EVALUATION OF THE RELATIONSHIP BETWEEN SINGLE KERNEL WHEAT HARDNESS AND END-USE QUALITY MEASUREMENTS

by

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INTRODUCTION

Means for assessing end-use quality of wheat during its transport from farmer to miller are needed in the grain industry. Current classification methods attempt to categorize grain by its growth region, growth season, and hardness (Wheat Flour Institute, 1976). These determinations are made by visual appraisal of wheat samples. However, accurate identification by visual means has been impeded by the increasing popularity of cross-bred varieties produced from different classes for production characteristics (increased yield and disease resistance).

The importance of accurate wheat classification is linked to the requirements of the milling and baking industries. Wheat from different classes is used in the manufacture of different cereal food products (Wheat Flour Institute, 1976). The most notable examples are the hard and soft wheat classes. Hard wheats are used primarily for yeast-leavened products such as breads, while soft wheats are used for pastry products, cookies, and cakes. The processing of these two wheat classes into flour is also different. Soft wheats tend to be reduced to a smaller particle size and experience less starch damage than do hard wheats during milling. Problems arise if a soft wheat is processed in a hard wheat mill as sifting is impaired by the cohesiveness of soft wheat flour particles. Low percentages of soft wheats are, however, milled with hard wheats. This mixing is done for economic purposes as soft wheat is often purchased at a lower price than hard wheat (Personal Communication, Wingfield, J. G., Kansas State University Grain Science Dept., 1988).

Individual kernel wheat hardness testers have been developed

(Eckhoff et al. (1988), Lai et al. (1985)) in an attempt to classify wheat by its hardness. Testing has shown considerable variability in hardness within variety as well as between varieties. Overlap exists in the hardness values measured by these instruments when comparing hard and soft wheats. This study was undertaken to determine if this inter-varietal variability between individual kernels is an indication of the kernels' end-use characteristics.

OBJECTIVES

The objective of this study is to evaluate the relationship between the peak shearing force required to slice individual wheat kernels and the resultant flour quality as determined by micro-milling, mixograph, and micro-baking analyses.

LITERATURE REVIEW

Hardness Testing

Numerous hardness testers have been developed to evaluate physical properties of wheat. These instruments were designed for use as either batch or single kernel measurements. Properties measured include: resistance to grinding, modulus of elasticity, modulus of deformability, crushing resistance, shearing resistance, and puncture resistance.

An instrument commonly employed to measure bulk grinding resistance is the modified barley pearler. This instrument was used by Chesterfield (1971) for the analysis of wheat hardness. The resistance to grinding is determined by grinding 20g of wheat in the pearler and weighing of the resulting stock caught over a 20W wire. This value, as a percentage of the initial 20g is defined as the pearling value.

The Brabender (C. W. Instruments Inc., South Hackensack, NJ) hardness tester is also used to measure grinding resistance. Torque during grinding, time to grind, and energy in grinding are recorded by a pen attached to the torque arm of a Farinograph. One- and two-step methods for use with this instrument are described by Obuchowski and Bushuk (1980).

In a similar grinding experiment, Williams (1986) attempted to classify wheat cultivars by measuring fluctuations in rpm of a Udy grinder during wheat grinding. A measurement of the difference in rpm from starting time to minimum recorded rpm was found to be inversely correlated to the wheat hardness characteristics of starch damage (-0.84), gassing power (-0.79), and water absorption (-0.79).

Bulk measuring systems are suitable for use with homogeneous samples of wheat. However, wheat varies in kernel hardness, and these methods cannot give a true indication of variability within a wheat sample. Also, problems in data interpretation occur when evaluating samples containing mixtures of hard and soft wheat varieties. As the hardness recorded for a bulk sample tends to represent the average sample hardness, a mixture of extreme hard and soft wheat may appear similar to a homogeneous sample of softer hard wheat when evaluating with a bulk measurement.

Single kernel hardness research has focused primarily on penetration tests. Such tests tend to measure the endosperm properties of wheat as opposed to properties of the bran which tend to influence grinding measurements. Naumov (1957) determined a factor referred to as "brittleness" by shearing single wheat kernels between two knife edges. Shear stress was calculated by dividing the measured rupture load by the cross-sectional area of the wheat kernel. The method appeared to have merit for use in classification. However, its applicability for grain classification was minimal due to the excessive time requirement for completion of a test. Zoerb (1961) also attempted to measure shear stresses in wheat grains but encountered difficulties in obtaining a true shear test using a circular punch. The circular punch would not deliver a clean separation of the punched area from the rest of the kernel being tested.

Grosh (1959) used the MIAG (Buhler-Miag Inc., Minneapolis, MN) Micro-hardness Tester for kernel hardness evaluation in a study of wheat absorption of water. The MIAG tester consists of a diamond point upon which a 1000g weight is placed. To determine wheat hardness, individual kernels are punctured with the point, and the resulting indentation measured with a dissecting binocular microscope. In a similar test, Katz (1959) adapted a Barcol Impressor for wheat hardness testing, but instead of measuring the indentation of the kernel, Katz measured the deflection of a diamond stylus during kernel testing. Differences in deflection were noted at different locations on the individual wheat kernels.

Work to determine wheat's elastic properties was done by Arnold (1969). Arnold analyzed the stress-deformation behavior of the wheat kernel through use of a photoelastic model. The model was prepared from "Araldite", and a circular polariscope was used to indicate the stress distributions. Modulus of elasticity determinations were also made by Shelef and Mohsenin (1967) for various stress configurations. These included: a parallel plate arrangement for whole grains with crease down, a spherical indenter, a cylindrical indenter, and a parallel plate configuration for use on pearled core specimens.

Recent work in kernel hardness testing has attempted to automate single kernel systems. Lai et al. (1985) discussed the development of a continuous, automated single kernel hardness tester (Cask-Hat) designed to delineate hard from soft wheat varieties. Included in the discussion was an analysis of compression, shear, and puncture tests for their classification accuracy. Dr. Carl Norris (USDA, Beltsville MD), has produced an instrument which determines kernel hardness by analyzing the recorded sounds generated during grinding of individual kernels on an Udy mill (Personal Communication, Wheat Classification Meeting, 1987).

Eckhoff et al. (1988) have developed a single kernel tester which transports kernels via a rotating plate to a bearing mounted shearing edge. The shearing edge fits in a groove cut in the side of the plate. Force measurements are made with a load cell attached to the cutting edge support. Kernel size is also recorded with the instrument.

Wheat Quality Evaluation
(Micro-Milling, Micro-Baking, Mixograph Analyses)

Wheat quality takes on different definitions throughout the grain processing system. For the miller, quality often is defined by flour yield, (Finney and Yamakazi, 1967). However, milling quality may also take into account ease of grinding and sifting to obtain the yield. The baker will tend to look for a consistent product with respect to protein content, mixing, and baking characteristics, (Wheat Flour Institute, 1976). The micro-milling, micro-baking, and mixograph procedures are techniques used for laboratory-scale evaluation of wheat quality.

Micro-milling is the use of small-scale milling equipment to produce flour from small samples of wheat which is representative of the flour that would be produced with a commercial or experimental mill. The need for effective micro-milling processes is paramount in plant breeding programs where years may be required before enough surplus seed is attained for normal milling tests on new varieties.

The mixograph as described by Finney (1972) examines water absorption and mixing characteristics of flour doughs. A mixogram produced during a mixograph analysis indicates absorption, mixing tolerance, and mixing time requirement.

Van Scoyk (1939) reported that micro-baking uses small samples of flour to produce baked products indicative of products produced with large-scale analytical baking procedures. Another advantage of the micro-baking procedure over conventional baking methods is ease of reproducibility. In bread-making, the features analyzed include loaf volume, crumb color, crumb texture, and external appearance.

Geddes and Sibbitt (1933) made comparisons of bread loaves produced from 100g, 50g, and 25g of flour to determine whether loaves made from less than 100g of flour, supplied satisfactory flour quality evaluations. Baking was done with a procedure in compliance with the existing AACC baking procedure except for use of smaller pans and machine mixing of doughs. From the analysis, there was evidence that a larger coefficient of variability between mean loaf volumes was found in loaves of less than 100g when compared to 100g loaves. However, flours of different baking quality were easily differentiable in the smaller loaves.

An experimental mill for 100g wheat samples was tested by Geddes and Frisell (1935) for milling and baking effectiveness of the resulting flour. The mill was a modified Allis-Chalmers experimental mill with roller surface width reduced from six inches to one inch. Comparisons of flour produced by the micro-mill were made to milling output from a standard Allis-Chalmers experimental mill. Lower flour yields and recovery of total product were observed from the micro-mill. Protein content of the two milled flours showed no differences. Flour ash content was significantly higher using the smaller mill. Differences in wheat cultivars were adequately noted on the micro-mill. The baking evaluation also showed evidence of effective differentiation in the quality of the wheat flours. A high correlation existed between loaf volumes and similar external characteristics of the baked loaves.

In a later comparison of bread loaves made from 25g and 100g flour quantities, Van Scoyk (1939) made evaluations using four different baking tests. The effect of mechanical versus conventional dough moulding on bread was compared. A series bake allowed the production of fermentation time vs. loaf volume curves, and a checkerboard test, proposed by Clark (1937), was conducted to observe the influence of different mixing and fermentation times on bread characteristics. The checkerboard test or Latin square test is so-called because loaves are placed on the baking sheet in an arrangement consistent with the layout of a Latin square statistical design for evaluation of two variables. From the study, the effects in the bread-making process were found to be as informative with smaller loaves as with larger loaves.

A Hobart grinder was used by McCluggage et al. (1941) to produce micro-milled flour samples for comparison to samples from a larger scale Buhler mill. The micro-baking results of that flour were analyzed for their reproducibility. Significant differences were noted between millings and baking occurring on different days. Pan type (high or low) also affected baking, but both were equally efficient in variety discrimination. Ash and protein content were higher in the micro-milled flour than the Buhler milled flour. Loaf volume for micro-baked 25g loaves had a correlation of +0.97 to 100g loaves. A method for reducing the high ash content of micro-milled flour obtained using a Hobart grinder was proposed by Finney and Yamakazi (1946). In their analysis, a reduction in flour ash content from ~ 1% to 0.45% was accomplished with proper tempering of the wheat, pre-breaking the kernels with a Tag-Heppenstahl moisture meter, and reduced first break feed rates.

A wheat quality report was published by the Hard Winter Wheat Quality Laboratory (1963) analyzing the 1962 wheat crop. The report announced a micro-milling procedure using a Brabender 3-break milling head, Brabender 3-reduction milling head, and a Ro-Tap sifter. The system was capable of flour yields averaging greater than 65%. Ash contents of the flour produced by the procedure were near 0.40%.

Shogren et al. (1969) discussed a baking procedure employing 10g of (14% MB) flour which used optimum mixing time, water absorption, potassium bromate, and a formula of 10g flour (14% MB), 0.6g sugar, 0.15g salt, 0.3g shortening, 0.2g yeast, 0.4g nonfat dry milk, and 0.05g of 60° L. malt syrup. National sheeting rolls with a roll gap of 2.5mm were employed. Dough moulding was done with a fixed wood base and a plastic and wood sled. Loaves were baked for 15 minutes at 118° C. A correlation coefficient of 0.98 was reported between the 10g and 100g loaf volumes.

A 10g flour mixograph procedure was described by Finney and Shogren (1972) which made use of a modified 35g mixograph having smaller bowls, reduced planetary and bowl pins, and adjusted arm damping. Specific operating procedures were also listed.

The optimized straight-dough breadmaking method for 100g flour samples was summarized by Finney (1984). The method has been applied successfully to 10g loaves, (Shogren and Finney, 1984). The optimized method described the role of the basic baking ingredients flour, water, yeast, sugar, salt, shortening as well as the effects of nonfat dried milk, malt, and potassium bromate on bread-baking. Ascorbic acid was proposed as an adequate replacement for potassium bromate and nonfat dried milk in the process. Effects of a formula using no sugar on bread loaves were also shown.

Wheat Hardness as a Quality Evaluation

Questions concerning hardness testing have been raised relative not only to the measurements' classification accuracy but also with reference to their quality assessment potential. Obuchowski and Bushuk (1984) noted high correlations ($p = .01$) between the bulk hardness measurements, wheat hardness index, pearling resistance index, and time of grinding to the end-use measurements, vitreousity, hectolitre weight, farinograph absorption, and dough stability. The bulk hardness tests also correlated well with Zeleny sedimentation test values and bread scores (Zeleny, 1960).

Pomeranz et al. (1987) conducted a study similar to that of Obuchowski and Bushuk on hard red winter, hard red spring, and soft red winter wheat classes. Bulk wheat hardness was determined by Brabender microhardness, particle size index, near-infrared reflectance, Stenvert hardness, kernel density, and starch damage. Flour characteristics evaluated included bake mixing time, water absorption, mixograph analysis, loaf volume, and crumb grain.

Pomeranz et al. (1987) assigned a milling rating to sampled wheat varieties based on their ability to mill as a hard wheat and suitability for mixing with other wheats for hard wheat milling. Hard red spring (HRS) had the highest flour yield and protein content followed by durum, hard red winter (HRW), club, soft white western (SWW), soft red winter (SRW), and soft white eastern (SWE) wheats (Table I). Wheat hardness indices, near-infrared reflectance and particle size index, had correlations in excess of 0.9 with the milling rating (Table II).

TABLE I

Mean Values of Studied Parameters in Wheats[1]

Parameter	HRW (16)	HRS (10)	SRW (10)	SWE (10)	SWW (10)	CLB (10)	DUR (11)
Test wt. (lb/bu)	60.9	61.4	61.9	61.8	61.0	60.7	61.8
1000 Kernel wt. (g)	28.0	32.1	33.3	37.8	36.0	29.1	39.3
Wheat							
Density (g/cc)	1.46	1.46	1.43	1.42	1.44	1.45	1.46
Ash (%)	1.57	1.56	1.48	1.49	1.46	1.34	1.59
Protein (%)	11.68	13.69	9.65	9.29	9.97	10.48	13.35
Flour Yield (%)	72.9	75.2	71.8	69.6	72.1	72.7	70.4
Mill rating (hardness))	6.1	7.3	3.3	1.9	3.2	3.4	9.5
Starch damage (%)	7.0	7.2	4.4	4.2	5.0	4.4	13.8
BMHT (sec)	29.0	28.1	59.5	56.6	42.3	45.7	24.9
SHT (sec)	49.8	49.6	31.8	31.6	31.0	32.0	52.1
PSI (%)	28.0	26.5	41.7	41.3	36.6	38.4	15.7
Abrasion (%)	63.8	61.7	44.2	40.2	40.8	47.1	64.6
NIR	65.1	72.9	26.7	24.2	27.5	28.3	109.2
Flour protein (%)	10.74	13.11	8.56	8.16	8.87	9.42	12.63
Bake absorption (%)	63.93	67.52					
Mixograph development time (min)	3.70	3.59	3.30	3.01	2.24	1.99	2.76
Bake mix time (min)	3.92	4.76					
Loaf volume (cc)	879	985					
Crumb Grain	3.67	2.47					
Specific loaf volume (cc/1% protein)	58.71	56.00					
Cookie diameter (cm)			9.51	9.46	9.22	9.36	

[1] As cited by Pomeranz et al. (1987)

TABLE II

Linear Correlation Coefficients Between Functional Properties and Hardness Indices[1]

	Wheat Hardness (milling)	Wheat Protein	Starch Damage
Wheat			
Density	0.560	0.596	0.460
Protein	0.748	1.000	0.545
Starch damage	0.845	0.545	1.000
BMHT	-0.794	-0.754	-0.649
SHT (sec)	0.837	0.692	0.759
PSI	-0.911	-0.784	-0.894
Wheat abrasion	0.812	0.698	0.689
NIR	0.942	0.788	0.901

[1] As cited by Pomeranz et al. (1987)

Separate baking tests were run on the hard and soft wheat classes. Hard wheats were baked into bread, and soft wheats into cookies. HRW had the longest mixograph development time with HRS, SRW, SWE, durum, SWW, and club following. Hard red spring wheat had higher bake mixing times and loaf volume than HRW but lower specific volumes (based on percent protein). Soft red winter had the largest cookie diameters of the soft wheats.

MATERIALS AND METHODS

Samples and Preparation

Samples of the hard red spring (HRS) variety, Marshall, the hard red winter (HRW) varieties, Scout 66 and Mustang, and the soft red winter (SRW) variety, Pike, were obtained for evaluation. Scout 66, Mustang, and Pike were grown at the St. John's Experiment Station in Stafford County, Kansas. All three varieties were fungicide treated. Mustang and Pike were irrigated and were harvested in 1987. Scout was harvested in 1986 under dryland conditions. The HRS variety, Marshall, was supplied by the Federal Grain Inspection Service. No history of the sample was available.

Selection of the HRW and SRW varieties was based upon results from previous hardness testing (Eckhoff et al. 1988) performed with the KSU Wheat Hardness Tester. In the analyses, Pike had a significant overlap of its hardness distribution profile (in excess of 25%) with the Scout 66 and Mustang hardness distribution profiles. The spring wheat was chosen based on its availability, for comparison of the HRS and HRW classes.

Sample preparation consisted of initial size separations with a Ro-Tap sifter. Only kernels caught over a #7 Tyler sieve were used in testing. Kernel moisture content was maintained at near 12% by tying 25g of wheat samples in cloth mesh and placing of the bundles in sealed aquariums (Fig. 1). Placed in the aquariums was tygon tubing connected to bottles containing 78% to 22% glycerin-water mixtures. Also connected in-line with the glycerin-water bottles was a bottle containing a cupric

Figure 1. Moisture conditioning aquarium.

sulfate-water mixture for mold prevention. Air was pumped through the bottles to the aquariums by an air compressor (Fig. 2).

Hardness Separations

Hardness testing of wheat varieties was done on alternating days to negate the effects of fluctuating air humidities which might affect wheat moisture content. It was felt that in comparing the soft and hard wheat samples, testing conditions should be as similar as possible. The instrument used for hardness measurements is shown in Figure 3. It was developed at the USDA Grain Marketing Lab, Manhattan, KS. A brass shearing edge was placed on the tester so as to simulate the shearing action of the KSU Wheat Hardness Tester. The drive on the mechanism was a Bodine (Bodine Electric Co., Chicago, IL) 1/20 hp gear motor, series 400, with dc speed controller, model 567G9014. During testing, individual kernels were placed manually under the shearing edge. A cam connected to the motor drove the kernels up into the edge.

A 100-lb capacity Daytronic (Daytronic Inc., Miamisburg, OH) load cell, model 152A-100, was located above the cutting edge. Power to the loadcell was provided with 120 ac voltage reduced to 5 volts ac by a Shaevitz LPM-210 amplifier module (Shaevitz Engineering, Canden, NJ). As the cam was operated, a slotted disk turned to initiate a micro-switch, and allow the loadcell signal to be output. The switching also provided a threshold output to the computer, signaling beginning of data acquisiton. The loadcell output signal was run through a series 150k ohm resistor, 0.22 uF capacitor filter to reduce noise effects.

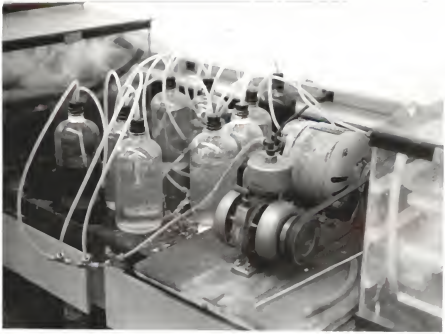


Figure 2. Parallel connection of glycerin-water bottles.

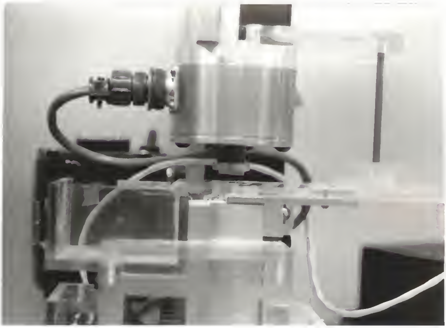


Figure 3. Single kernel testing unit.

A Tecmar Labmaster (Scientific Solutions Inc., Solon, OH) data acquisition unit with a 12-bit A/D converter processed the bipolar signal from the load cell. The computer used was a Zenith 150 model with software programmed in Microsoft C language (see Appendix I). During data collection, the breakage curve for individual kernels tested was temporarily stored and scanned for the peak breakage force (Fig. 4).

Three plexiglas partitions were located on the hardness tester for storage of broken kernels after testing. These slots represented low, middle, and high peak force ranges. The break points for the separations were variety specific and determined from prior data by splitting the hardness distributions into equal thirds. The appropriate grouping number for placement of a broken kernel was displayed following data processing, and kernel fragments were manually moved to these storage areas. Following daily testing, broken kernels were placed in glass jars and refrigerated.

Testing Procedures

A preliminary evaluation was conducted on wheat varieties Scout, Mustang, Pike, and a hard red spring market sample. The study's purpose was to examine effects of deviations from Finney's (1966) standard micro-milling procedure on quality characteristics: flour yield, protein content, mixing time, and loaf volume, and to compare effects of the use of broken and whole kernels on quality determinations. The variation in milling flow involved the use of an 80-mesh screen for flour sieving as opposed to a 100-mesh screen.

The primary experiment involved the following analyses:

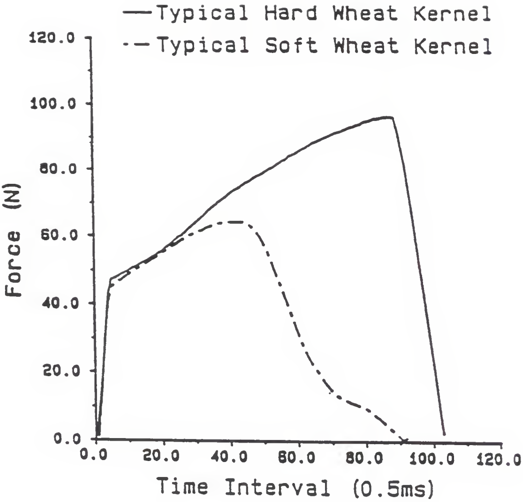


Figure 4. Typical breakage curves for hard and soft wheat kernels.

1) Milling flour yield,

2) Proximate,

3) Mixograph, and

4) Analytical Baking.

Three replicates were used for each variety hardness group. A flowchart of the entire testing procedure is presented in Figure 5.

Milling

One hundred gram wheat samples were tempered by placing the wheat into plastic bags and adding the required amount of water. Moisture measurements were made prior to tempering with a Motomco Dickey-john (Dickey-john Corp., Auburn, IL) moisture meter and by A.A.C.C. method 44-15A. The bags were shaken following the moisture addition to obtain a thorough mixing. The wheat was then allowed to sit overnight (at least 18 hours) to allow moisture equilibration.

Samples were milled on Brabender (C. W. Instruments, Inc., South Hackensack, NJ) Quadromat Jr. break and reduction rolls (Fig. 6) using the flowchart shown in Figure 7. Milled hard wheat samples were sifted for 4 minutes following the initial break, 3 minutes following the first reduction, and 2 minutes following the second reduction. For the soft wheat samples, sifting was 6, 5, and 4 minutes for break, first reduction, and second reduction grindings, respectively. To reduce losses, the plexiglas shield covering the rolls was removed after break and second reduction milling. Rolls were then brushed and blown with compressed air to recover as much stock as possible.

Bran, shorts, 1st reduction flour, 1st middlings flour, and 2nd

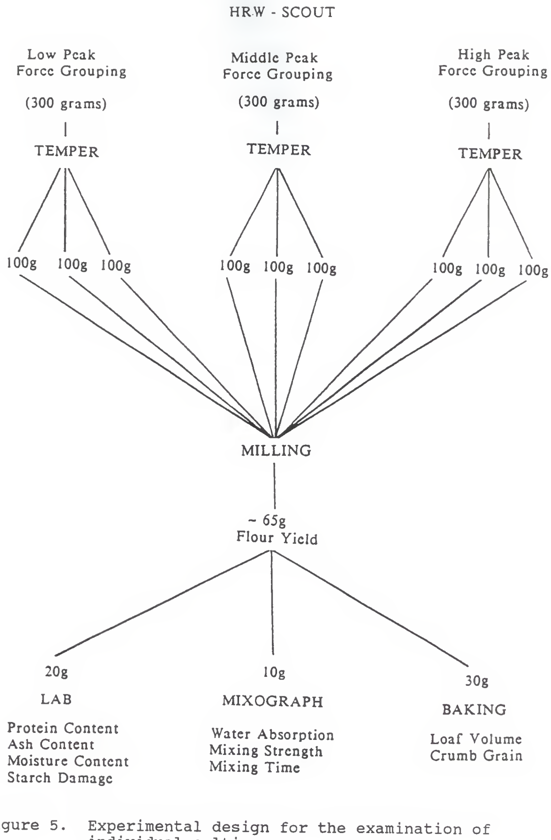


Figure 5. Experimental design for the examination of individual cultivars.

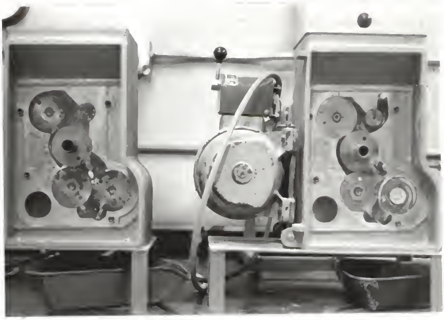


Figure 6. Brabender Quadromat Jr. break and reduction rolls.

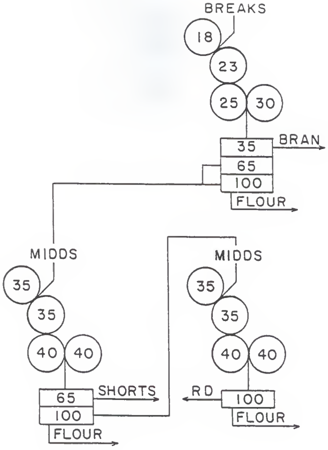


Figure 7. Micro-experimental flow of break and reduction or middlings stock, together with roll corrugations per inch and Tyler sieve openings per inch. Going from top to bottom, break roll spirals are 1.5, 1.0, 1.0, and 0.5 inch per foot, and reduction or middling roll spirals are 1.0, 0.5, 1.0, and 0.5 inch per foot. Distances between first-, second-, and third-break rolls are 0.063, 0.03, 0.0035, and 0.002 inch, respectively. Distances between first-, second-, and third-middling rolls are 0.0015, 0.002, and 0.0015 inch, respectively. As reported by Finney and Bolte, 1985. An 80-mesh screen was used in place of the 100-mesh screen.

middlings flour were weighed and recorded. Twenty grams of flour from each sample was then allotted for lab evaluations. Tests were carried out to determine flour moisture, ash, and protein contents and to evaluate starch damage. Procedures used were in compliance with A.A.C.C. standards 44-15A, 08-01, 46-11, 76-30A, 80-60, 22-18, respectively.

Mixograph

A lab standard 10g mixograph (National Equipment, Omaha, NE.) was used in the mixograph analyses (Fig. 8). Ten-gram flour samples (14% MB) were mixed at an optimum water absorption, determined during the preliminary testing. Mixing took place for 8 minutes. Mixograms were generated for each hardness division of the three variety replicates. Individual mixograms were analyzed for dough mixing time and mixing strength. Finney and Shogren's (1972) 10g mixograph procedure was followed during all experiments.

Optimum water absorption was determined during the preliminary test. For the HRS and HRW varieties, an absorption of 62% was first examined and 55% used for the SRW variety. Mixographs were then run at 2% above, and 2% below the starting absorption. A fourth mixogram was then produced at an additional 2% higher or lower absorption if needed.

Analytical Baking

Baking was done in compliance with Shogren and Finney's (1984) 10g micro-baking procedure. Ingredients consisted of 10g flour (14% MB), 100ppm ascorbic acid, 0.2% malted barley flour, Breadlac (Galloway West, Fondolac, WI) NFDM, 3% Crisco shortening, and 0.076g Fermipan (Gist-

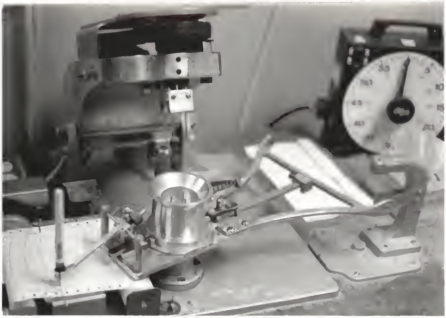


Figure 8. Ten-gram mixograph.

Brocabes, USA, Charlotte, NC) yeast. Flour samples were mixed to optimum mobility based on their mixograms. Modified National (Omaha, NE) sheeting rolls with stops and guards removed were used for dough sheeting. The roll gap for sheeting was set at 2.5mm. Dough moulding was done with a plastic and wood sled run over a fixed wood base as described by Shogren and Finney (1984).

The baking followed a 180-minute fermentation at 30° C. Moulding and proofing were for 57 minutes. Punching during fermentation was done at 105, 155, and 180 minutes. Loaves were then baked for 13 minutes at 232° C, cooled and loaf volume measurements made with a funnel volumeter using dwarf rapeseed displacement.

Loaves were baked in duplicate with loaf volume, loaf weight, and proof height measurements recorded for each loaf. Details of the apparatus are described by Shogren and Finney (1984).

RESULTS AND DISCUSSION

EXAMINATION OF WHOLE VS. BROKEN KERNELS AND MICRO-MILLING SIEVE SIZES

Milling Analysis

Scout, Mustang, and the HRS market sample (not Marshall), gave similar milling results with respect to bran, shorts, and flour yields (Table III). The use of an 80-mesh screen resulted in higher break and 1st middlings flour than a 100-mesh screen for all samples. Overall flour yields for the two screens were nearly equal for all the hard wheat classes. Pre-broken (by hardness testing) kernels gave slightly higher break and 1st middlings yields than whole kernels. The pre-broken kernels also gave slightly lower 2nd middlings yields but produced more total flour.

The different mesh screens significantly affected results for the soft wheat sample, Pike. Flour yield was reduced using the 100-mesh screen as compared to the 80-mesh screen. This was as expected. Due to this result, the soft wheat sifting time was increased during additional testing to approximately twice that for the hard wheats. The increased sifting time allowed production of flour of similar protein and ash contents to that of the hard wheat varieties.

Chemical Analysis

No differences were noted in the moisture, ash, and protein contents of milled whole kernels sieved with the 80 vs. 100-mesh screens (Table IV). Starch damage (%) also showed no differences in flour sieved

TABLE III

Preliminary Test - Milling Analysis

Variety	Bran (%)	Shorts (%)	Flour (%)			
			Br	1M	2M	Total
SCOUT						
whole kernel, 80 sieve	27	2	24	37	4	65
broken kernel, 80 sieve	24	2	26	39	3	67
whole kernel, 100 sieve	27	2	19	31	13	63
MUSTANG						
whole kernel, 80 sieve	31	3	24	33	4	61
broken kernel, 80 sieve	30	3	25	34	2	61
whole kernel, 100 sieve	32	3	19	27	13	59
PIKE						
whole kernel, 80 sieve	41	5	16	17	13	47
broken kernel, 80 sieve	39	5	19	19	10	48
whole kernel, 100 sieve	42	9	8	8	12	28
HRS						
whole kernel, 80 sieve	27	3	25	39	3	67
broken kernel, 80 sieve	26	3	25	40	3	67
whole kernel, 100 sieve	27	2	17	33	14	64

TABLE IV

Preliminary Test - Chemical Analysis

Variety		Moisture (%)	Protein (%)	Ash (%)	SD[1] (%)
SCOUT					
	Whole Kernels	12.5	12.9	1.33	
Flour	Whole Kernels, 80 sieve	14.4	11.1	0.37	6.05
Flour	Broken Kernels, 80 sieve	13.2	12.3	0.40	6.34
Flour	Whole Kernels, 100 sieve	14.3	11.6	0.37	7.34
MUSTANG					
	Whole Kernels	9.5	15.4	1.90	
Flour	Whole Kernels, 80 sieve	14.3	12.5	0.43	4.12
Flour	Broken Kernels, 80 sieve	13.4	13.2	0.46	6.34
Flour	Whole Kernels, 100 sieve	14.0	12.9	0.44	5.78
PIKE					
	Whole Kernels	9.1	13.4	1.77	
Flour	Whole Kernels, 80 sieve	13.0	11.1	0.41	3.81
Flour	Broken Kernels, 80 sieve	13.0	11.1	0.44	4.63
Flour	Whole Kernels, 100 sieve	13.0	10.8	0.40	5.01
HRS					
	Whole Kernels	10.2	14.6	1.72	
Flour	Whole Kernels, 80 sieve	14.0	12.5	0.44	5.64
Flour	Broken Kernels, 80 sieve	13.4	13.2	0.46	7.65
Flour	Whole Kernels, 100 sieve	14.0	13.3	0.43	7.15

[1] Starch damage

with the different meshes. As expected, Pike, the soft wheat, had the lowest percent starch damage. The hard red spring sample had the highest starch damage with the two hard red winter varieties falling between the HRS and SRW samples.

Broken kernels had slightly higher flour protein and ash contents, and lower flour moisture contents than whole kernels sieved with the 80-mesh screen. The lower flour moisture content was an anomaly as it would seem that the broken kernel flour would have more quickly equilibrated to a higher moisture content. The higher protein and ash contents were encountered in the pre-broken kernel flour due to the poor separation between endosperm, and bran and germ. A protein and ash gradient exists within wheat kernels where the protein and ash contents become higher as one moves from the center of a kernel outward toward the bran (Personal Communication, Eustace, W. D., Kansas State University Grain Science Dept., 1988). Consequently, the poorer separation of bran and germ from endosperm resulted in higher ash and protein contents for the flour from the pre-broken kernels.

Mixograph Analysis

Optimum water absorption percentages of 60% for Marshall, 62% for Scout and Mustang, and 55% for Pike were determined (Figs. 9-11). Broken kernels produced slightly reduced mixing times for all three varieties (Table V). This was assumed to be a result of the slightly higher ash content in the broken kernel flour. No differences were observed for the flours sieved with the 80 vs. 100-mesh screens. Mixing strength and stability was similar for flour from the different sieves.

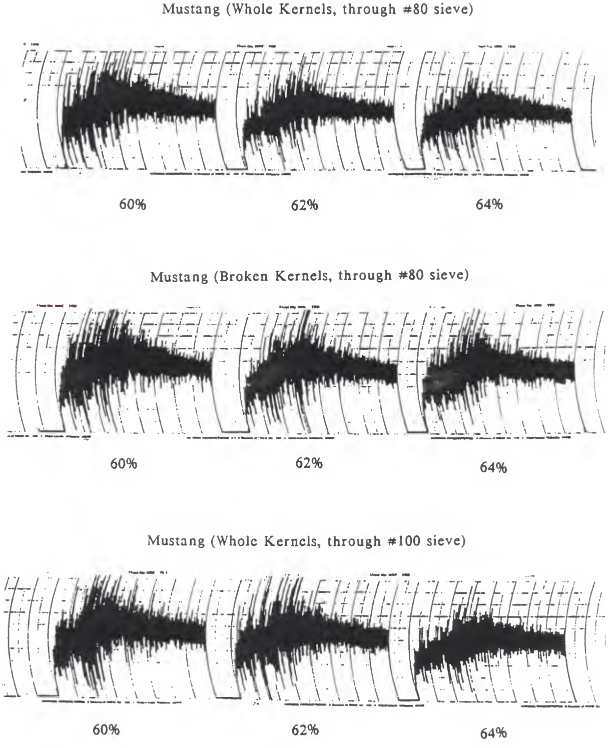
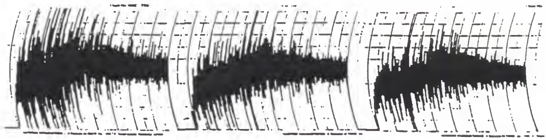


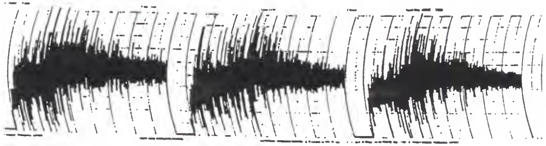
Figure 9. Preliminary mixograms (Mustang) for determination of optimum water absorption and analysis of sieve size effects.

Pike (Whole Kernels, through #80 sieve)



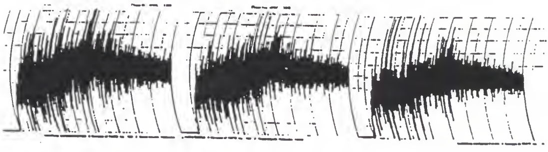
53% 55% 57%

Pike (Broken Kernels, through #80 sieve)



53% 55% 57%

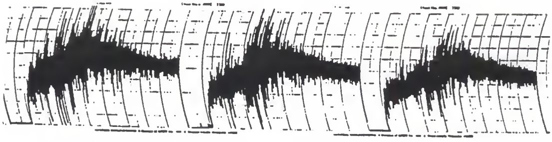
Pike (Whole Kernels, through #100 sieve)



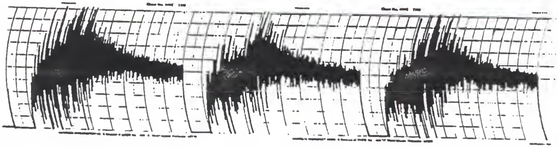
53% 55% 57%

Figure 10. Preliminary mixograms (Pike) for determination of optimum water absorption and analysis of sieve size effects.

Scout (Whole Kernels, through #80 sieve)



Scout (Broken Kernels, through #80 sieve)



Scout (Whole Kernels, through #100 sieve)

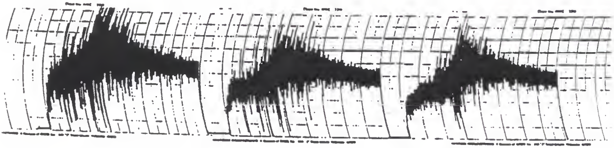


Figure 11. Preliminary mixograms (Scout) for determination of optimum water absorption and analysis of sieve size effects.

TABLE V

Preliminary Test - Mixograph Analysis

Variety	Mixing Time (min)	Mixing Strength (lines)
SCOUT (62%)		
Whole Kernels, 80 sieve	3:45	6.0
Broken Kernels, 80 sieve	3:05	6.0
Whole Kernels, 100 sieve	3:15	5.8
MUSTANG (62%)		
Whole Kernels, 80 sieve	3:45	6.0
Broken Kernels, 80 sieve	3:10	6.0
Whole Kernels, 100 sieve	3:30	5.8
PIKE (55%)		
Whole Kernels, 80 sieve	3:50	5.6
Broken Kernels, 80 sieve	3:30	5.5
Whole Kernels, 100 sieve	3:50	5.5

Analytical Baking Analysis

A micro-baking analysis showed no differences in loaf volumes due to the different screen sizes (Table VI). Variations in loaves due to the use of broken kernel flour as compared with whole kernel flour also were not evident.

HARDNESS VS. QUALITY EVALUATIONS

Data for all milling, chemical, mixing, and baking measurements are listed by variety in Appendix II. Variety hardness data is listed in Appendix III.

Variety Comparisons

A SAS (SAS Institute Inc., Cary, NC) ANOVA was conducted to compare variety relationships with respect to the quality factors: flour yield, time to optimum mixing, loaf volume, and protein. The variables were analyzed for significant differences between variety through use of a Least Significant Difference test with the alpha value set at .05. The results of the ANOVA analysis are listed in Table VII.

The hard wheat varieties Marshall, Scout, and Mustang were not significantly different in flour yield. Mean yields of 67.0%, 66.4%, and 65.3% were recorded for Scout, Mustang, and Marshall, respectively. The soft red winter wheat, Pike, had a significantly different mean flour yield of 55.6% as compared to the hard wheats.

Mustang and Scout were significantly different from each other and from Pike and Marshall in terms of optimum mixing time. The recorded mixograms are shown in Figures 12-15. Mean values of 3.70, 3.49, 3.05, and 2.24 minutes were recorded for Pike, Marshall, Mustang, and Scout,

TABLE VI

Preliminary Test - Baking Analysis

Variety	Loaf Volume (cc)	Loaf Weight (g)
SCOUT		
Whole Kernels, 80 sieve	81	12.8
Broken Kernels, 80 sieve	79	12.7
Whole Kernels, 100 sieve	81	12.8
MUSTANG		
Whole Kernels, 80 sieve	92	12.9
Broken Kernels, 80 sieve	91	12.6
Whole Kernels, 100 sieve	90	12.7
PIKE		
Whole Kernels, 80 sieve	72	12.5
Broken Kernels, 80 sieve	73	12.6
Whole Kernels, 100 sieve	72	12.5

TABLE VII

Variety Comparisons - Mean Quality Measurements[1]

Variety	Flour Yield (%)	Mixing Time (min)	Loaf Volume (cc)	Protein (%)
SCOUT	67.0 a	2:14 a	75.3 a	11.5 a
MUSTANG	66.4 a	3:03 b	86.6 b	12.8 b
PIKE	55.6 b	3:42 c	72.0 c	10.5 c
MARSHALL	65.3 a	3:29 c	76.1 a	12.5 d

[1]Means within columns with different letters are significantly different ($p < .05$).

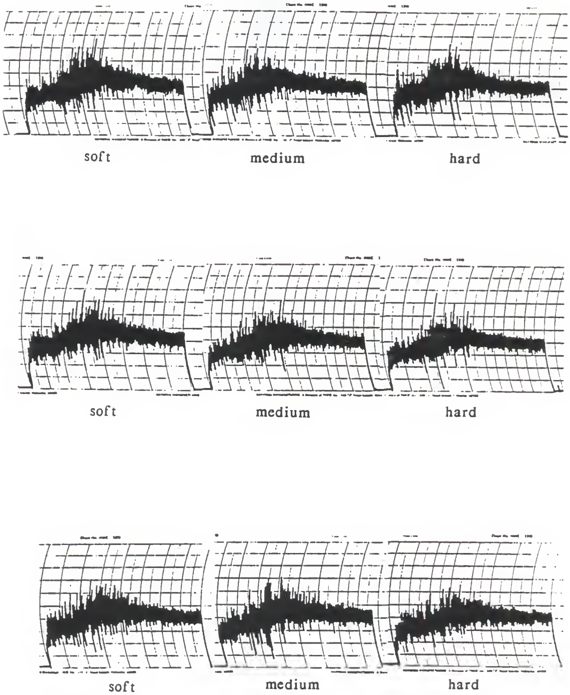


Figure 12. Mixograph analysis (60%) by hardness grouping - Marshall.

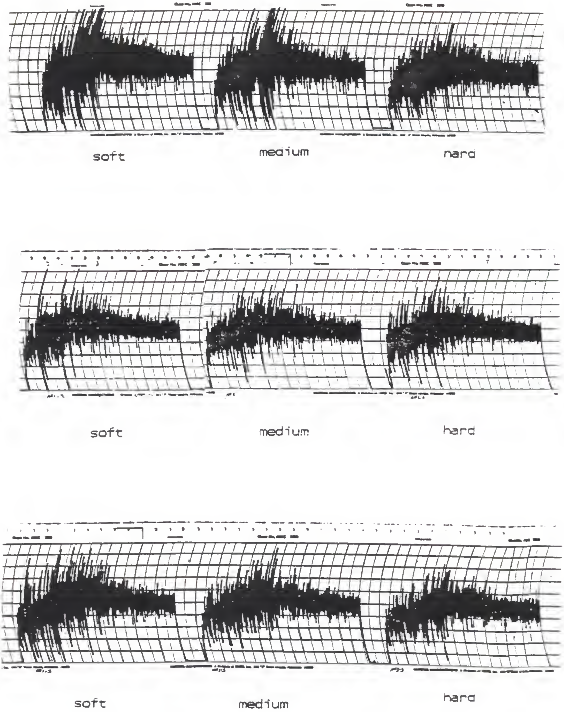


Figure 13. Mixograph analysis (62%) by hardness grouping - Mustang.

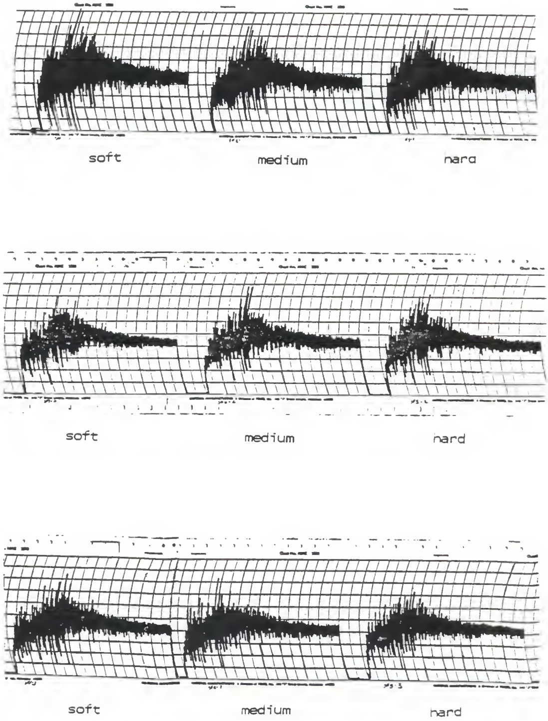


Figure 14. Mixograph analysis (55%) by hardness grouping - Pike.

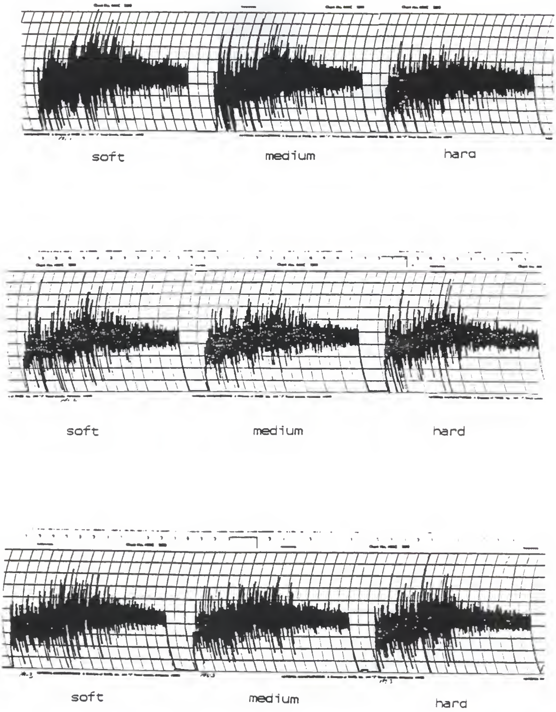


Figure 15. Mixograph analysis (62%) by hardness grouping - Scout.

and 2.24 minutes were recorded for Pike, Marshall, Mustang, and Scout, respectively.

For loaf volume, Mustang had the highest average (86.64 cc) and was significantly different than the other three varieties (Figs. 16-19). Pike was also significantly different with an average loaf volume of 71.98 cc. Marshall and Scout recorded average mean loaf volumes of 76.07 cc and 75.28 cc, respectively.

The final evaluation measure, protein content, revealed significant differences between all varieties. Mustang had a mean protein content of 12.84%, Marshall a mean of 12.47%, Scout a mean of 11.46%, and Pike a mean of 10.46%.

Hardness Comparisons

The same four measurements were used to evaluate differences (analyzed with the SAS ANOVA LSD procedure) due to the hardness of kernels. Flour yield was the only measure to show a significant difference due to hardness. Results from the analysis for data combined from the four different varieties, by hardness grouping, are listed in Table VIII. Table IX lists results for within variety comparisons (by hardness) of flour yield.

For the combined flour yield data, hardness group #1 (softer kernels) had a mean of 62.0%. Hardness group #2 recorded an average of 63.7%, and group #3 (harder kernels) had a mean of 65.1%. All groups were significantly different at the .05 level.

In analyzing the within variety flour yield variance, only the Scout hardness groupings #2 and #3 were not significantly different. For

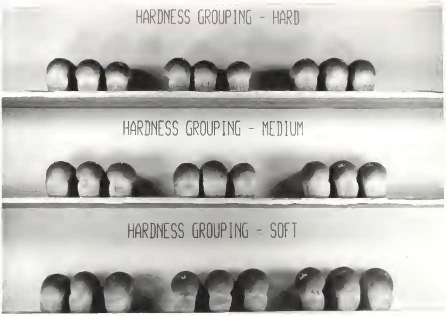


Figure 16. Baking analysis by hardness grouping - Marshall (columns indicate replicates).

Figure 17. Baking analysis by hardness grouping - Mustang (columns indicate replicates).

Figure 18. Baking analysis by hardness grouping - Pike (columns indicate replicates).

Figure 19. Baking analysis by hardness grouping - Scout (columns indicate replicates).

TABLE VIII

Hardness Groupings Comparisons -Mean Quality Measurements[1]

Hardness Grouping	Flour Yield (%)	Mixing Time (min)	Loaf Volume (cc)	Protein Content (%)
Soft Kernels	62.00 a	3:12 a	78.6 a	11.85 a
Medium Kernels	63.72 b	3:08 a	77.0 a	11.74 a
Hard Kernels	65.06 c	3:01 a	76.9 a	11.83 a

[1]Means within columns with different letters are significantly different ($p < .05$).

TABLE IX

Flour Yield (%) Within Variety Comparisons by Hardness Grouping[1]

Hardness Grouping	Marshall (HRS)	Mustang (HRW)	Pike (SRW)	Scout (HRW)
Soft Kernels	63.3 a	64.7 a	54.4 a	65.6 a
Medium Kernels	65.7 b	66.2 b	55.1 b	67.5 b
Hard Kernels	67.0 c	68.3 c	57.4 c	68.0 b

[1]Means within columns with different letters are significantly different ($p < .05$).

Scout, hardness groupings #1, #2, and #3 recorded average flour yields of 65.6%, 68.0%, and 67.5%, respectively. Marshall recorded average yields of 63.3%, 65.7%, and 67.0% for hardness groupings #1, #2, and #3, respectively. Mustang had mean yields of 64.7%, 66.2%, and 68.3% for the respective hardness groupings. The soft wheat variety, Pike followed the same pattern as the hard wheats with softer kernels producing a lower mean flour yield than harder kernels. Values of 54.4%, 55.1%, and 57.4% were recorded for the #1, #2, and #3 hardness groups.

These flour yield results imply that a shearing force measurement for individual kernels gives an indication of how the kernels will mill. Milling yield for harder kernels of a variety is higher than milling yield for softer kernels of the same variety. The question which naturally follows this hardness-milling observation is what is the potential for using a single kernel hardness test as a milling yield predictor.

A further observation of the data reveals that the soft wheat, Pike, retained distinct end-use characteristics different from the hard wheats regardless of hardness. This could pose problems with using the hardness test for a milling yield predictor as Pike has shown an overlap in hardness with the HRW varieties, Scout and Mustang (Eckhoff et al., 1988).

Nevertheless, the apparent correlation of single kernel hardness within variety to milling yield does give a positive indication that some form of physical kernel measurement should be able to predict a wheat sample's milling characteristics. A shearing single kernel test has now been briefly evaluated for effectiveness as a measure of end-use quality; this study should be continued with more varieties and with larger samples. Other forms of single kernel hardness testing (ie. grinding) should also be evaluated for their effectiveness in wheat classification on a quality basis.

Finally, a wheat sample's characteristics when milling are changed from what they are during storage by the tempering process. The degree of tempering is different for hard and soft wheats. A single kernel hardness test has been shown to be 95% effective in classifying wheat samples as hard or soft. Thus, a hardness test could be used to identify the tempering requirement of a wheat sample. Another study should possibly be conducted to evaluate how a hardness test run on wheat after tempering would serve in predicting milling yield.

CONCLUSIONS

Harder wheat kernels were found to produce a higher milling flour yield than softer kernels of the same variety. This occurrence was found to hold true for the hard red winter wheat varieties, Scout and Mustang, the hard red spring wheat variety, Marshall, and the soft red winter variety, Pike. A 3% difference in flour yield was observed between the hardest grouping and the softest grouping. A significant difference was also observed between mean flour yield for the soft wheat sample and the hard wheat samples.

No significant differences due to hardness were observed in quality measurements of protein content, mixing time, and loaf volume. Variety comparisons of protein content indicated differences between all the varieties analyzed. Mustang had the highest mean protein content at 12.84% and Pike had the lowest at 10.46%.

Pike and Marshall had the longest mixtimes at 3:42 and 3:29 minutes, respectively. These values were significantly different from the mixtimes for Mustang and Scout of 3:03 and 2:14 minutes.

In terms of mean loaf volume, Mustang was significantly different from the other varieties at a value of 86.64 cc. Pike was also significantly different at 71.98 cc. No differences were observed between the Marshall and Scout varieties which produced mean loaf volumes of 76.07 cc and 75.28 cc, respectively.

When comparing the measurements of the harder soft wheat kernels to those of the softer hard wheat kernels, it was observed that the different classes retain their end-use characteristics regardless of hardness.

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The Federal Grain Inspection Service also deserves mention for making available the opportunity for me to work in the wheat hardness area. Their cooperation and support are appreciated.

Finally, thanks to the several student workers who had to suffer through the many hours of shearing wheat kernels that were necessary to perform this evaluation.

APPENDIX I

Data Acquisition Program

WHEAT HARDNESS DATA ACQUISITION PROGRAM

```
/*******************   Call to Tecmar Libraries   *******************/

#include <stdio.h>
#include <tecmem.h>
#include <display.h>
#include <conio.h>

/***************   Initialization of External Arrays   ***************/

int data[10000];
int val[100];
char line[80];
int maxf[105];

/***********************   Main Function   **********************/

main()
{

      register int      *pt;
      int         v,v2,t;
      int         m,endno;
      int         i,key_pressed,j;
      int         star,go;
      int         ptr,vave;
      float       ave;
      int         chan;
      char        f[10],line[80];
      int         max,no;
      int         end,y;
      int         good,count;
      char        buff[10];
      int         *start,*endit;
      int         p;

      FILE  *fp;

      chan = 6;

      base = (unsigned char far *) LMP;

      MRESET();

/***********   Input of Tested Variety and Determination of   ***********/
/***********               Sorting Criteria                   ***********/

      scr_clr(INTENS|fgWH);
      prints(6,10,INTENS|fgR,"Input filename - ");
      while(fgets(line,79,stdin) == NULL);
```

```
            sscanf(line,"%s",f);

        scr_spos(8,15);
        keybd_flush();
        printf("The filename is %s\n\n\n\n\n\n",f);
            if((f[2] == 0x50) || (f[2] == 0x70))
                p = 1;
            if((f[2] == 'M') || (f[2] == 'm'))
                p = 2;
            if((f[0] == 'M') || (f[0] == 'm'))
                p = 2;
            if((f[0] == 0x50) || (f[0] == 0x70))
                p = 1;
            if((f[0] == 'H') || (f[0] == 'h'))
                p = 3;
            if((f[2] == 'H') || (f[2] == 'h'))
                p = 3;
/*      printf("p = %d\n",p);*/

/*******************  Load Cell Initialization  *********************/



        printf("\t\tHit RETURN to initialize load cell\n");

        while(!kbhit());
        keybd_flush();
        scr_clr(INTENS|fgWH);
        scr_spos(13,10);
        ADCNTROL(AUINCOFF|GAIN1);
        ADCHAN(chan);
        ave = 0;

        for(ptr = 0; ptr < 100; ptr++) {

            STCONV();
            while((ADSTATUS() & AD_DONE) == 0);
                val[ptr] = READATOD();

                ave = ave + (float) val[ptr];
        }

        for(ptr = 0; ptr < 99; ptr += 5) {
            printf("# = %5d\tval = %10d\n",ptr,val[ptr]);
        }
        printf("AVERAGE = %.2f\n",(ave/100.0));

        printf("If AVERAGE is not near 5, restart program.\n");
        printf("IF a KERNEL is Discolored, Small or Shrivelled DO NOT
USE.\n\n");
```

```
/******************   Main Loop for 100 Kernels   *******************/

for(no = 1; no < 101; no++) {

          v = (ave/100.0);
          v2 = 25 - v;

          prints(23,20,INTENS|fgR|bgB,"Hit Return to Collect Data");
          prints(24,20,INTENS|fgR|bgB,"Hit ESC to Exit ");
          while(!kbhit());
            key_pressed = keybd_getkey();
            if(key_pressed == 0x011b) {
                goto done;
            }
          keybd_flush();
          scr_clr(INTENS,fgWH);
          scr_spos(6,1);
          printf("\tTRIGGER %d \n",no);


/*************   Check for Load Cell Threshold Value   *************/

     while(count < 4) {

          STCONV();
          while ((ADSTATUS() & AD_DONE == 0));
          v = READATOD();
          if(kbhit() != 0) {

               key_pressed = keybd_getkey();
               if(key_pressed == 0x011b)
                    goto done;
               keybd_flush();
          }
          if( (v > (ave/100.0) - 25) && (v < (ave/100.0) + 25) )
               count++;
          else
               count = 0;
     }
     count = 0;


     while(v > (ave/100.0) - 50) {

          if(kbhit() != 0) {

               key_pressed = keybd_getkey();
               if(key_pressed == 0x011b)
                    goto done;
          }
          STCONV();
```

```
            while((ADSTATUS() & AD_DONE) == 0);
            v = READATOD();
      }

/**********************   Data Collection   **********************/

      for(j = 1; j < 5000; j++);
      start = &data[0];
      endit = &data[10000];
      for(pt = start; pt < endit; pt++) {
            STCONV();
            while (( ADSTATUS() & AD_DONE) == 0);
            v = READATOD();
            *pt = v;
      }
      end = j;

/*****************   Option to redo kernel if not hit   ****************/
/*****************      squarely at cross-section      ****************/

      scr_spos(6,20);
      printf("*");
      scr_spos(10,10);
      printf("Would you like to redo Kernel? (y/n)  ");

            while(fgets(line,79,stdin) == NULL);
            sscanf(line,"%s",buff);
            keybd_flush();
            if(buff[0] == 'y' || buff[0] == 'Y'){
                  good = 0;
                        no--;
                  }
            else
                  good = 1;
            /*    WBH 10-28-87 ; Changed default to 'n' instead of 'y'
                  for the ability to hit return to continue */


/*******************   Peak Force Determinations   *******************/



      if(good == 1) {
            max = 0;
            star = 0;
            go = 0;

            for(pt = &data[1000], y = 1000; pt < &data[10000]; pt++,y++)
{
                  *pt = *pt + v2;
                  if(*pt < max){
                        max = *pt;
```

```
                m = y;
            }
        }

        maxf[no] = -((float) (data[m]));
        scr_spos(15,20);
        printf("MAX FORCE = %.2f\t%d\n",(float) maxf[no],m);

/************   Determination of Kernel Hardness Grouping   ************/
/************              (Variety-Specific)               ************/

/***********   Note:  Numbers represent Loadcell mV output   ***********/

        if (p == 1) {                              /* Pike */
            if(maxf[no] < 183.6)
               printf("\n\n\tKernel goes to #1 slot\n");
            if(maxf[no] > 197.8)
               printf("\n\n\tKernel goes to #3 slot\n");
            if((maxf[no] < 197.8) && (maxf[no] > 183.6))
               printf("\n\n\tKernel goes to #2 slot\n");
        }

        else if (p == 2) {                         /* Mustang */
            if(maxf[no] < 205.4)
               printf("\n\n\tKernel goes to #1 slot\n");
            if(maxf[no] > 231.6)
               printf("\n\n\tKernel goes to #3 slot\n");
            if((maxf[no] < 231.6) && (maxf[no] > 205.4))
               printf("\n\n\tKernel goes to #2 slot\n");
        }

        else if (p == 3) {                         /* Marshall */
            if(maxf[no] < 210)
               printf("\n\n\tKernel goes to #1 slot\n");
            if(maxf[no] > 236)
               printf("\n\n\tKernel goes to #3 slot\n");
            if((maxf[no] < 236) && (maxf[no] > 210))
               printf("\n\n\tKernel goes to #2 slot\n");
        }

        else {                                     /* Scout */
            if(maxf[no] < 200.4)
               printf("\n\n\tKernel goes to #1 slot\n");
            if(maxf[no] > 227.6)
               printf("\n\n\tKernel goes to #3 slot\n");
            if((maxf[no] < 227.6) && (maxf[no] > 200.4))
               printf("\n\n\tKernel goes to #2 slot\n");
        }

    good = 0;
  }
done:
```

```
/********************   Data Written to File   *******************/

  endno = no;
  if((fp = fopen(f,"w")) == NULL)
      printf("Error in opening file");

  for(no = 1; no < endno; no++) {

      fprintf(fp,"\t%.2f\n", (float) maxf[no]);
  }

      fclose(fp);
      scr_clr(INTENS|fgWH);
}
```

APPENDIX II

Raw Data

TABLE II-I

Raw Milling Yield Data (%)[1]

Variety	Hardness Group	Bran	Shorts	Break	1R	2R	Yield
MARSHALL	Soft	25	2	36	27	2	65
MARSHALL	Soft	24	2	33	28	3	64
MARSHALL	Soft	28	2	33	26	2	61
MARSHALL	Medium	25	2	35	29	2	66
MARSHALL	Medium	24	2	33	28	3	64
MARSHALL	Medium	24	2	34	29	2	65
MARSHALL	Hard	23	2	34	30	2	66
MARSHALL	Hard	24	2	37	29	2	66
MARSHALL	Hard	24	2	35	30	2	67
MUSTANG	Soft	26	1	26	34	1	61
MUSTANG	Soft	27	2	27	37	3	67
MUSTANG	Soft	28	2	26	37	4	67
MUSTANG	Medium	25	1	24	37	1	62
MUSTANG	Medium	26	2	28	37	2	67
MUSTANG	Medium	26	2	28	38	3	69
MUSTANG	Hard	25	1	26	37	1	64
MUSTANG	Hard	26	2	27	38	3	68
MUSTANG	Hard	25	2	28	41	2	71
PIKE	Soft	35	1	27	22	2	51
PIKE	Soft	36	3	25	25	5	55
PIKE	Soft	35	2	25	25	7	57
PIKE	Medium	33	1	28	22	2	52
PIKE	Medium	35	3	27	25	5	57
PIKE	Medium	35	3	28	22	6	56
PIKE	Hard	34	1	28	23	2	53
PIKE	Hard	34	3	26	27	4	57
PIKE	Hard	--	3	29	29	4	62
SCOUT	Soft	27	1	28	33	1	62
SCOUT	Soft	27	2	28	35	3	66
SCOUT	Soft	26	2	28	38	3	69
SCOUT	Medium	25	1	26	36	1	63
SCOUT	Medium	26	2	28	37	2	67
SCOUT	Medium	27	2	30	38	2	70
SCOUT	Hard	26	1	25	37	1	63
SCOUT	Hard	26	2	27	39	2	68
SCOUT	Hard	25	2	28	39	2	71

[1]Roll gaps were reset before the milling of Marshall. Mustang, Pike, and Scout were milled prior to the acquisition of the Marshall sample.

TABLE II-II

Raw Flour Chemical Analyses Data (%)[1]

Variety	Hardness Group	MC	AC	PC	SD
MARSHALL	Soft	15.6	0.45	12.1	3.59
MARSHALL	Soft	15.7	0.41	12.9	6.86
MARSHALL	Soft	15.3	0.44	12.5	4.04
MARSHALL	Medium	15.2	0.41	12.6	4.62
MARSHALL	Medium	15.4	0.42	12.3	4.58
MARSHALL	Medium	15.5	0.41	12.2	4.07
MARSHALL	Hard	15.5	0.42	12.4	4.37
MARSHALL	Hard	15.5	0.43	12.4	4.61
MARSHALL	Hard	15.7	0.41	12.3	5.59
MUSTANG	Soft	13.6	0.42	13.3	4.58
MUSTANG	Soft	13.9	0.42	12.9	4.40
MUSTANG	Soft	13.8	0.41	12.7	4.62
MUSTANG	Medium	14.0	0.41	12.6	4.21
MUSTANG	Medium	13.8	0.42	12.5	4.05
MUSTANG	Medium	13.8	0.40	13.0	4.75
MUSTANG	Hard	14.2	0.41	12.7	4.50
MUSTANG	Hard	13.8	0.40	12.6	5.14
MUSTANG	Hard	13.9	0.41	13.1	4.79
PIKE	Soft	13.4	0.40	10.4	2.95
PIKE	Soft	14.1	0.40	10.6	2.83
PIKE	Soft	13.4	0.38	10.4	4.26
PIKE	Medium	13.9	0.38	10.4	2.40
PIKE	Medium	13.9	0.39	10.5	2.38
PIKE	Medium	14.1	0.36	10.2	2.91
PIKE	Hard	13.5	0.40	10.3	-
PIKE	Hard	14.0	0.39	10.6	3.05
PIKE	Hard	13.9	0.39	10.7	3.82
SCOUT	Soft	14.1	0.40	11.3	5.14
SCOUT	Soft	14.7	0.43	11.4	4.09
SCOUT	Soft	14.3	0.41	11.2	4.83
SCOUT	Medium	14.6	0.41	11.6	5.35
SCOUT	Medium	14.7	0.41	11.6	4.46
SCOUT	Medium	14.1	0.42	11.3	4.58
SCOUT	Hard	14.6	0.41	11.7	4.60
SCOUT	Hard	14.7	0.40	11.5	4.36
SCOUT	Hard	14.3	0.42	11.5	4.93

[1]MC - Moisture Content, AC - Ash Content, PC - Protein Content, SD - Starch Damage

TABLE II-III

Raw Mixing and Analytical Baking Data

Variety	Hardness Group	Mixing Time (min)	Loaf Volume (cc)
MARSHALL	Soft	3:55	77.2
MARSHALL	Soft	3:50	78.7
MARSHALL	Soft	3:25	79.7
MARSHALL	Medium	3:15	76.2
MARSHALL	Medium	3:45	74.3
MARSHALL	Medium	3:10	74.7
MARSHALL	Hard	3:00	74.0
MARSHALL	Hard	3:30	73.8
MARSHALL	Hard	3:35	76.0
MUSTANG	Soft	2:40	90.5
MUSTANG	Soft	2:50	87.5
MUSTANG	Soft	3:25	84.3
MUSTANG	Medium	3:00	86.0
MUSTANG	Medium	3:10	85.7
MUSTANG	Medium	3:25	85.3
MUSTANG	Hard	2:55	85.2
MUSTANG	Hard	3:05	85.5
MUSTANG	Hard	3:15	89.8
PIKE	Soft	3:35	72.7
PIKE	Soft	3:20	74.0
PIKE	Soft	4:15	71.7
PIKE	Medium	3:50	73.5
PIKE	Medium	3:25	73.5
PIKE	Medium	4:05	67.8
PIKE	Hard	3:50	71.3
PIKE	Hard	3:30	72.7
PIKE	Hard	3:55	70.7
SCOUT	Soft	2:35	78.3
SCOUT	Soft	2:20	76.7
SCOUT	Soft	2:20	71.7
SCOUT	Medium	2:20	78.3
SCOUT	Medium	2:15	77.7
SCOUT	Medium	2:20	70.3
SCOUT	Hard	2:00	75.0
SCOUT	Hard	1:50	76.3
SCOUT	Hard	2:25	73.2

APPENDIX III

Wheat Hardness Data

Table III-1. Hardness Data for Evaluated Wheat Varieties

TABLE III-1

Hardness Data for Evaluated Wheat Samples[1]

Variety	Mean Peak Force (N)	Standard Deviation
MARSHALL	57.47	16.03
MUSTANG	48.15	11.21
PIKE	37.56	8.62
SCOUT	44.77	11.04

[1]Data was collected on the KSU Wheat Hardness Tester. Sample size was 400 kernels.

EVALUATION OF THE RELATIONSHIP BETWEEN SINGLE KERNEL WHEAT HARDNESS AND END-USE QUALITY MEASUREMENTS

by

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This study was conducted to evaluate the relationship between single kernel wheat hardness measurements and end-use quality of the resulting flour as determined by micro-milling, mixograph, and micro-baking analyses.

Four wheat varieties from three wheat classes were used for the evaluation. Samples of Scout and Mustang (hard red winter), Pike (soft red winter), and Marshall (hard red spring) were sorted by hardness testing into three variety-specific groupings of soft, medium, and hard kernels.

The tested kernels were analyzed for milling characteristics using a 100g micro-milling procedure. Before the analysis of the sheared kernels, the effect of milling broken kernels vs. whole kernels was examined. During micro-milling, the use of an 80-mesh flour sieve as opposed to a 100-mesh sieve was employed, and this deviation from the standard micro-milling procedure was also investigated.

Flour obtained from the milling was analyzed in the laboratory for percent protein, ash, and moisture content. Percent starch damage was also determined. The mixing characteristics of the flour were identified with a 10g mixograph procedure. The primary measure obtained from the mixographs was time to optimum mixability.

A 10g micro-baking procedure was used to produce bread loaves from the remaining sample flour. Loaf volumes were recorded for all bread loaves.

An examination of resulting data indicated significant differences in flour yield due to hardness. This difference was noted in all varieties. Harder kernels produced a 3% higher flour yield than softer kernels.

No significant differences due to hardness were observed in quality measurements of protein content, mixing time, and loaf volume. Furthermore, when comparing the measurements of the harder soft wheat kernels to those of the softer hard wheat kernels, it was observed that the different classes retained their end-use characteristics regardless of hardness.