant. The F_2 heading date was significantly and closely negatively correlated with leaf damage in the F_2 and F_3, with growth habit in the F_2 and F_3 and correlated to a lesser extent (0.43**) with ascorbic acid. On the other hand, partial correlations were low and nonsignificant, except for growth habit. Also, in contrast, simple correlations for heading date and plant height was very low and nonsignificant but the partial correlation was high (0.75**). The correlations of F_3 heading date and these characters were very much the same as was found for F_2.

Plant height: Both simple and partial correlation coefficients, although statistically highly significant, were relatively low and of little value for prediction purposes. Even the correlation of F_2 and the mean of F_3 was only 0.32*. There appears no problem in combining shortness of plant stature with any of the characters studied.

DISCUSSION

The objectives of combining short stature and lodging resistance with greenbug resistance, cold resistance and more productive forage types appears to be possible in the cross of Aim x Will barleys. Attempts to develop indices of cold hardiness in early generations by simple means were not so successful.

Ascorbic acid content of green leaves has been used with some success to measure and forecast cold tolerance in wheat by Andrews and Roberts (3) and Futrell and Pilgrim (8), but Atkins et al. (2) did not find it satisfactory for oats. No previous record on its use in barley is recorded. While ascorbic acid content of leaves was correlated significantly with leaf damage, the correlations were not nearly as high as with leaf damage estimates. Ascorbic acid tests are difficult to make and are influenced greatly by environmental conditions and stage of plant growth. However, in the absence of actual low temperature for evaluating material, ascorbic acid tests might be used with some measure of success. The correlations of ascorbic acid with leaf rust and greenbug reaction were of interest and may be significant.

Leaf damage estimates, even where conditions were not severe enough to cause differential winterkilling, appear to be fairly satisfactory for estimating cold tolerance of hybrid populations in the early generations of barley. Leaf damage varies greatly with the low temperature conditions, and no doubt errors will be made. Further evaluation may be necessary in later generations. These observations agree with those of Rhode and Pulham (17) and others. While leaf damage was correlated and is influenced by growth habit, recombinations of higher producing forage types with greater cold tolerance do not appear to be impossible to develop. Height and earliness were associated with growth habit but in multiple regression analysis these associations were greatly reduced. It appears that any height or maturity class could be combined with any given growth habit as needed for a given area.

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