CORRELATED INHERITANCE OF STEM RUST REACTION, NITROGEN CONTENT OF GRAIN AND KERNEL WEIGHT IN A BARLEY CROSS

by

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Correlated Inheritance of Stem Rust Reaction, Nitrogen Content of Grain and Kernel Weight in a Barley Cross

INTRODUCTION

One of the objectives of barley breeding programs in Canada is the production of a stem rust resistant, smooth awned variety with good malting quality. In order to facilitate the breeding procedure it is necessary to understand the mode of inheritance and the inter-relationship of the characters involved. It was with this in mind that the present study was undertaken.

Criteria of malting quality were studied rather than actual malting quality characteristics for several reasons. The criteria studied, namely barley nitrogen content and kernel weight, are used by the plant breeder to eliminate undesirable hybrids in early generations after the cross. The determination of these criteria requires a much smaller sample of grain and much less time and equipment than the actual malting test.

Nitrogen content is an indicator of malting quality because within varieties it is closely related to malt extract, malt diastatic activity, malt proteolytic activity and malt wort nitrogen. It is related in a lesser degree to malt loss, malt starch liquefying activity and hours to steep. (Anderson et al. (1)).

Within varieties, kernel weight is related to malt extract, malt wort nitrogen, malt starch liquefying activity and hours to steep (the number of hours required for barley to reach 44 per cent moisture when imersed in water). Small

kernels produce a malt with low extract which is undesirable for the brewing industry. Barley with low kernel weight is very difficult to clean properly, especially as regards wild oats. Small kernels also result in greater loss during the cleaning process.

As nitrogen content and kernel weight are indicators of malting quality, their relationship to stem rust resistance is important in a breeding program the objective of which is stem rust resistant malting barley.

If the quality criteria are genetically independent of the factor for stem rust reaction, no difficulty should be encountered in obtaining the desirable combination of low nitrogen content and high kernel weight with stem rust resistance. However, from examination of the malting data on many stem rust resistant hybrids, it appears that the above combination is difficult to obtain.

Review of Literature

Studies on the inheritance of stem rust reaction in barley have been few.

Shands (10) reported in 1939 that Chevron (C.I.IIII) was selected and named at Chico, California in 1918. It was selected from seed originally obtained at the Swiss Seed Experimental Station, Zurich, Switzerland. This seed represented an improved domestic variety obtained by the Swiss Station from Canton Lucerne, Switzerland. Peatland (C.I. 5267) was selected from part of the same original lot at the Minnesota Agricultural Experimental Station in 1916.

Shands (10) found Chevron resistant to stem rust (*Puccinia graminis tritici*, Eriks. and Henn.) under severe epidemics in 1935 and 1937. In 1937 it showed an average of one per cent stem rust. The resistance of Chevron was shown to be dominant and due to a single factor in crosses with Wisconsin Pedigree 38, Velvet and two smooth awned hybrids X 152 and X 169. A cross of Oderbrucker X Chevron gave the same result.

Mains and Martini (7) found Chevron to be highly resistant to three physiologic races of mildew (*Erysiphe graminis hordei*, March.) and highly susceptible to leaf rust (*Puccinia anomola*, Rostr.).

Tidd (12) showed Chevron to be highly resistant to races 6 and 7 of barley mildew.

Immer *et al* (6) found Chevron resistant to races 10, 14, 15, 17, 19, 21, 24, 34, 40, 48, 49, 53, 55, 56, 59, 97, 139 and 147, and susceptible to race 39 of stem rust in the seedling

stage. They also found that seedling reaction could be used as a test for adult plant reaction.

Powers and Hines (8) in a Peatland X Glabron cross found resistance to stem rust dominant and due to single factor pair Tt. Stem rust races 17, 38 and 49 were used. The factors for stem rust reaction and barbing of the awns were not linked. Reid (9) obtained similar results in a cross of Barbless and Peatland.

Brookins (3) working with Peatland, located the factor pair Tt for stem rust reaction in the seventh linkage group. He found that seedling reaction to physiologic races 19, 39 and 56 was monohybrid with resistance dominant. The same factor pair controlled the mature plant reaction to a large number of physiologic races.

Shands (11) in a study to determine an adequate sample for determination of 1,000 kernel weight, found 400 kernels to be sufficient for an accurate determination.

Anderson et al (1) found that, within varieties, as total barley nitrogen increases, malt extract decreases and diastatic activity, malt loss, wort nitrogen, proteolytic activity and starch liquefying power in the malt increase. The simple correlations between total barley nitrogen and wort nitrogen, malt extract, diastatic activity and proteolytic activity were significant beyond the one percent point. They also found that kernel weight within varieties was significantly and positively related to hours to steep and malt extract. Kernel weight, within varieties, was significantly and inversely correlated with wort nitrogen and starch liquefying activity.

Anderson et al (2) pointed out that the barley variety O.A.C. 21, on the recommendation of the Canadian maltsters and on the basis of malting tests, is the most suitable variety in Canada for malting purposes. In the descriptions given by them of malting quality of 28 varieties, O.A.C. 21 is described as having a medium sized kernel and medium nitrogen content over a wide range of environmental conditions. Its malt extract, diastatic activity and wort nitrogen are high. Little loss occurs in extract during malting. O.A.C. 21 produces a mellow, well modified malt with a maximum of extractives.

In the same paper, Chevron is faulted in all three barley characters. It is very high in nitrogen, very low in kernel weight and percent heavy grade barley. These faults result in a low extract although enzymatic activity is good.

Peatland, a sister selection of Chevron, appears to be better than Chevron, but not equal to O.A.C. 21 in either kernel or malt characters.

Material and Methods

O.A.C. 21 was selected as the susceptible parent because it is the standard of quality for six-row malting barley in Canada. It has been used extensively in barley breeding programs. It is a good yielding, rough-awned, six-row , blue aleurone variety.

For the resistant variety there were two alternatives, Chevron or Peatland. Chevron was chosen because it is poorer in quality than Peatland, especially in the two quality factors being studied. It was thought, that the greater the contrast between the parents, the more chance there would be of obtaining clear-cut information.

Chevron is generally low in yield. It is a rough-awned, six-row, white aleurone variety.

In 1941, the cross O.A.C. 21 X Chevron was made in the field. Fifty-six F_o seeds were obtained. In the fall of 1941, thirty-one of these seeds were sown in the greenhouse and 26 germinated. Six of these F_1 plants were used to make the backcross to the parent recessive for stem rust reaction. (O.A.C. 21 was known to be the recessive parent from observations on previous crosses of the same nature.) Twenty-nine seeds of the backcross were obtained. The remaining twenty F_1 plants were harvested for the F_2 population to be grown in the field in 1942.

In the spring of 1942 the 25 F_o seeds, saved from the original 56, the 29 backcross seeds, and seed from the twenty F_1 greenhouse plants were sown in the field with both parents. Nineteen F_1 plants and 26 backcross plants grew. These plants

were subjected to an artificial epidemic of stem rust.

This epidemic was brought about by inoculating susceptible border rows with a mixture of a large number of races of stem rust. These races were supplied by the Dominion Laboratory of Plant Pathology, Winnipeg. Two methods of inoculation were used. The inoculation rows were dusted with dry spores on an evening when it seemed reasonable to expect a heavy dew. The other method consisted of injecting a suspension of spores in water into border plants with a hypodermic needle.

In the fall, all of the plants were pulled by hand and taken inside for stem rust readings. A total of 592 F_2 plants was obtained.

After the rust readings were made, 200 F_2 plants were selected at random from the whole F_2 population. A number was assigned to each of the 592 plants, each number was then written on a card. Two hundred cards were drawn at random from the 592 available. The 200 F_2 plants corresponding to the cards were threshed and used for the F_3 population.

The seed of each of the 200 plants was divided into two lots. Twenty-five kernels, taken at random from each plant, were placed in one lot to be used for determination of stem rust reaction and genotype of the line. The remaining seed of each F_2 plant comprised the other lot for use in the quality studies.

In the spring of 1943 the lot for stem rust determination was planted with both parents. These plants were subjected to an artificial epidemic of stem rust induced by the procedure described above. The other lot, for quality studies, was

planted at another location. In this case, each line was planted in a single row with both parents occuring at ten-row intervals.

The planting for quality determinations was dusted with sulphur to prevent infection by stem rust. In this way, the results on the quality factors would be comparable for the different genotypes; since both susceptible and resistant plants would be free of rust.

Stem rust readings for all the material were made on a percentage basis. The amount of stem rust was recorded as 100 percent when approximately 37 percent of the actual area of the stem surface was covered with rust. Clark et al (4). The percentage interval was ten with the range from ten to 100 percent. When rust was present in an amount closer to zero than to ten percent, the reading was taken as a trace. When no pustules could be found on the stems the recording was zero.

Among the F_3 lines those showing zero or trace on all plants were classified as resistant. The lines showing more than ten percent rust on all plants were rated as susceptible. Those showing both resistant (zero or trace) and susceptible plants (more than ten percent) were classified as segregating.

Thousand kernel weight was determined by counting 500 kernels at random from each F_3 line, weighing these and multiplying by two.

For nitrogen content, a random sample from each line was ground in a Wiley mill equipped with a $\frac{1}{2}$ mm. screen. A five gram sample was sent to the Grain Research Laboratory, Winnipeg,

where duplicate determinations were made on an oven dry basis using two-gram samples.

Statistical methods used were the Chi-square test for goodness of fit, the Chi-square test for independence and association, simple and partial regression, simple and partial correlation, and fitting actual frequencies to the theoretical normal frequencies. The methods were as described by Goulden (5).

Results and Discussion

1. Inheritance of Stem Rust Reaction.

Table 1. shows the reaction to stem rust of both parents, the F_1, the backcross, and the F_2.

Table 1. Stem Rust Reaction of the Parents, F_1, Backcross and the F_2 in the Cross O.A.C. 21 X Chevron.

	Rust Reading in Percent										
	0	t	10	20	30	40	50	60	70	80	Total
O.A.C. 21				1	4	9	6	9	3	1	33
Chevron	14	22									36
F_1	1	18									19
Backcross		14	1	1	1	3	3	1	1	1	26
F_2	53	368	14	18	38	36	32	21	9	3	592

In Table 1. it is evident that resistance to stem rust is dominant because all of the F_1 plants are resistant. The resistant hybrids, however, appear to be less resistant than the resistant parent. Chevron, the resistant parent, had 61.1 percent of its plants in the trace group, while in the F_1 94.7 percent were in the trace group. In the backcross resistant class, 100 percent were in the trace group and in the F_2 resistant class 87.7 percent were in the trace group. The higher percentages of plants in the trace group in the offspring suggest that one or more modifying factors are present. This slightly influences the progeny towards

susceptibility. However, the modifying factors do not have enough influence to take any plant out of the resistant class or to be of practical significance.

In order to classify the F_2 offspring of the cross as resistant or susceptible to stem rust, the breeding behaviour of 194 F_2 plants was studied in the F_3. All of the plants except two, which showed zero or trace in the F_2 were either resistant or segregating in the F_3. The two lines that were neither resistant nor segregating showed 40 percent stem rust. The parent plants of these two lines probably escaped full infection in the F_2. It would appear, therefore, that in classifying all F_2 plants showing zero or trace as resistant, the error of classification is so small as to have no appreciable effect on the genetic ratios obtained.

The plants that showed 20 percent or more rust in the F_2, when grown in the F_3 all showed a heavy infection of rust. All F_2 plants that showed 20 percent or more rust are therefore correctly classified as susceptible.

The seed from the fifteen plants showing ten percent rust were grown for classification (14 in the F_2 and one in the backcross population). The progeny of the plant in the backcross was resistant and it may therefore be classified as resistant. Of the 14 plants in the F_2 showing ten percent rust, 11 were resistant or segregating in F_3 and may therefore be included in the resistant class. The remaining three were susceptible in the F_3 and consequently may be called susceptible in the F_2.

Table 2. Summary of Stem Rust Reaction of the Parents, F_1, Backcross and F_2 in the Cross O.A.C. 21 X Chevron.

	Resistant Actual	Resistant Theor.	Susceptible Actual	Susceptible Theor.	Theor. ratio	Chi-square	Probability
O.A.C. 21	0		33				
Chevron	36		0				
F_1	19		0				
Backcross	15	13	11	13	1:1	0.62	0.50 - 0.30
F_2	432	444	160	148	3:1	1.30	0.30 - 0.20

Table 2. shows the summarized and corrected classification of the data from Table 1. The fit of the actual to the theoretical ratios in the backcross and the F_2 populations is respectively very good. This is especially true of the backcross where it is shown that a deviation from the 1:1 ratio, as great or greater than that found, would be expected by chance in from 30 to 50 percent of the cases. In the F_2 the corresponding deviation from the 3:1 ratio would be expected in from 20 to 30 percent of the cases.

Of the 194 lines grown in the F_3, 46 were resistant, 94 segregated and 54 were susceptible. When these results were fitted to a 1:2:1 ratio, Chi-square was 0.79 with P between 0.70 and 0.50. This obviously is an excellent fit.

In view of the above results, it may be concluded that the inheritance of the degree of susceptibility and resistance to stem rust, exhibited respectively by O.A.C. 21 and Chevron, is governed by a single pair of factors with resistance dominant. Since

Chevron and Peatland are sister selections, it seems reasonable to assume that they have identical genotypes for stem rust resistance. This factor has been designated as Tt by Powers and Hines (8). It was found by Brookins (3) to be in the seventh linkage group. If the factor is Tt then the genotype of O.A.C. 21 for stem rust reaction is tt and for Chevron TT.

Figures 1, 2 and 3 show the amount of stem rust present on typical plants of the parents, F_1, F_2, and F_3.

Fig. 1. Stem Rust infection on the parents and F_1.

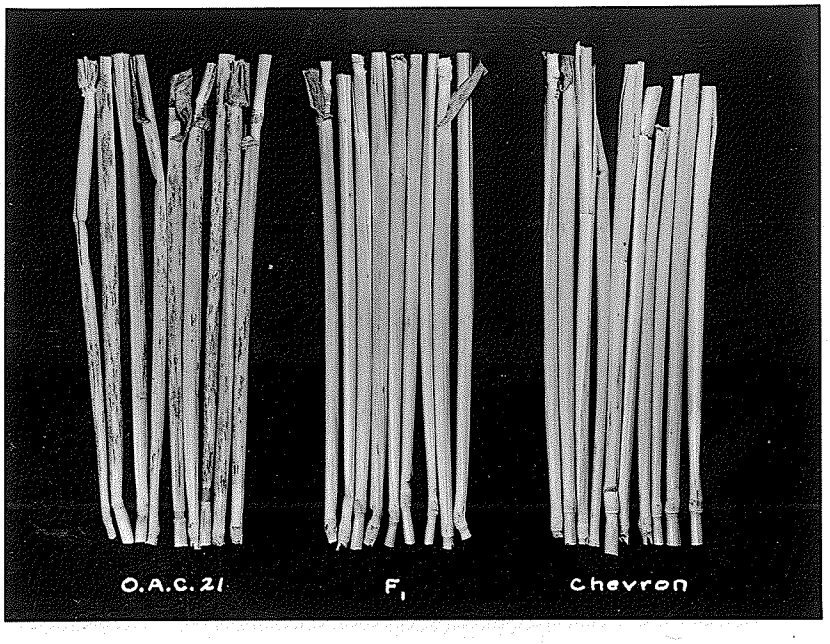


Fig. 2. Range of Stem Rust Infection on F_2 Plants.

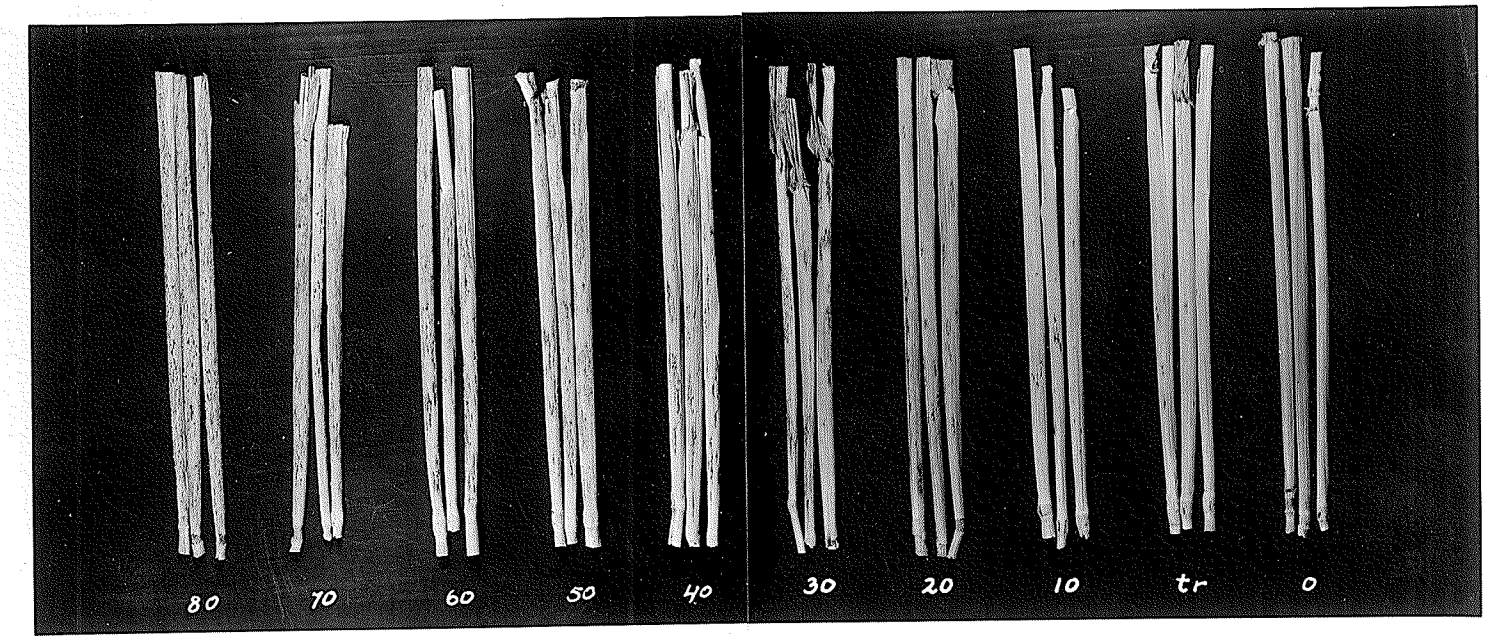
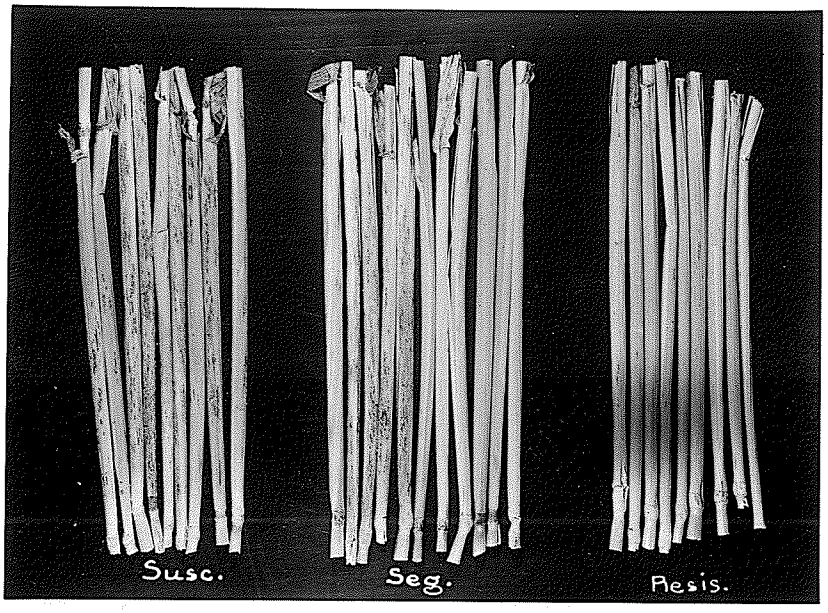


Fig. 3. The three groups of reaction to stem rust in the F_3.



2. Quality Studies.

A. Inheritance of Nitrogen Content.

In the F_3 generation of the cross, 187 of the 200 lines sown produced enough seed for quality determinations. The lines used for this purpose are those grown in the plot where stem rust infection was prevented. Nitrogen content was determined for each line as described previously. The stem rust reaction of the lines was known since a sample of each line was exposed to stem rust infection in a separate nursery. Thus, the genotype with regard to stem rust reaction, was known for each line.

Table 3. Frequency Distribution of Nitrogen Content in Percent for the Parents and the Different Genotypes in the F_3.

	Percent Nitrogen									
	2.145	2.245	2.345	2.445	2.545	2.645	2.745	2.845	2.945	3.045
O.A.C. 21	1	0	6	12	2					
Chevron		2	0	1	6	8	3	1		
Parent Totals	1	2	6	13	8	8	3	1		
F_3 Susc.	1	3	8	13	14	4	8	2	1	
F_3 Seg.		4	8	18	21	13	13	8	4	1
F_3 Resis.	1	1	2	5	12	12	5	1	3	1
F_3 Totals	2	8	18	36	47	29	26	11	8	2

The F_3 data presented in Table 3 indicates transgressive segregation for nitrogen content. When the combined distribution of the F_3 groups is compared to the combined distribution of the parents, ten (or 5.35 percent) of the F_3 lines exceeded the parents in nitrogen content. It is interesting to note that the F_3 segregating group, as would be expected, has the complete range of nitrogen content (with the exception of the lowest class, in all probability missed due to chance) exhibited by the combined resistant and susceptible F_3 groups.

If transgressive segregation has occurred, lines lower in nitrogen content than the parents would be expected. However, results similar to these are obtained repeatedly in breeding programs when an attempt is made to increase or decrease a quantitative character if the maximum or minimum limit is being approached. A good example of this is yield. Two high yielding types are often crossed and the resulting progeny almost invariably have many lower yielding lines and very few or no higher yielding lines. The same can be said for nitrogen in the present study. O.A.C. 21 is probably nearer the lower limit for nitrogen content than Chevron is near the upper limit. Consequently there is a tendency toward high nitrogen in the progeny of this cross.

In view of this definite tendency we would expect to have more F_3 lines with higher nitrogen content, in relation to the parents, than lines with lower nitrogen content. The population studied was small and as only ten lines out of 187 exceeded the resistant parent in nitrogen content, it is understandable why no lines lower than the susceptible parent occurred in this population.

As the inheritance of nitrogen content in all probability is quantitative, the F_3 totals for each nitrogen class were fitted to the theoretical normal frequency distribution. Table 4 presents the results. Chi-square was 6.06 and the P value at the 30 percent point was 6.06. This is a good fit and indicates that nitrogen content exhibits typical quantitative inheritance and is dependent on multiple factors.

Table 4. Theoretical Normal Frequencies and Actual Frequencies for Percent Nitrogen in the F_3.

Nitrogen Class	Theoretical Normal Frequency	Actual Frequency
2.145	2.61	2
2.245	8.14	8
2.345	19.02	18
2.445	31.13	36
2.545	39.98	47
2.645	37.70	29
2.745	26.46	26
2.845	13.82	11
2.945	5.38	8
3.045	1.54	2

B. Inheritance of Kernel Weight.

Thousand kernel weight data were obtained on the same 187 F_3 lines as were used for nitrogen determinations. The data are presented in the same manner as for nitrogen content.

The distribution of thousand kernel weight for the parents and F_3 is given in Table 5.

Table 5. Frequency Distribution of Thousand Kernel Weight in Grams for the Parents and Different Genotypes in the F_3.

	Thousand Kernel Weight (1000KW) in Grams													
	19.495	20.495	21.495	22.495	23.495	24.495	25.495	26.495	27.495	28.495	29.495	30.495	31.495	32.495
O.A.C. 21							1	2	3	6	5	3	1	
Chevron					2	6	8	4	1					
Parent Totals					2	6	9	6	4	6	5	3	1	
F_3 Susc.					1	2	2	17	15	9	2	4	0	2
F_3 Seg.			1	2	0	10	23	23	21	7	2	1		
F_3 Resis.	1	1	1	2	5	10	13	6	4					
F_3 Totals	1	1	2	4	6	22	38	46	40	16	4	5	0	2

Transgressive segregation for kernel weight is indicated by the data presented in Table 5. When the combined distribution for the F_3 groups is compared to the combined distribution of the parents, eight (or 4.28 percent) of the F_3 lines fall below the parents and cover a range of four kernel weight classes. Similarly, two (or 1.07 percent) of the F_3 lines exceed the parents but both lines are in the kernel weight class immediately above the limit of the parents. It is interesting to note that the range of the F_3 segregating group falls exactly between the ranges of the resistant and the susceptible groups. It does not, however, cover

the complete range of the combined F_3.

As indicated above, kernel weight tends to be lower in the progeny than in the parents just as nitrogen content tends to be higher in the progeny than in the parents. This tendency towards low kernel weight can perhaps be explained in the same manner as the tendency toward high nitrogen content. O.A.C. 21, the susceptible parent, may be nearer to the upper limit for kernel weight than Chevron, the resistant parent, is to the lower limit. Thus, the chances of obtaining a lower kernel weight in relation to the parents, are greater than of obtaining a higher kernel weight.

As the inheritance of thousand kernel weight appears to be typically quantitative, the F_3 totals for each kernel weight class were fitted to the theoretical normal frequency distribution. The results are presented in Table 6. The Chi-square value was 10.74 with the P value between the ten percent point (10.64) and the five percent point (12.59). This is again a good fit. The fit, however, is not as close as for nitrogen. The above result indicates that the inheritance of kernel weight is that of a typical quantitative character and is governed by multiple factors.

Table 6. Theoretical Normal Frequencies and Actual Frequencies for 1000 K.W. in the F_3.

1000 K.W. Class	Theoretical Normal Frequency	Actual Frequency
19.495	.08	1
20.495	.33	1
21.495	1.50	2
22.495	4.95	4
23.495	12.55	6
24.495	24.11	22
25.495	35.15	38
26.495	39.01	46
27.495	35.40	40
28.495	18.53	16
29.495	10.27	4
30.495	3.75	5
31.495	1.09	0
32.495	.24	2

C. Relationship of the Factors for Nitrogen Content and Kernel Weight to the Factor for Stem Rust Reaction.

This section is concerned with determining as far as possible, whether or not linkage exists between the factor for stem rust reaction and the factors governing nitrogen content and kernel weight. It is not concerned with the effect of stem rust infection on nitrogen content or kernel weight.

The data involved in the following tables and discussion are from known genotypes for the stem rust reaction factor and from plants protected against rust infection. These data for percent nitrogen content, 1000 kernel weight and stem rust reaction were examined by means of simple and partial correlation coefficients. Tables 7, 8, and 9 were used for the calculations.

Table 7. Correlation Table for Nitrogen Content and Stem Rust Reaction.

		Stem rust reaction x			
	Assumed Classes	1	2	3	Frequency
	Actual Classes	Resis.	Seg..	Susc.	y
Nitrogen Content (%) y	1 (2.10 2.19)	1	0	1	2
	2 (2.20 2.29)	1	4	3	8
	3 (2.30 2.39)	2	8	8	18
	4 (2.40 2.49)	5	18	13	36
	5 (2.50 2.59)	12	21	14	47
	6 (2.60 2.69)	12	13	4	29
	7 (2.70 2.79)	5	13	8	26
	8 (2.80 2.89)	1	8	2	11
	9 (2.90 2.99)	3	4	1	8
	10 (3.00 3.09)	1	1	0	2
Frequency	x	43	90	54	187

Table 8. Correlation Table for 1000 Kernel Weight and Stem Rust Reaction.

1000 Kernel weight (grams) y: Assumed Classes	Actual Classes	Stem Rust Reaction x: 1 Resis.	2 Seg.	3 Susc.	Frequency y
1	19.00 19.99	1			1
2	20.00 20.99	1			1
3	21.00 21.99	1	1		2
4	22.00 22.99	2	2		4
5	23.00 23.99	5	0	1	6
6	24.00 24.99	10	10	2	22
7	25.00 25.99	13	23	2	38
8	26.00 26.99	6	23	17	46
9	27.00 27.99	4	21	15	40
10	28.00 28.99		7	9	16
11	29.00 29.99		2	2	4
12	30.00 30.99		1	4	5
13	31.00 31.99			0	0
14	32.00 32.99			2	2
Frequency x		43	90	54	187

Table 9. Correlation table for nitrogen content and 1000 kernel weight.

1000 kernel weight (grams)
x

Assumed Classes	Actual Classes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Frequency y
	2.10															
1	2.19							1	1							2
	2.20															
2	2.29							1	3	2	2					8
	2.30															
3	2.39						1	2	5	6	1	2			1	18
	2.40															
4	2.49		1			1	2	7	11	8	3	1	2			36
	2.50															
5	2.59	1	0	1	1		4	11	14	6	7		2			47
	2.60															
6	2.69				1	3	7	6	5	5	2					29
	2.70															
7	2.79					2	4	4	5	7	1	1	1		1	26
	2.80															
8	2.89						4	3	1	3						11
	2.90															
9	2.99			1	2			3	1	1						8
	3.00															
10	3.09									2						2
Frequency x		1	1	2	4	6	22	38	46	40	16	4	5	0	2	187

Nitrogen Content (%)
y

Both the simple and partial correlation coefficients are presented in Table 10.

Table 10. Simple and Partial Correlation Coefficients.

Simple Correlation / Partial Correlation	Nitrogen Content %	Stem Rust Reaction	1000 Kernel Weight
Nitrogen Content %		-.1697^{x}	-.2065^{xx}
Stem Rust Reaction	-.0761		.5098^{xx}
1000 Kernel Weight	-.2855^{xx}	.6397^{xx}	

xx 1% level of significance attained.

x 5% level of significance attained.

In Table 10 the partial correlation coefficients were calculated with the item not involved held constant. The simple correlation coefficients are in the upper right hand corner and the partial correlation coefficients are in the lower left hand corner. In the following discussion of the correlation coefficients, it should be understood that in the frequency distributions resistance to stem rust represents the lowest class and susceptibility the highest class.

On examining Table 10 it will be noted that the simple correlation coefficient between nitrogen content and stem rust reaction is negative and quite low, but significant at the

five percent point. When kernel weight is held constant the partial correlation coefficient remains negative but becomes insignificant. In other words, as susceptibility to stem rust increases, nitrogen content decreases to a small extent. However, when the effect of kernel weight is removed the amount of decrease in nitrogen content becomes insignificant.

Both the simple and the partial correlation coefficients for kernel weight and stem rust reaction are positive and highly significant. This means that as susceptibility to stem rust increases kernel weight also increases.

The simple correlation coefficient between nitrogen content and kernel weight is negative and significant at the one percent point. When the effect of stem rust reaction is held constant the partial correlation remains negative, becomes larger and is still significant at the one percent point. Therefore, as kernel weight increases nitrogen content decreases or vice versa.

In Tables 7. and 8. numerical values of equal magnitude were substituted for the stem rust reaction groups. In view of the fact that the stem rust reaction groups are not actually numerical, combined frequency distributions were tested for independence and association by means of the Chi-square test. This was done to check the reliability of the correlation coefficients for nitrogen content and stem rust, and, kernel weight and stem rust. Following are Tables 11. and 12. used for above tests. Chi-square in both cases was corrected for continuity by the method developed by Yates (13) and described by Goulden (5).

Table 11. Combined Frequency Table for Stem Rust Reaction and Arbitrary Nitrogen Classes.

Rust Class		% Nitrogen content 2.10 2.39	2.40 2.49	2.50 2.59	2.60 2.69	2.70 2.79	2.80 3.09	Totals
Resis.	actual	4	5	12	12	5	5	43
	theoretical	6.44	8.28	10.81	6.67	5.98	4.83	
Seg.	actual	12	18	21	21	13	13	90
	theoretical	13.47	17.33	22.62	13.96	12.51	10.11	
Susc.	actual	12	13	14	4	8	3	54
	theoretical	8.09	10.39	13.59	8.37	7.51	6.06	
Total		28	36	47	29	26	21	187

$x2 = 10.54$ P = .20(9.80) - .10(12.02)

Table 12. Combined Frequency Table for Stem Rust Reaction and Arbitrary 1000 Kernel Weight Classes.

Rust Class		1000 Kernel Weight 19.00 24.99	25.00 25.99	26.00 26.99	27.00 27.99	28.00 32.99	Totals
Resis.	actual	20	13	6	4	0	43
	theoretical	8.28	8.74	10.50	9.20	6.21	
Seg.	actual	13	23	23	21	10	90
	theoretical	17.33	18.29	22.14	19.25	12.99	
Susc.	actual	3	2	17	15	17	54
	theoretical	10.40	10.97	13.28	11.55	7.80	
Total		36	38	46	40	27	187

$x^2 = 50.93$ P = .01(16.81)

In the case of nitrogen content and stem rust reaction there is no evidence of association as shown by Chi-square because in from ten to twenty percent of the cases deviations such as obtained would be due to chance. This is the same general conclusion which may be arrived at from the correlation coefficient between these two characters.

With regard to kernel weight and stem rust reaction, there is good agreement between the results obtained by both the test for independence and association and the correlation coefficients. In this case both tests show a strong relationship between these two characters.

It has been shown earlier in this paper that stem rust reaction is governed by a single factor and nitrogen content and kernel weight are governed by multiple factors. We can then assume, in view of the above results, that a fairly large percentage of the factors governing kernel weight are linked with the factor for stem rust reaction. We may also assume that very few or none of the factors governing nitrogen content are linked with the factor for stem rust reaction. However, there is a correlation between nitrogen content and kernel weight. This is shown by the significant correlations in Table 10. and by Anderson et al (1). Through this correlation and the association between kernel weight and stem rust reaction, nitrogen is indirectly affected to a small extent by the genetic constitution of a plant for stem rust reaction.

The close linkage between kernel weight and stem rust reaction has been broken. A rust resistant F_3 selection made (by the author) in 1943 from a bulk lot of the same cross was found to have high kernel weight. The 1000 kernel weight of

the selection was 34.46 grams as compared to a weight of 34.16 grams for a comparable sample of O.A.C. 21.

In order to demonstrate graphically the interrelation of the factors for nitrogen content and stem rust, and, the factors for 1000 kernel weight and stem rust, regression lines were plotted. Following are the simple and partial regression coefficients.

	Simple Regression Coefficient	Partial Regression Coefficient
Nitrogen Content (%) on Stem Rust Reaction	-.4262[x]	-.2185
1000 K.W. (grams) on Stem Rust Reaction	1.3425[xx]	1.2872[xx]

xx 1% level of significance attained.

x 5% level of significance attained.

The regression graphs for nitrogen on stem rust are shown in figures 4 and 5. The simple regression line shows that as recessive genes for stem rust reaction increase nitrogen content decreases slightly. However, when the effect of kernel weight is removed the regression line becomes almost flat and is insignificant.

The regression graphs for 1000 kernel weight on stem rust reaction are shown in figures 6 and 7. Both simple and partial regression lines are practically identical. In this case as recessive genes for stem rust reaction increase 1000 kernel weight increases. This is the reverse of the combination desirable for good quality rust resistant barley.

Fig. 4. Simple Regression Graph for Nitrogen Content (%) on Stem Rust Reaction.

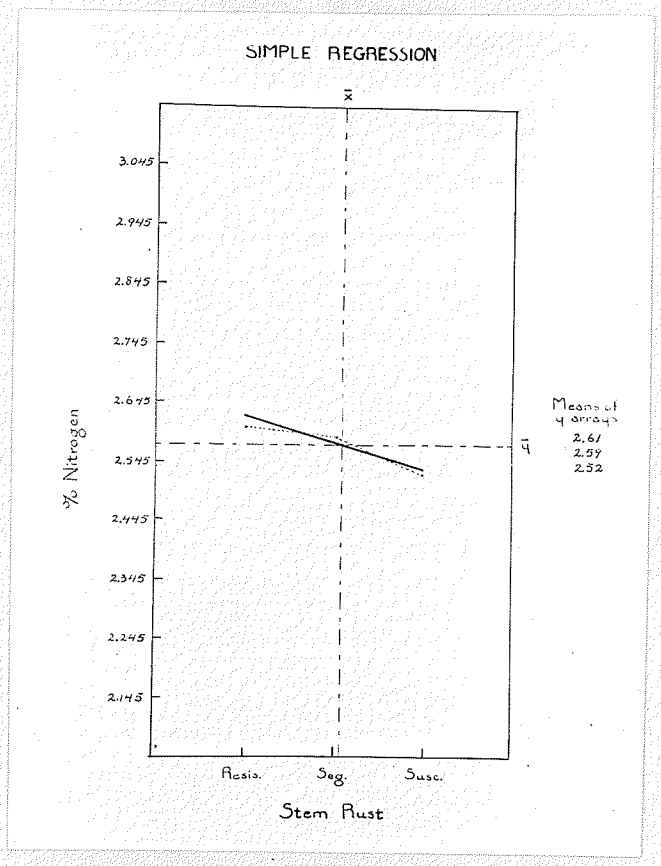


Fig. 5. Partial Regression Graph for Nitrogen Content (%) on Stem Rust Reaction.

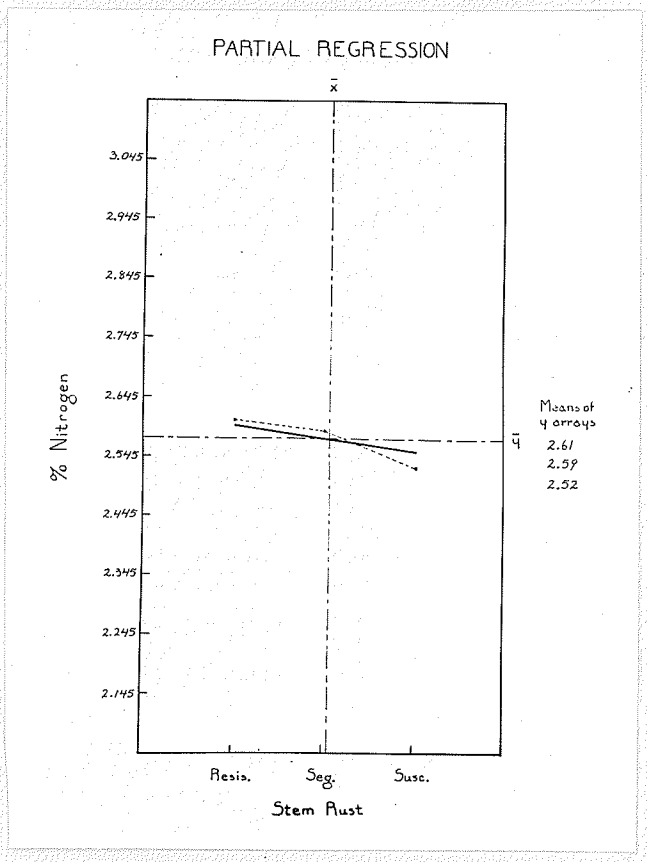


Fig. 6. Simple Regression Graph for 1000 Kernel Weight (grams) on Stem Rust Reaction.

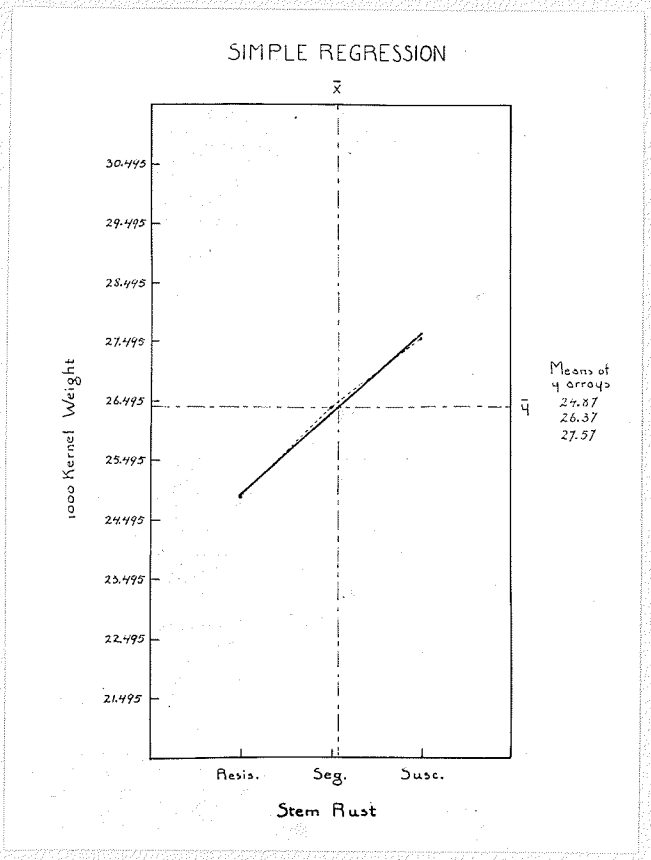
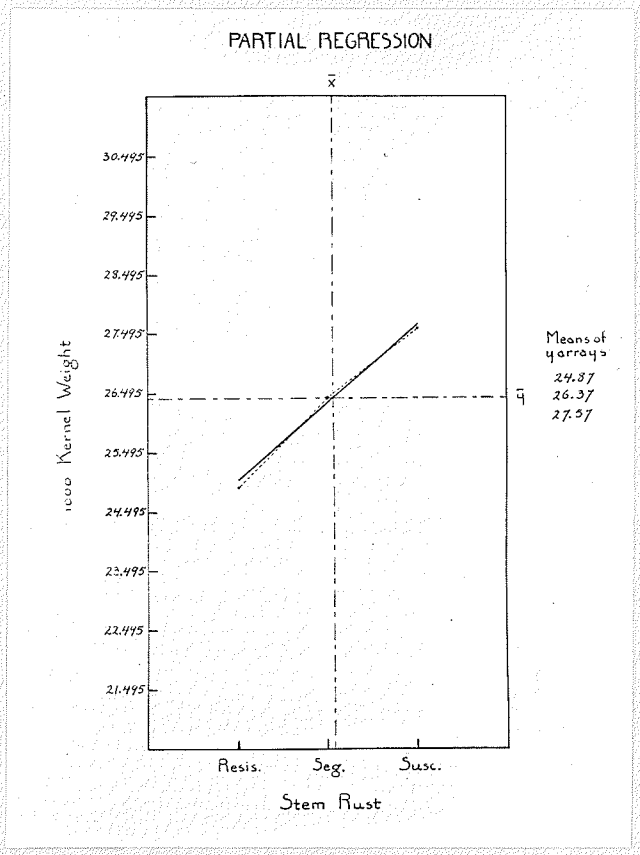


Fig. 7. Partial Regression Graph for 1000 Kernel Weight (grams) on Stem Rust Reaction.



Summary and Conclusions

In the cross O.A.C. 21 X Chevron, the inheritance of stem rust is governed by a single factor pair with resistance dominant. This factor is probably the same as that found in Peatland by Powers and Hines (8). There is evidence that one or more minor factors modify the reaction of the resistant offspring towards susceptibility. However, the effect of such modifying factors are of no practical significance.

The inheritance of nitrogen content in the same cross is governed by multiple factors. There is a definite tendency for nitrogen content in the F_3 progeny to be higher than that of the parents genetically comparable for the stem rust factor.

The inheritance of kernel weight is also governed by multiple factors. In this case, there is a definite tendency towards lower kernel weight in the F_3 progeny than in the parents genetically comparable for the stem rust factor.

None or few of the factors for nitrogen content are directly associated or linked with the factor for stem rust reaction. However, some of these factors are apparently associated with it indirectly through its relation to kernel weight. This indirect relationship results in a weak association of high nitrogen content with rust resistance.

A large proportion of the factors for 1000 kernel weight appear to be linked with the factor for stem rust reaction. This linkage is fairly close and results in rust resistance being associated with low kernel weight. However, this linkage was broken when a much larger population was used.

In a breeding program with the objective of producing stem rust resistant barley with good malting quality, using Chevron or possibly Peatland as the source of rust resistance, it would be advisable to grow much larger populations than would be necessary if no linkage existed between kernel weight and the stem rust factor.

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