RELATIONSHIP OF SPIKE DENSITY WITH GRAIN QUALITY AND AGRONOMIC CHARACTERS IN SIX-ROWED WINTER BARLEY

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QUALITY AND AGRONOMIC CHARACTERS

IN SIX ROWED WINTER BARLEY

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

CHAPTER I

INTRODUCTION

Developing barley (_Hordeum vulgare_ L.) cultivars with acceptable malting and brewing quality, requires selection for a large number of quality and agronomic characters. Barley breeders are faced with the task of developing cultivars with improved grain yield, yield stability, and the proper pattern of quality characteristics to meet the demands of producers as well as those of the malting and brewing industry. Progress is often slow due to rigid quality demands and various inherent relationships that appear to exist between quality and agronomic characters. A change of one character may cause an unacceptable change in one or several others.

The major objective in the Oklahoma barley breeding program is to develop productive, winter-hardy barley cultivars with suitable malting characteristics. Presently there is no production of malting barley within the state, however, projections by the malting and brewing industry indicate that production of winter malting barley in Oklahoma may well be needed to meet future demands. In this regard, Busch Agricultural Resources, Inc., St. Louis, Missouri, has provided substantial research grants during the past five years to assist the Oklahoma State University barley breeding program in its efforts to develop winter-type malting barleys. Traditionally, Oklahoma barleys were feed barleys which are characterized by relatively compact spikes.

However, a lax spike would appear to be more desirable since cultivars with this character produce grain which is more acceptable for malting purposes. Consequently, there is an interest in utilizing lax spike barley types in the breeding program. Information concerning the relationships of spike density with important agronomic and quality characters would be helpful to the breeder. Therefore, the objectives of this study were to determine: 1) the relationship of spike density vs. grain quality characters, 2) the relationship of spike density vs. grain yield, 3) the relationship of grain yield vs. grain quality characters and, 4) genotype performance over several locations and years.

CHAPTER II

LITERATURE REVIEW

In the development of new malting barley cultivars in the U.S.A., the germplasm base has been relatively narrow. Eslick and Hockett (1975) reviewed the pedigrees of Midwestern barleys and indicated that no more than eleven outside germplasm sources have been introduced since 1900. The use of a narrow germplasm base is mandated by rather specific requirements which must be met if a new cultivar is to be accepted by the malting and brewing industry. Acceptable cultivars for malting and brewing are found only in crosses between relatively high quality parents, which almost without exception are closely related spring types (Wych and Rasmusson, 1983).

Winter barley cultivars are currently considered as unsuitable for malting purposes because of high kernel protein content and or kernel color (Peterson and Foster, 1973). However, in Europe, improved hardiness of recently released six-rowed winter types, along with yield advantages seen by producers, have caused some malsters and brewers to use the plentiful supplies of six-rowed winter types (Burger and LaBerge, 1985).

In the U.S.A., a candidate cultivar must meet rigid requirements for malting and brewing. Peterson and Foster (1973), and Berger and LaBerge (1985) reviewed malting requirements and presented a list of recommended values for malting quality characteristics. They suggested acceptable values for kernel shape, kernel size, hull characteristics, grain protein, and germination percentages which would be desirable for malting processes. Their report also included the industry requirements for malt factors and the desired values for each. Malt factors were: total protein, soluble protein, soluble/total protein ratio, extract (fine grind), fine-coarse grind difference, diastatic power, alpha amylase, wort viscosity, and wort turbidity. Anderson and Reinbergs (1985) stated that characters which can be easily identified are: kernel plumpness, germination, protein content, soluble protein, extract, and enzyme activity.

Barley breeders have been exploring the possibilities of early generation selection for those quality characters which are easily identified. Foster et al. (1967) used predication tests in the F_2 generation as a basis for selection in the F_3 generation. However, based on heritability estimates and correlation coefficients, their results were unsatisfactory. Rasmusson and Glass (1965), and Foster et al. (1967) found that heritabilities in the F_3 generation were relatively high for diastatic power, intermediate for kernel plumpness, and low for extract and protein. Foster et al. (1967) indicated that progress should be possible when selecting for those characters in the F_3 generation. Rasmusson and Glass (1965), however, said that diastatic power could be easily influenced by selection in the F_3 or later generations but gains for kernel plumpness, extract, and protein were so low as to raise doubts about routine testing in the F_3 generation. Indeed, Piper and Rasmusson (1984) recommended screening and selection in later generations for those characters with intermediate or low heritabilities.

The difficulties that breeders face in screening for malting and brewing quality within segregating generations, can be complicated by inherent relationships that exist among malting characters. This has been pointed out by several researchers. Grain protein was found to be positively correlated with diastatic power which is undesirable. Extract was negatively correlated with diastatic power which was another undesirable relationship. However, a desirable relationship was noted between extract and grain protein which was negatively correlated (Rasmusson and Glass, 1965, Foster et al., 1967, Peterson and Foster, 1973). These relationships among quality characters demonstrate some potential difficulties breeders face when attempting to improve one character while maintaining desired levels of others. However, improvements have been made in many malting and brewing characters as well as in agronomic traits (Wych and Rasmusson, 1983).

Breeding to improve grain yield is based upon manipulation of biomass and yield components to maximize economic yield per unit area (Simmonds, 1979). Rasmusson and Cannell (1970) found that indirect selection for yield through yield components was very effective in certain situations but could not be recommended as a routine procedure since yield components are determined at different times in the growth cycle of the plant which allows them to be differentially affected by variations in the environment. In a study of developmental allometry and its implication to grain yield in barley; Hamid and Grafius (1978) measured tillers/unit area, kernels/spike, kernel weight, leaf area, and culm diameter. They found that culm diameter was positively correlated with leaf area and number of kernels/spike. In addition, leaf area was positively correlated with number of kernels/spike. Grafius et al.

(1976) had previously reported negative correlations between spikes/unit area and number of kernels/spike and between number of kernels/spike and kernel weight. They found that as grain yield increased, negative correlations between those variables intensified. This was believed to be due primarily to component compensation. Benbelkacem et. al. (1984) found that kernel plumpness was positively correlated with kernel weight. They also reported that high tillering genotypes could be characterized as having a lower percentage of plump kernels and a smaller culm diameter which resulted in a greater degree of lodging. Simmons et al. (1982) concluded there was no clear advantage for any particular tillering capacity in achieving high yields. Grafius et al. (1976) said that grain yield was most highly dependent upon some intermediate level of number of kernels/spike, with appropriate balances of number of spikes/unit area and kernel weight. Puri et. al. (1982), and Rasmusson (1987) identified kernel weight and kernel weight/spike as having stronger direct effects on improving grain yield than other characters.

A number of plant breeders have also studied relationships between agronomic and quality characters. Den Hartog and Lambert (1953), and Peterson and Foster (1973) found that grain yield was positively correlated with extract and kernel plumpness, and negatively correlated with grain protein. In manipulating these agronomic and quality components a breeder may, however, encounter difficulties. Grafius (1978) reported that traits arising simultaneously from the same meristem will be harder to manipulate independently than those separated in space and time. If strong correlations exist between characters which arise from the same meristem simultaneously, it should be expected that manipulating them independently would be difficult because of minimal cause and effect expression. He also stated that component size and numbers have an inverse relationship.

According to Rasmusson (1987), certain morphological characters can be extremely important to grain yield. The most outstanding example of this was found in the improvement of yield via selection for short stature in wheat, sorghum, and rice. The malting industry also has preferences concerning the morphology of the barley plant. Hoskins (1982) indicated that the malting industry currently favors barley genotypes with lax spikes. The preference arises from the belief that plants with lax spikes shed moisture from the spike more readily. Furthermore, since the seed are spaced at greater intervals, they can dry more quickly. This quick-dry capability should tend to reduce fungal growth on the kernel of the barley and hence result in brighter colored grain which is highly desirable. This may or may not be true. This author has found no reference in the literature to support or disprove these views.

Utilizing isogenic lines derived from a cross between a two-rowed barley and a six-rowed barley, McGuire and Hockett (1983) studied the effect of the lax spike character on certain malting quality characters. In their study, the lax spike character was associated with reduced kernel weight, reduced wort nitrogen:malt nitrogen ratio, and reduced alpha amylase activity, all of which are undesirable. In a study of agronomic and quality characters, however, Den Hartog and Lambert (1953) found little or no association of spike density with other characters.

Researchers have indicated that inheritance of spike density is not clearly understood and stated that spike density is determined by multiple factors (Smith, 1951). Brinkman and Luk (1979) found that barley genotypes which were typified as having nodding heads in which the spikes were bent beyond ninety degrees from vertical were brighter in kernel color. They suggested that barley breeders should consider both natural kernel brightness and spike nodding angle as selection criteria for developing varieties with improved kernel brightness. It appears that additional investigations are needed to resolve questions concerning the effects of spike density in relation to malting quality and agronomic characters.

CHAPTER III

MATERIALS AND METHODS

Eight winter barley genotypes were included in this study. They were: 'ORWF8328','ORFB75075-1','ORWF8011' from Oregon; 'WA1430-77','Kamiak', and 'Showin' from Washington; 'Wintermalt' from New York; and 'OK82850' from Oklahoma. These genotypes, all six-rowed barleys, were chosen because they represent a range of spike densities, plant type, grain yield potential, malting quality, and genetic background. Wintermalt was chosen as a check cultivar for its malting characteristics. Wintermalt was developed in New York and released jointly by Cornell University and Oklahoma State University. The eight genotypes are listed in Table 1 in order of their spike densities from lax to compact. These genotypes were entries grown in the Western Winter Barley Regional Nursery which is normally grown at a number of locations in barley producing areas of the Western United States.

This study consists of three separate experiments using the eight barley genotypes. The first experiment was conducted over four regional locations in 1984 and is hereafter referred to as the regional tests. The four regional locations were: Goodwell OK, Farmington NM, Aberdeen ID, and Logan UT. The second experiment was conducted at Goodwell over two years. Data were collected at Goodwell in 1986 and combined with the 1984 Goodwell data for use in a two year study for subsequent analyses. The third experiment was conducted in the greenhouse at

Stillwater OK in 1985 and 1986. All plots in the three experiments were irrigated. Agronomic procedures and fertilizer applications were made according to good crop husbandry procedures.

REGIONAL TESTS

Measurements were taken at the following four locations in the 1984 season: Goodwell, Farmington, Aberdeen, and Logan. Soil types for these four locations are given in Table 2. Spike samples and yield data were obtained from those four stations in the 1984 Western Winter Barley Regional Nursery for subsequent measurements and analyses. Project leaders at Logan, Farmington, and Aberdeen provided spike samples and performance data from their respective stations. At maturity six typical spikes were harvested from each plot at random. All values used in the analyses were means from the six spikes sampled per plot, with the exception of grain yield. Spike density was measured in millimeters as the mean length of ten rachis internodes in the center of the spike. Kernels/spike were determined by counting the number of kernels on each of six spikes. Kernel weight was obtained by dividing the kernel weight/spike by the number of kernels/spike. Percent grain protein was determined by the Kjeldahl method of analysis.

Grain yield was determined in slightly different fashion at each regional location (see Table 3 for plot information). Grain yield was obtained by harvesting one row of each plot at Goodwell, and by harvesting the center two rows of each plot at Aberdeen. At Farmingtion and Logan, grain yield was obtained by harvesting the entire plot with a plot combine harvester.

Analyses of variance were conducted for each location and over all four locations for the six traits described above. All genotypes were ranked from high to low with the exception of percent grain protein which was ranked from low to high since low protein is desired for malting purposes. Simple correlations were calculated for all possible two-way comparisons of variables at each location and over locations.

GOODWELL TESTS

The eight winter barley genotypes mentioned earlier, were grown in a randomized complete block design in two years at Goodwell (1984 and 1986). Variables measured at Goodwell in 1986 were grain yield, spike density, kernels/spike, kernel weight, and percent grain protein and were measured as described above in the regional tests. Grain yield in 1986, however, was determined by harvesting the entire plot with a plot combine harvester. There were four replications in 1986. Plot size was 4.0 m^2 and seeding rates were 67.3 kg/ha in each test. Seeding and harvest dates in the 1984 test were 18 October 1983 and 28 June 1984 respectively. Seeding and harvest dates in the 1986 test were 10 October 1985 and 25 June 1986 respectively.

Analyses of variance and simple correlations were conducted for each year and over the two years of the study. Malting data corresponding to the 1984 and 1986 Goodwell Tests was obtained from the Cereal Crops Research Unit (Barley and Malt Lab), USDA, ARS, Madison, Wisconsin. These data are included for making comparisons, however, since the samples were bulks from the replicated tests, no analyses are provided for the twelve malting quality characters given.

GREENHOUSE TESTS

A study was conducted in a randomized complete block design with three replications over two years in the Small Grains Greenhouse at the Stillwater Research Station. Seeds were planted 12 December 1985 and 6

October 1986 in flats and placed in temperature controlled chambers for vernalization. After vernalization, seedlings were transplanted 29 January and 6 January in 1985 and 1986 respectively. Ten plants of each genotype were grown in 1.12 m rows with 30.5 cm spacings between rows. One row represented a plot.

At maturity each plant was harvested individually. The best spike from each plant was harvested separately. Plots were harvested 20 May and 27 May in 1985 and 1986 respectively. Variables measured in the greenhouse tests were grain yield, kernel weight/spike, spike density, kernels/spike, kernel weight, percent grain protein, harvest index, and grain color. The data were collected from the ten spikes per plot with the exception of grain yield, harvest index, and grain color which was measured on a sample from the entire plot.

Grain yield was determined by the weight of grain harvested per plot. Harvest index was obtained by harvesting the entire above ground part of the plant. The samples were allowed to air dry for two weeks after which the total plant weight (biomass) was recorded. Harvest index was calculated by dividing the total weight of grain by the biomass weight. Grain color was determined using an Agtron optic meter (model M-40-A) coupled with a scale meter (Agtron model M-31-A). Readings indicate percent of light reflected from grain samples. The Agtron meter was calibrated using a 00 and 63 filter for the zero and one hundred percent calibration respectively.

For the greenhouse tests, analyses of variance were conducted for each year and over years. Simple correlations were calculated on all variables for each year and over years.

CHAPTER IV

RESULTS AND DISCUSSION

REGIONAL TESTS

An analysis of variance for six traits was conducted for each of the regional locations (Table 4). Those locations were Goodwell, OK, Farmington, NM, Aberdeen, ID, and Logan, UT . Significant differences for genotypes were evident for all variables at Aberdeen and Farmington and all but grain yield at Goodwell. At Logan, significant differences for genotypes were detected for spike density, kernel weight, and grain yield. There were no differences between genotypes for percent grain protein, kernel weight/spike or kernels/spike at Logan.

Combined analysis of variance over the four regional locations showed significant differences among locations and genotypes for all six variables. Also, there were highly significant genotype by location interactions for all variables (Table 5).

Mean performance of the genotypes varied across locations and all six variables. However, spike density varied less than other traits across genotype rankings from location to location (Table 6, 7, and 8). Mean spike density was highest at Goodwell (3.09mm). Mean spike densities were: 2.86, 2.83, and 2.73mm at Logan, Aberdeen, and Farmington respectively (Table 6, 7, and 8). The group comprising the four most lax genotypes, based on the combined locations means (Table 8), were consistently grouped at Goodwell, Aberdeen, and Logan and differed at Farmington by only one genotype. Those four lax genotypes were: ORWF8328, WA1430-77, ORFB75075-1, and Showin at Goodwell , Aberdeen, and Logan. Based on the mean over locations ORWF8011 had the highest spike density (3.86mm) and Showin had the lowest (3.06mm).

Based on the mean of the eight genotypes, mean kernels/spike was highest at Goodwell (58.76) and lowest at Aberdeen (42.97). Four location means (Table 8) showed the highest genotype for kernels/spike had the lowest spike density (OK82850). Also, the top four genotypes for kernels/spike were ranked as the bottom four genotypes for spike density.

Mean kernel weight was highest at Logan (44.41mg) and lowest at Goodwell (34.22mg). Four location means (Table 8) showed that ORWF8011 was the highest ranking genotype (40.71mg) and OK82850 was the lowest (34.99mg).

The highest mean kernel weights/spike was reported at Logan (2.51g) and the lowest at aberdeen (1.70g). The four location means (Table 8) showed the top four ranking genotypes for Kernel weight/spike were also the four lowest ranking genotypes for spike density.

Grain protein was ranked from low to high. The lowest mean percent grain protein was reported at Farmington (9.83%) and the highest was reported at Aberdeen (11.73%) (Table 6 and 7). The four location means (Table 8) showed ORWF8011 was the lowest percent grain protein value and Kamiak had the highest.

Mean grain yield was highest at Farmington (7782 kg/ha) and lowest at Aberdeen (3797kg/ha)(Table 6 and 7). Four location means (Table 8) showed that 3 of the highest yielding genotypes were among the top four ranked genotypes for spike density. The genotype with the highest mean yield was also the highest for mean spike density (ORWF8328).

Coefficients of variation for grain yield were high at Goodwell and Aberdeen. This could have been due to heavy winter kill in some plots at Goodwell and at Aberdeen due to high levels of damage caused by Fusarium Snow Mold (*Fusarium nivale*). ORWF8011 was the highest ranking genotype averaged across variables at Goodwell and Aberdeen. The highest ranking genotypes over the variables of study at Farmington and Logan were ORWF8328 and WA1430-77 respectively (Table 6, 7, and 8).

Correlation coefficients between variables at each regional location are presented in Table 9. Significant negative correlations were observed between spike density and kernels/spike at Goodwell (r = -0.91**) and Logan (r = -0.72*). This suggests that as spike density increases the result may be fewer kernels/spike. Breeders should consider this when developing suitable cultivars. However, this relationship was non-significant at Farmington and Aberdeen. There were no significant relationships between spike density and kernel weight at any of the four regional locations. A significant positive correlation was observed for spike density and grain yield at Aberdeen (r = 0.76**), however, this relationship was not significant at any of the other three regional locations. The correlation between spike density and kernel weight/spike was significant only at Goodwell (r = -0.70**). Spike density and percent grain protein were significantly correlated only at Goodwell (r = 0.95**). This comparison was non-significant at the other three locations.

Correlations between kernels/spike and kernel weight/spike were significant at Goodwell (r = 0.84**), Farmington (r = 0.74**), and

Aberdeen (r = 0.94**). This comparison was non-significant at Logan (r = 0.54). Kernels/spike was negatively correlated with percent grain protein at Goodwell (r = -0.79**) and at Farmington (r = -0.84**). This comparison was non-significant at Aberdeen (r = 0.22) and Logan (r = 0.01) (Table 9).

Over the four regional locations there were only three comparisons which were correlated at levels of significance (Table 10). The number of kernels/spike was positively correlated with kernel weight/spike (r = 0.75**). This relation was known and is self evident. Grain yield was negatively correlated with percent grain protein. As grain yield increased, percent grain protein would be expected to decrease. Over locations (Table 10), spike density showed little or no relation with the other variables of this study. Although within individual locations spike density was correlated with several variables, these relations may be true only for that particular environment and year. Correlations of the five variables studied vs. spike density diminish across locations. Plant breeders should be able to develop lax spike barley genotypes for a particular area of adaptation without adversely altering the other five variables of this study.

GOODWELL TESTS

The analysis of variance for each year at Goodwell showed significant differences among genotypes for all variables except grain yield in each year (Table 11). In 1984 there were high levels of winter kill within plots which may explain the large coefficient of variation (C.V. = 24.27) for grain yield. Some plots suffered minor hail damage on 14 May 1986, which could explain the high coefficients of variation

(C.V. = 17.65) for the determination of grain yield for that year. The hail damaged some plots more than others due to differences in maturity.

The analysis of variance over the two year study at Goodwell showed significant differences between years for four of the six variables (Table 12). Spike density, kernel weight, percent grain protein, and grain yield were significantly different from one year of the study to the next. Significant differences were seen among genotypes for all variables with the exception of grain yield. Also, there were significant genotype by year interactions for all variables but grain yield.

Genotype performance and ranking changed from one year of the study to the next (Table 13). Even so; in each year the top four values for spike density, i.e. laxness, consisted of the same four genotypes. In each year of study and in the two years means OK82850 had the lowest spike density value and the highest value for kernels/spike (Table 13 and 14).

Simple correlation coefficients between variables differed slightly from the first year to the second at Goodwell (Table 15). In both years a significant negative correlation coefficient was found for spike density vs. kernels/spike. In 1984 a significant negative correlation was observed for spike density vs. kernel weight/spike (r = -0.70*). This relationship was negative but non-significant in 1986. Spike density vs. percent grain protein was significant and positive in 1984 but was non-significant in 1986. Kernels/spike was significantly correlated with kernel weight/spike in 1984 (r = 0.84**) and 1986 (r = 0.71*). A significant negative correlation was observed for kernels/spike vs. percent grain protein in 1984 (r = -0.79**) however, this relation was positive and non-significant in 1986. Kernel weight/spike was significantly correlated with percent grain protein in 1986 (r = 0.83**) however, this relation was negative and non-significant in 1984.

Simple correlations for spike density vs. kernels/spike and for spike density vs. kernel weight/spike over the two years combined data at Goodwell were negative and significant (r = -0.79** and r = -0.52* respectively). The comparison between kernels/spike and kernel weight/spike was positive and significant (Table 16).

Bulked seed from each entry grown in the Goodwell Tests was submitted to the Barley and Malt Laboratory at Madison, WI, in 1984 and 1986. These data (Table 17) are included to provide an indication of where winter malting barleys stand as far as quality is concerned. None of the genotypes examined in this study meets industry standards for acceptance as malting types.

GREENHOUSE TESTS

The analysis of variance for each year in the greenhouse study demonstrated significant differences among genotypes for all variables but percent grain protein in 1985 and all but grain color in 1986 (Table 18). The analysis of variance over years showed there were differences between years for all variables except spike density (Table 19). Also, there were significant differences among genotypes for all variables except percent grain protein. Genotype by year interactions were significant for kernels/spike, kernel weight, grain color, and harvest index but not for spike density, kernel weight/spike, percent grain protein, or grain yield (Table 19).

Mean performance of genotypes in 1985 were higher for all but two variables (Table 20). Mean kernel weight and percent grain protein in 1986, exceeded those in 1985. In the Greenhouse Tests, two additional traits, grain color and harvest index were measured, as well as the six traits measured in previous tests. Rankings of genotypes for each variable changed from one year of the study to the next. However, as in three of the regional tests and both years of the Goodwell tests, the top four values for spike density in each year of the Greenhouse Test included the same four genotypes. Coefficients of variation for grain yield were high in both years of study perhaps due to non uniform temperatures across the test area in the greenhouse. Combined years mean data are presented in Table 21.

Simple correlation coefficients between pairs of variables studied in the greenhouse tests revealed several relationships. Significant positive correlations were found for: spike density vs. harvest index in 1985 ($r = 0.84^{**}$) and spike density vs. grain color in 1986 ($r = 0.91^{**}$); kernels/spike vs. kernel weight/spike in 1985 and 1986; grain yield vs. harvest index in 1986; and also grain yield vs. kernel weight in 1986. Significant negative correlation coefficients were found for: spike density vs. kernel weight in 1986 ($r = -0.71^{*}$); kernel weight/spike vs. grain protein in 1986; grain yield vs. percent grain protein in 1986; and percent grain protein vs. harvest index in 1986 (Table 22).

Simple correlations calculated as an average of two years data in the greenhouse study showed a number of significant relationships some of which were not present in separate years analysis. With regard to spike density, the combined years analysis (Table 23) showed only one significant correlation, which was a negative correlation with kernel weight (r = -0..51*). Kernels/spike was positively correlated with grain yield, kernel weight/spike, grain color, and harvest index. Kernels/spike was negatively correlated with kernel weight and percent grain protein. Grain yield was positively correlated with kernel weight/spike, grain color, and harvest index. It was negatively correlated with percent grain protein. Kernel weight/spike was positively correlated with grain color and harvest index. It was negatively correlated with percent grain protein. Grain color was also positively correlated with harvest index (Table 23).

CHAPTER V

SUMMARY AND CONCLUSIONS

With regard to spike density, there were significant differences for genotypes at each of the locations in the regional tests. In the combined analysis over regional locations there were significant differences between genotypes as well as significant genotype by location interactions for spike density. This was also true for the other five traits measured.

The analysis of variance for each year in the Goodwell test and combined years analysis showed significant differences among genotypes for spike density and all other variables with the exception of grain yield. There were significant genotype by year interactions observed for all variables with the exception of grain yield.

In each year of the greenhouse test there were significant differences among genotypes for spike density and all other variables measured with the exception of grain protein in 1985 and grain color in 1986. The combined years analysis showed significant differences between genotypes for all variables with exception of grain protein. There were no significant genotype by year interactions for spike density, kernel weight/spike, percent grain protein, and grain yield, however, there were for all of the other variables measured.

In tables presenting mean data over variables, the order of listing the genotypes was based on the spike density means over the four regional tests. The top four genotypes (i.e. lax spike) were ORWF8328, WA1430-77, ORFB75075-1, and Showin. The bottom four genotypes (i.e. dense spike) were Wintermalt, ORWF8011, Kamiak, and OK82850.

In the regional tests at Goodwell, Aberdeen, and Logan; the top four spike density values included the top four genotypes for this trait as previously stated. At Farmington the top four spike density values included three of the top four genotypes mentioned earlier. In each year of the Goodwell (1984 and 1986) and greenhouse (1985 and 1986) tests the top four values for spike density included the top four genotypes mentioned previously. This was also true for the combined years data for each of these tests. Therefore, in all tests but one, the top four spike density values included the same four genotypes.

With regard to spike density, there were several important relationships with other traits over the tests conducted. There was a significant negative relationship between spike density and kernels/spike at Goodwell and Logan in 1984 (Regional Tests) and Goodwell in 1986 (Goodwell Tests). This indicates that lax spike genotypes tend to have fewer kernels/spike. Spike density was positively correlated with grain yield at Aberdeen. This would be a desirable relationship for breeding objectives. There was a significant negative correlation for spike density vs. kernel weight in the 1986 greenhouse test. Percent grain protein at Goodwell (1984) showed a significant positive correlation with spike density. This relation would be highly undesirable for breeding objectives. Grain color (AGTRON) was positively correlated with spike density in one of the two years it was measured in the greenhouse test (1986). Since high AGTRON values are desirable, the relationship observed between spike density and grain color would be desirable.

In conclusion, considering all tests, spike density was not consistently correlated with any variable with the possible exception of kernels/spike. Also, there were no consistent associations involving grain yield. These data indicate there would be no serious undesirable side effects to breeding for lax spike types. In addition, the consistency of genotype performance noted for spike density across these tests, should lend confidence to breeders concerning the effectiveness of selection for this character in heterozygous populations. With regard to the malting data (Table 17), no trends were noted regarding spike density and the 12 quality variables listed in that table. None of the eight genotypes evaluated in these tests had satisfactory overall malting quality. Finally, in terms of a breeding program wherein the lax spike character is to be emphasized, genotypes ORWF8328 and ORFB75075-1 appear to be worthwhile as potential parents in a crossing program. These genotypes were characterized as having lax spikes, high grain yield, good kernel weights, and reasonable percent grain protein values.

LITERATURE CITED

1. Anderson,M. K., and E. Reinbergs. 1985. Barley. ed. D. C. Rasmusson. Agronomy Monograph No. 26. American Society of Agronomy. Madison. Wisconsin. 1985.

2. Benbelkacem, A., M. S. Mekni, and D. C. Rasmusson. 1984. Breeding for high tiller number and yield in barley. Crop Science. 24:968-972.

3. Brinkman, M. A., and T. M. Luk. 1979. Relationship of spike nodding angle and kernel brightness under simulated rainfall in barley. Canadian Journal of Plant Science. 59:481-485.

4. Burger, W. C., and D. E. LaBerge. 1985. Barley. ed. D. C. Rasmusson. Agronomy Monograph No. 26. American Society of Agronomy. Madison. Wisconsin. 1985.

5. Den Hartog, G. T., and J. W. Lambert. 1953. The relationships between certain agronomic and malting quality characters in barley. Agronomy Journal. 45:208-212.

6. Eslick, R. F., and E. A. Hockett. 1975. Genetic engineering as a key to water use efficiency. Agricultural Meteorology. 14:13-23.

7. Foster, A. E., G. A. Peterson, and O. J. Banasik. 1967. Heritability of factors affecting malting quality of barley. Crop Science. 7:611-613.

8. Grafius, J. E. 1978. Multiple characters and correlated response. Crop Science. 18:931-934.

9. Grafius, J. E., R. L. Thomas, and J. Barnard. 1976. Effect of parental component complementation on yield and components of yield in barley. Crop Science. 16:673-677.

10. Hamid, A. A., and J. E. Grafius. 1978. Developmental allometry and its implication to grain yield in barley. Crop Science. 18:83-86.

11. Hoskins, P. 1982. Anheuser-Busch, Inc., Goodwell, OK. Personal Communication.

12. McGuire, C. F., and E. A. Hockett. 1983. Relationship of V, i and L alleles with malting quality of bonneville barley. Field Crops Research. 7:51-60.

13. Peterson, G. A., and A. E. Foster. 1973. Malting barley in the United States. Advances In Agronomy. 25:327-378.

14. Piper, T. E., and D. C. Rasmusson. 1984. Selection for low protein in barley. Crop Science. 24:853-854.

15. Puri, Y. P., C. Q. Qualset, and W. A. Williams. 1982. Evaluation of yield components as selection criteria in barley breeding. Crop Science. 22:927-931.

16. Rasmusson, D. C. 1987. An evaluation of ideotype breeding. Crop Science. 27:1140-1146.

17. Rasmusson, D. C., and R. Q. Cannell. 1970. Selection for grain yield and components of yield in barley. Crop Science. 10:51-54.

18. Rasmusson, D. C., and R. L. Glass. 1965. Effectiveness of early generation selection for four quality characters in barley. Crop Science. 5:389-391.

19. Simmonds, N. W. 1979. Principles of Crop Improvement. Longman Inc., New York. 1979. Chapter 3.

20. Simmons, S. R., D. C. Rasmusson, and J. V. Wiersma. 1982. Tillering in barley: genotype, row spacing, and seed rate effects. Crop Science. 22:801-805.

21. Smith, L. 1951. Cytology and genetics of barley. The Botanical Review. 17:156-157.

22. Wych, R. D., and D. C. Rasmusson. 1983. Genetic improvement in malting barley cultivars since 1920. Crop Science. 23:1037-1044.

APPENDIXES

Table 1. Six-rowed winter barley genotypes evaluated in this study.

Genotype	Pedigree		Source
ORWF8328	Belts.67-1608/Schuyler/3/Dicktoo/2/Hiproly		Oregon
WA1430-77	NB69296/WA1245-68		Washington
ORFB75075-1	Belts.67-1608/Schuyler/3/Dicktoo/Cascade /2/Hiproly		Oregon
Showin	68-1448/WA2116-67		Washington
Wintermalt	Traill/Hudson	(Joint Release)	New York, Oklahoma
ORWF8011	WA2116-67/Belts.67-1623		Oregon
Kamiak	Bore/Hudson		Washington
OK82850	Post reselection		Oklahoma

Table 2. Soil type at the four sites in the Regional Tests, 1984.

Location	Soil Type
Goodwell,OK	Richfield clay loam: fine montmorillonitic, mesic, Aridic Argiustolls.
Farmington,NM	Kinnear fine sandy loam: mixed, mesic typic Camborthids.
Aberdeen,ID	Declo silt loam: mixed, mesic Xerollic Calciorthids.
Logan,UT	Nibley silty clay loam: fine, mixed mesic aquic Argiustolls.

Table 3. Field plot design in the Regional Tests, 1984.

Location	Plot Dimension	No. Of Rows	Row Spacing	Seeding Rate
			---cm---	--kg/ha--
Goodwell,OK	1.3 X 3.1m	4	30.5	67.3
Farmington,NM	1.5 X 6.1m	6	25.4	112.1
Aberdeen,ID	1.4 X 2.4m	4	35.6	95.3
Logan,UT	1.4 X 3.4m	4	30.5	112.1

Table 4. AOV of six variables, for eight winter barley genotypes in the Regional Tests, 1984.

			Mean Square Values					
			Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
Loc	Model	d.f.	x10-2			x10-4	x10-2	
GD	Rep.	2	2.12	26.59	10.07	2.37	8.68	1005
	Geno.	7	155.42**	73.76**	10.81*	1217.71*	73.73*	6268
	Error	14	0.90	13.45	3.58	416.08	19.05	10599
	C.V.		3.06	6.24	5.53	10.12	3.75	24.27
FM	Rep.	3	4.48	52.79	0.99	1005.20	297.39**	26671
	Geno.	7	115.56**	114.35**	49.17**	2907.83**	129.21*	146480**
	Error	21	2.62	28.35	7.29	497.63	52.73	7998
	C.V.		5.91	11.02	7.56	12.94	6.96	14.10
AB	Rep.	3	2.26	3.39	2.48	52.86	95.88*	33261**
	Geno.	7	117.92**	157.84**	15.58**	2900.42**	135.84**	35104**
	Error	21	1.73	17.33	2.01	338.29	22.83	5881
	C.V.		4.64	9.68	3.57	10.78	4.07	20.19
LN	Rep.	3	4.17	28.80	0.47	550.53	29.76	3689
	Geno.	7	159.20**	61.66	34.73**	1178.13	38.24	6328**
	Error	21	4.82	30.26	1.51	746.72	27.50	1589
	C.V.		7.66	10.48	2.97	12.55	4.64	9.75

*,** = Significance at 0.05 and 0.01 levels of probability respectively.
GD=Goodwell, FM=Farmington, AB=Aberdeen, LN=Logan.

Table 5. Combined AOV of eight winter barley genotypes over locations in the Regional Tests, 1984.

Source	d.f.	Mean Square Values: Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
Location	3	0.59**	1236.46**	324.83**	1.65**	10.85**	428812**
Rep/Loc	11	0.03	28.01	2.91	0.04	1.16**	17534**
Genotype	7	4.64**	160.30**	46.51**	0.26**	0.83*	60437**
G x L	21	0.27**	82.44**	21.26**	0.18**	0.97**	44580**
Error	77	0.02	23.16	3.60	0.05	0.31	6145
C.V.		5.69	9.60	4.99	11.86	4.99	16.89

*,** = Significance at 0.05 and 0.01 levels of probability respectively. G=Genotype, L=Location.

Table 6. Mean performance of eight winter barley genotypes for six variables at the Goodwell and Farmington locations, Regional Tests, 1984.

Location and Genotype	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
Goodwell,OK						
ORWF8328	3.97(1)	51.67(8)	35.91(2)	1.86(7)	12.28(8)	5123(1)
WA1430-77	3.67(3)	53.78(7)	30.60(8)	1.65(8)	11.89(6)	4286(4)
ORFB75075-1	3.82(2)	58.00(5)	35.32(4)	2.05(4)	12.28(7)	4443(2)
Showin	3.34(4)	55.66(6)	34.49(5)	1.91(6)	11.58(5)	3946(6)
Wintermalt	2.85(5)	62.00(2)	35.32(3)	2.18(3)	11.46(4)	3743(7)
ORWF8011	2.60(6)	61.44(3)	36.13(1)	2.23(1)	11.25(3)	4270(5)
Kamiak	2.53(7)	60.77(4)	32.76(7)	1.99(5)	11.10(2)	3713(8)
OK82850	1.95(8)	66.83(1)	33.23(6)	2.22(2)	11.04(1)	4406(3)
Mean	3.09	58.76	34.22	2.01	11.61	4185
C.V.	3.06	6.24	5.53	10.12	3.75	24.27
L.S.D. 0.05	0.16	6.42	3.31	0.35	0.76	1800
Farmington,NM						
ORWF8328	3.57(1)	53.12(1)	40.11(1)	2.14(1)	9.94(3)	7012(4)
WA1430-77	3.51(2)	45.71(7)	37.54(3)	1.70(4)	10.24(4)	7145(3)
ORFB75075-1	2.58(4)	50.96(3)	30.25(8)	1.53(7)	10.60(6)	6925(5)
Showin	2.45(6)	48.29(6)	33.10(6)	1.60(5)	10.49(5)	5915(7)
Wintermalt	2.81(3)	36.46(8)	36.73(4)	1.32(8)	11.53(8)	1782(8)
ORWF8011	2.56(5)	50.91(4)	39.88(2)	2.04(2)	9.94(2)	7782(1)
Kamiak	2.14(8)	48.62(5)	32.89(7)	1.59(6)	10.81(7)	6865(6)
OK82850	2.26(7)	52.29(2)	35.10(5)	1.83(3)	9.83(1)	7280(2)
Mean	2.73	48.29	35.70	1.71	10.42	6338
C.V.	5.91	11.02	7.56	12.94	6.96	14.10
L.S.D. 0.05	0.23	7.83	3.97	0.32	2.02	1315

Table 7. Mean performance of eight winter barley genotypes for six variables at the Aberdeen and Logan locations, Regional Tests, 1984.

Location and Genotype	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
Aberdeen,ID						
ORWF8328	3.35(2)	34.16(7)	38.12(7)	1.30(8)	11.73(6)	4885(1)
WA1430-77	3.24(4)	33.83(8)	41.46(3)	1.40(7)	11.13(1)	3660(6)
ORFB75075-1	3.37(1)	39.12(6)	38.66(6)	1.51(6)	11.65(5)	4772(2)
Showin	3.33(3)	47.87(3)	40.51(4)	1.93(2)	11.36(3)	4047(4)
Wintermalt	2.38(7)	48.12(2)	39.59(5)	1.91(3)	11.44(4)	2907(7)
ORWF8011	2.54(5)	48.25(1)	41.57(1)	2.01(1)	11.33(2)	3860(5)
Kamiak	2.40(6)	45.62(5)	41.48(2)	1.87(4)	12.79(8)	4182(3)
OK82850	2.04(8)	46.83(4)	36.06(8)	1.69(5)	12.44(7)	2070(8)
Mean	2.83	42.97	39.68	1.70	11.73	3797
C.V.	4.64	9.68	3.57	10.78	4.07	20.19
L.S.D. 0.05	0.19	6.12	2.08	0.27	0.70	1127
Logan,UT						
ORWF8328	3.73(1)	49.04(7)	42.51(3)	2.09(5)	11.52(6)	4165(3)
WA1430-77	3.34(3)	49.58(6)	44.41(1)	2.20(4)	10.87(1)	4215(2)
ORFB75075-1	3.49(2)	52.21(4)	42.35(4)	2.21(3)	11.56(7)	4032(5)
Showin	3.18(4)	47.75(8)	42.02(5)	2.01(8)	11.01(3)	3887(7)
Wintermalt	2.36(5)	57.16(1)	40.13(7)	2.30(2)	10.90(2)	4872(1)
ORWF8011	2.33(6)	56.79(3)	44.13(2)	2.51(1)	11.27(4)	4145(4)
Kamiak	2.32(7)	50.24(5)	40.61(6)	2.05(6)	11.57(8)	3900(6)
OK82850	2.17(8)	56.91(2)	35.11(8)	2.01(7)	11.52(5)	3465(8)
Mean	2.86	52.46	41.40	2.17	11.27	4085
C.V.	7.66	10.48	2.97	12.55	4.64	9.75
L.S.D. 0.05	0.32	8.09	1.81	0.40	0.77	586

Table 8. Mean performance of eight winter barley genotypes for six variables over four locations, Regional Tests, 1984.

Genotype	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
ORWF8328	3.63(1)	46.68(7)	39.38(2)	1.84(6)	11.31(5)	5308(1)
WA1430-77	3.42(2)	45.19(8)	39.03(3)	1.74(8)	10.98(2)	4862(4)
ORFB75075-1	3.28(3)	49.54(5)	36.73(7)	1.81(7)	11.47(7)	5083(2)
Showin	3.06(4)	49.51(6)	37.73(5)	1.86(5)	11.08(3)	4482(6)
Wintermalt	2.58(5)	50.20(4)	38.12(4)	1.91(3)	11.32(6)	3298(8)
ORWF8011	2.50(6)	53.87(2)	40.71(1)	2.19(1)	10.92(1)	5064(3)
Kamiak	2.33(7)	50.68(3)	37.21(6)	1.87(4)	11.60(8)	4728(5)
OK82850	2.12(8)	54.97(1)	34.99(8)	1.92(2)	11.22(4)	4298(7)
Mean	2.86	50.08	37.92	1.89	11.23	4640
C.V.	5.69	9.60	4.99	11.86	4.99	16.89
L.S.D. 0.05	0.11	3.49	1.38	0.16	0.40	570

Table 9. Simple correlation coefficients of six variables for eight winter barley genotypes at each of four locations, Regional Tests, 1984.

Goodwell,OK	Kernels /Spike	kernel Weight	Grain Yield	Kernel Wt /Spike	% Grain Protein
Spike Density	-0.91**	0.10	0.47	-0.70*	0.95**
Kernels/Spike		0.03	-0.44	0.84**	-0.79**
kernel Weight			0.26	0.55	0.19
Grain Yield				-0.23	0.62
Kernel Wt/Spike					-0.55
Farmington,NM.					
Spike Density	-0.08	0.60	-0.01	0.33	-0.17
Kernels/Spike		-0.01	0.89**	0.74*	-0.84**
Kernel Weight			0.03	0.65	-0.37
Grain Yield				0.69*	-0.85**
Kernel Wt/Spike					-0.88**
Aberdeen,ID.					
Spike Density	-0.66	0.17	0.76*	-0.55	-0.55
Kernels/Spike		0.06	-0.50	0.94**	0.22
Kernel Weight			0.34	0.37	-0.33
Grain Yield				-0.33	-0.17
Kernel Wt/Spike					0.09
Logan,UT.					
Spike Density	-0.72*	0.54	0.07	-0.19	-0.01
Kernels/Spike		-0.44	0.17	0.54	0.01
Kernel Weight			0.42	0.51	-0.33
Grain Yield				0.56	-0.58
Kernel Wt/Spike					-0.27

*,** = Significance at the 0.05 and 0.01 levels of confidence respectively.

Table 10. Simple correlation coefficients of six variables for eight winter barley genotypes over four locations, Regional Tests, 1984.

	Kernels /Spike	Kernel Weight	Grain Yield	Kernel Wt /Spike	% Grain Protein
Spike Density	-0.24	0.17	0.05	-0.11	0.16
Kernels/Spike		-0.30	0.06	0.75**	-0.09
Kernel Weight			-0.19	0.38*	0.03
Grain Yield				-0.04	-0.69**
Kernel Wt/Spike					-0.08

*,** = Significance at the 0.05 and 0.01 levels of confidence respectively.

Table 11. AOV of six variables for eight winter barley genotypes at Goodwell in each of two years, Goodwell Tests.

			Mean Square Values					
			Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
Year	Model	d.f.	x10-2			x10-4	x10-2	
1984	Rep.	2	2.12	26.59	10.07	2.37	8.68	1005
	Geno.	7	155.42**	73.76**	10.81*	1217.71*	73.73*	6268
	Error	14	0.09	13.45	3.58	416.08	19.05	10599
	C.V.		3.06	6.24	5.53	10.12	3.75	24.27
1986	Rep.	3	3.05	1.42	9.43	233.20	31.78	6896
	Geno.	7	201.34**	149.49**	30.75**	2481.83**	203.74*	9268
	Error	21	2.38	10.12	2.99	136.16	60.73	4758
	C.V.		5.24	5.55	4.86	5.77	5.85	18.53

*,** = Significance at the 0.05 and 0.01 levels of confidence respectively.

Table 12. A combined AOV of eight winter barley genotypes for six variables over two years, Goodwell Tests.

		Mean Square Values					
Source	d.f.	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
Year	1	0.30**	32.77	23.93**	0.0004	39.16**	37009*
Rep/Y	5	0.03	11.49	9.69*	0.0141	0.23	4540
Genotype	7	3.51**	197.56**	19.98**	0.2684**	1.32**	12749
G x Y	7	0.05**	25.69*	21.59**	0.1015**	1.46**	2788
Error	35	0.02	11.45	3.23	0.0248	0.44	7095
C.V.		4.45	5.85	5.14	7.81	5.28	21.35

*,** = Significance at the 0.05 and 0.01 levels of confidence respectively.
G = Genotype, Y = Year.

Table 13. Mean performance of eight winter barley genotypes over six variables for two years, Goodwell Tests.

Genotype	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
1984 Goodwell						
ORWF8328	3.97(1)	51.67(8)	35.91(2)	1.86(7)	12.28(8)	5123(1)
WA1430-77	3.67(3)	53.78(7)	30.60(8)	1.65(8)	11.89(6)	4286(4)
ORFB75075-1	3.82(2)	58.00(5)	35.32(4)	2.05(4)	12.28(7)	4443(2)
Showin	3.34(4)	55.66(6)	34.49(5)	1.91(6)	11.58(5)	3946(6)
Wintermalt	2.85(5)	62.00(2)	35.32(3)	2.18(3)	11.46(4)	3743(7)
ORWF8011	2.60(6)	61.44(3)	36.13(1)	2.23(1)	11.25(3)	4270(5)
Kamiak	2.53(7)	60.77(4)	32.76(7)	1.99(5)	11.10(2)	3713(8)
OK82850	1.95(8)	66.83(1)	33.23(6)	2.22(2)	11.04(1)	4406(3)
Mean	3.09	58.76	34.22	2.01	11.61	4241
C.V.	3.06	6.24	5.53	10.12	3.75	24.27
L.S.D. 0.05	0.16	6.42	3.31	0.35	0.76	1800
1986 Goodwell						
ORWF8328	3.53(3)	54.55(6)	35.46(4)	1.93(6)	13.45(6)	4017(3)
WA1430-77	3.59(2)	52.20(7)	39.22(2)	2.04(3)	13.45(7)	4152(2)
ORFB75075-1	3.65(1)	56.65(4)	34.06(7)	1.92(7)	13.22(5)	3480(5)
Showin	3.51(4)	49.62(8)	35.38(5)	1.71(8)	13.02(2)	3332(7)
Wintermalt	2.52(6)	57.05(3)	34.50(6)	1.96(4)	13.12(4)	3210(8)
ORWF8011	2.52(5)	65.67(2)	39.28(1)	2.58(1)	14.97(8)	3970(4)
Kamiak	2.42(7)	55.07(5)	35.66(3)	1.95(5)	12.82(1)	3352(6)
OK82850	1.79(8)	66.97(1)	30.75(8)	2.04(2)	13.10(3)	4437(1)
Mean	2.94	57.22	35.53	2.01	13.39	3743
C.V.	5.24	5.55	4.86	5.77	5.85	18.53
L.S.D. 0.05	0.22	4.67	2.54	0.17	1.13	971

Table 14. Mean performance of eight winter barley genotypes for six variables over two years, Goodwell Tests.

Genotype	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)
ORWF8328	3.72(2)	53.32(6)	35.66(2)	1.90(6)	12.95(7)	4491(1)
WA1430-77	3.63(3)	52.88(7)	35.53(3)	1.88(7)	12.36(3)	4210(3)
ORFB75075-1	3.72(1)	57.23(5)	34.60(6)	1.98(4)	12.82(6)	3893(5)
Showin	3.44(4)	52.21(8)	35.00(4)	1.80(8)	12.41(4)	3496(7)
Wintermalt	2.67(5)	59.17(3)	34.85(5)	2.06(3)	12.41(5)	3439(8)
ORWF8011	2.56(6)	63.86(2)	37.94(1)	2.43(1)	13.38(8)	4099(4)
Kamiak	2.47(7)	57.52(4)	34.42(7)	1.97(5)	12.09(1)	3507(6)
OK82850	1.86(8)	66.91(1)	31.82(8)	2.12(2)	12.22(2)	4424(2)
Mean	3.00	57.89	34.97	2.01	12.58	3944
C.V.	4.45	5.85	5.14	7.81	5.28	21.35
L.S.D. 0.05	0.15	3.67	1.95	0.17	0.72	914

Table 15. Simple correlation coefficients of six variables over eight winter barley genotypes in each of two years, Goodwell Tests.

1984 Goodwell	Kernels /Spike	kernel Weight	Grain Yield	Kernel Wt /Spike	% Grain Protein
Spike Density	-0.91**	0.10	0.47	-0.70*	0.95**
Kernels/Spike		0.03	-0.44	0.84**	-0.79**
Kernel Weight			0.26	0.55	0.19
Grain Yield				-0.23	0.62
Kernel Wt/Spike					-0.55
1986 Goodwell					
Spike Density	-0.76*	0.39	-0.23	-0.39	-0.18
Kernels/Spike		-0.26	0.55	0.71*	0.58
Kernel Weight			-0.01	0.47	0.38
Grain Yield				0.46	0.20
Kernel Wt/Spike					0.83**

*,** = Significance at the 0.05 and 0.01 levels of confidence respectively.

Table 16. Simple correlation coefficients of six variables for eight winter barley genotypes over two years, Goodwell Tests.

	Kernels /Spike	kernel Weight	Grain Yield	Kernel Wt /Spike	% Grain Protein
Spike Density	-0.79**	0.23	0.15	-0.52*	0.07
Kernels/Spike		-0.19	0.18	0.76**	-0.07
Kernel Weight			-0.06	0.49	0.41
Grain Yield				0.13	-0.24
Kernel Wt/Spike					0.20

*,** = Significance at the 0.05 and 0.01 levels of confidence respectively.

Table 17. Western Winter Barley Nursery (WWBN), Goodwell, OK, Malting data of the bulk samples of 3 replications with rankings.

Year and Genotypes Selected From WWBN	Barley Protein (%)	Barley Kernel Weight (mg)	%Plump Barley On 6/64 Screen	Barley Color AGTRON	Malt Extract (%)	Ext. Diff. Fine-Course (%)	Wort Color Score	Clarity of Wort	Wort Protein (%)	Protein Ratio: Soluble % of Total	Diastatic Power (Deg)	Alpha Amylase 20 Deg. Units	Over-All Rank Value
---1984---													
ORWF8328	13.7(5)	28.8(9)	20.3(8)	68(10)	69.2(10)	4.9(8)	1.3	Hazy	3.83(11)	28.3(11)	126(3)	22.0(11)	11
WA1430-77	13.6(4)	26.4(12)	14.0(12)	76(5)	69.6(8)	5.1(9)	1.5	Hazy	4.15(6)	30.0(8)	121(4)	23.9(7)	8
ORFB75075-1	13.9(7)	29.6(4)	22.8(7)	67(11)	69.5(9)	4.2(5)	1.3	Hazy	3.89(9)	27.9(12)	103(9)	19.7(12)	9
Showin	13.5(3)	29.3(5)	17.5(9)	69(9)	70.9(7)	2.6(2)	1.1	Hazy	3.97(8)	29.7(9)	126(3)	26.5(4)	5
Wintermalt	13.0(1)	29.2(6)	38.6(3)	70(8)	74.7(3)	4.3(6)	1.2	Hazy	4.45(4)	34.1(3)	115(5)	26.3(5)	2
ORWF8011	14.2(9)	31.2(2)	17.1(10)	71(7)	69.2(10)	4.2(5)	1.3	Hazy	4.28(5)	30.5(7)	102(10)	23.9(7)	9
Kamiak	13.1(2)	28.3(10)	27.3(6)	77(4)	72.1(5)	5.8(11)	1.2	Hazy	3.85(10)	29.6(10)	115(5)	22.2(10)	6
OK82850	13.8(6)	28.9(8)	61.9(2)	64(12)	71.8(6)	4.8(7)	1.3	Hazy	3.61(13)	26.3(13)	106(8)	23.3(8)	7
Best Entry	13.7(5)	29.0(7)	30.2(4)	80(2)	74.9(2)	2.4(1)	-2.8	Hazy	4.86(1)	35.5(1)	110(7)	30.3(2)	1
Spring check	11.2	39.7	82.5	64	80.0	2.2	1.6	Hazy	4.56	42.1	91	26.4	-
---1986---													
ORWF8328	17.3(16)	27.7(14)	24.0(18)	40(4)	70.2(15)	4.4(12)	1.3	Sl.H.	4.91(9)	28.8(16)	116(8)	31.4(15)	18
WA1430-77	14.2(6)	31.3(7)	61.3(5)	40(4)	71.2(11)	4.3(11)	1.8	Sl.H.	5.06(7)	35.6(4)	110(10)	31.6(14)	5
ORFB75075-1	15.8(11)	27.5(15)	27.9(17)	32(9)	71.0(12)	3.4(4)	1.4	Sl.H.	4.95(8)	31.3(12)	126(5)	33.0(11)	15
Showin	17.4(5)	28.3(12)	32.9(16)	43(3)	70.9(13)	2.2(2)	1.5	Sl.H.	5.49(2)	32.0(11)	149(1)	36.3(9)	10
Wintermalt	14.1(5)	30.2(9)	61.9(4)	39(5)	74.4(3)	3.5(5)	1.4	Hazy	4.89(10)	34.4(8)	122(6)	33.4(8)	1
ORWF8011	15.7(10)	31.4(6)	34.3(14)	40(4)	71.2(11)	4.3(11)	1.8	Sl.H.	5.65(3)	35.4(5)	134(4)	39.0(4)	8
Kamiak	14.8(8)	30.2(9)	52.6(10)	38(6)	73.8(5)	4.0(8)	1.8	Clear	5.22(4)	35.2(6)	105(13)	36.9(7)	6
OK82850	13.5(3)	27.3(16)	68.1(2)	25(11)	71.5(10)	5.0(15)	1.5	Hazy	4.04(16)	29.3(15)	106(12)	24.0(18)	17
Best Entry	15.9(12)	42.0(1)	86.1(1)	40(4)	74.9(2)	2.0(1)	1.6	Sl.H.	5.13(6)	32.5(10)	117(7)	40.5(3)	1
Spring Check	11.0	39.9	91.6	63	80.8	1.2	1.5	Clear	5.50	52.1	118	48.0	-

In 1984, fourteen entries were submitted from the WWBN from Goodwell for malting tests.
In 1986, eighteen entries were submitted from the WWBN from Goodwell for malting tests.

Table 18. AOV of six variables for eight winter barley genotypes in each of two years, Greenhouse Tests, 1985 and 1986.

Model	df	Mean Square Values: Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)	Grain color AGTRON	Harvest Index (%)
		x10-2			x10-4				x10-4
1985									
Rep.	2	4.95	11.60	3.77	594.12	22.53	631	1.24	12.50
Geno.	7	231.34**	208.94**	53.28**	2209.07**	39.19	22096*	21.95**	53.50**
Error	14	1.38	26.75	9.31	411.45	31.62	6646	0.48	4.64
C.V.		3.63	10.23	7.24	9.67	38.00	17.41	1.38	5.09
1986									
Rep.	2	3.30	30.75	4.15	679.04*	0.50	3609	4.33	104.66**
Geno.	7	192.69**	220.52**	57.30**	3350.35**	4.79**	21993**	5.12	62.08**
Error	14	1.48	13.16	6.02	159.66	0.89	2555	2.40	11.85
C.V.		3.74	10.63	5.43	8.57	5.48	23.76	3.68	12.65

*,** = Significance at 0.05 and 0.01 levels of probability respectively.

Table 19. A combined AOV of eight winter barley genotypes for six variables over two years, Greenhouse Tests, 1985 and 1986.

		Mean Square Values							
Model	df	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)	Grain Color AGTRON	Harvest Index (%)
Year	1	0.001	3228.00**	109.87**	4.64**	70.81*	783363**	818.40**	0.27**
Rep/Y	4	0.041*	21.18	3.97	0.06	11.37	2120	2.79	0.01**
G	7	4.208**	383.17**	58.63**	0.51**	28.68	35102**	21.50**	0.01**
G x Y	7	0.033	46.30*	51.96**	0.04	15.31	8986	5.57**	0.01**
Error	35	0.014	19.96	7.67	0.03	16.26	4601	1.45	0.001
C.V.		3.69	10.56	6.34	9.47	25.18	19.92	2.60	8.27

*,** = Significance at 0.05 and 0.01 levels of probability respectively.
G = Genotype, Y = Year.

Table 20. Mean performance of eight winter barley genotypes over eight variables for each of two years, Greenhouse Tests, 1985 and 1986.

Year and Genotype	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)	Grain color AGTRON	Harvest Index (%)
1985								
ORWF8328	4.16(1)	57.46(2)	40.60(5)	2.33(2)	12.23(1)	5750(1)	51.96(2)	0.47(2)
WA1430-77	3.86(4)	54.53(3)	38.95(7)	2.13(4)	13.96(6)	4050(6)	50.96(5)	0.41(5)
ORFB75075-1	4.08(2)	62.83(1)	40.01(6)	2.51(1)	12.33(2)	5676(2)	51.26(4)	0.49(1)
Showin	3.91(3)	41.73(7)	40.69(4)	1.67(8)	23.30(8)	3600(8)	51.96(3)	0.44(3)
Wintermalt	2.70(6)	45.26(6)	48.93(1)	2.19(3)	13.30(3)	5173(3)	48.16(7)	0.39(6)
ORWF8011	2.66(7)	53.93(4)	37.37(8)	2.00(6)	15.86(7)	4256(5)	52.96(1)	0.42(4)
Kamiak	2.72(5)	38.06(8)	48.16(2)	1.80(7)	13.80(5)	3786(7)	50.66(6)	0.38(7)
OK82850	1.79(8)	50.36(5)	42.45(3)	2.10(5)	13.60(4)	5163(4)	44.60(8)	0.37(8)
Mean	3.23	50.52	42.14	2.09	14.80	4681	50.31	0.42
C.V.	3.63	10.23	7.24	9.67	38.00	17.41	1.38	5.09
L.S.D. 0.05	0.20	9.05	5.34	0.35	9.84	1427	1.22	0.03
1986								
ORWF8328	4.08(2)	44.93(2)	41.20(6)	1.80(2)	16.56(4)	2010(4)	42.50(4)	0.26(5)
WA1430-77	3.83(3)	30.26(6)	47.24(4)	1.38(6)	16.46(3)	2210(3)	43.66(1)	0.31(3)
ORFB75075-1	4.14(1)	46.00(1)	40.79(7)	1.84(1)	16.33(2)	2840(2)	43.03(3)	0.31(2)
Showin	3.63(4)	30.63(5)	38.96(8)	1.12(7)	18.06(6)	1170(8)	43.13(2)	0.25(6)
Wintermalt	2.71(7)	34.93(4)	45.33(5)	1.52(4)	16.73(5)	2000(5)	41.53(6)	0.27(4)
ORWF8011	2.87(5)	29.56(7)	50.90(1)	1.42(5)	19.60(8)	1290(7)	41.93(5)	0.21(7)
Kamiak	2.82(6)	19.93(8)	47.65(3)	0.91(8)	18.20(7)	1700(6)	41.03(7)	0.21(8)
OK82850	1.87(8)	36.73(3)	49.29(2)	1.78(3)	15.86(1)	3796(1)	39.66(8)	0.33(1)
Mean	3.24	34.12	45.17	1.47	17.22	2127	42.05	0.26
C.V.	3.74	10.63	5.43	8.57	5.48	23.76	3.68	12.65
L.S.D. 0.05	0.21	6.35	4.29	0.22	1.65	885	2.71	0.06

Table 21. Mean performance of eight winter barley genotypes for eight variables over two years, Greenhouse Tests, 1985 and 1986.

Year and Genotype	Spike Density (mm)	Kernels /Spike (#)	Kernel Weight (mg)	Kernel Wt /Spike (g)	Grain Protein (%)	Grain Yield (kg/ha)	Grain color AGTRON	Harvest Index (%)
ORWF8328	4.13(1)	51.20(2)	40.90(6)	2.06(2)	14.40(2)	3880(3)	47.23(2)	0.36(2)
WA1430-77	3.85(3)	42.40(4)	43.10(5)	1.76(5)	15.21(5)	3130(5)	47.31(4)	0.36(3)
ORFB75075-1	4.12(2)	54.42(1)	40.40(7)	2.17(1)	14.33(1)	4258(2)	47.15(5)	0.40(1)
Showin	3.77(4)	36.18(7)	39.83(8)	1.40(7)	20.68(8)	2385(8)	47.55(1)	0.34(5)
Wintermalt	2.71(7)	40.10(6)	47.13(2)	1.85(4)	15.01(4)	3587(4)	44.85(7)	0.33(6)
ORWF8011	2.77(6)	41.75(5)	44.14(4)	1.71(6)	17.73(7)	2773(6)	47.45(2)	0.32(7)
Kamiak	2.77(5)	29.00(8)	47.91(1)	1.35(8)	16.00(6)	2743(7)	45.85(6)	0.29(8)
OK82850	1.83(8)	43.55(3)	45.87(3)	1.94(3)	14.73(3)	4480(1)	42.13(8)	0.35(4)
Mean	3.24	42.32	43.66	1.78	16.01	3404	46.19	0.34
C.V.	3.69	10.56	6.34	9.47	25.18	19.92	2.60	8.27
L.S.D. 0.05	0.14	5.28	3.28	0.19	4.76	802	1.42	0.03

Table 22. Simple correlation coefficients of six variables over eight winter barley genotypes for each of two years, Greenhouse Tests, 1985 and 1986.

1985	Kernels /Spike	Kernel Weight	Grain Yield	Kernel Wt /Spike	Grain Protein	Grain Color	Harvest Index
Spike Density	0.40	-0.40	0.09	0.28	0.14	0.70	0.84**
Kernels/Spike		-0.66	0.67	0.85**	-0.48	0.18	0.68
Kernel Weight			-0.01	-0.18	-0.21	-0.45	-0.57
Grain Yield				0.89**	-0.68	-0.29	0.41
Kernel Wt/Spike					-0.76*	-0.09	0.51
Grain Protein						0.28	0.02
Grain Color							0.63
1986							
Spike Density	0.41	-0.71*	-0.31	0.12	-0.09	0.91**	-0.02
Kernels/Spike		-0.50	0.47	0.92**	-0.61	0.19	0.57
Kernel Weight			0.17	-0.13	0.26	-0.56	-0.08
Grain Yield				0.66	-0.80*	-0.46	0.86**
Kernel Wt/Spike					-0.63	-0.06	0.67
Grain Protein						0.06	-0.88**
Grain Color							-0.04

*,** = Significance at the 0.05 and 0.01 levels of confidence respectively.

Table 23. Simple correlation coefficients of six variables over eight winter barley genotypes over two years, Greenhouse Tests, 1985 and 1986.

	Kernels /Spike	Kernel Weight	Grain Yield	Kernel Wt /Spike	% Grain Protein	Grain Color	Harvest Index
Spike Density	0.28	-0.51*	-0.06	0.12	0.07	0.31	0.19
Kernels/Spike		-0.63**	0.82**	0.95**	-0.60**	0.70**	0.84**
Kernel Weight			-0.25	-0.36	-0.09	-0.50*	-0.45
Grain Yield				0.90**	-0.67**	0.69**	0.91**
Kernel Wt/Spike					-0.69**	0.64**	0.84**
Grain Protein						-0.29	-0.47
Grain Color							0.87**

*,** = Significance at the 0.05 and 0.01 levels of confidence respectively.

VITA 2

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Master of Science

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