AGRONOMIC AND MALTING CHARACTERISTICS OF EIGHTEEN VARIETIES AND EXPERIMENTAL LINES OF WINTER BARLEY GROWN IN OKLAHOMA

By

JAMES ALLAN GILCHRIST

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Thesis Approved:

Lewis H. Edwards
Thesis Adviser

Lavoy I. Croy

Robert D Morrison

D Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

The malting industry in the United States consumed approximately 128 million bushels of malting barley in 1971. The projected use of malt barley in 1975 is 145 million bushels. The fact that malting barley is not in surplus today has been pointed out by Jensen (18). The barley to fulfill the increasing needs of the future will come from several sources. No doubt, the principal source will be from increased production in areas now producing malting barley. A second source could be an increase in the import of Canadian barley. An additional possible source which has gained support in the past few years is the opening of new geographical regions of the United States to production of malting barley by the development of a winter type malting barley. With the exception of a small acreage of winter malting barley produced in Missouri, all malting barley produced in the United States comes from spring barleys.

For a winter barley to be successful as a malting barley, it must possess the malting qualities presently desired in the spring barleys used for malting. Winter barley has been bred for feed purposes in the past. Protein content has been increased to a value that is above the desired level for malting barley. Little attention has been given to kernel size distribution which is also an important consideration in determining the acceptability of barley for malting purposes. In general, the percentage of large plump kernels in winter barley is below that desired in malting barley and the protein content is higher than desired.

The primary objectives of this study are: (1) to investigate the possibility of producing good winter malting barleys in Oklahoma; and (2) to survey 18 winter barley lines and varieties for their potentials as malting barleys for Oklahoma or as sources of germplasm for the development of a winter malting barley for Oklahoma.

CHAPTER II

REVIEW OF LITERATURE

Malting barley is an important consideration in barley production because of the higher price offered by the maltster for malting barley in contrast to feed barley. The amount of this premium is determined by the malting quality of the barley. Anderson, Meredith, and Sallans (4) pointed out that medium size and uniformity are two important physical kernel characteristics of good malting barley. They also indicated that a low protein percentage, high extract percentage, and high diastatic power are important chemical characteristics of high quality malting barley. Foster, Peterson, and Banasik (15) used three characteristics as a "prediction test" to evaluate barley for malting potential. These characteristics were per cent nitrogen, per cent extract, and diastatic power.

To breed a winter malting barley with the spring malting quality presently desired, winter habit must not contribute any deleterious attributes to the malting quality. Smith (30) investigated the relationship of winter habit and malting quality in twelve crosses using hardy winter varieties and high malting quality spring lines as parents. F_3 family bulks made within each cross according to growth habit (spring, intermediate, and winter) revealed no significant difference among growth habit groups for malting quality. Smith concluded it should be possible to breed a winter barley with a spring type quality pattern.

Several workers have investigated the production of malting barley in regions of winter barley production. Day (10) studied the yield and quality of spring malting barley varieties grown as winter annuals under irrigation at Mesa, Arizona. A few of the spring varieties were high yielding but none of the high yielding varieties had an acceptable level of all malting quality characteristics desired in high quality malting barley. Mader (22) concluded it would be difficult to produce malting barley in Oklahoma year after year because of the uncertainty of climatic conditions. Mason and Cox (23) reported the main advantage of sowing spring varieties in fall or winter in Essex County, England was the enhanced quality which resulted from the longer growing season. Studies at Lubbock, Texas (22) indicated that barley produced under irrigation was suitable for malting providing the right varieties were used and irrigation water was applied at the proper time. Commercial scale production of a two-row winter malting barley has been reported in Missouri (13).

Protein - Extract - Diastatic Power

Protein content in barley is directly related to the value of the barley for malting (6). A low protein content is desired in barley intended for malting purposes. Barley protein content influences the amount of malt extract and diastatic power of malt. High protein in malting barley results in malts which, when mashed and extracted, produce worts with high soluble protein. High protein barley also causes difficulties in the malting and brewing process and produces malts with undesirably high enzymatic activity for brewers malt. This often leads to changes in processing and in beer character, both of which are undesirable (6).

Extract percentage must be high before the maltster can produce an economical malt. Extract percentage is the proportion of soluble material which can be extracted from malt which has been ground and mashed with water. The importance of high extract lies in its direct relationship to the amount of beer which can be made from a given amount of malt (21).

Malt diastatic power is a measure of the ability of the malt to convert the soluble starch of the malt and adjuncts added to the malt to fermentable sugars. A relatively high malt diastatic power is desired in brewing malts (10).

Anderson, Sallans, and Meredith (5) studied intravarietal relations between barley and malt properties and found indications that those environmental factors that affect total nitrogen content also affect most other properties to a greater or lesser extent. Thus, when working with samples of one variety or closely related lines, a determination of nitrogen content should provide considerable information on the general malting qualities of the sample. When working with plants from a single variety or progenies from a single cross, several workers (28, 17, 11, 5) found that high protein content tended to be associated with a high diastatic power and low extract. Streeter and Pfiefer (32) reported a positive correlation between barley protein and malt diastatic power and a negative correlation between barley protein and malt extract when correlations were calculated across locations, varieties, and a heterogeneous group of treatments. Harris and Banasik (16) found a significant negative intervarietal correlation between barley nitrogen content and barley extract but a nonsignificant intervarietal correlation between nitrogen content and diastatic power. Results between stations showed a highly significant positive correlation of barley nitrogen with barley diastatic power and a highly significant negative correlation between barley protein and barley extract. Johnson and Aksel (19) found an association between low barley nitrogen and high malt extract in a study involving a 12-parent diallel cross. In general, the correlation between barley protein and extract appears to vary when calculated between varieties but is consistently negative when calculated within a variety or cross. The correlations between barley protein and malt or barley diastatic power appear to be positive and significant when calculated within a variety or between closely related lines but fail to show significance when calculated between non-related varieties or lines. This association could impede the breeder when selecting within a cross for low protein and high extract.

Yield

Yielding potential is a prime consideration of the producer when selecting a variety. If an acceptable winter malting barley is to be grown in Oklahoma, it must possess both the quality of a spring malting barley and a yield potential near that of the adapted feed varieties presently grown in Oklahoma. Den Hartog and Lambert (11) recognized the fact that one of the problems confronting the barley breeder is the development of lines which are high both in malting quality and yielding capacity, inasmuch as a considerable number of present varieties are either high yielding feed varieties or low yielding malting varieties. Day (10) found that some spring malting barleys gave yields comparable to adapted feed varieties when grown as winter annuals under irrigation.

Den Hartog and Lambert (11) found high yields to be associated with high kernel weight, high bushel weight, low protein, low diastatic power, and high extract. Dickson et al. (28) reported positive correlations between yield and test weight and yield and kernel weight and a negative correlation of yield with malt diastatic power. Johnson and Aksel (19) found yield to be negatively correlated with nitrogen. Hsi and Lambert (17) reported a positive correlation of yield with test weight, kernel weight, and extract and a negative correlation of yield with protein, diastatic power, and heading date. The only undesirable association apparent with yield is the negative correlation between yield and diastatic power.

Test Weight

Test weight has been used in the past to determine the price of malting barley at the local elevator. However, test weight is not an adequate measure of the value of barley for malting purposes within the approximate limits of 45 to 48 pounds per bushel (21). Two samples of barley having the same test weight may vary considerably as to the percentage of plump and thin kernels present.

Harris and Banasik (16) found that varieties and location of growth had significant effects on test weight but year effects were not significant when five spring varieties of barley were grown for three years at six locations in North Dakota. The ranges in test weight were 1.1, 4.7, and 1.3 lb/bu for varieties, locations and years respectively. Hsi and Lambert (17) found interannual correlation of test weight significant and also reported a positive correlation of test weight with yield, kernel weight, and barley extract. Den Hartog and Lambert also found test weight to be positively correlated with yield, kernel weight, and barley extract (11). A positive correlation of test weight with extract and a negative correlation of test weight with nitrogen content and diastatic power was reported by Harris and Banasik (16). Rutger, Schaller, and Dickson (28) found high test weight to be associated with late maturity, tallness, high yield, high percentage of plump kernels, and a high malt extract percentage. Test weight appears to be associated with high malting quality with the exception of the negative correlation between test weight and diastatic power.

Kernel Size

Kernel size distribution as measured by percentages of plump (kernels remaining on a 6/64 inch sieve) and thin (kernels passing through a 5/64 inch sieve) kernels is an important consideration when determining the acceptability of barley for malting purposes. Anderson, Meredith, and Sallans (4) pointed out that medium size and uniformity were two important physical kernel characteristics of malting barley. Official Grain Standards of the United States specify that malting barley must not contain more than 15 per cent of barley and other materials which will pass through a 20 gage metal sieve with slotted perforations 4 7/8 /64 inch wide and 3/4 inch long. Maltsters prefer barley which has no thin kernels and price discounts are assessed as thin barley increases above three to five per cent (21). Anheuser-

Busch, Inc. has specified the requirements of greater than 60 per cent plump kernels and less than five per cent thin kernels as requirements for barley to be accepted as malting barley (13).

A two-row winter barley with acceptable kernel size for malting purposes has been produced in Missouri (13). Day (10) grew 20 spring varieties as winter annuals under irrigation and found that most of the varieties produced seed of acceptable size for malting purposes. Brewer and Poehlman (8) pointed out that kernel size may be a limiting factor in the production of winter malting barley in some years.

Rutger, Schaller, and Dickson (28) reported a significant positive correlation between barley plump kernels and malt extract and a significant negative correlation between plump kernels and malt diastatic power. Streeter and Pfiefer (32) found that a high percentage of plump kernels was associated with a low malt diastatic power when two two-row spring barleys were evaluated. When four six-row spring barleys were evaluated, no significant correlation of barley assortments with malt diastatic power was observed. This points out the fact that caution should be used when making broad generalizations between two-row and six-row relationships. Rasmusson and Glass (27) found that associations of plump kernel percentages with extract and diastatic power were not consistent when the F_3 generation of eight crosses were evaluated. Brewer and Poehlman (8) studied the effects of harvesting at different moisture levels on the kernel size of a winter barley line grown in Missouri. They found significant increases in kernel plumpness were present as moisture content at harvest time decreased from 50 per cent down to about 30 per cent with no significant increase when moisture dropped below 30 per cent. This indicates that early harvesting by swathing would be possible to escape hazards which would otherwise lower the quality of the barley for malting.

Thousand Kernel Weight

A high thousand kernel weight or average kernel weight is desirable in malting barley. Harris and Banasik (16) found that varieties, locations, and years had significant effects on the thousand kernel weight of grain produced from five spring varieties of barley produced in three years at six locations. Hsi and Lambert (17) found low inter-generation correlations when the F_5 and F_6 generations of ten crosses involving a common parent were evaluated, indicating a low heritability for kernel weight. Borthakur and Poehlman (9) found evidence that substantial improvement in kernel weight of the winter barley line Mo.B-475 could be made by crossing it to the spring malting varieties Larker and Trophy. This indicates that the kernel weight component can be successfully transferred from the spring malting varieties to winter barleys with low average kernel weights.

Den Hartog and Lambert (11) found kernel weight to be positively correlated with extract when ten crosses involving a common parent were evaluated. Similar associations of high thousand kernel weight with high extract percentage have been noted by several workers while investigating both inter- and intra-varietal relationships (5, 16, 17). Den Hartog and Lambert (11) indicated that thousand kernel weight could serve as an index of extract potential. A negative association between thousand kernel weight and diastatic power was reported by Meredith and Anderson (24). Thousand kernel weight appears to be affected by the environment to a considerable extent and is positively associated with malting quality.

Germination

A high germination energy and capacity are necessary before barley can be used for malting purposes. Germination energy is a measure of the rapidity of germination and germination capacity is a measure of total germination. A high and uniform germination of 95 to 100 per cent is needed to produce a high quality malt (21). During the malting process, low germination and uneven germination both result in a lowering of the malt extract percentage which is extremely undesirable. Anderson, Sallans, and Meredith (5) stated that germination appears to be controlled mainly by environmental factors and it is only infrequently that there is evidence of a varietal effect on this character.

CHAPTER III

MATERIALS AND METHODS

Composition of Entries

This study consisted of 18 entries of varying origin. Several of these were selected for their potentials as malting barley. Five entries were released varieties and 11 were experimental lines. All were of the winter type growth habit.

Four entries in this study were Oklahoma developed cultivars. Two were the commercially grown varieties Kerr and Rogers and two were experimental lines. The two experimental lines were St 654757 from the cross Tenkow/Rogers and St 654853 from the cross 2*Rogers/Kearney. The varieties Rogers and Kerr were developed by the Oklahoma Agriculture Experiment Station. Rogers is a mid-tall variety of winter barley that stands well. Rogers has a plump kernel, high test weight, and is resistant to powdery mildew. It is susceptable to greenbug damage and some winterkilling is observed in northwestern Oklahoma and in the Panhandle. Kerr is similar to Rogers in yield, mildew resistance, test weight, and straw characters. Kerr is superior to Rogers in winterhardiness and exhibits greenbug tolerance. The varieties Kerr and Rogers are both midseason to late in maturity.

Barsoy was the only Kentucky entry in this study. It was developed by the Department of Agronomy, University of Kentucky. Barsoy is an early maturing, stiff strawed barley with high test weight.

Compared to Rogers, Barsoy heads six to eight days earlier and is two to four inches shorter. Barsoy is susceptible to loose smut and has some resistance to mildew.

Cass and the seven experimental lines from Michigan were developed at the Michigan Agricultural Experiment Station where emphasis was placed on malting quality. Cass is a mid-tall variety with good test weight and is midseason in maturity. It was never grown on a large commercial scale because of its marginal quality.

The Texas variety Era, developed at Texas A & M, was released in 1968 as a feed barley and is a tall, early maturing barley with medium winterhardiness. It is very susceptible to leaf rust, has some resistance to mildew, and has good straw and high test weight.

The four New York lines all originated from a cross involving the winter feed barley Hudson and the spring malting variety Trail. These lines were developed at Cornell University where emphasis was placed on malting quality.

Field Layout

The experimental design was a randomized complete block with four blocks per location and two locations. Each block contained 18 plots. Each plot was three meters long and consisted of four rows with 30 centimeters between rows.

The Stillwater test (location one) was planted on October 6, 1970, and the Lahoma test (location two) was planted on October 13, 1970. The plots were seeded at the rate of 40 grams per plot which is equivalent to 108 kg/ha. The fields at both locations received approximately 35 kg/ha each of P_2O_5 and NH_4NO_3 as preplant fertilizer. Both tests received a supplemental application of 45 kg/ha of actual nitrogen in the form of NH_4NO_3 as a topdressing in March of 1971. Both fields were fallowed the year prior to this study.

The field at location one was located on the Agronomy Research Station at Stillwater, Oklahoma. The soil was a Kirkland silt loam which is an upland unit on plane or weakly concave slopes averaging about one per cent. This soil has a grayish-brown silt loam surface six to ten inches deep over a dark grayish-brown, blocky, compact claypan. The subsoil is very slowly permeable. The field at location two was located on the Agronomy Research Station at Lahoma, Oklahoma. The soil was a Pond Creek silt loam which is a deep well-drained soil on nearly level to gently sloping uplands. The surface is a dark brown silt loam and the subsoil is a reddish-brown silty clay loam. This soil has a high water holding capacity.

Characters Investigated

The following characters were observed on all plots except where noted.

Heading date was determined as the number of days from January 1 to the time when 75 per cent of the heads were emerged from the boot. Heading date was recorded on plots at location one only. Plant height was determined as the average distance in centimeters from the soil surface to the spike tips of the plants. Plant height was observed at location one only. Yield was determined as the weight in grams of grain produced from two 2.4 m rows which were prepared by cutting 0.3 m from each end of the center two rows of each plot. The harvested area per plot was 1.44 m^2. The yield per plot was converted to kilograms per hectare before statistical analysis. Tillers/meter^2 were determined as the number of seed bearing tillers in a random 30 cm section of one of the harvested rows. Kernel weight was determined from the weight in grams of 200 kernels chosen at random from the grain yield sample of each plot.

The average number of kernels per spike was computed using the following formula:

$$\frac{\left(\dfrac{\text{Grain yield in grams per meter}^2}{\text{average weight per kernel in grams}}\right)}{\text{number of spikes per meter}^2}$$

Kernel protein content was determined by standard Kjeldahl methods according to AACC cereal laboratory procedures (2). The analysis was performed in the cereal chemistry laboratory, Oklahoma State University. Test weight was estimated in pounds per bushel on the basis of one random sample. This value was converted to kilograms per hectoliter prior to statistical analysis.

Kernel size assortment was determined by placing a random 100 g sample on a 5/64" x 3/4" and a 6/64" x 3/4" slotted screen on a barley grader set with a three minute timing. Plump kernels were determined from the percentage of the 100 g sample remaining on the 6/64" screen. Medium kernels were determined from the percentage of the 100 g sample passing through the 6/64" but remaining on the 5/64" screen. Thin kernels were determined from the percentage of the 100 g sample passing through both screens.

Germination was determined from 100 kernels selected at random from the yield sample. These kernels were steeped for 48 hours and then placed in a saturated humidity germinator following the procedures described in "Methods of Analysis of the American Society of Brewing Chemists" (3). Germination energy was determined as that portion of the 100 kernel sample which showed signs of germination after 72 hours in the germinator. Germination capacity was determined as that portion of the 100 kernel sample which showed signs of germination after 120 hours in the germinator.

Statistical Analysis

Statistical analyses were carried out on all characters observed using one sample per plot. Analyses of variance were calculated for each character by location and for the data of combined locations. The effects of entries, locations, and location x entry interactions on the characters under study were obtained from these analyses.

To evaluate the possible relationships between characters, simple correlations were computed for each character with each of the other characters. The coefficient of simple correlation (r_{xy}) between two variables X and Y was determined by the formula:

$$r_{XY} = \sqrt{\frac{\sum xy}{\sum x^2 \cdot \sum y^2}}$$

where $\sum x^2$ is the error sum of squares of the deviations of the variable X; $\sum y^2$ is the error sum of squares of the deviations of the variable Y; and $\sum xy$ is the error sum of products of the variables X and Y. Correlation coefficients were calculated for the combined data from both locations with the exception of plant height and heading date where one location data only was used.

Duncan's new multiple range test (14) was used to group the ranked entry averages over locations for each character into groups significantly different at the .05 level of probability. Plant height and heading date were grouped using location one averages only.

CHAPTER IV

RESULTS AND DISCUSSION

The 1971 growing season at both locations was characterized by moisture stress at critical periods in the development of winter barley (7). Location one received 5.61 inches below the normal moisture during the period from March 1 - June 1, 1971, with below normal moisture in November and December of 1970 also. Location two was also under moisture stress with 8.51 inches below normal moisture during the period from October 1, 1970 to July 1, 1971. No winter killing was observed at either location.

Protein Content

Entries had a significant effect on protein content at both locations (Tables XIV and XV). The significant difference between replications at the Stillwater test (Table XIV) illustrates the necessity of replications when evaluating protein content. Location one produced grain with an average protein content of 14.0 per cent and location two produced grain with an average protein content of 13.5 per cent. The effect of locations on protein content was significant at the .05 level of confidence (Table XVI). The highly significant location x entry interaction effect on protein (Table XVI) indicated that the entries had a differential response to the two locations. This interaction was best illustrated by the varieties

Era and Rogers. Era dropped from 15.2 per cent protein at Stillwater to 13.6 per cent protein at Lahoma whereas Rogers increased from 13.3 per cent protein at Stillwater to 14.5 per cent protein at Lahoma.

The experimental lines St 654757 and N.Y. 6005-15 had plot averages of 15.1 per cent and 15.0 per cent, respectively, and were significantly higher than all other entries (Table I). Rogers, with an average of 13.9 per cent, and Kerr with an average of 13.7 per cent were intermediate with respect to the protein content of the other entries. Anheuser-Busch, Inc. (13) has specified a protein content of between 9.0 per cent and 12.5 per cent as necessary before the barley is accepted as malting barley. The four Michigan lines 62-447-10, 62-447-30, 62-447-18, and 62-447-34 along with the Michigan variety Cass produced grain at the Lahoma test which was under 12.5 per cent in protein content. These entries were significantly lower in the two-test average than all other entries (Table I). The New York lines as a group produced grain which was higher in protein content than grain produced by the Michigan lines. N.Y. 6005-16 had the lowest average protein content of the New York lines with 14.3 per cent. The Texas variety Era was relatively high in protein content with a two test average of 14.4 per cent. The Kentucky variety Barsoy averaged 14.1 per cent protein.

Considering the importance of low protein content in high quality malting barley, it appears that the Michigan lines possess a higher potential as malting barley or sources of germplasm for the development of a more desirable malting barley. The failure of any of the entries at the Stillwater test to produce grain with less than 12.5 per cent protein indicates that it may be difficult to develop a

TABLE I

PERCENT PROTEIN

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent.No.	Loc.1	Rank	Loc.2	Rank	2-Test Avg.
St 654757	9	14.7	7	15.5	1	15.1
N. Y. 6005-15	11	15.2	2	14.8	2	15.0
N. Y. 6005-18	13	14.9	3	14.1	7	14.5
St 654853	10	14.7	6	14.3	4	14.5
Era	18	15.2	1	13.6	10	14.4
N. Y. 6005-19	14	14.7	5	13.9	8	14.3
N. Y. 6005-16	12	14.5	8	14.1	6	14.3
Mich 62-420-11	8	14.1	9	14.2	5	14.1
Barsoy	17	15.0	4	13.4	11	14.1
Rogers	1	13.3	13	14.5	3	13.9
Kerr	2	13.6	10	13.8	9	13.7
Mich 62-448-24	6	13.4	12	13.4	12	13.4
Mich 62-449-22	7	13.4	11	13.0	13	13.2
Mich 62-447-10	4	13.3	15	12.0	16	12.6
Mich 62-447-30	15	12.9	18	12.4	14	12.6
Cass	3	13.0	17	12.2	15	12.6
Mich 62-447-18	5	13.3	14	11.9	17	12.6
Mich 62-447-34	16	13.0	16	11.2	18	12.1

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

a variety which will produce grain with an acceptably low protein content in dry years. Cultural practices aimed at the reduction of protein could help with this problem.

The Malting Barley Improvement Association (6) lists several methods aimed at the reduction of protein content of grain: (1) careful selection of non-fallow fields supplied with large amounts of soil moisture; (2) reduction of nitrogen fertilizer if soil moisture is short at planting time; (3) application of adequate amounts of phosphorous and other needed plant nutrients; (4) adequate weed, insect, and disease control. Barley protein content is closely related to soil moisture and tends to increase in dry years (12). The only way to adequately control the soil moisture level is by proper irrigation. Stone and Tucker (31) reported a linear relationship between nitrogen fraction in the grain and quantity of water applied prior to and through vegetative growth of the plant. A possible explanation of the water-grain nitrogen effect would include not only the dilution effect of higher yields but also the leaching of nitrate below the potentially high nutrient absorption zone.

Plump Kernels

The highly significant differences between entries at both locations indicate genetic differences between entries are present for the character plump kernels (Tables XIV and XV). The overall plot average for plump kernels was 26.3 per cent. No significant difference between the Stillwater test average of 26.4 per cent and the Lahoma test average of 26.1 per cent was indicated in the combined locations analysis of variance (Table XVI). The entries responded differently to the two locations as was indicated by the significant location x entry interaction (Table XVI). The differential response of the entries Barsoy and Mich 62-420-11 was illustrative of this interaction. The variety Barsoy produced a plot average of 34.5 per cent plump kernels at Stillwater and increased to an average of 69.0 per cent at Lahoma whereas the Michigan line 62-420-11 dropped from 50.6 per cent plump kernels at Stillwater to 28.8 per cent at Lahoma (Table II).

A plump kernel percentage of greater than 60 per cent is desired in malting barley but lower values are accepted when a high degree of uniformity is present. None of the entries at the Stillwater test produced grain with greater than 60 per cent plump kernels. Although Era and Barsoy had respective averages of 68.6 per cent and 69.0 per cent at Lahoma, their two-test averages were below 60 per cent. These two entries, Era and Barsoy, were significantly higher in plump kernels content than all other entries in the two-test averages. Mich 62-420-11 produced 50.6 per cent plump kernels at Stillwater but dropped to 28.8 per cent at Lahoma. The Oklahoma variety Kerr also produced a relatively high percentage of plump kernels at the Stillwater test but averaged a low 14.1 per cent at the Lahoma test. It averaged 30.7 per cent plump kernels and was eighth in the two-test averages. The Michigan entries 62-447-30, Cass, 62-447-34, and 62-447-18 all had two test averages between 30 and 40 per cent. The New York lines produced grain with low percentages of plump kernels indicating they were not adapted well to Oklahoma conditions for this character. New York 6005-18, 6005-15, and 6005-16 produced grain with two-test averages of less than ten per cent plump kernels and ranked 16th, 17th and 18th, respectively. These results indicate that the production of barley

TABLE II

PERCENT PLUMP KERNELS

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent.No.	Loc. 1	Rank	Loc. 2	Rank	2-Test Avg.
Era	18	48.4	2	68.6	2	58.5 *
Barsoy	17	34.5	6	69.0	1	51.7 *
Mich 62-420-11	8	50.6	1	28.8	8	39.7
Mich 62-447-30	15	34.8	5	37.4	4	36.1
Cass	3	40.1	4	30.9	6	35.5
Mich 62-447-34	16	33.5	7	36.7	5	35.1
Mich 62-447-18	5	26.3	10	39.9	3	33.1
Kerr	2	47.3	3	14.1	13	30.7
St 654757	9	30.6	8	23.8	9	27.2
Mich 62-447-10	4	24.6	11	29.4	7	27.0
St 654853	10	23.0	12	20.1	10	21.6
Rogers	1	27.2	9	14.8	12	21.0
Mich 62-448-24	6	11.5	14	13.6	14	12.6
N. Y. 6005-19	14	7.7	16	16.9	11	12.3
Mich 62-449-22	7	12.7	13	8.4	15	10.5
N. Y. 6005-18	13	10.9	15	8.1	16	9.5
N. Y. 6005-15	11	6.4	17	6.1	17	6.3
N. Y. 6005-16	12	6.1	18	3.7	18	4.9

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

with a high percentage of plump kernels may be difficult in years of limited moisture such as the 1970-71 season.

Thin Kernels

Similar to plump kernels percentages, there were significant differences between entries at both locations for the percentage of thin kernels (Tables XIV and XV). The overall plot average for percentage thin kernels was 22.2 per cent. The location mean square for thin kernels indicated no significant difference in the average percentage of thin kernels in grain produced at each location (Table XVI). The Lahoma plots were more variable than the Stillwater plots with the Lahoma plots producing a range of 60.2 per cent compared to a 38.6 per cent range in the Stillwater plots. A highly significant location x entry interaction indicated that the entries responded differently to the environments of the two locations.

Official Grain Standards of the United States (33) specifies that barley classed as malting barley must not contain more than 15 per cent of barley and other materials which will pass through a 4-7/8/64" slotted sieve. Maltsters prefer grain with a lower percentage of thin kernels than this. In the present study the entries Era, Mich 62-447-34, Mich 62-447-18, Barsoy, Mich 62-447-30, Mich 62-447-10, Cass, and Mich 62-420-11, listed in order of increasing thin kernels content, produced grain with a two-test average under 15.0 per cent (Table III). These entries were significantly lower in thin kernel content than all other entries. The Oklahoma varieties Kerr and Rogers produced 23.9 per cent and 24.4 per cent thin kernels, respectively and were intermediate with respect to the other entries. The New York lines had high percentages

TABLE III

PERCENT THIN KERNELS

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent.No.	Loc.1 (%)	Rank	Loc.2 (%)	Rank	2-Test Avg. (%)
N.Y. 6005-16	12	44.1	1	62.3	1	53.2
N.Y. 6005-15	11	34.6	3	50.4	2	42.5
Mich 62-449-22	7	29.9	4	43.3	3	36.6
N.Y. 6005-18	13	25.2	7	41.1	4	33.1
N.Y. 6005-19	14	36.4	2	25.2	10	30.8
Mich 62-448-24	6	27.1	6	32.2	6	29.6
St 654853	10	28.8	5	27.4	7	28.1
Rogers	1	22.2	8	26.7	9	24.4
Kerr	2	9.1	15	38.7	5	23.9
St 654757	9	19.2	9	27.0	8	23.1
Mich 62-420-11	8	9.8	13	19.4	11	14.6
Cass	3	8.9	16	15.0	12	12.0
Mich 62-447-10	4	10.6	12	11.9	13	11.2
Mich 62-447-30	15	10.6	11	7.9	14	9.2
Barsoy	17	13.7	10	4.0	17	8.9
Mich 62-447-18	5	9.7	14	6.0	16	7.8
Mich 62-447-34	16	6.8	17	6.7	15	6.7
Era	18	5.5	18	2.1	18	3.8

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

of thin kernels. The New York line 6005-19 had the lowest percentage of thin kernels (30.8 per cent) of the New York entries. These findings indicate there is much room for improvement in the kernel size distribution of Oklahoma grown winter barley.

Thousand Kernel Weight

Genetic differences between entries for the component kernel weight were indicated by the significant effect of entries at both locations (Tables XIV and XV). The overall plot average thousand kernel weight was 27.8 g. Location mean square indicated no significant difference between the averages of the two locations (Table XVI). The location x entry interaction was significant at the .01 level of confidence, indicating the entries responded differently to the two location environments (Table XVI). The two locations were similar in the range of values for thousand kernel weight. Location one ranged from 21.2 g produced by N. Y. 6005-18 to 32.8 g produced by the two-row Michigan line 62-420-11. The Lahoma test ranged from 22.2 g produced by the New York line 6005-15, to 34.7 g produced by the Texas variety Era. Era had a two-test average of 32.9 g and was significantly higher in thousand kernel weight than all entries except Mich 62-447-18 which averaged 31.9 g. The two Oklahoma varieties Kerr and Rogers produced average thousand kernel weights of 26.7 g and 25.4 g, respectively, and were intermediate with respect to the other entries. The four New York lines produced thousand kernel weights ranging from 22.8 g for 6005-16 to 24.0 g for 6005-19 and these four entries were significantly lower in thousand kernel weight than all other entries.

If thousand kernel weight is considered as an index of extract

TABLE IV

THOUSAND KERNEL WEIGHT

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent.No.	Loc.1 (grams)	Rank	Loc.2 (grams)	Rank	2-Test Avg. (grams)
Era	18	31.2	2	34.7	1	32.9
Mich 62-447-18	5	31.0	4	32.9	2	31.9
Mich 62-420-11	8	32.8	1	30.4	8	31.6
Mich 62-447-34	16	31.1	3	31.9	4	31.5
Mich 62-447-30	15	30.1	6	32.2	3	31.2
Mich 62-447-10	4	30.7	5	31.3	6	31.0
Cass	3	29.7	8	31.5	5	30.6
Barsoy	17	25.9	13	31.2	7	28.6
St 654757	9	28.7	9	26.7	10	27.7
Mich 62-448-24	6	25.7	14	28.1	9	26.9
Kerr	2	30.0	7	23.3	16	26.7
Mich 62-449-22	7	26.9	10	26.3	11	26.6
St 654853	10	26.0	12	25.5	12	25.7
Rogers	1	26.7	11	24.1	15	25.4
N.Y. 6005-19	14	22.5	17	25.4	13	24.0
N.Y. 6005-18	13	21.2	18	25.3	14	23.3
N.Y. 6005-15	11	23.5	15	22.2	18	22.8
N.Y. 6005-16	12	23.1	16	22.6	17	22.8

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

as Den Hartog and Lambert (11) suggested, the Michigan lines appear to have a higher value as potential malting varieties than the other entries with the exception of Era. A thousand kernel weight above 30 g is desirable in malting barley. At location one, six entries produced thousand kernel weights above 30 g. These entries included the variety Era and the five Michigan lines 62-447-18, 62-420-11, 62-447-34, 62-447-30 and 62-447-10. These six entries along with the varieties, Cass and Barsoy, produced thousand kernel weights above 30 g at the Lahoma test.

Test Weight

The entry effect on test weight was significant at the .01 level of confidence at both locations (Tables XIV and XV). This indicates that genetic differences are present between entries for test weight. The Lahoma plots had an average test weight of 54.1 kg/hl and a range of 12.5 kg/hl. The Stillwater test had an average of 56.5 kg/hl and a range of 6.5 kg/hl. The 2.4 kg/hl difference between location averages was significant at the .05 level of confidence (Table XVI). The entries produced grain with higher test weight when planted at Stillwater than when planted at Lahoma. Location x entry interaction effect on test weight was significant at the .01 level of confidence. This interaction of entries with locations is best illustrated by the entries Barsoy and Kerr in Table V. Barsoy increased from 59.1 kg/hl at Stillwater to 62.1 kg/hl at Lahoma whereas Kerr decreased from 59.7 kg/hl at Stillwater to 53.4 kg/hl at the Lahoma test. The variety Barsoy produced grain with a two-test average test weight of 60.6 kg/hl which was significantly higher than all other entries (Table V). The

TABLE V

TEST WEIGHT

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent. No.	Loc. 1 (kg/hl)	Rank	Loc. 2 (kg/hl)	Rank	2-Test Avg. (kg/hl)
Barsoy	17	59.1	3	62.1	1	60.6
Mich 62-447-18	5	58.7	4	58.6	2	58.6
Cass	3	58.4	5	56.3	3	57.4
Mich 62-447-34	16	59.7	2	54.9	7	57.3
Kerr	2	59.7	1	53.4	11	56.6
Mich 62-447-10	4	58.1	6	55.0	5	56.6
Mich 62-447-30	15	57.3	8	55.7	4	56.5
Rogers	1	57.0	9	54.6	8	55.8
Era	18	57.0	10	53.7	10	55.3
Mich 62-448-24	6	54.1	15	55.0	6	54.5
St 654853	10	55.1	13	52.9	12	54.0
Mich 62-420-11	8	57.3	7	50.5	17	53.9
Mich 61-449-22	7	55.2	12	52.5	13	53.8
N. Y. 6005-15	11	55.5	11	52.0	14	53.7
N. Y. 6005-19	14	52.8	18	53.9	9	53.3
N. Y. 6005-16	12	55.0	14	51.0	16	53.0
St 654757	9	53.3	16	52.0	15	52.6
N. Y. 6005-18	13	53.3	17	49.6	18	51.4

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

Michigan lines ranked higher in test weight averages than the New York lines.

Official Grain Standards of the United States specify a test weight greater than 55.3 kg/hl as the lower acceptable value for test weight of barley classed as malting barley (32). Grade No. 1 malting barley must have a test weight above 60.5 kg/hl. The latter value is desired by maltsters. Eleven entries at the Stillwater test produced grain with test weights above 55.3 kg/hl while none of the entries had test weights above 60.5 kg/hl (Table V). Four entries at the Lahoma test produced grain with test weights above 55.3 kg/hl and one entry, Barsoy, produced grain which was above the Class 1 requirement of 60.5 kg/hl. All of the New York lines produced grain with two-test averages below the 55.3 kg/hl requirement for malting barley. The New York line 6005-15 had the highest test weight of the New York entries which was 53.7 kg/hl (Table V). If test weight is considered to be positively correlated with extract as several workers have found (11, 17, 28), then the Kentucky variety Barsoy, and the Michigan entries 62-447-18, Cass, and 62-447-34 should have more desireable extract potentials than other entries in this study. The Oklahoma varieties Kerr and Rogers had average test weights of 56.6 kg/hl and 55.8 kg/hl respectively, and were intermediate with respect to the other entries.

Yield

Differences among entries in yield were significant at the .01 level at both locations (Tables XIV and XV). This effect was expected because of the broad range in regions of development of the entries.

The Stillwater test had an average plot yield of 3,166 kg/ha and the Lahoma test averaged 2,907 kg/ha. The 259 kg/ha difference in average plot yield of the two locations was not statistically significant, indicating no difference in the location average yields (Table XVI). Location x entry interaction had a significant effect ($P < .01$). This indicated that the entries tended to respond differently to the environments of the two locations with respect to yield. Indicative of this differential response were the two entries Era and Kerr. Era increased from 3,615 kg/ha at Stillwater to 4,119 kg/ha at Lahoma while Kerr decreased from 4,010 kg/ha at Stillwater to 3,253 kg/ha at Lahoma (Table VI).

The four commercial feed varieties Era, Kerr, Rogers and Barsoy ranked from first to fourth in the two-test yield averages. The Texas variety Era had a plot average of 3,867 kg/ha and was significantly higher than all entries except Kerr in the two-test averages (Table VI). The highest yielding New York line was 6005-18 with an average yield of 3,367 kg/ha. The highest Michigan line, 62-447-30, yielded 3,087 kg/ha and was sixth in the ranked two-test averages. The New York lines appeared to be better adapted to Oklahoma for yield than the Michigan lines. Cass, the Michigan released winter barley with malting potentials, produced a low yield of 2,546 kg/ha and was 16th in the two test averages.

Tillers

The effect of entries on the number of tillers/m^2 was significant at the .01 level of confidence at both locations (Tables XV and XVI). This indicated genetic differences among entries were present for this

TABLE VI

YIELD

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent.No.	Loc.1 (kg/ha)	Rank	Loc.2 (kg/ha)	Rank	2-Test Avg. (kg/ha)
Era	18	3615	3	4119	1	3867
Kerr	2	4010	1	3253	4	3632
Rogers	1	3926	2	2967	6	3451
Barsoy	17	3312	6	3421	2	3367
N.Y. 6005-18	13	3337	5	3396	3	3367
Mich 62-447-30	15	3203	8	2959	8	3081
St 654853	10	3304	7	2816	12	3060
Mich 62-449-22	7	3480	4	2613	14	3056
Mich 62-447-10	4	3152	9	2942	9	3047
N.Y. 6005-15	11	2984	13	2959	7	2972
Mich 62-448-24	6	3077	10	2858	10	2967
Mich 62-447-18	5	3035	11	2841	11	2938
Mich 62-447-34	16	3035	12	2673	13	2854
N.Y. 6005-19	14	2665	16	2993	5	2829
St 654757	9	2858	14	2329	17	2593
Cass	3	2598	18	2530	15	2564
Mich 62-420-11	8	2791	15	2261	18	2526
N.Y. 6005-16	12	2614	17	2370	16	2492

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

character. The Stillwater test had a plot average of 593 tillers/ m^2 compared to a plot average of 422 tillers/m^2 at the Lahoma test. The effect of locations on tillers/m^2 was significant at the .05 level. Entries produced more tillers/m^2 when planted at Stillwater than when planted at Lahoma (Table XVI). The location x entry interaction failed to reach significance indicating a uniform response of the entries to the two locations (Table XVI).

The four entries Kerr, Rogers, Barsoy, and St 654853 ranked from first to fourth respectively in the number of tillers/m^2 produced at each location (Table VII). The Oklahoma varieties Kerr and Rogers had two-test averages of 736 and 647 tillers/m^2,respectively. The highest ranked Michigan line in the two-test averages was Mich 62-447-34 which produced 541 tillers/m^2. The New York lines produced fewer tillers/m^2 than the Oklahoma varieties Kerr and Rogers. New York 6005-19 produced 448 tillers/m^2 and was the highest ranked New York line in the two-test averages. The Texas variety Era had a two-test average of 480 tillers/m^2 and was intermediate with respect to the other entries. Cass, the Michigan released winter malting barley, produced a low value of 423 tillers/m^2.

Rasmusson and Cannel (26) pointed out that the number of heads per plant is determined at an early stage of development in cereal crops. A greater moisture stress at the Lahoma test during early stages is a possible explanation for the lower number of tillers produced at Lahoma.

TABLE VII

TILLERS PER SQUARE METER

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent.No.	Loc.1	Rank	Loc.2	Rank	2-Test Avg.
Kerr	2	853	1	619	1	736
Rogers	1	767	2	527	2	647
Barsoy	17	722	3	487	3	604
St 654853	10	692	4	479	4	585
Mich 62-447-34	16	624	5	458	8	541
Mich 62-447-10	4	592	8	471	6	532
Mich 62-447-30	15	565	9	474	5	519
Mich 62-420-11	8	600	7	409	9	504
St 654757	9	606	6	401	11	503
Era	18	501	16	460	7	480
Mich 62-447-18	5	541	12	409	10	475
N. Y. 6005-19	14	541	11	355	12	448
Mich 62-449-22	7	536	13	353	14	444
Mich 62-448-24	6	533	14	350	16	441
N. Y. 6005-18	13	544	10	317	17	436
Cass	3	495	17	353	15	423
N. Y. 6005-15	11	527	15	315	18	421
N. Y. 6005-16	12	423	18	352	13	387

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

Kernels Per Spike

Genetic differences between entries for the kernels/spike component were indicated by the significant entry effect on this component at both locations (Tables XIV and XV). There was a uniform response of the entries to the two location environments indicated by the non-significant location x entry interaction effect (Table XVI). The Stillwater test had a plot average of 20.8 kernels/spike compared to the Lahoma test average of 26.4 kernels/spike. The 5.6 kernels/spike difference in the location averages was significant at the .05 level of confidence. Entries tended to produce more kernels/spike when planted at Lahoma than when planted at Stillwater. The Stillwater test ranged from 14.7 kernels/spike produced by Mich 62-420-11 to 29.8 kernels/spike produced by N. Y. 6005-18. The range at the Lahoma test was from 18.2 kernels/spike produced by Mich 62-420-11 to 44.8 kernels/spike produced by N. Y. 6005-18. The wider range of values at the Lahoma test indicated that the plots at Lahoma were more variable than the plots at Stillwater.

The four New York lines excelled in the production of kernels/spike by producing the four highest two-test averages (Table VIII). the New York line N.Y. 6005-18 ranked first in the two-test averages with 37.3 kernels/spike. Mich 62-449-22 was the highest ranked Michigan line with a two-test average of 27.4 kernels/spike. The Oklahoma varieties Kerr and Rogers averaged 19.6 and 22.1 kernels per spike and ranked 15th and 8th respectively.

Germination Energy and Capacity

The effect of entries on germination energy was significant at

TABLE VIII

KERNELS/SPIKE

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent.No.	Loc.1	Rank	Loc.2	Rank	2-Test Avg.
N. Y. 6005-18	13	29.8	1	44.8	1	37.3
N. Y. 6005-15	11	25.3	4	42.0	2	33.6
N. Y. 6005-16	12	27.2	2	33.7	4	30.4
N. Y. 6005-19	14	21.7	7	34.0	3	27.8
Mich 62-449-22	7	25.9	3	28.9	6	27.4
Mich 62-448-24	6	22.7	6	29.6	5	26.1
Era	18	24.5	5	26.2	7	25.3
Rogers	1	20.5	8	23.7	8	22.1
St 654853	10	18.6	11	22.8	12	20.7
Cass	3	18.3	12	23.0	10	20.6
Mich 62-447-18	5	19.1	10	21.7	14	20.4
Barsoy	17	17.9	14	22.8	11	20.3
St 654757	9	17.3	15	22.5	13	19.9
Mich 62-447-30	15	19.6	9	20.1	15	19.8
Kerr	2	16.0	17	23.3	9	19.6
Mich 62-447-10	4	18.2	13	20.0	16	19.1
Mich 62-447-34	16	16.9	16	18.7	17	17.8
Mich 62-420-11	8	14.7	18	18.2	18	16.4

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

TABLE IX

GERMINATION ENERGY

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent.No.	Loc.1 (%)	Rank	Loc.2 (%)	Rank	2-Test Avg. (%)
Mich 62-447-18	5	98.0	2	100.0	1	99.0
Era	18	97.5	3	100.0	2	98.8
Cass	3	98.0	1	98.5	11	98.3
Mich 62-447-34	16	96.8	4	99.5	5	98.1
Mich 62-447-10	4	96.8	5	98.5	13	97.6
N.Y. 6005-18	13	95.8	9	99.3	6	97.5
Mich 62-447-30	15	96.3	8	98.5	12	97.4
Barsoy	17	96.3	7	98.3	14	97.3
N.Y. 6005-19	14	96.5	6	96.8	17	96.6
Mich 62-448-24	6	95.5	10	97.5	16	96.5
Rogers	1	90.0	11	100.0	3	95.0
N.Y. 6005-15	11	90.0	12	98.0	15	94.0
Kerr	2	88.8	13	99.0	9	93.9
St 654853	10	85.8	15	99.8	4	92.8
Mich 62-420-11	8	86.0	14	99.0	8	92.5
Mich 62-449-22	7	83.8	17	99.3	7	91.5
N.Y. 6005-16	12	84.5	16	95.8	18	90.1
St 654757	9	77.3	18	98.8	10	88.0

Averages not connected by the same line are significantly different at the .05 level of probability.

TABLE X

GERMINATION CAPACITY

LOCATION AVERAGES BY ENTRY AND DUNCAN'S SIGNIFICANT RANGES FOR TWO-TEST AVERAGES

Entry	Ent. No.	Loc. 1 (%)	Rank	Loc. 2 (%)	Rank	2-Test Avg. (%)	
Era	18	98.8	1	100.0	1	99.4	*
Mich 62-447-18	5	98.0	2	100.0	2	99.0	*
Cass	3	98.0	3	99.0	12	98.5	*
Mich 62-447-34	16	96.8	7	99.5	6	98.1	*
Barsoy	17	97.5	4	98.8	14	98.1	*
Mich 62-447-10	4	97.3	5	99.0	10	98.1	*
Mich 62-447-30	15	96.3	8	99.0	11	97.6	* *
N. Y. 6005-18	13	95.8	9	99.3	7	97.5	* *
N. Y. 6005-19	14	97.3	6	96.8	17	97.0	* *
Mich 62-448-24	6	95.8	10	97.8	16	96.8	* *
Rogers	1	92.0	11	100.0	3	96.0	* * *
St 654853	10	89.0	13	100.0	4	94.5	* * *
Kerr	2	89.0	14	99.8	5	94.4	* * *
N. Y. 6005-15	11	90.3	12	98.3	15	94.3	* * *
Mich 62-420-11	8	86.8	15	99.0	9	92.9	* * *
Mich 62-449-22	7	85.0	17	99.3	8	92.1	* *
N. Y. 6005-16	12	95.3	16	96.0	18	90.6	* *
St 654757	9	78.8	18	98.8	13	88.8	*

Two-test averages not connected by the same line are significantly different at the .05 level of probability.

the Stillwater test but failed to reach significance at the Lahoma test (Tables XIV and XV). Germination capacity was significantly affected by entries at both locations. The statement by Anderson, Sallans, and Meredith (5) indicating that germination appears to be controlled mainly by environmental factors is supported by the results of this study. The failure of entry effects on germination to reach significance at location two and the large magnitude of location mean square in comparison with entry mean square for germination energy and germination capacity in the combined locations analysis of variance indicate that location of growth was the major source of variation in germination energy (Table XVI). Grain from the Stillwater test had an average germination energy of 91.8 per cent compared with the Lahoma test average of 98.7 per cent. Stillwater had an average germination capacity of 92.6 per cent while Lahoma had an average of 98.9 per cent. The location effect on germination energy and germination capacity was significant at the .01 level of confidence (Table XVI). Entries produced more viable grain when grown at Lahoma than when grown at the Stillwater location. Location x entry interaction effect on germination was significant at the .01 level (Table XVI) indicating that the entries had a differential location response for germination energy.

The Stillwater test ranged from 77.3 per cent germination energy for St 654757 to 98.0 per cent for Cass and Mich 62-447-18. The Lahoma test ranged from 95.8 per cent germination energy for N.Y. 6005-16 to 100 per cent for Mich 62-447-18 and Era. A germination energy of greater than 95 per cent is needed for the production of high quality malt. With proper cultural practices and proper storage of grain after harvest, germination should present no problem to the production of malting barley in Oklahoma.

Plant Height

Plant height was observed at Stillwater only. Entry effects were significant at the .01 level of confidence indicating genetic differences were present between entries for the character plant height (Table XIV). Entries tended to be associated in groups according to region of development (Table XI). The Oklahoma entries ranged from 69.9 cm for Kerr to 75.6 cm for St 654757 and were the tallest as a group. St 654757 was significantly taller than all other entries. The Michigan entries were intermediate in plant height and ranged from 60.3 cm for Mich 62-448-24 to 68.6 cm for the Michigan variety Cass. The New York lines were shortest as a group and ranged from 50.2 cm for N.Y. 6005-19 to 60.3 cm for N. Y. 6005-15. The Kentucky variety Barsoy was relatively short with a plot average of 52.1 cm and ranked 17th.

Heading Date

Heading date was observed at Stillwater only. Entry effects on heading date were significant at the .01 level of confidence indicating that genetic differences were present for this character (Table XIV). The location average heading date was 113 days after January 1 which was April 22. The latest maturing entry in the location average was Mich 62-420-11 (Table XII). The Oklahoma entries were quite uniform as a group with a one day range in average heading date. Rogers and Kerr both averaged 117 days as their plot heading date. The New York entries were all intermediate in heading date. The earliest maturing

TABLE XI

HEIGHT

DUNCAN'S SIGNIFICANT RANGES FOR LOCATION ONE AVERAGES

Entry	Ent. No.	Loc. 1 (cm.)
St 654757	9	75.6
Rogers	1	70.5
St 654853	10	69.9
Kerr	2	69.9
Cass	3	68.6
Era	18	66.7
Mich 62-449-22	7	65.4
Mich 62-447-10	4	64.8
Mich 62-447-30	15	63.5
Mich 62-447-18	5	63.5
Mich 62-447-34	16	62.2
Mich 62-420-11	8	62.2
Mich 62-448-24	6	60.3
N. Y. 6005-15	11	60.3
N. Y. 6005-18	13	57.2
N. Y. 6005-16	12	55.9
Barsoy	17	52.1
N. Y. 6005-19	14	50.2

Averages not connected by the same line are significantly different at the .05 level of probability.

TABLE XII

HEADING DATE[1]

DUNCAN'S SIGNIFICANT RANGES FOR LOCATION AVERAGES

Entry	Ent. No.	Loc. 1
Mich 62-420-11	8	119
St 654757	9	118
Rogers	1	117
St 654853	10	117
Kerr	2	117
Mich 62-449-22	7	116
N. Y. 6005-15	11	114
N. Y. 6005-16	12	114
Mich 62-448-24	6	114
N. Y. 6005-19	14	112
N. Y. 6005-18	13	111
Mich 62-447-30	15	110
Era	18	109
Cass	3	109
Mich 62-447-10	4	109
Mich 62-447-18	5	109
Mich 62-447-34	16	109
Barsoy	17	108

Averages not connected by the same line are significantly different at the .05 level of probability.

[1]Values correspond to days after Jan. 1, 1971.

New York line was 6005-18 which headed at 111 days and the latest maturing N. Y. line was 6005-15 which headed at 114 days. The Kentucky variety Barsoy had the earliest average maturity with an average of 108 days.

Heading date as a measure of maturity is important to the individual breeder as it relates to the specific region of intended production. In Oklahoma early maturing varieties do better in the majority of years because these varieties escape some of the moisture stress and disease hazards generally present during the latter part of the growing season.

Correlation

Simple correlations for all possible pairs of characters are presented in Table XIII. A significant positive correlation was found between yield and test weight; higher yielding entries tended to produce grain with a higher test weight. This finding is in agreement with other workers (11, 17, 28). Den Hartog and Lambert (11) found that bushel weight was positively correlated with yield when simple coefficients and partial coefficients of the fifth order were calculated from 150 F_5 lines of ten barley crosses. They concluded that bushel weight appeared to be a fairly reliable criterion of yielding ability. Rutger, Schaller, and Dickson (28) found a positive correlation between test weight and plump kernel percentages in the F_4 generation of an intervarietal malting barley cross. Den Hartog and Lambert (11) found a positive association between average kernel weight and bushel weight. In the present study, the positive correlation of bushel weight with thousand kernel weight and plump kernels percentage approached but

Table XIII

SIMPLE CORRELATIONS
(102 d.f.)

	PROTEIN CONTENT	PLUMP KERNELS	MEDIUM KERNELS	THIN KERNELS	GERM. ENERGY	GERM. CAPACITY	TILL/M^2	YIELD	KERNEL WEIGHT	KERNELS/ SPIKE	HEADING DATE[1]	HT.[1]
TEST WEIGHT	-.054	+.193	-.048	-.122	-.015	+.018	-.005	+.238*	+.141	+.173	+.236	+.191
PROTEIN CONTENT		-.289**	-.167	+.408**	-.190	-.228*	+.119	-.394**	-.173	-.280**	+.151	-.243
PLUMP KERNELS			-.379**	-.527**	-.030	-.035	+.004	+.197*	+.187	+.064	+.051	+.050
MEDIUM KERNELS				-.586**	+.138	+.119	+.007	+.196*	+.311*	+.081	-.356**	+.059
THIN KERNELS					-.106	-.084	-.012	-.353**	-.446**	-.131	+.300*	-.098
GERM. ENERGY						+.968**	+.006	+.118	-.034	-.034	-.137	-.212
GERM. CAPACITY							-.034	+.121	-.051	+.002	-.153	-.175
TILL/M^2								+.089	-.045	-.655**	+.029	-.129
YIELD									+.192	+.443**	-.139	+.267
KERNEL WEIGHT										-.034	+.134	+.070
KERNELS/ SPIKE											-.119	+.094
HEADING DATE												-.141

*Significant at the .05 level of probability.
**Significant at the .01 level of probability.
[1]These variables observed at location one only. Combinations involving them computed with 51 d.f.

failed to reach .05 level of significance in both instances. The failure of these correlations with test weight to reach significance could possibly be explained by the broad differences in threshability of the entries.

Protein content was positively correlated with thin kernels and negatively correlated with plump kernels. This relationship is desirable from the standpoint of the malting barley breeder in that a high plump kernel percentage and low protein are both desired in malting barley. These results indicate that the breeder could select for kernel plumpness and as a secondary result of this selection obtain lower protein content. Correlation of protein content and germination capacity was significant ($P < .05$) and negative. High kernel protein content appears to be detrimental to high germination. High protein content in malting barley causes erratic germination of the grain (6). A significant negative correlation of protein content with yield indicated that the higher yielding entries produced grain with lower protein content. Neatby and McCalla (25) also found a marked tendency for high yielding lines and varieties to be low in protein. Den Hartog and Lambert (11) found yield to be negatively associated with protein when simple and partial correlations were calculated from 150 F_5 lines from ten barley crosses. This association of low protein with high yields is desirable from the malting barley standpoint. Producers can increase malting quality by decreasing protein as a result of management for maximum yields.

Plump and medium kernels were positively correlated with yield and thin kernels showed significant negative correlation with yield. This indicates that high yielding entries would produce grain more desirable for malting purposes because of the larger kernel size. Rutger, et al. (29) found correlations between kernel plumpness and yield to be significant and positive when 102 random F_4 lines from an intervarietal cross were evaluated. This relationship also indicates that the producer can manage for maximum production and as a secondary effect increase the malting quality of the barley produced.

At the Stillwater test, per cent medium kernels was negatively correlated with heading date and per cent thin kernels was positively correlated with heading date. This indicated that early maturing entries had more favorable conditions during their kernel filling period. This relationship was most likely due to the increasing moisture stress during the latter portion of the growing season. The positive association of plump kernels with earliness indicates that the breeder should select early maturing lines to get maximum kernel plumpness.

Number of tillers per square meter had a high negative correlation with kernels per spike. This indicates that entries producing a high number of kernels per spike tended to have fewer tillers per square meter and entries with a high number of tillers tended to have a lower number of kernels per spike. Adams (1) attributed such negative correlations between yield components to compensatory effects. Ketata (33) reported a high negative correlation between tillers per unit area and kernels per spike when three varieties of hard red winter wheat were studied at Stillwater. The negative relationship between kernels per spike and tillers per unit area could constitute a hinderance to selection based on these yield components. The breeder would have to select for the combination of kernels per spike and tillers per unit area which gave maximum yields.

A relatively high positive correlation of yield with kernels per spike was present. Entries producing a high number of kernels per spike tended to yield higher than entries with a low number of kernels per spike. Kernels per spike was the only yield component which showed significant correlation with yield. The positive correlation of yield with kernel weight approached significance but the correlation between yield and tillers per unit area was low and non significant. Ketata (33) found that kernel weight was more closely correlated with yield than tiller number or kernels per spike.

Protein content was negatively correlated with the number of kernels per spike. This indicates that kernels from entries which had a high number of kernels per spike were lower in protein content than kernels from entries which produced a low number of kernels per spike. This negative correlation between protein and kernels per spike could possibly be due to the higher yield associated with a larger number of kernels per spike.

CHAPTER V

SUMMARY AND CONCLUSIONS

The primary objectives of this study were: (1) to investigate the possibility of producing a winter malting barley in Oklahoma; and (2) to survey 18 winter barley lines and varieties as possible winter malting barleys for Oklahoma or sources of germplasm for use in the development of a winter malting barley for Oklahoma.

Agronomic and malting characteristics were evaluated for each of eighteen entries grown in replicated nursery plots at two locations. Characters analyzed were: yield, tillers/m^2, kernels/spike, kernel weight, kernel size assortment, germination, and kernel protein content. Plant height and heading date were observed at location one only. Analyses of variance were calculated from the data of each location individually and the combined data of the two locations. Simple correlations were calculated using two-location data for combinations not involving plant height or heading date. Two-location entry averages for each character were ranked into groups which were significantly different at the .05 level of probability using Duncan's multiple range test.

Analyses of variance indicated that significant differences between entries were present at both locations for all characters except germination energy. The analysis of variance of location two indicated no significant differences between entries for germination energy. Significant differences between locations existed for all characters except plump and thin kernels, kernel weight, and yield. Tillers/m^2 and kernels/spike were the only characters not showing significant location x entry interaction.

The more important characters in this study in relation to acceptability of the grain for malting purposes were protein content, kernel size assortment, kernel weight, test weight, and germination. The five Michigan entries 62-447-34, 62-447-18, Cass, 62-447-30, and 62-447-10 showed more potential for protein content than the other entries in this study. These five entries produced grain at location two which was in the preferred range for protein content of less than 12.5 per cent and were significantly lower in two-test averages than all other entries. Protein content was a limiting factor at location one where all entries produced grain with greater than the upper desired value of 12.5 per cent. The two entries, Era and Barsoy, produced grain at location two which was in the desired range for kernel plumpness of greater than 60 per cent. These two entries showed higher potential for kernel size assortment by producing significantly higher two-test averages than all other entries for plump kernels and two-test averages of less than 10 per cent thin kernels. Kernel plumpness was a limiting factor at location one where none of the entries produced greater than 60 per cent plump kernels. However, the F-test for equality of variances indicated no significant differences between the average percentage of plump kernels produced at the two locations.

Thousand kernel weights above 30 g were produced by the five Michigan lines, 62-447-18, 62-420-11, 62-447-34, 62-447-30, 62-447-10, and the Texas variety, Era, at both locations. The entries Cass, Barsoy, and St 654757, were not significantly lower in two-test average kernel weights than the above entries. The New York entries revealed very little potential for kernel weight and produced significantly lower average kernel weights than all other entries. The variety Barsoy which had a two-test average test weight of 60.6 kg/hl was significantly higher in test weight than all other entries in this study. Eleven entries at location one produced test weights above the lower limit of 55.3 kg/hl specified by the U. S. Grain Standards for malting barley. Four entries at location two were above this value. Location one had a significantly higher average test weight than location two.

Germination energy and capacity were indicated to be more affected by location of growth than by entry effects by the large magnitude of the location mean square in comparison with the entry mean squares present in the combined analysis of variance. Location two had a high average germination energy of 98.7 per cent.

Simple correlations indicated an association of high yield with the desirable malting barley characters of high test weight, high percentages of larger kernels, low percentages of thin kernels, and low protein content. These correlations indicate that management practices aimed at increasing yields would tend to increase the malting quality of the barley produced. Earliness was found to be desirable because of the higher percentage of large kernels associated with early maturity at location one. The only correlation which could possibly interfere with breeding procedures was the high negative correlation between tillers/meter^2 and kernels/spike.

It was concluded from this study that the entries Cass, Barsoy, Michigan lines: 62-447-30; 62-447-34; 62-447-18; 62-447-10; 62-420-11, and Era possess potential as germplasm for improvement of characters important in malting barley. None of the entries were high enough in all desired characteristics studied to be considered for direct use as a commercial malting barley for Oklahoma. Moisture stress could limit the production of barley acceptable for malting purposes in some years by causing the production of small kernel size and high protein content. It appears that a high quality malting barley could be produced in years when moisture is not extremely limiting. However, more research is needed on the quality of malt produced from barley grown in Oklahoma before the breeder can develop such a high quality malting barley for Oklahoma.

Cultural practices appear to have an intimate relationship to the production of malting barley. As malting qualities of Oklahoma grown winter barleys are studied and improved, the cultural practices which allow maximum expression of desirable malting quality characters should also be studied and developed. Different areas of the state such as the higher rainfall regions of eastern Oklahoma should also be investigated in relation to the production of malting barley.

TABLE XIV

LOCATION ONE ANALYSIS OF VARIANCE MEAN SQUARES

Source df	Replication 3	Entry 17	Error (Rep x Ent) 51
Height	44.30 **	175.36 **	9.06
Heading Date	1.87	59.56 **	1.64
Protein	0.76 **	2.86 **	0.10
Plump Kernels	131.34 **	875.89 **	28.49
Medium Kernels	13.01	217.66 **	29.93
Thin Kernels	74.71	557.96 **	31.70
Tillers/Meter^2	160088.00	45021.00 **	8327.50
Yield	36976.00	670602.00 **	113881.00
Kernel Weight	0.30	48.21 **	1.38
Test Weight	7.05 *	20.48 **	2.24
Germination Energy	6.75	156.50 **	15.81
Germination Capacity	4.20	137.27 **	14.84
Kernels/Spike	237.13 **	71.41 **	17.38

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

TABLE XV

LOCATION TWO ANALYSIS OF VARIANCE MEAN SQUARES

Source df	Replication 3	Entry 17	Error (Rep x Ent) 51
Protein	1.0	5.20	0.21
Plump Kernels	312.67 **	1416.50 **	27.93
Medium Kernels	20.49	367.72 **	31.67
Thin Kernels	417.40 **	1209.10 **	42.50
Tillers/Meters^2	8015.90	26464.00 **	6214.40
Yield	1033337.00 **	809048.00 **	161425.00
Kernel Weight	20.03 **	62.34 **	1.83
Test Weight	35.56 **	35.36 **	5.17
Germination Energy	1.27	5.26	2.87
Germination Capacity	1.04	4.95 *	2.35
Kernels/Spike	51.68	237.84 **	41.08

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

TABLE XVI

COMBINED LOCATIONS ANALYSIS OF VARIANCE MEAN SQUARES

Source	Error 1 (Rep in Loc)	Location	Error 2 (a)[1]	Entry	Loc x Ent
df	6	1	102	17	17
Protein	0.88	11.06 *	0.153	6.75 **	1.30 **
Plump Kernels	222.0	4.03	28.2	1889 **	448 **
Medium Kernels	16.76	896.5 **	30.8	397 **	197 **
Thin Kernels	245.6	1007	37.1	1546 **	221 **
Tillers/Meter^2	84052	1054844*	7271	64319 **	7167
Yield	535156	241851	137653	1180093**	299557 *
Kernel Weight	10.17	8.75	1.61	93.7 **	16.8 **
Test Weight	21.31	202.4 *	3.71	43.3 **	12.6 **
Germ. Energy	4.01	1681 **	9.34	83.0 **	78.7 **
Germ. Capacity	2.62	1412 **	8.59	75.2 **	67.0 **
Kernels/Spike	144	1152 *	29.23	266 **	42.8

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

[1]a represents replications x entries in locations

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VITA

James Allan Gilchrist

Candidate for the Degree of

Master of Science

Thesis: AGRONOMIC AND MALTING CHARACTERISTICS OF EIGHTEEN VARIETIES AND EXPERIMENTAL LINES OF WINTER BARLEY GROWN IN OKLAHOMA

Major Field: Agronomy

Biographical:

Personal Data: Born in Mooreland, Oklahoma, November 15, 1947, son of Jack and Genevive Gilchrist.

Education: Graduated from Seiling High School, Seiling, Oklahoma, in 1966. Received Bachelor of Science degree in Agronomy from Oklahoma State University in 1971. Completed requirements for the Master of Science degree in May, 1972.

Professional Experience: Graduate Assistant, Department of Agronomy, Oklahoma State University, Stillwater, Oklahoma, January, 1971 to May, 1972.