

A CORRELATION STUDY OF VARIOUS AGRONOMIC
AND QUALITY CHARACTERS IN BARLEY

by

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Introduction

Increased yield and improved malting quality are two important objectives in a barley improvement program. Numerous factors, both environmental and hereditary, determine the expression of these characters, making the effective selection of individual plants or their progeny extremely difficult. The plant breeder is confined to selection of certain desirable characters which are visible. He can only hope that some of these selections will prove satisfactory as to yield and quality when the testing stage is reached. Therefore he is forced to select very large numbers of plants in order to increase his chances of obtaining high yield and good quality in combination with other desirable characters. Any knowledge which tends to increase the efficiency of visual selection toward this end will prove invaluable to the barley breeder.

Frankel (5) states that increases in productivity are accomplished in two ways: (1) by overcoming limiting factors, the effects of which can be observed and (2) by assembling productivity genes. The main increases in yield have been achieved by overcoming these limiting factors, that is, such factors as condition disease susceptibility, drought susceptibility, and susceptibility to shattering, rather than by assembling productivity genes. The principal difficulty in selecting for productivity genes arises from the fact that yield components are so subject to environmental variation that the recognition of favorable genotypes is difficult even in replicated yield trials. Genetic concepts require segregating populations greatly exceeding in number those which can be included in such a trial. Hence the efficiency of selection of single plants and their immediate progenies constitutes a major problem in selection for yield itself.

In order to increase the efficiency of selection of single plants

for yield and quality it is necessary to determine if these invisible characters are associated with any observable characters. With this in mind numerous workers have carried out correlation studies in the various cereal crops. However, relatively few of these studies have been concerned with barley. As far as the author has been able to determine, only two such studies have been published in Canada and these have dealt only with characters pertaining to quality. The present study was undertaken to determine the possible relationship between yield, nitrogen content, and certain plant and seed characters in barley. The main object is to determine whether any one character is closely enough associated with yield or with nitrogen content to be used as a guide in selecting single plants or the progeny of single plants.

Review of Literature

Numerous studies involving the correlation of plant characters with yield have been carried out with many crops in the last thirty five years. Many of these studies have been made in the cereal crops, wheat, oats, and barley. Since this study is directly concerned with barley, the literature reviewed here will be that which is most closely allied to the subject; namely, studies in wheat and barley, with some mention of oats.

It is interesting to note that as early as 1821, Sir Humphrey Davy (4) remarked that it was unfortunate that so many high yielding grains "preferred to lie upon the ground". In 1919, almost one hundred years later, Garber and Olson (6) reported that they found no significant correlation between yield and lodging in a study involving 15 strains of barley. In a study of 146 varieties of wheat, Goulden and Elders (7) found a negative correlation between yield and straw strength. Kiesselbach et al. (12) found no correlation between yield and lodging in a study involving spring wheat, oats and barley. Leasure et al. (14) also reported no correlation between yield and breaking strength of straw in barley.

Goulden and Elders (7) found a negative correlation between yield and days to head in wheat. Bridgford and Hayes (3) working with 61 strains of varieties of wheat reported this relationship to be positive. Wexelsen (23) in his paper on quantitative inheritance and linkage in barley reported that date of heading was correlated with the factors for large teeth on the lemma nerves, the factor for two row, the factor L for long haired rachilla, and the factor R for rough awns.

Kohls (13) reported a positive correlation between yield and height of plant from a study involving 7 varieties of barley. Bridgford and

Hayes (3) reported the same relationship in wheat. Robertson and Koonce (20) studied 41 varieties of barley and reported a positive correlation between these two characters. Leasure et al.(14) also working with barley, reported a positive relationship as had the previous workers. However, Kiesselbach et al.(12) reported no correlation between yield and height of plant in barley, oats, or wheat. Boyce et al.(2) stated that selection for straw length did not increase the efficiency of selection for yield, in wheat.

Quisenberry (19) in a field study of winter and spring wheats, found a significant positive correlation between yield and number of kernels per head, and between number of kernels per head and 1000 kernel weight (K.W.). Thayer and Rather (22) reported that yield of barley was affected by rate of seeding; that the extent of tillering, length of head, and number of kernels per head decreased as the rate of seeding increased. They believed number of kernels per head to be associated with yield. Boyce et al.(2) stated that the only yield component consistently varying with total yield in their study of wheat, was the number of kernels per head.

Thayer and Rather (22) had suggested a positive correlation between yield and head length in barley and this was found to be so in the study conducted by Leasure et al.(14). They also reported a positive correlation between yield and test weight in barley as had Kohls (13) and Robertson and Koonce (20). The same highly significant positive relationship was reported to exist in wheat by Hayes et al.(8), Bridgford and Hayes (3), and by Kiesselbach et al.(12). Worzella (24) found kernel weight to be positively correlated with test weight in wheat.

Quisenberry (19) found significant positive correlation between yield and 1000 K.W. in wheat as did Bridgford and Hayes (3). Worzella (24)

found no correlation between 1000 K.W. and purple straw color in wheat, whereas Middleton and Herbert (16) reported that in each of three years purple strawed types produced kernels which were significantly heavier than those from white lines.

Anderson et al.(1) conducted a study involving seven varieties of barley and found a negative correlation between 1000 K.W. and nitrogen content and between 1000 K.W. and saccharifying activity. Lejeune (15) studying F₃ lines of a Chevron x O.A.C. 21 cross, also found a negative correlation between 1000 K.W. and nitrogen content. He reported a positive correlation between 1000 K.W. and stem rust reaction.

Thayer and Rather (22) believed yield to be closely associated with the extent of tillering in barley. They stated that as the rate of seeding increased, the extent of tillering decreased and that yield was also decreased. Hunter (10) reported that the high yield of the barley varieties Spratt-Archer and Spratt was associated with high tiller survival.

Goulden and Elders (7) found a negative correlation between yield and susceptibility to stem rust in wheat. They also found that a negative relationship was indicated for yield and susceptibility to leaf rust. Bridgford and Hayes (3) also reported a negative correlation between yield and susceptibility to leaf rust in wheat.

Anderson et al.(1) reported that they found a definite association between nitrogen content and saccharifying activity. They studied seven varieties of barley and stated that this is an intravarietal relationship and does not apply between varieties. Environmental conditions which tend to produce high nitrogen barleys also tend to produce barleys high in saccharifying activity and produce malts of

correspondingly high activity.

Neatby and McCalla (17) reported a high negative correlation between yield and protein content in both wheat and barley. Hunter (10) reported the same relationship in the barley varieties Spratt-Archer and Spratt. He concluded that further efforts to increase the yield in this type of barley by breeding would automatically tend to give types with a lower nitrogen content than the present form. He stated that this association between high yield and low nitrogen content could cause difficulty in breeding high nitrogen feed barleys.

Sprague (21) reported variations in the expression of characters in wheat under different climatic conditions. Immer and Ausemus (11) compared the behavior of varieties of oats and wheat under different conditions of environment and in different seasons. They found some differences in the correlations of the same characters at different places and in successive years. Worzella (24), in reporting on his correlation study in wheat, stated that the magnitude of interannual correlations for protein, 1000 K.W. and test weight, although highly significant, was rather low indicating that environmental conditions greatly influence the expression of these characters.

Powers (18) found differences in the reaction of genes contributing to quantitative characters when in combination with different qualitative characters. He stated that the nature of interaction of factors affecting seed weight per plant, height of plant, number of spikes per plant, and length of awn was such that the visible effect of a certain factor is greater, the greater the number of factors involved.

It is apparent that differences in interaction between genes controlling quantitative characters occur and that no general rule can be given at the present time that will describe all conditions.

Materials and Methods

This study was undertaken to determine the possible relationships between yield, nitrogen content, tillers per plant, 1000 kernel weight (K.W.), length of head, and aleurone color. These specific characters were chosen for the following reasons; nitrogen content and 1000 K.W. are used in early generation testing as an indication of malting quality, tillers per plant and length of head have been reported to be associated with yield, and it was suspected that yellow aleurone color might be correlated with high yield since many yellow feed barleys are exceptionally high yielders.

The material for this study originated in the Barley Improvement Project carried on by the Division of Plant Science at The University of Manitoba. In 1949, 516 plant rows from a cross of Montcalm x Vantage were undergoing selection in F₅. This cross was selected for the study because Vantage had been outyielding Montcalm quite consistently and therefore it was thought that the range in yield among these lines would be quite wide. Lines with blue aleurone and lines with yellow aleurone occurred in approximately equal proportions. In selecting among these F₅ lines, those having yellow aleurone were considered more promising, with respect to high yield, than those with blue aleurone, on the average. It was thought that these lines would be relatively homozygous for the characters to be studied and that they would be similar enough genetically to ensure that any relationships which might be discovered would be due to the action of genes controlling the characters studied and not due to the effects of other widely divergent characters. It is impossible to include all of the varietal characters in a study of this scope. By studying the segregates from one cross, rather than a number of different varieties, it was thought that the effects of widely divergent varietal characters would be minimized.

For example, these lines had all been selected in earlier generations for rust resistance and were all resistant or nearly so, therefore stem rust had no influence on their yields.

In 1949, a sample of each of these 516 lines was collected and threshed for seed. It was decided to set up two tests, each made up of 98 lines with Montcalm and Vantage included as check varieties. Therefore 196 lines were taken at random from the 516 lines harvested. These were then divided into two lots of 98 lines, each lot consisting of approximately one-third yellow aleurone lines and two-thirds blue aleurone lines. The blue aleurone samples were visually inspected and classed as grey-blue, blue-grey, blue, and dark blue. A line number was assigned to each sample and a record of the corresponding aleurone color was kept.

Each test was randomized in four replications. A single row plot $19\frac{1}{2}$ feet long was used with one foot spacing between plots. Two extra rows were sown at each end of each replicate to overcome border effect. The rate of seeding employed was 300 kernels per plot. This slightly-lower-than-normal rate was adopted to encourage tillering of the plants. A V-belt seeder was used to sow the tests.

The study was carried at a different location in each of two years, at Headingley, Manitoba, in 1950, and at the University in 1951. Yield, mean number of tillers per plant, mean length of head, and 1000 K.W., were determined for each plot in each of the two years. Nitrogen content of a composite sample of all four replicates of each line was determined in 1950 only. Aleurone color was rechecked in 1951.

The following method was used to determine the mean number of tillers per plant in each plot. Seedling counts and head counts were made in a three foot portion of each plot. In order to overcome border

effect these counts were made three feet in from the stake end of the plot. As soon as the tests were seeded the stakes were aligned and solidly fixed at the end of each plot. A six foot 1"x2" board was marked off into two three foot sections. As soon as all of the seedlings had emerged the seedling counts were made. The aforementioned board was laid along the plot with one end flush with the stake and the seedlings were counted beginning at the centre mark on the board. These counts were recorded for each plot. When the plots were completely headed out, the heads in the identical three foot portion of each plot were counted and recorded, using the same board. The mean number of tillers per plant was then calculated by dividing the number of heads by the number of seedlings and subtracting 1 for the main culm.

In order to determine the mean length of head per plot in 1950, one foot of each plot was harvested separately from the main plot. This sample was placed in a paper bag which was marked with the plot number and line number. These samples were taken after one foot had been trimmed off each end of the plots just prior to harvesting. However, it was felt that this method was not entirely satisfactory in that it did not provide a random sample of the whole plot. Therefore, in 1951, a random sample of heads was collected from each plot. These samples were placed in half pound paper bags which had been previously labelled with plot number and line number. A stapler was used to close the bags. This seemed to be a much more efficient method of sampling and the process of measuring the heads was speeded up considerably due to greater ease of handling the samples. In each year ten heads from each plot were measured in centimeters by means of calipers. The mean length of the ten heads was recorded for each plot. In each year a total of 8000

heads were measured.

As stated previously, the aleurone color of each line was determined on the seed used in the tests. In 1951 the aleurone color was determined in the field as a check on the previous determination. This check was made on only one replicate of each test as aleurone color is influenced little by soil heterogeneity. For the purpose of calculating correlation coefficients, the values 1 to 5 were assigned to the color classes dark blue to yellow respectively.

The yield of each plot was determined in each year. One rod of each plot was harvested after trimming to overcome border effect. Each plot was sickled, placed in a cotton bag, and labelled with plot number, variety number, and line number. The bags were stooked and when they had dried sufficiently they were taken indoors and threshed. The grain from each plot was weighed and the weight recorded in grams. This weight was later converted to bushels per acre.

The 1000 K.W. was determined from the threshed grain for each plot. Because of the time involved in making this determination on each of 800 plots only 100 kernels were weighed and this weight was multiplied by 10. It was thought that as each line was replicated four times, this method would be fairly accurate.

As it was impossible to obtain nitrogen determinations on each of the 800 plots, these determinations were obtained from composite samples of 100 grams made up of 25 grams from each of the four replicates in each line. Nitrogen determinations were made by the Barley Improvement Institute Laboratory in Winnipeg. The data on nitrogen content were obtained in 1950 only, as it was impossible to have the 1951 determinations made in time to be included in this study.

Analyses of variance were calculated for all characters except nitrogen content and aleurone color, which were not determined by replicates. Simple product moment correlation coefficients were then calculated by an abbreviated covariance method as given by Hayes and Immer (9). Complete analyses of covariance were not calculated. Sums of products were calculated from the variety totals and these sums of products, together with the sums of squares obtained from the analyses of variance, were used to calculate the correlation coefficients. All possible simple correlation coefficients were calculated in each test in each year. It was then decided to analyse the two tests as one large test of 800 plots. This step was justified in that the yields of Montcalm and of Vantage were nearly identical in the two tests in each year. All simple correlations were then calculated on the basis of 200 lines in order to show the general relationship between the various characters in the combined test as compared to those found in each of the smaller tests. A two year average correlation coefficient for each relationship was calculated from the overall simple correlation coefficients by the "Z" method as given by Hayes and Immer (9). These average values were used in calculating the partial and multiple correlation coefficients. The method employed in these calculations was the "the abbreviated Doolittle solution used to obtain the Inverse of a Square Matrix", as outlined by G. B. Oakland, Statistical Branch of The Dominion Science Service.*

* Unpublished

Results and Discussion

Analysis of the data for each character showed that there were significant differences between lines for all characters in each year. Results were considered significant in all cases when the 5% level of significance was attained with the F test. The F values, L.S.D.'s, and the ranges for each character in each year are presented in Table 1.

Table 1. F Values, Least Significant Differences,
and Range for Each Character in Each Year.

Character	Year	F value	L.S.D.	Range
Yield	1950	2.69**	6.66 bu./acre	21.8 - 45.7 bu.
	1951	2.37**	18.58 bu./acre	46.7 -104.6 bu.
Tillers	1950	1.81**	0.28 tillers	.04 - .76 til.
	1951	1.43**	0.39 tillers	.70 -2.60 til.
Head length	1950	4.21**	0.81 cm.	5.07 - 8.35 cm.
	1951	9.94**	0.58 cm.	6.32 - 9.62 cm.
1000 K.W.	1950	9.71**	0.92 gms.	32.47 -43.42 g.
	1951	5.51**	3.16 gms.	33.75 -46.12 g.
Aleurone	1950	Not Analysed		1 - 5
	1951	Not Analysed		1 - 5
Nitrogen	1950	Not Analysed		1.56 - 2.18%
	1951	No Data Obtained		

** 1% level of significance attained

It is noted in the range column of Table 1 that there was a considerable difference in crop performance in the two years. The overall means for yield, tillers, head length, and 1000 K.W., were

much greater in 1951 than in 1950. The range from low to high was also greater in 1951 for each character. Two factors, namely location and weather conditions, must be considered in offering an explanation of these results.

When this study was planned it was intended that the tests would be located at the University in both years. In 1950, however, the plot fields at the University were flooded until early summer and it was impossible to use the land for experimental work in that year. Field plots of the Division of Plant Science, including this project, were moved to land obtained for the purpose at Headingley, a distance of approximately 20 miles from the University. In 1951 the plots were grown at the University. The soil at Headingley is a slightly alkalized Red River clay which is lower in fertility than the Riverdale soil in the plots at the University. This latter is an immature alluvial soil with relatively good physical properties and a silty clay texture. The Headingley land had produced a crop of potatoes in 1949 and had not been well cultivated in that year. The land at the University had been well summerfallowed in 1950, and, having had flood deposits laid down also, it produced a very heavy stand of barley in 1951. Location, therefore, was probably largely responsible for the differences noted in the two years results.

Weather conditions in 1950 delayed seeding of the plots to June 6th and were only moderately favorable during the growing season. By contrast, seeding was accomplished by May 7th in 1951, and, with the exception of a rather dry May, the season favored heavy growth.

In order to determine the consistency of varietal performance in the two years a rank correlation coefficient was calculated between the yield totals of the lines in each year. This coefficient, $r_{x.y} = +.30$,

is rather low. This result indicates that a number of the lines which ranked high in yield in 1950, were shifted to a lower rank in 1951. This was borne out by inspection of the data. While inter-year correlations were not calculated for the other characters studied, the data indicated that similar shifts occurred for them. There is evidence that the inter-year changes in these characters are related to those in yield inasmuch as the simple correlations in table 2 show reasonably good agreement between years. Therefore it may be concluded that environmental conditions influence the yield of individual lines by determining the extent of expression of characters which contribute toward yield.

Table 2 presents simple correlation coefficients as calculated in each test in each year; in the combined tests in each year; and the two year average simple correlations, between all characters studied. The two year average correlation coefficient was calculated to show the general relationships between characters and also for use in calculating the partial and multiple correlations. The main purpose in presenting table 2 in this manner is to show the variations which occurred in some of the correlations between the same characters in the individual tests as compared to the general relationship found when the correlations were calculated on the basis of one combined test of all 200 lines.

It is apparent in table 2 that certain relationships are relatively constant for the two years. The general relationship between yield and number of tillers per plant is positive and significant in both years. The correlation between yield and 1000 K.W. is also significantly positive in both years although of a slightly lower order than the yield - tiller relationship. There is no

Table 2. Simple Correlation Coefficients Calculated For Each Test in Each Year; For The Two Tests Combined in Each Year; and Two-Year-Average of The Combined Tests. (average r calculated by the "z" method) (9).

Variable	Test No.	Tillers			1000 K. W.			Head Length			Aleurone			Nit.
		1950	1951	Av.	1950	1951	Av.	1950	1951	Av.	1950	1951	Av.	
Yield	1	+0.38	+0.34		+0.08	+0.05		-0.06	-0.07		+0.11	+0.04		-0.38
	2	+0.09	+0.08		+0.20	+0.39		+0.21	-0.05		+0.01	-0.03		-0.32
	1&2	+0.25	+0.23	+0.2449	+0.14	+0.20	+0.1732	+0.06	-0.07	-0.0050	+0.06	+0.01	+0.0350	-0.36
Tillers	1				-0.31	-0.20		-0.50	-0.33		+0.08	-0.13		-0.03
	2				-0.33	-0.29		-0.46	-0.33		-0.19	-0.20		+0.09
	1&2				-0.32	-0.26	-0.2950	-0.48	-0.33	-0.4080	-0.05	-0.15	-0.0997	+0.01
1000 K.W.	1							+0.21	-0.22		+0.29	+0.04		+0.26
	2							+0.49	+0.07		+0.10	+0.03		+0.19
	1&2							+0.38	-0.07	+0.1605	+0.19	+0.03	+0.1096	+0.23
Head Length	1										+0.08	+0.16		-0.15
	2										+0.13	+0.17		-0.17
	1&2										+0.11	+0.16	+0.1375	-0.14
Aleurone	1													-0.05
	2													+0.10
	1&2													+0.02

Levels of significance: Individual tests, $r_{.05} = .195$ $r_{.01} = .254$
 Combined tests, $r_{.05} = .138$ $r_{.01} = .181$
 Average of Combined tests, $r_{.05} = .138$ $r_{.01} = .181$

significant correlation between yield and length of head in either year. However, when the correlations between yield and each of these characters in the individual tests are examined, further observations can be made. In Test #1 there is a highly significant positive correlation between yield and tillers per plant whereas in Test #2 there is no correlation indicated between these characters. In Test #2 there is a significant positive correlation between yield and 1000 K.W. but this correlation is not indicated in Test #1. With regard to yield and head length there is no correlation between these characters in Test #1. In Test #2 there is a significant positive correlation shown between yield and head length in 1950. This correlation was not evident in 1951. It will be noted that in 1950 when the positive relationship between yield and head length occurred, the correlation between yield and 1000 K.W. was considerably lower than in 1951, and there was no correlation between yield and tillers per plant. These results indicate that yield is influenced by these characters and also that expression of any one of these characters is influenced to some extent by the expression of the other two. Further evidence of this interrelationship between these characters is seen when the simple correlations between number of tillers per plant and 1000 K.W., number of tillers per plant and head length, and 1000 K.W. and head length, are examined in table 2. There is a consistent significant negative correlation between number of tillers and 1000 K.W., and between number of tillers and length of head. A significant positive correlation occurred between 1000 K.W. and head length in 1950 but did not occur in 1951. These results are interpreted to indicate that when an increase in tillering occurs there is some increase in yield, but that this increase is not proportional since there is a corresponding decrease in

1000 K.W. and in head length. Similarly when the extent of tillering is limited, the heavier kernels and longer heads produced tend to compensate for any large decrease in yield which might be expected from lack of tillers.

Table 2 also shows certain relationships which were found in only one of the two years indicating that environmental factors influence these relationships considerably. In 1950 there is a significant positive correlation shown between aleurone color and 1000 K.W. suggesting that lines with yellow aleurone tended to produce heavier kernels in that year. Also in 1950 there is a highly significant positive correlation shown between head length and 1000 K.W. indicating that, in that year, there was a definite relationship between long heads and high kernel weight. In 1951 the positive correlation shown between head length and aleurone color is significant indicating a tendency for those lines having yellow aleurone to produce longer heads in that year.

Also included in table 2 are the simple correlation coefficient for nitrogen content and all other characters, in 1950. These results will be discussed in full at this point as this character was not included in the calculation of the partial correlation coefficients. It will be noted that there is a significant negative correlation between yield and nitrogen content in both tests. This result indicates that as yield increases the nitrogen content of the grain decreases. This is in agreement with the reports of Hunter (10) and of Neatby and McCalla (17).

A significant positive correlation between nitrogen content and 1000 K.W. is shown in both tests indicating that as 1000 K.W. increases nitrogen content of the grain also increases. This result is not in agreement with the findings of Anderson et al.(1), or Lejeune (15), who

both reported a significant negative correlation between these characters. Anderson et al.(1) found this negative relationship to exist in seven different varieties of barley, and Lejeune reported it in F₃ lines from a cross of Chevron x O.A.C. 21. Therefore it seems unlikely that the positive relationship in this study is peculiar to the material studied. It is more probable that this relationship is the result of environmental conditions prevailing in 1950, and no definite relationship can be established on the basis of the results in that year.

A significant negative correlation between nitrogen content and head length is indicated in both tests. This result indicates that those lines which produced long heads had a tendency to produce grain of a lower nitrogen content. However this correlation coefficient is barely significant at the 5 % level and no conclusive relationship can be established.

No significant correlations were found between nitrogen content and either tillers per plant or aleurone color. The lack of association between nitrogen content and tillering, even though both are related to yield, may be an indication that any genes governing nitrogen content and associated with yield, are in a different location than those genes governing tillering which are associated with yield. With respect to aleurone color and nitrogen content, the results indicate that there is no association between genes controlling these characters.

With respect to the relationships between nitrogen content and other characters, it is well known that environmental factors are important in determining nitrogen content of grain, and there is little doubt that these same factors have an effect on the expression

of other quantitative characters in this study. When the 1951 data on nitrogen content are available, they will show whether or not the influence of environment on 1000 K.W. and head length corresponds to the influence of environment on nitrogen content.

Table 3 presents the two year average simple correlation coefficients and the corresponding partial correlation coefficients.

Table 3. Simple and Partial Correlation Coefficients

Variables	Simple Correlation Coefficients	Partial Corr. Coefficients
Yield.Tillers	+ .2449**	+ .3274**
Yield.1000 K.W.	+ .1732*	+ .2589**
Yield.Headlength	-.0050	+ .0950
Yield.Aleurone	+ .0350	+ .0310
Tillers.Headlength	-.4080**	-.3862**
Tillers.1000 K.W.	-.2950**	-.3145**
Tillers.Aleurone	-.0997	-.0351
1000 K.W.Headlength	+ .1605*	+ .0113
1000 K.W.Aleurone	+ .1096	+ .0692
Headlength.Aleurone	+ .1375*	+ .0997

* 5 % level of significance attained

** 1 % level of significance attained

On examining Table 3 and comparing the partial correlation coefficients with the corresponding simple correlation coefficients, it will be noted that when the effects of all other characters studied are held constant, the relationships between each of tillers per plant, 1000 K.W., and head length, with yield become more pronounced. This is further evidence that there is an interaction of these three

characters in influencing yield. The results seem to indicate that genes for extensive tillering are associated with genes governing kernel weight and with genes governing head length, and that there is considerable association between all of these genes and yield. It is probable that conditions favorable to the full expression of genes for extensive tillering are not favorable to the full expression of genes for heavy kernels and long heads and vice versa. Therefore this interaction of genes has a stabilizing effect rather than a cumulative effect on yield in that the negative effects of some genes are offset by the positive effects of other genes. As long as this type of association exists between genes for tillering, 1000 K.W., head length, and yield, it will be impossible for the plant breeder to select for increased yield on the basis of any one of these characters alone. However this association of characters may be of some use in selection in that one can select for high tillering and long heads to some extent, and be reasonably sure of not getting too high a 1000 K.W.. High 1000 K.W. is an undesirable character in a malting barley. Selection for the best possible combination of tillering and head length should result in some increase in yield.

It will be noted in table 3 that the partial correlation coefficients proved to be significant in only four of the ten relationships and that these four coefficients attained the 1 % level of significance. Of the four characters included in the calculation of partial correlations with yield, only tillers per plant and 1000 K.W. are shown to be significantly correlated with yield. These correlations, as previously stated, are positive, and are in agreement with the findings of previous workers. Thayer and Rather (22) and Hunter (10) both reported a positive relationship between yield and tillering. Bridgford



and Hayes (3) and Quisenberry (19) reported positive correlation between yield and 1000 K.W. in wheat, and the results of this study show that the same relationship exists in barley.

Highly significant negative correlations are shown to exist between tillers per plant and head length, and between tillers per plant and 1000 K.W.. The partial correlations show that the effects of the other characters studied are practically negligible, with respect to these relationships.

Neither the simple nor the partial correlation coefficient for yield and head length is significant, although there is a trend toward a positive correlation when the effects of the other characters studied are eliminated. This is to be expected since other workers have reported positive simple correlation between these characters. Thayer and Rather (22) have suggested a positive relationship between yield and head length, and a significant positive simple correlation was reported by Leasure et al. (14).

It is of interest to note that there is practically no difference between the simple and partial correlations for yield and aleurone color. This result indicates that genes controlling aleurone color are not associated with genes controlling any of the other characters studied. There is further evidence for this assumption in that no correlation is shown to exist between aleurone color and any other character in the study.

The simple correlation coefficient for 1000 K.W. and head length is shown to be positive and significant. Elimination of the effects of the other characters studied reduced this correlation to insignificance. This result suggests that certain genes associated with 1000 K.W. and head length are more closely associated with tillers per plant and

yield. When the effects of tillers and yield are eliminated the relationship between 1000 K.W. and head length is also eliminated.

The multiple correlation coefficient for yield and all characters studied was calculated to be $R = .3678$. This coefficient attains the 1 % level of significance but, when squared, gives only 13.53 % as the percentage of the variability in yield accounted for by its association with the characters studied. The multiple correlation for yield with tillers per plant and 1000 K.W. was calculated to be $R = .3549$. Squaring this coefficient gives 12.60 % as the percentage of the variability in yield accounted for by its association with these two characters. It is evident then that tillers per plant and 1000 K.W. accounted for practically all of the variability in yield in this study. However since such a large percentage of the variability is not accounted for, it may be concluded that numerous other characters must be considered when selecting for high yield in barley.

Summary and Conclusions

A replicated study of 196 lines of barley, from a cross of Montcalm x Vantage, was carried out to determine the possible relationships between yield, nitrogen content, head length, tillers per plant, 1000 K.W., and aleurone color. The lines were homozygous and had been selected for rust resistance in earlier generations. Montcalm and Vantage were included twice in each year as check varieties. This study was carried for two years at a different location in each year. Both simple and partial correlations were determined between all characters with the exception of nitrogen content. Only the simple correlations were determined in one year between nitrogen content and the other characters in the study.

Tillers per plant and 1000 K.W. were both found to be positively correlated with yield, the partial correlation being more pronounced in each case. Head length and 1000 K.W. were both found to be negatively correlated with number of tillers per plant and the partial correlation indicated that the other characters studied had little influence on these relationships. An interaction of genes for these characters, in relation to yield, is indicated. This interaction has a stabilizing, rather than a cumulative, effect on yield, in that factors responsible for increases in one character seem to be responsible for corresponding decreases in one or more of the other characters which influence yield.

A significant negative correlation was found between yield and nitrogen content. A significant negative correlation was also found between nitrogen content and head length, whereas a significant positive correlation was indicated between nitrogen content and 1000 K.W.. No correlation was indicated between either tillers per plant or aleurone

color and nitrogen content. These relationships are indicated by simple correlation coefficients in one year only.

No significant correlation was found between yield and head length or between 1000 K.W. and head length, and aleurone color was not correlated with any of the characters studied.

The multiple correlation coefficient for yield and the other characters studied was significantly positive. Squaring this coefficient gave only 13.53 % as the percentage of the variability in yield accounted for by its association with the characters studied, and 12.60 % of the total variability in yield was accounted for by its association with tillers per plant and 1000 K.W. alone.

One can conclude from this study that, although tillers per plant, 1000 K.W., and head length do influence yield in barley, no single character in this study is closely enough correlated with yield to be of value in selecting high yielding lines of barley in the early generations of a breeding program. It may also be concluded that environmental factors have a pronounced effect on the expression of characters which contribute towards higher yield in barley.

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