KERNEL HARDNESS AND ITS RELATION TO CERTAIN QUALITY CHARACTERS OF COMMON WHEAT

by

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CHAPTER I

INTRODUCTION

Improvement of the milling and baking properties in common wheat is one of the most difficult challenges facing the wheat breeder. Quality of the wheat kernel is a very complex character and is conditioned to a large degree by environment. Poor quality lines are difficult to identify in early generations due to insufficient seed for accurate milling and baking tests. Consequently, progenies of both high and low quality lines are grown until sufficient amounts of seed are obtained in order to perform the numerous quality tests.

Kernel hardness is the oldest test for quality and one that can be observed and measured more easily than other quality traits. If kernel hardness is highly correlated with other quality characters of wheat such as protein content, sedimentation value, and mixing time, it would be a useful aid to wheat improvement programs. Early-generation lines which possess a low kernel hardness index could be discarded while those with a high index and of desirable agronomic type could be retained for subsequent quality tests. The variations of kernel hardness and the limits of correlations between kernel hardness and other quality characters should be known before applying such a procedure in a breeding program.

Oklahoma, which is second in hard winter wheat production in the United States, has a great potential to produce high quality wheat.

Information concerning the year to year variation in kernel hardness and the relationship of kernel hardness to other quality characteristics of wheat grown at Stillwater could be useful in a quality breeding program for Oklahoma, since most breeding projects are conducted at the Agronomy Research Station in Stillwater.

Abbott (4) stated that a prompt and early quality evaluation for a great number of samples would enhance the breeding program. Using hardness as an indicator of quality may establish the breeding program on an individual F_2 plant basis, which has been accepted as an ideal procedure by the breeders to save time and money.

The scope of this study was to determine the relationship between kernel hardness and three quality characteristics using three of the most prominent methods of determining kernel hardness.

The objectives of the investigation were:

1) To attempt to find a quick, consistent and unbiased method of determining the degree of kernel hardness of wheat;
2) To estimate the effect of environment on kernel hardness;
3) To correlate kernel hardness as measured by these methods with three quality characteristics in order to establish the value of kernel hardness as a selection method in a quality improvement program.

CHAPTER II

REVIEW OF LITERATURE

Nature of Kernel Hardness

Kernel hardness is related to the density of the endosperm. Degree of hardness depends on the proportion of protein to starch and the behavior of these materials in the ripening of the grain (24).

Hackel (27) stated that in vitreous kernels, the proteinaceous materials occupy the spaces between the starch grains. In soft kernels there are many small air spaces around the starch granules. Lyon and Keyser (36), Freeman (24), Roberts (48), Percival (44), Carleton (12), Berg (9), and Bradbury et al. (11) also reported the existence of air spaces between starch granules in soft kernels.

Cobb (16) accepted the idea that the starch granules are held in a network of protein. He also noticed that the outer cells of the endosperm contain more protein than the inner parts. He stated that when the grain is hard and rich in protein it contains large amounts of small-sized starch granules in the endosperms (17). Lyon and Keyser (36) and Berg (9) confirmed Cobb's results. Roberts (48), on the other hand, found that in seven out of ten cases the diameters of the starch grains in the hard portions of the kernels were greater than the starch granules of soft portions.

Greer et al. (26) reported that the interstices between the large starch granules of the outer cells were filled by the smaller starch granules in soft endosperms and by the dense protein matrix in hard endosperms. The protein matrix maintains a smooth appearance and protects the cell material from dispersion in the hard kernels. Therefore, the endosperms of hard wheats show some cracks along the cell walls and produce particles of one or more cells in a crystalline appearance, when pressure is applied under high moisture conditions. The soft endosperms break down into structureless masses and the cracks develop through cells liberating the contents (25).

Alexandrov and Alexandrova (5) reported that the small starch granules of vitreous endosperm are rounded and separated by protein material. In floury endosperm, they are packed closely and many-sided leaving little space for nitrogeneous material. They believed that hardness is related to the morphology of the starch bed. If the small starch granules are few, as in the endosperms of true hard wheats, the more protein material will fill up the spaces resulting in a harder kernel. They also stated that the cell walls of hard endosperm were thicker than those of soft wheats.

Determination of Kernel Hardness

The hardness of wheat kernels has been determined for years by many workers without using a standard method. Shollenberger and Coleman (52), Clark (13), Shollenberger and Kyle (53), and Mangels (37) determined the hardness by visual inspection. They normally classified dark kernels as hard or vitreous kernels. Hayes et al. (29), Aamodt and Torrie (1, 2), Aamodt et al. (3), and Wright (64) estimated the vitreousness by examining the cross sections of cut kernels. They classified completely vitreous and starchy kernels as hard and soft, respectively. Endosperms which showed small spots of starch were grouped arbitrarily into medium groups.

Cobb (14, 15) reported the first objective measurement of kernel hardness. He used a biting or crushing device to determine the hardness of wheat grains. Harper and Peter (28) used a wheat tester to measure the kernel hardness. One hundred kernels were tested in the machine under a pressure of four pounds per kernel[1] and numbers of uncut kernels were accepted as the index of kernel hardness.

Soule and Vanater (54) and Shaw and Gaumnitz (51) employed a pair of ordinary pincers to measure the hardness. Roberts (47, 49) used a grain crusher, which crushes the kernels under different pressures, to evaluate the hardness of wheats. Newton et al. (43) developed and used another hardness machine to measure the kernel hardness. Jelinek (31) reported a hardness machine which was used in his laboratory. The kernels were cut through in this machine and the indicator of the device showed the hardness in numbers on the scale. He cut through 300 kernels and calculated average hardness.

Cobb (17), Lyon and Keyser (36), Roberts (48), and Berg (9) reported the determination of the kernel hardness by measuring the size of starch granules in the endosperms of wheat kernels. The endosperm samples were shaken up in alcohol, stained and mounted for measurement with a Bausch and Lomb Filar micrometer. The starch granules visible in any given field were measured. Average of five

[1] The authors did not mention any specific area for pressure applied.

hundred measurements for each ten-grain sample were recorded (48).

Cutler and Brinson (19) proposed the granulation test or particle size index test to measure kernel hardness. They ran 50 grams of ground wheat through a "Ro-Tap" equipped with 60- and 270-mesh metal sieves. The meal on each sieve as well as that in the pan was weighed and recorded and the granulation number was calculated. Worzella and Cutler (62) modified this procedure. They used the percentage of material through the finer sieve as the particle size index. According to them a low index indicates large particles of flour usually associated with hard wheats. The particle size index test has been used by Worzella (61), Fifield et al. (22, 23), Berg (9), Barmore et al. (7), and Symes (56, 57).

Taylor et al. (58) reported that they determined kernel hardness using a "Strong-Scott" barley pearler attached to a 1/8 h. p. direct drive electric motor. They tested 20 grams of wheat in the pearler which ran for three minutes. They removed the grain and rubbed off material from the machine and screened it with a 20-mesh screen. The percentage of material which remained on the screen was the pearling index. A higher pearling index represented a harder wheat. McCluggage (39) proposed a standard technique to use with the barley pearler. Kramer and Albrecht (35), Kellenbarger and Swenson (34), Bowman et al. (10), Middleton et al. (40), Beard and Poehlman (8), Barmore et al. (7) and Davis et al. (20) used the barley pearler to measure kernel hardness in their researches. Hehn and Barmore (30) stated that the common laboratory method of determining kernel hardness is to use a standard laboratory barley pearler. According to Zeleny (65) no serious attempt appears to have been made to standardize the equipment and procedures for determining pearling index.

Milner and Shellenberg (42) reported that they used a Brabender hardness tester to determine kernel hardness. This tester was a small burr mill fitted to the dynamometer coupling of the farinograph in place of the regular dough mixing bowl. Tests for hardness were made using 200-gram samples. The curves traced on the farinograph paper were measured for maximum height in Brabender units and for area, by means of a planimeter, in metric units (41).

Katz et al. (32, 33) modified a Barcol impressor, which has been used to test soft metals, to measure the hardness of individual kernels or even parts of a single wheat grain. The hardness was measured by pressing down on the framework of the impressor with the hand until the flat part of the impressor spindle is in contact with the section of kernel on the slide. The dial reading was recorded as the hardness number of a particular point on the wheat kernel.

Correlations Between Kernel Hardness and Protein Content, Mixing Time, and Sedimentation Value

Roberts (49), Clark (13), Newton et al. (29), Worzella (61), and Wright (64) found no significant correlation coefficients between protein content and kernel hardness. Mangels (37) reported that correlation between dark kernels and protein content showed considerable seasonal variation and the degree of correlation was low. Davis et al. (2) concluded that percentage of protein and kernel hardness were correlated, but the degree and sign of this relationship may vary from population to population. Mangels and Sanderson (38) found significant correlation between vitreous kernels and protein content in 1922 and

and 1924; but the correlation coefficient in 1923 was not significant. Fifield et al. (22) found a significant negative correlation between particle size index values of kernel hardness and protein content in spring wheat.

Harper and Peter (28) stated that flinty kernels contained more protein than starchy ones. Shollenberger and Coleman (52) wrote that there was a close relationship between kernel hardness and protein content. Coleman et al. (18) reported that the r values were significant, but the estimation of the percentage of vitreous kernels was only a general index of protein content of the wheat. Shollenberger and Kyle (53) found a fairly significant correlation coefficient between the kernel hardness and protein content. Waldron (59) and Wheeting and Vandecaveye (60) reported significant negative correlation between protein content and the percentage of yellowberry; indicating a positive relationship between kernel hardness and protein content. Aamodt and Torrie (1, 2) reported significant correlations between kernel texture and protein content. They stated that when material was grown on certain soil types, there existed a highly significant positive correlation between kernel texture and protein content. Milner and co-workers (41) reported high correlation coefficients between Brabender hardness tester values and protein content. Bowman et al. (10) found a significant correlation between pearling index and flour protein.

The correlation between kernel hardness and sedimentation value was reported by Wright (64). He stated that high vitreous kernels were associated with low sedimentation scores. Wright concluded that the vitreousness of a sample affected the results of the sedimentation test and a modification in the method of preparing flour samples for sedimentation test would improve the consistency of results.

Correlations between kernel hardness and mixing time have not been reported in the literature which has been reviewed.

CHAPTER III

MATERIALS AND METHODS

The genetic material used in this study consisted of the parent and the F_4, F_5, and F_7 generations of the cross Triumph X CI 12406. Triumph, an early maturity variety, was developed by Mr. Joseph Danne, El Reno, Oklahoma, and released in 1940. It quickly won wide acceptance by Oklahoma growers and is currently the leading variety in the state. The parentage of CI 12406 is Marquillo-Oro X Oro-Tenmarq. CI 12406, an experimental strain with strong gluten properties, is characterized by a long mixing time. The cross was originally made to combine the high gluten strength of CI 12406 with the early maturity of Triumph (50). The lines, which were tested in the present study with respect to kernel hardness, can be traced back to two F_1 plants grown in 1957. Additional information about the genetic material grown in Stillwater is given in Table I.

The data for protein content, mixing time and sedimentation tests of the F_4, F_5, and F_7 generations had been previously obtained by the Milling and Baking Laboratory of the Oklahoma Agricultural Experimental Station. In obtaining these data, standard procedures of Cereal Laboratory Methods were followed (6).

Protein Content: 1.0 gram wheat samples were tested applying the boric acid modification of the Kjeldahl procedure. The factor, 5.7,

TABLE I

EVALUATION OF GENETIC MATERIAL

Year Grown	Generation Number[1]	Number of Families	Number of Lines	Material Grown As	Selection Based On
1959-1960	F_4	112	112	Bulk progeny plant rows	Maturity, test weight, height
1960-1961	F_5	36	36	Bulk progeny-progeny plant rows	Quality data
1962-1963	F_7	7	236	Progeny head row selections	Agronomic characters and quality

[1] F_6 was not evaluated because of limited seed supply.

was employed for the conversion of nitrogen values to percent protein. The protein data were reported on a 14 percent moisture basis.

Mixing Time: 35 gram flour samples of 14 percent moisture basis were tested using a Swanson-Working mixograph.

Sedimentation Test: The procedure outlined by Pinckney et al. (45) was followed for the determination of sedimentation value. The method involved continuous mixing of a graduated cylinder containing a suspension of 3.2 grams of flour in 75 ml. of 0.05 N Lactic acid solution for five minutes. Immediately after mixing, the cylinder was placed in an upright position, and after an interval of five minutes the volume of the sediment was read. The sedimentation value of the sample was multiplied by the appropriate factor to obtain the corrected sedimentation score (45).

For the present study kernel hardness of the F_4, F_5, and F_7 generations of the Triumph X CI 12406 cross were determined by three different methods in 1966. These methods were as follows: 1) cutting (visual), 2) barley pearler, and 3) Brabender hardness tester.

Cutting Method: A Mark's grain tester was used to cut the kernels transversely. Four replications were tested for each sample. For each replication, 50 kernels were cut and scored visually for number of vitreous and non-vitreous kernels. Vitreous kernels were those that showed no starchy spots at all. This scheme is in accordance with that used by other workers (29, 52, 53, 64). The percentage of vitreous kernels was used as the kernel hardness score. This procedure has been used by other researchers (21, 29, 64).

Barley Pearler: A Strong-Scott laboratory barley pearler equipped with a 1/4 horse power electric motor, driven at 1725 r.p.m., and with a timer was used to determine the pearling indexes of the samples. Ten-gram wheat samples were placed in the pearler running at full speed. Sixty seconds later the slide outlet was opened and 15 seconds later the motor was stopped. The pearled wheat was screened with a 20-mesh sieve to remove the dust and powdered material. The wheat which stayed on the 20-mesh screen was weighed. The mean of two replications was multiplied by 10 to obtain the pearling index.

The Brabender Hardness Tester: F_4 and F_5 generations were tested using a single stage Brabender hardness tester. Because of shortage of F_7 material this generation could not be tested by this method. Ten-gram wheat samples for each replication were ground in the small mill of the tester. The heights of the curves for each replication of the samples were measured in metric units, instead of Brabender units, because some of the curves were beyond the limits of Brabender values. The mean of the curves of two replications was recorded as the relative hardness value of a sample.

The kernel hardness data were analyzed by variance analyses methods similar to those described by Steel and Torrie (55). Data from each of the three methods were first analyzed separately for each generation.

The cutting method was highly subjective and in order to determine the repeatability of this method, variance analyses were made involving two, three and four replications (determinations) per sample. Also, the standard errors of two and three replications from these analyses were compared with the standard errors for four replications in order to determine the efficiency of replications for the cutting method.

The kernel hardness data of each method were combined and the combined data were analyzed by appropriate procedures (55) in order to determine the importance of variation due to years and family X year interaction.

The linear correlation analyses were made applying the formulae and procedures given by Ezekiel and Fox (21). The coefficients of linear correlations between kernel hardness scores of the three methods and protein content, mixing time and sedimentation value were calculated for each generation.

CHAPTER IV

RESULTS AND DISCUSSION

Determination of Kernel Hardness

A summary of the kernel hardness scores for the parents and lines as determined by each method is presented in Table II. The cutting method resulted in hardness scores easily distinguishing the two parents. This was true also for the barley pearler method, although the results were less striking. The average hardness scores for the Brabender hardness tester, however, were not conclusive. Variation for kernel hardness among the Triumph X CI 12406 lines was significant at the one percent level of probability for each of the determination methods (Table III).

The Cutting Method

The cutting method involves the visual rating kernel cross sections; and consequently, hardness scores determined by this method are affected by the skill and physical ability of the operator. Although it is subjective (65), the cutting method may be based on standard procedures and objective rules to some extent. In the present study, vitreous and starchy kernels were determined without much difficulty. Some kernels showed small starchy spots at first appearance; however, when these spots were scratched with a dissecting needle the

TABLE II

AVERAGE KERNEL HARDNESS SCORES OF TRIUMPH X CI 12406

AND PARENTS IN THREE GENERATIONS

Genetic Material	Percent vitreous kernels Cutting method			Pearling index			Brabender Hardness Tester Score in cm	
	F_4 1959-1960	F_5 1960-1961	F_7 1962-1963	F_4 1959-1960	F_5 1960-1961	F_7 1962-1963	F_4 1959-1960	F_5 1960-1961
Triumph	77	34	34	43.4	49.2	45.4	17.1	13.7
CI 12406	95	95	90	56.6	--[1]	54.5	16.8	--[1]
Triumph X CI 12406 Range	52-94	40-99	18-88	43.2-67.3	52.0-71.7	39.3-60.0	9.8-20.5	11.4-20.1
Average	81	70	52	48.9	55.6	50.8	14.6	14.8

[1] Kernel hardness test could not be run because of the shortage of material.

TABLE III

THE F VALUES OF THE THREE DETERMINATION METHODS

Method	1960 Lines	1960 Replications	1961 Lines	1961 Replications	1963 Lines	1963 Replications
Cutting	10.86**	4.19*	19.01**	3.96*	20.58**	0.12
Pearl. Index	26.43**	1.29	4.45**	1.12	7.14**	0.16
Brab. Tester	6.58**	11.96**	3.78**	1.77	--	--

*significant at 5% level

**significant at 1% level

underlying parts were vitreous. Kernels showing starchy spots could not be classified objectively. They were grouped into an intermediate class. The numbers of completely vitreous kernels in a sample seemed to offer the most reliable basis for classification. Consequently, samples were classified according to the percentage of completely vitreous kernels. The same procedure was followed by the other workers (29,64). The cutting method is most effective in determining kernel hardness when all samples have completely starchy or vitreous kernels. Otherwise, there are difficulties in the classification of intermediate kernels. For this method, differences between replications were significant in the F_4 and F_5 data (Table IV). These significant F values imply that the determination of vitreous kernels could not be made without some degree of sampling error by the cutting method. The ratio of the standard errors of two and three replications to those of four replications are shown in Table V. By using two replications instead of four the standard error is increased by 11 percent.

If the replication numbers are three instead of four the standard error increases by nine percent (Table V). An average of five minutes was spent for each replication in the cutting method (Table VI). Ten minutes may be saved using two replications instead of four. By using only two replications the standard error will increase to around 10 percent with small numbers of samples.

TABLE IV

THE F VALUES OF TWO, THREE AND FOUR REPLICATIONS OF THE CUTTING METHOD

Replication Number	1960 Lines	1960 Replication	1961 Lines	1961 Replication	1963 Lines	1963 Replication
2	4.90**	6.05	8.72**	2.43	11.57**	0.12
3	7.54**	5.77**	13.46**	1.76	15.71**	0.13
4	10.86**	4.19**	19.01**	3.96*	20.58**	0.12

*significant at 5% level
**significant at 1% level

TABLE V

THE EFFICIENCY VALUES OF THE CUTTING METHOD

Replication	Year 1960	1961	1963	Average
2 vs 4	1.16	1.23	1.01	1.11
3 vs 4	1.09	1.17	1.03	1.09

The Barley Pearler

The pearling indexes of samples were significantly different among lines (Table III). The replications were not significantly different in these tests. These results are in agreement with the general idea that the pearling index is an objective test and consequently, not subject to subjective influences of the operator. The barley pearler test was satisfactory even though the standard procedure could not be strictly followed. The barley pearler was equipped with a current interrupting type timer, which was not proposed by McCluggage (39). The moisture content of the wheat samples was not measured, because McCluggage (39) reported that the moisture content of hard wheat between certain limits (7-15%) did not affect the pearling index. Two replications were used instead of three as suggested by McCluggage (39), because there was not enough seed for more replications. Grading of the pearled wheat samples was easily accomplished between two hardness extremes. Therefore, it would be an objective procedure in a breeding program in comparing lines with a known check variety.

TABLE VI

TIME SPENT FOR EACH METHOD TO DETERMINE THE KERNEL HARDNESS

Method	Hours in 1960	1961	1963	Total	For one sample in minutes
Cutting	38.0	12.5	83.0	133.5	20.0
Pearler	7.6	2.5	16.5	26.6	4.0
Brab. Tester	5.2	1.8	--	7.0	3.0

The Brabender Hardness Tester

The Brabender hardness tester showed significant hardness differences among the lines (Table III). A standard procedure could not be followed from the literature. Although some researchers reported that they used 200-gram samples, only 10-gram wheat samples were tested for each replication, because of seed shortage. One of the main difficulties was measuring the heights of the curves on the Brabender recording paper. Milner et al. (41) measured the curve heights in Brabender units. In this experiment the heights of the curves were measured in metric units, because the recording needle extended beyond the Brabender scale. It has been reported that (41) the areas of the curves were measured in metric units and these values were used to represent the relative hardness. It is logical that if the curve area is measured in metric units, the curve height can also be measured in these units. The Brabender hardness tester did not seem completely satisfactory when 10-gram wheat samples were tested. There was no evidence from this study to accept or reject the report that the size of kernels affects the results (41). More time was spent in measuring the heights of the curves than in testing the samples. It may be stated that a standard procedure should be established for the use of the Brabender hardness tester with small samples, since at the present time there was no standard procedure for small samples.

None of the methods used in this study to determine kernel hardness seemed to be completely satisfactory. Each of them had some advantages and disadvantages. The Brabender hardness tester was the fastest of the three methods. This tester was easy to operate and the samples were tested under almost ideal working conditions, because of few problems with recording and cleaning operations. On the other hand, the Brabender hardness tester did not give reliable results with small samples. Consequently, the use of this tester in a breeding program is questionable unless a standard procedure can be established.

The speed of the machine in the tests and the unit of measurement should not vary from generation to generation. The barley pearler was faster and more objective than the cutting method. It also was more reliable than the Brabender hardness tester with small samples. Working conditions with the barley pearler were more difficult for an operator than the Brabender hardness tester. The timer needs to be checked frequently and the slide outlet should be opened at the same time for each replication. The barley pearler was cleaned after each sample run. The cleaning operation was time consuming. The barley pearler could possibly be used in a breeding program to evaluate the lines in respect to kernel hardness comparing with known check varieties The cutting method was more subjective than the other two methods, and it also was very slow. Although the reliability increased, when the replications increased, this procedure reduced the repeatibility of the cutting method. For best results, standard lighting systems and working conditions are necessary in making these determinations. However, the cutting method may be used in a breeding program with known check varieties, because it was more convenient for the small samples than the other two. The operational time may also be shortened in this method by recording only the completely vitreous or starchy kernels and reducing the sample sizes from 50 kernels.

Effect of Environment on Kernel Hardness

For these analyses, families constituted the genetic units and lines derived from the same F_2 family were averaged to obtain the kernel hardness score for each family. The variation due to years was highly significant for the cutting, the barley pearler, and the

Brabender hardness tester methods (Tables VII and VIII). The year source of variation was significant at the one percent level of probability. Also, the family source of variation was significant at the same level. The family X year interaction was also significant for the cutting and the barley pearler methods, but not for the Brabender hardness tester method. These results favor the old and widely accepted idea that kernel hardness is largely influenced by environmental factors.

TABLE VII

THE F VALUES FROM THE COMBINED DATA OF THREE YEARS

Source of variation	Method	
	Cutting	Pearler
Family	79.32**	25.94**
Year	171.37**	16.31**
Family X Year	9.06**	2.39

*significant at 5% level
**significant at 1% level

Aamodt and Torrie (2) stated that kernel texture could be masked by environment. In the present study the significant F values for families showed that there were differences between families for the different years in Stillwater, even though environment affected the kernel hardness. The significant family X year interaction indicated that some families may show different kernel hardness in different years. Aamodt and Torrie (1, 2) also reported that in the brown soil area near Edmonton (Canada), a satisfactory differentiation in kernel hardness was obtained only in moist years. Differences among families were observed in Stillwater in different years, probably due primarily to rainfall. The annual precipitation was 53.63 inches, 38.14 inches, and 32.95 inches in 1960, 1961, and 1963 respectively.[1]

TABLE VIII

THE F VALUES OF THE COMBINED DATA OF F_4 AND F_5 FOR EACH DETERMINATION METHOD

Source of variation	Method: Cutting	Method: Pearler	Method: Brabender
Family	20.98**	5.87**	3.01**
Year	120.37**	390.43**	17.54**
Family X Year	6.66**	4.41**	0.94

*significant at 5% level
**significant at 1% level

The materials tested in the present study were grown on the same type of soil for successive years. Therefore the effect of different soil types on kernel hardness was probably of no consequence here. However, there still was an environmental influence on kernel hardness. This variation was due to years and family X year interaction. It was obvious from the present study that climate affected kernel hardness and different moisture and/or temperature conditions could bring about the differences among the families with respect to kernel hardness.

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[1] Based on crop year (July - June).

Correlations Between Kernel Hardness and Protein Content, Mixing Time, and Sedimentation Value

In general there were no strong associations between any of the kernel hardness scores and the three quality characters (Tables IX - XII). Inconsistencies in the correlation coefficients from one year to the next were noted. It was also apparent that the relationships between the three determination methods were relatively low and in some cases negative. There were, however, evidences of trends involving certain associations and these will be presented subsequently in more detail.

Correlations Among Methods of Testing

The coefficients of correlation between the determination methods were generally low, although some of them were statistically significant. Correlation coefficients obtained from the F_4 data (1960) are shown in Table IX. There was esentially no correlation between the hardness scores from the cutting method with either the pearling index or the Brabender hardness tester. There was an indication of negative correlation between the pearling index and the Brabender hardness tester.

For the F_5 data (1961) the correlations among the hardness determination methods were much the same as those described above. None of the correlation coefficients between the testing methods was statistically significant in this generation. (Table X)

The correlations involving the F_7 data (1963) showed somewhat closer association between the hardness determination methods

(Table XI). The r value between the cutting method and the barley pearler was 0.431 and significant at the one percent level of probability. The coefficient of determination of this correlation was 0.18. Eighteen percent of the variation in the pearling indexes was associated with the vitreousness of the samples.

TABLE IX

THE COEFFICIENTS OF CORRELATIONS IN 1960

	Pearling Index	Brabender H-tester	Protein Content	Mixing Time	Sedimentation Score
% Vitreous kernels	0.193*± 0.09	0.021± 0.094	0.103± 0.095	-0.066± 0.095	-0.104± 0.095
Pearling Index		-0.203*± 0.09	-0.129± 0.093	0.198*± 0.091	-0.085± 0.094
Brabender H-tester			0.323**± 0.085	-0.188*± 0.092	0.229*± 0.091

*significant at 5% level
**significant at 1% level

TABLE X

THE COEFFICIENTS OF CORRELATIONS IN 1961

	Pearling Index	Brabender H-tester	Protein Content	Mixing Time	Sedimentation Score
% Vitreous kernels	0.304± 0.163	0.019± 0.174	0.449**± 0.124	0.589** 0.102	0.286± 0.143
Pearling Index		0.032± 0.174	0.029± 0.174	0.062± 0.173	0.055± 0.173
Brabender H-tester			0.181± 0.168	0.001 0.174	0.039 0.173

**significant at 1% level

TABLE XI

THE COEFFICIENTS OF CORRELATIONS IN 1963

	Pearling Index	Protein Content	Mixing Time	Sedimentation Score
% Vitreous Kernels	0.431**± 0.052	0.238**± 0.060	0.144*± 0.060	0.329**± 0.057
Pearling Index		0.267**± 0.059	0.099± 0.063	0.291**± 0.058

*significant at 5% level

**significant at 1% level

The correlation coefficients among the kernel hardness scores of the determination methods in 1960 and those in 1961 are shown in Table XII. The r values were generally low and negative. There was no correlation between the pearling indexes of the two following years. This statement also is true for the Brabender hardness tester. The r value of the correlation between the cutting method results of 1960 and those of 1961 was 0.409 and significant at the five percent level of probability. The r^2 of this correlation was 0.16. Although it had a low r^2 value, this association indicated that the cutting method could give more reliable results than the barley pearler and the Brabender hardness tester methods. The r value of the correlation between the cutting method scores of the F_4 in 1960 and the pearling index of the F_5 in 1961 was very low (0.038), supporting the results of Beard and Poehlman (8).

TABLE XII

THE COEFFICIENTS OF CORRELATIONS BETWEEN THE KERNEL HARDNESS IN 1960 AND THE KERNEL HARDNESS, PROTEIN CONTENT, MIXING TIME, AND SEDIMENTATION VALUE IN 1961

	% Vitreous Kernels	Pearling Index	Brabender H-tester	Protein Content	Mixing Time	Sedimentation Score
% Vitreous Kernels	0.409*± 0.149	0.038± 0.179	-0.345± 0.158	-0.269± 0.167	-0.133± 0.176	-0.282± 0.165
Pearling Index	0.255± 0.165	0.174± 0.172	-0.064± 0.176	-0.364*± 0.153	0.233± 0.167	0.196± 0.170
Brabender H-tester	-0.294± 0.163	0.090± 0.178	0.301± 0.163	-0.275± 0.166	0.333± 0.159	0.031± 0.175

*significant at 5% level

Correlation Between Kernel Hardness and Protein Content

There was essentially no correlation between the protein content and the kernel hardness scores of the cutting, the barley pearler methods in F_4 (Table IX). The r value of the correlation between the Brabender hardness tester scores and the protein content was 0.323 and significant at the one percent level of probability. The r^2 of this association was 0.10. Ten percent of the variability in the protein content was associated with the Brabender hardness tester scores.

The coefficients of correlation between kernel hardness scores and the protein content were low for the barley pearler and the Brabender hardness tester methods in F_5 (Table X). A closer relationship between the cutting method scores and the protein content was observed in this generation. The r value of this correlation was 0.449 and significant at the one percent level of probability. The r^2 was 0.20. Twenty percent of the variation in the protein content was associated with the vitreous kernels.

The r values of the correlation between the protein content and the kernel hardness scores of the cutting and the barley pearler methods were small in F_7 data (Table XI). Although these r values were low they were significant at the one percent level of probability; no doubt because of the large number of lines involved in these correlations. This was the only generation in which two kernel hardness methods showed significant r values with protein content. The r and r^2 values between the cutting method scores and the protein content were 0.238 and 0.05 respectively. Although it was statistically significant this association was not too reliable, because it had a very low r^2 value. The r and r^2 values between the pearling index and the protein content were 0.267 and 0.07 respectively. The barley pearler showed a very low but statistically significant correlation with protein content in only one of the three years in the present study.

To recapitulate, the correlations between kernel hardness as determined by the three methods and protein content were generally very low, although some of the r values were statistically significant. The low association of kernel hardness and protein content indicated that it cannot be used effectively in a breeding program at least by the methods used here to measure kernel hardness. Other workers reported significant correlation between kernel hardness and protein content. These r values had a range between 0.39 and 0.8 (1, 18, 38, 41, 52, 53). The significant correlation coefficients between the vitreous kernels (cutting method scores) and the protein content corroborated the results of other researchers (1, 2, 18, 28, 38, 52, 53). Correlation of the pearling index with the protein content was very low and this agreed with the reports of some researchers (10, 20, 58). A high correlation between the Brabender hardness tester scores and protein content was reported by Milner and co-workers (41). The low but statistically significant correlation between these two variables in the present study should be interpreted very carefully, because of the nonexistence of a standard procedure for evaluating hardness from small samples by this method.

Correlation Between Kernel Hardness and Mixing Time

The coefficients of correlation between kernel hardness and mixing time were very low in the F_4 data (Table IX). The r value between the pearling index and mixing time was 0.198 and significant at the five percent level of probability. The r^2 of this correlation was 0.04. The r value between the Brabender hardness tester scores and mixing time was -0.188 and significant at the same probability level. The r^2 of this negative association was 0.03. The coefficients of these very weak correlations were, however, statistically significant. This correlation is very questionable and it is not strong enough to be of much biological importance.

In the F_5 data (1961), the cutting method scores showed a closer relationship with the mixing time (Table X). The r value of this association was 0.589 and significant at the one percent level of probability. The r^2 was 0.34 and was the highest of the r^2 values obtained in the analyses. Thirty-four percent of the variation in the mixing time was associated with vitreousness of the samples.

Small r values were obtained in the F_7 for the correlation between kernel hardness and mixing time (Table IX). The r value between the cutting method scores and mixing time was 0.144 and significant at the five percent level of probability. The r^2 of this correlation was 0.02 and very low. It should be stated that this association was practically nil.

Correlations between kernel hardness and mixing time showed fluctuations and inconsistencies in the three generations. The barley pearler and the Brabender hardness tester scores showed a very low association with mixing time. The correlation between the cutting method scores and mixing time was significant in two of the three generations. The r value of this correlation was the largest of the r values obtained in the present study (0.589). This may be interpreted as a dependable association for only one generation. However, the correlation based on F_7 was low. Correlations between kernel hardness and mixing time have not been reported by researchers in the literature reviewed. A relatively high correlation in only one of the three generations indicated that the relationship between kernel hardness and mixing time was questionable.

Correlation Between Kernel Hardness and Sedimentation Value

The coefficients of correlation between the kernel hardness scores and the sedimentation value were low and some of them were negative in F_4 and F_5 (Tables IX, X). The r value between the Brabender hardness tester scores and the sedimentation value was 0.229 in F_4 and significant at the five percent level of probability. The r^2 of this correlation was 0.05. Only five percent of the variation in the sedimentation scores was associated with the Brabender hardness tester scores. This correlation was not strong enough to be accepted even as a questionable relationship between them.

The cutting method and the barley pearler scores were associated with the sedimentation value in F_7 (Table XI). The r values of these associations were 0.329 and 0.291 for the cutting method and the barley pearler respectively. These small r values were significant at the one percent level of probability. The r^2 of the association between the vitreous kernels and the sedimentation scores was 0.10. Wright reported a significant negative correlation between cutting method scores and sedimentation scores. The r value of that correlation was -0.339. He stated that the vitreousness of a sample affected the results of the sedimentation test and high percentage of vitreous kernels were associated with low sedimentation scores (64). However, the positive r value of this correlation in the present study implies the reverse of his statement.

The correlation between kernel hardness and sedimentation scores was very low and showed variations in different years. Although some of them were statistically significant none of the correlation coefficients was high enough to be accepted as good positive relationships between kernel hardness and sedimentation value.

In general, the coefficients of correlation between kernel hardness and protein content and kernel hardness and sedimentation value reflected the general trend of other worker's findings. The r values obtained in the present study showed fluctuations in different years as did the r values reported by many workers. The r values of correlation between kernel hardness and protein content in the present study were lower than the same r values obtained by other workers (2, 41, 60); they were in the same range with some reported r values (1, 18, 38, 53, 64) and they were higher than some r values (13, 20, 22, 29, 43, 49, 61, 64). Correlations between kernel hardness and the three quality characters were not strong enough to support the reports (1, 2) that kernel hardness could be used as an indicator of quality in a breeding program. Correlations between kernel hardness and mixing time and kernel hardness and protein content seemed to be more reliable than the association of kernel hardness and sedimentation value.

CHAPTER V

SUMMARY AND CONCLUSIONS

Kernel hardness of three generations of the Truimph X C.I. 12406 cross were determined by the three following methods: a) cutting, b) barley pearler, c) Brabender hardness tester. The kernel hardness scores of each method were analyzed separately to find a convenient method of determing the degree of kernel hardness in a breeding program. Kernel hardness of wheat samples can be determined by applying either the cutting or the barley pearler methods. The cutting method was the most convenient of the three methods to measure kernel hardness in a breeding program.

The combined data of each method were analyzed to estimate the effect of environment on kernel hardness. Analyses of the combined data for each method showed significant influence of environment on kernel hardness. Genetical variation was also important. Consequently kernel hardness may be used in breeding programs to evaluate the progeny lines.

The kernel hardness scores of each method were correlated with three known quality characteristics to establish the value of kernel hardness as a selection method in a quality improvement program of wheat. The generally weak associations found between kernel hardness and the three quality characteristics indicated that selecting for quality on the basis of kernel hardness would be of limited value; at least by the methods used here to measure kernel hardness. There is little argument about the use of protein content, mixing time, and sedimentation value as factors for evaluating the overall milling and baking quality. These are determined by standard procedures and are generally accepted by research laboratories as well as the trade. It appears that if kernel hardness is, indeed, related to quality, then a method of more accurately measuring hardness will have to be found in order to obtain dependable correlations between kernel hardness and these quality characteristics.

LITERATURE CITED

1. Aamodt, O. S. and J. H. Torrie. 1935. Kernel Texture as an indicator of quality in hard red spring wheats. Can. Jour. Res. 13:79-88, Sec. C.

2. __________, and __________. 1935. Studies on the inheritance of and the relation between kernel texture and protein content in several spring wheat crosses. Can. Jour. Res. 13:202-219, Sec. C.

3. __________, __________, and A. Wilson. 1935. Studies of the inheritance of and the relationships between kernel texture, grain yield and tiller-survival in crosses between Reward and Milturum spring wheat. Jour. Am. Soc. Agron. 27:256-266.

4. Abbott, D. C. 1956. Research in cereal chemistry at Oklahoma A & M College. Proceedings of 5th Annual Wheat Institute p. 42-48, Oklahoma A & M College, Stillwater, Oklahoma.

5. Alexandrov, W. G., and O. G. Alexandrova. 1935. Uber den anatomischen Bau des Endosperms in Weizenkorn. Flora 130: 21-38.

6. American Association of Cereal Chemists. 1962. Cereal Laboratory Methods 7th Edition. Am. Ass. Cereal Chem. St. Paul, Minn.

7. Barmore, M. A., E. F. Seeborg, C. R. Bresson, O. J. Lewis, F. A. Flay and C. C. Weeks. 1953. Quality characteristics of wheat varieties grown in the western region in 1952. Western Wheat Quality Lab. Pull. Wash.

8. Beard, B. H., and J. M. Poehlman. 1954. A study of quality as measured by the pearling test, in crosses between hard and soft wheats. Agron. Jour. 46:220-223.

9. Berg, S. O. 1947. Is the degree of grittiness of wheat flour mainly a varietal character. Cereal Chem. 24:274-283.

10. Bowman, F., L. Maharg and J. M. Poehlman. 1951. Testing Missouri soft wheat flours for quality: methods and variety comparisons. Missouri Agr. Exp. Sta. Research Bul. 480.

11. Bradbury, D., M. M. McMasters and I. M. Cull. 1956. Structure of the mature wheat kernel III. microscopic structure of the endosperm of hard red winter wheat. Cereal Chem. 33:361-373.

12. Carleton, M. A. 1924. The Small Grains. McMillan Company. New York.

13. Clark, J. A. 1926. Breeding wheat for high protein content. Jour. Am. Soc. Agron. 18:648-661.

14. Cobb, N. A. 1896. The hardness of the grain in the principal varieties of wheat. Agr. Gazette of New South Wales 1896 (5):279-299.

15. __________. 1896. The relative hardness of Australian and American Fife Wheats. Agr. Gazette New South Wales 1896(6): 430-437.

16. __________. 1904. Universal nomenclature for wheat. Agr. Gazette New South Wales 15:363-374.

17. __________. 1904. Universal nomenclature for wheat. Agr. Gazette New South Wales 15:509-513.

18. Coleman, D. A., H. B. Dixon, and H. C. Fellows. 1927. A comparison of some physical and chemical tests for determining the quality of gluten in wheat and flour. Jour. Agr. Res. 34:241-264.

19. Cutler, C. H., and G. A. Brinson. 1935. The granulation of whole wheat meal and a method of expressing it numerically. Cereal Chem. 12:120-129.

20. Davis, W. H., G. K. Middleton, and T. T. Hebert. 1961. Inheritance of protein, texture and yield in wheat. Crop Sci. 1:235-238.

21. Ezekiel, M., and K. A. Fox. 1959. Methods of Correlation and Regression Analysis. John Wiley and Sons Inc. New York.

22. Fifield, C. C., C. H. Bode, H. C. Fellows, R. Weaver, J. F. Hayes, A. Christie, B. E. Rothgeb and E. Hoffecker. 1945. Quality characteristics of wheat varieties grown in the Western United States, DSDA Tech. Bul. 887.

23. __________, __________, __________, __________, __________, __________, T. F. Hartsing and E. Hoffecker. 1950. Milling and baking experiments with wheat varieties grown in the Western United States, 1936-1945. USDA Tech. Bul. 1014.

24. Freeman, G. F. 1918. Producing Bread-making wheats for warm climates. Jour. Heredity. 9:211-226.

25. Greer, E. N., and J. J. C. Hinton. 1950. The two types of wheat endosperm. Nature. 165:746-748.

26. __________, __________, C. R. Jones, and N. L. Kent. 1951. The occurrence of endosperm cells in wheat flour. Cereal Chem. 28:58-67.

27. Hackel, E. 1890. The True Grasses-Trans. by F. L. Schribner and E. A. Southworth. Henry Holt and Company, N. Y.

28. Harper, J. N., and A. M. Peter. 1904. Studies on the relation between certain physical characters of wheat kernel and its chemical composition, and a proposed method for improving wheat by the selection of seed. Kentucky Agr. Exp. Sta. Bul. 113.

29. Hayes, H. K., F. R. Immer, and C. H. Bailey. 1929. Correlation studies with diverse strains of spring and winter wheats, with particular reference to the inheritance of quality. Cereal Chem. 6:85-96.

30. Hehn, E. R., and M. A. Barmore. 1965. Breeding wheat for quality. Advances in Agronomy. 17:85-114.

31. Jelinek, J. 1927. Apparatus for the determination of hardness of the kernel. First International Conference on Breadstuffs. Prague, Procl. Vol:1 356-357.

32. Katz, R., A. B. Cardwell, N. D. Collins, and A. E. Hostetter. 1959. A new grain hardness tester. Cereal Chem. 36:393-401.

33. ____________, N. D. Collins, and A. B. Cardwell. 1961. Hardness and moisture content of wheat kernels. Cereal Chem. 38:364-369.

34. Kellenbarger, S., and S. P. Swenson. 1948. Pearling index and wheat meal fermentation time in two winter wheat crosses. Jour. Am. Soc. Agron. 40:929-939.

35. Kramer, H. H., and H. R. Albrecht. 1948. The adaptation to small samples of the pearling test for kernel hardness in wheat. Jour. Am. Soc. Agron. 40:422-431.

36. Lyon, T. L., and A. Keyser. Winter wheat - nature and causes of a "yellow berry" in hard winter wheat. Nebr. Agr. Exp. Sta. Bul. 89.

37. Mangels, C. E. 1927. A study of dark, hard kernel and protein content of hard red spring wheat. Jour. Agr. Res. 34:157-166.

38. ____________, and T. Sanderson. 1925. The correlation of the protein content of hard red spring wheat with physical characteristics and baking quality. Cereal Chem. 2:107-112.

39. McCluggage, M. E. 1943. Factors influencing the pearling test for kernel hardness in wheat. Cereal Chem. 20:686-700.

40. Middleton, G. K., C. E. Bode and B. B. Bayles. 1954. Comparison of quantity and quality of protein in certain varieties of soft wheat. Agron. Jour. 46:500-502.

41. Milner, M., C. P. Farrel, and R. Katz. 1954. The separation of grain by projection II. Systematic differences in physical properties and composition of wheat fractions. Cereal Chem. 31:326-333.

42. ____________, and J. A. Shellenberger. 1953. Physical properties of weathered wheat in relation to internal fissuring detected radiographically. Cereal Chem. 30:202-212.

43. Newton, R., W. H. Cook, and J. G. Malloch. 1927. The hardness of the wheat in relation to protein content. Sci. Agr. 8:205-213.

44. Percival, J. 1921. The Wheat Plant - A Monograph. E. P. Dutton and Comp. N. Y.

45. Pinckney, A. J., W. T. Greenaway, and L. Zeleny. 1957. Further developments in the sedimentation test for wheat quality. Cereal Chem. 34:16-35.

46. Poehlman, J. M., and E. Bowman. 1945. The production of quality in Missouri soft wheat. Missouri Agr. Exp. Sta. Bul. 487.

47. Roberts, H. F. 1910. A quantitative method for the determination of hardness in wheat. Kansas Agr. Exp. Sta. Bul. 167.

48. ____________. 1919. Yellow - berry in hard winter wheat. Jour. Agr. Res. 18:155-169.

49. ____________. 1921. Relation of hardness and other factors to protein content of wheat. Jour. Agr. Res. 21:507-522.

50. Schlehuber, A. M. 1956. Varieties and quality. Proceedings of 5th Annual Wheat Institute p. 35-36. Oklahoma A & M College, Stillwater, Oklahoma.

51. Shaw, G. W., and A. J. Gaumnitz. 1911. California white wheats. Calif. Agr. Exp. Sta. Bul. 212.

52. Shollenberger, K. H., and D. A. Coleman. 1926. Relation of kernel texture to the physical characteristics, milling and baking qualities, and chemical composition of wheat. USDA Bul. 1420.

53. ____________________, and C. F. Kyle, 1927. Correlation of kernel texture, test weight per bushel, and protein content of hard spring wheat. Jour. Agr. Res. 35:1137-1151.

54. Soule, A. M., and P. O. Vanatter. 1903. Influence of climate and soil on the composition and milling qualities of winter wheat. Tennessee Agr. Exp. Sta. Bul. (Vol:16 No.4)

55. Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw - Hill Book Comp. N. Y.

56. Symes, K. J. 1961. Classification of Australian wheat varieties based on the granularity of their whole meal. Aust. Jour. Exp. Agr. Ani. Husb. 1:18-23.

57. __________. 1965. The inheritance of grain hardness in wheat as measured by the particle size index. Aust. Jour. Agr. Res. 16:113-123.

58. Taylor, J. W., B. B. Bayles and C. C. Fifield. 1939. A simple measure of kernel hardness in wheat. Jour. Am. Soc. Agron. 31:775-784.

59. Waldron, L. R. 1933. Yield and protein content of hard spring wheat under conditions of high temperature and low moisture. Jour. Agr. Res. 47:129-147.

60. Wheating, L. C., and S. C. Vandecaveye. 1937. Crop rotations. Part II. Wash. Agr. Exp. Sta. Bul. 344.

61. Worzella, W. W. 1942. Inheritance and interrelationship of components of quality, cold resistance and morphological characters in wheat hybrids. Jour. Agr. Res. 65:501-522.

62. ______________, and C. H. Cutler. 1938. Character analysis of winter wheat varieties. Jour. Am. Soc. Agron. 30:430-433.

63. ______________ and ____________. 1939. A critical study of technique for measuring granulation in wheat meal. Jour. Agr. Res. 58:329-341.

64. Wright, G. M. 1960. Vitreous grain in wheat and the relation of sedimentation and baking scores. New Zea. Jour. Agr. Res. 3:853-860.

65. Zeleny, L. 1964. Criteria of wheat quality. Wheat Chemistry and Technology edited by I. Hlynka, Am. Ass. Cereal Chem. St. Paul, Minn.

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