A METHOD FOR THE DETERMINATION OF THE MILLING PROPERTIES OF HARD RED WINTER WHEAT AND TESTS OF ITS RELIABILITY

by

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TABLE OF CONTENTS

INTRODUCTION

Milling as a science is rather new but as a process it is nearly as old as civilization. In ancient literature there are often references to milling. This early milling was of the most primitive type. As all things have improved with advancing civilization, milling has been no exception. This improvement has gone so far that at present milling is beginning to be regarded as a science more than an art.

As this scientific aspect on milling has developed, new methods have been introduced which have made it possible to study milling in laboratories as well as in large mills. One of the most important developments along this line has been that of the experimental mill.

The experimental mills are compact enough to be a part of the equipment of a laboratory. Results obtained from these mills are believed to be sufficiently comparable to those from large commercial mills to make possible the study of the behavior of small samples of wheat in milling. The value of such studies, however, is directly dependent upon the accuracy of the techniques used.

There has been no standardization of the techniques for using experimental mills. Such a standardization is imperative if the results obtained with these mills, as used in various laboratories, are to be comparable.

It was to develop laboratory techniques and to improve the evaluation of milling quality that these investigation were undertaken. The study was made in three parts: the development of laboratory technique, the evaluation of milling quality, and the testing of the reliability of laboratory techniques and methods of evaluating milling quality.

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REVIEW OF THE LITERATURE

Attempts to improve the early techniques began shortly after the introduction of experimental milling. One of the earliest experimental mills was described by Hays and Boss (1899). They did not attempt to obtain a refined flour. As a justification of their methods they wrote, "The milling tests to which these varieties of wheats were subjected are not new nor experimental in their principal features."

Angus and Richardson (1909) and Olsen (1911) evaluated their methods in the light of commercial practice and attempted to justify their methods as being comparable to those of large mills.

Ladd and Bailey (1911) compared the flour obtained on their experimental mill with commercial flours and concluded that the yields obtained were nearly the same but that the quality of the experimentally milled flour was slightly inferior. They also recognized the need of standardizing the test in that they recommended that a standard procedure should be adopted by the American Society of Milling and Baking Technologists.

The evolution of the experimental milling test has been directed so as to compare with commercial practices. One of the earliest improvements was in the use of water to condition wheat before milling. The use of conditioning in experimental milling was reported by Ladd and Bailey (1910), Stewart and Hirst (1910), Willard and Swanson (1911), Williams and Welton (1911), and many others. However, there seemed to be no fixed rule or scientific method to determine the degree of temperature, length of time or amount of water employed.

There is very little in the literature about experimental milling during the period from 1912 to 1930. The main reason, perhaps was that the workers were more interested in the results obtained than in the accuracy of the techniques they used.

Comparisons of Mills and Milling Techniques

The Allis and the Wolf experimental mills were the first to be widely adopted. The Allis mill was much like that in use today and featured the discontinuous flow. The Wolf mill was of the semi-automatic type and was really the forerunner of the newer types of automatic laboratory mills.

The introduction of improved types of experimental mills brought the problem of selecting a mill that would give results comparable with commercial practices. The first of these new mills was described by Mueller (1934). It consisted of two pairs of conical stones coupled with a small sifter. This mill was compared with the Allis experimental mill by Geddes and Aitken (1937) who concluded that this new mill did not give as good a differentiation of the qualities of the wheats as was secured by the Allis mill.

Zeigler (1938) described a new automatic mill which had already been introduced on the American continent as the Buhler Automatic experimental mill. This mill was designed to be similar in principle and operation to the larger commercial mills. It employed a continuous flow of three breaks and three reductions. The mill was much faster to use as there were no stocks to handle. This resulted in an increased output of work for the same expenditure of time.

A comparison of the Allis mill and the Buhler mill was made by McCluggage, Anderson and Larmour (1939) who concluded that "The greater speed and ease of operation of the Buhler mill, together with its very compact construction, commends it to cereal technologists, especially where the volume of routine work is large."

Micro Milling Techniques. Geddes and Aitken (1935) developed a new technique of milling and baking which required only 100 grams of wheat. In their milling they used a modified Allis mill which they had designed. After extensive tests they concluded that the final results obtained by their micro technique did not differ significantly from results secured by the regular procedure and the baking methods then commonly used in cereal laboratories.

Harris and Sanderson (1939) made a further study of the micro technique and arrived at the conclusion that the test was not accurate enough to predict results that might be obtained by the regular procedure but that it differentiated samples in the same way.

Comparisons of Experimental and Commercial Milling

Pascoe, Gortner and Sherwood (1930) made some comparisons between commercially and experimentally milled flours. They concluded that "...the 'commercial' flours and the 'experimental' flours, while differing materially in saccarogenic activity, did not differ appreciably in loaf volume."

Griffiths, Norris and Wenholz (1932) concluded that "While there are some differences of opinion as to the reliability of a laboratory mill in obtaining milling results which are in line with those obtained in a commercial mill, it is generally acknowledged that determination of dough or baking quality can be done accurately with flour produced in a laboratory mill."

A careful study of the correlations between experimental and commercial mills was made by Bailey and Markley (1933) and Markley and Bailey (1933) who found that while there was a poor correlation in the results of the milling tests there was a close agreement in the baking properties of the flour from both the experimental and commercial mills.

Cayzer and Jones (1938) made an extensive study of the effect of laboratory milling on baking properties and concluded that "There were differences between the commercial and laboratory flours in gassing power, but that these differences were insufficient to have an effect on baking quality."

As to the reliability of experimental milling tests Geddes and West (1930) made a statistical study of the reliability of the experimental milling test and concluded that one of the causes of variations in the results obtained was the differences in the milling techniques employed.

Markley and Treloar (1937) conducted a cooperative study of the effect of individual milling techniques on baking properties of the resulting flours. After testing three samples of wheat milled by 12 laboratories they stated that "The baking tests ...fail to differentiate the flours submitted by the laboratories for any one sample...."

Definitions of Milling Quality

Some of the earliest measures of milling quality were those expressed by Thatcher (1907) as follows: Chemical composition, percentage of various mill products, distribution of the chemical constituents of the wheat to the various mill products, and the quality and the color of the flour. Thomas (1917a, 1917b) defined milling quality as flour yield as adjusted for the color of the flour. Shollenberger and Clark(1924) also considered these factors as measures of milling quality.

Geddes, Malloch and Larmour (1932) stated that the "...commercial value of hard red spring wheat depends upon two factors, the quanity and the quality of flour the wheat is capable of yielding. The first factor depending on flour yield, is usually referred to as milling quality.."

Malloch, Geddes and Larmour (1932) stated, "..Although the possible yield of flour from any wheat is the main factor in milling quality, the miller also considers the tempering properties, the capacity to blend well with other wheats and the power required in milling...."

In the process of developing a philosophy of what should be included in the meaning of milling quality in wheat, the writer, through conversations with millers, agronomists, cereal chemists, and others and through extensive reading has concluded that the following four points should be included in the meaning of milling quality of wheat. (1) There should be a large yield of good quality flour, as measured by a baking test, (2) the wheat should not require extra or special treatment in preparing it for milling, (3) the flour should contain a high percentage of the protein found in the wheat and a low percentage of the wheat ash, and (4) as measured in the experimental milling test the wheat should yield as much feed as possible, at no loss in flour yield.

If the milling process were 100 percent perfect there would be no need to consider the amount of feed recovered since it is a reciprocal of the flour yield. However, since the efficiency is not perfect the feed recovery, when considered with the flour yield, is one measure of the efficiency of the milling process.

DEVELOPMENT OF LABORATORY TECHNIQUE

Measurement of Kernel Hardness

The work on kernel hardness was done by the "pearling test" developed by Taylor, Bayles, and Fifield (1939). Their fundamental procedure follows:

"1. Approximately 100 grams of wheat were placed on a No. 6 Tyler screen held over a No. 8. After shaking a definite number of times by hand, three 20-gram samples were weighed from the grain remaining on the No. 8 screen.

2. A sample was placed in the pearler and the latter started and run exactly three minutes.

3. The grain and rubbed-off material were removed from the machine, screened on a No. 20 screen, and the grains riding the screen weighed to the hundredth gram. From this weight the percentage pearled off was calculated."

In the present study of the pearling test the wheat was ground in a barley pearler which consists of a grinding stone enclosed inside a cage of wire screen. The machine used in these tests was an old-style pearler built by the Strong-Scott manufacturing company and was similar to that used by the Federal Grain Supervisors in grading malting barley.

<u>Preliminary Work.</u> A limited amount of preliminary work had been done which indicated there might be difficulties encountered in adapting the test to routine work. As a result, a series of experiments was designed to standardize the method of making the test.

<u>Modification of Procedure.</u> Since there seemed to be some fundamental weaknesses in the technique as used by Taylor, et al, the following modifications were adapted to the original procedure: (1) the sizing of the grain over the No. 10 and 8 screens was eliminated, (2) the results were expressed as weight of pearled wheat in grams instead of percentage pearled off. The elimination of the screening seemed to remove any bias in sampling that would have occured in samples of wheat which consisted of predominately large or small kernels.

The second modification eliminated one mathematical calculation. Furthermore, by expressing the results in grams of pearled wheat, an increase in the hardness was automatically shown by an increase in the resulting figure.

<u>Determination of Standard Errors.</u> Tables 1 and 2 give, respectively, the pearled weight of twenty replicates of hard and soft wheat for each of the various pearling times investigated. These data are presented to give an idea of the reproducibility of results.

Table 1. Weight in grams of pearled hard wheat after pearling for various lengths of time.

Trial No.	1 Min.	$1\frac{1}{2}$ Min.	2 Min.	3 Min.	4 Min.
1	17.14	17.34	15.77	14.10	12.29
2	17.95	16.80	15.31	14.30	11.47
3	17.75	17.45	15.57	14.19	12.11
4	17.52	17.01	15.65	13.95	12.18
5	17.43	16.90	15.79	13.59	12.04
6	17.81	17.05	15.45	14.11	12.35
7	17.87	16.76	15.97	14.00	12.83
8	17.75	16.82	15.80	14.31	12.00
9	17.71	17.16	15.63	13.65	12.12
10	17.35	16.71	15.81	14.28	12.13
11	17.68	16.33	15.47	14.10	12.44
12	17.10	16.66	15.54	14.34	11.63
13	18.10	17.20	16.20	14.17	11.83
14	17.99	16.60	15.67	14.24	11.93
15	17.80	16.72	15.54	14.01	12.21
16	18.01	16.54	15.56	14.33	11.90
17	18.13	17.50	15.85	14.07	12.19
18	17.85	17.20	15.65	14.36	12.16
19	18.13	16.83	15.55	14.02	12.22
20	17.84	16.76	15.68	13.80	11.95

Table 2. Weight in grams of pearled soft wheat after pearling for various lengths of time.

Trial No.	1 Min.	$1\frac{1}{2}$ Min.	2 Min.	3 Min.
1	17.18	15.73	13.36	9.72
2	16.83	15.23	13.35	9.61
3	16.90	14.91	13.13	9.37
4	17.41	15.40	13.40	10.23
5	17.13	14.90	13.25	9.94
6	16.91	14.85	13.30	9.95
7	16.69	15.03	12.83	10.00
8	16.78	15.19	13.80	10.05
9	16.90	14.90	13.77	10.01
10	16.80	14.92	13.86	9.90
11	16.97	15.21	13.58	10.22
12	17.02	14.95	13.25	9.30
13	17.11	15.53	13.40	9.82
14	17.00	15.23	13.45	9.43
15	16.82	14.37	14.12	9.71
16	16.74	14.67	13.24	9.87
17	16.97	15.11	13.12	9.00
18	16.77	14.71	13.12	9.00
19	17.00	14.54	13.37	88.33
20	17.02	15.51	13.34	9.38

Table 3 presents statistical constants calculated from the data of which Tables 1 and 2 are representative samples. In all, there were 60 replicates used in the calculation of these constants. On the basis of these results the time of three minutes was selected as best.

It should be noted from Table 3 that with an increase of pearling time there is a more rapid decrease in the pearled weight of soft wheat than that of hard wheat. This is a factor that helps to differentiate between hard and soft wheats; but which makes more difficult the selection of a procedure suitable for both types of wheat.

In all the later work the wheat was pearled for three minutes, except where otherwise noted. For soft wheat 1½ minutes was used as a standard time. (Later work has shown a possibility of using the same pearling time for both types of wheat.)

Table 4 presents the means of triplicate determinations on hard wheat at various pearling times. Similar data for soft wheat are presented in Table 5. These tables are included to show the reproducibility of results with replicates of the same sample.

Table 6 gives the statistical constants, calculated from Table 3 for the standard deviations of the means of triplicate determinations.

Table 3. Statistical constants for the pearling test using 60 replicates of the same sample.

Determination	Mean gm.	Standard Deviation[1] gm.	Coefficient of Variability[2]
Hard Wheat 1 Min.	17.75	0.295	1.66
" " 1½ "	16.91	0.309	1.83
" " 2 "	15.55	0.230	1.47
" " 3 "	14.10	0.215	1.52
" " 4 "	12.10	0.280	2.31
Soft Wheat 1 Min.	16.95	0.169	0.98
" " 1½ "	15.04	0.250	1.66
" " 2 "	13.40	0.293	2.18
" " 3 "	9.67	0.333	3.65

1/ $\bar{s} = \sqrt{\frac{s}{n}}$ where n is the number of replicates included in the mean.

2/ $C = \frac{s}{\bar{x}} \times 100$

Table 4. Means of triplicate determinations on hard wheat at various pearling times.

Trial No.	1 Min. gm.	1½ Min. gm.	2 Min. gm.	3 Min. gm.	4 Min. gm.
1	17.61	17.19	15.55	14.19	11.95
2	17.59	16.98	15.63	13.88	12.19
3	17.77	16.91	15.80	13.98	12.31
4	17.37	16.56	15.61	14.24	12.06
5	17.99	16.84	15.80	14.14	11.99
6	17.99	17.08	15.68	14.25	12.08

Table 5. Means of triplicate determinations on soft wheat at various pearling times.

Trial No.	1 Min. gm.	1½ Min. gm.	2 Min. gm.	3 Min. gm.
1	16.97	15.29	13.28	9.73
2	17.15	15.06	13.31	10.04
3	16.79	15.04	13.46	10.02
4	16.93	15.02	13.56	9.81
5	16.97	15.37	13.60	9.65
6	16.82	14.83	13.20	9.29

The errors that might be expected and the differences required for significance are tabulated in Table 7. These were calculated from the data in Table 3.

From Table 7 it can be readily seen that if the mean of three determinations were used instead of single determinations, the differences required for significance would be reduced nearly one half. Likewise, if the mean of twenty determinations were used instead of the mean of triplicates, the difference would again be reduced one half.

However, there was another factor to consider. If the test was to be practical for plant breeding work it would have to be accomplished quickly with a small amount of material. Obviously, the use of the mean of twenty determinations was out of the question and the practical limit was the mean of triplicate replications. Therefore, the remaining work was done using the mean of triplicate determinations as the acceptable value.

The Effect of Yellowberry Kernels. Since it is quite generally agreed that the spotted, starchy, yellow-colored kernels, known as yellowberries, are softer in kernel texture an experiment was designed to investigate the effectiveness of the pearling test to measure their hardness.

Table 6. Statistical constants for means of triplicate determinations.

Determination	Mean gm.	Standard Error of Means[3] gm.	Coefficient of Variability[2]
Hard Wheat 1 Min.	17.75	0.170	0.96
" " 1½ "	16.94	0.179	1.06
" " 2 "	15.55	0.130	0.84
" " 3 "	14.10	0.124	0.88
" " 4 "	12.10	0.162	1.33
Soft Wheat 1 Min.	16.95	0.098	0.58
" " 1½ "	15.04	0.144	0.96
" " 2 "	13.40	0.169	1.26
" " 3 "	9.67	0.202	2.08

2/ $C = \frac{s}{\bar{x}} \times 100$

3/ $\bar{s} = \sqrt{\frac{s}{n}}$ where n is the number of replicates included in the mean.

Table 7. Standard errors for various pearling determinations.

Type of Determination	Type of Wheat	Pearling Time min.	Standard Error gm.	Difference Required for Significance[4] gm.
Single	Hard	3	0.215 1/	0.43
		1½	0.309	0.61
	Soft	3	0.353 1/	0.71
		1½	0.250	0.50
Means of Triplicates	Hard	3	0.124 3/	0.25
		1½	0.179	0.36
	Soft	3	0.202 3/	0.40
		1½	0.144	0.29
Mean of Twenty Replicates	Hard	3	0.048 3/	0.10
		1½	0.069	0.14
	Soft	3	0.078 3/	0.16
		1½	0.056	0.12

1/ $s = \sqrt{\frac{\Sigma x^2}{n-1}}$

3/ $\bar{s} = \sqrt{\frac{s}{n}}$ where n is the number of replicates in the mean.

4/ Difference required = $2 \times \bar{s}$

A sample of hard wheat was hand picked into two groups.. One group of kernels consisted of yellowberries and theoother group contained the dark and vitreous kernels. Because of difficulty of making the separation and the limitation of time only one sample of wheat was thus tested. The results are given in Table 8.

Table 8. The pearled weight of various portions of a sample of Kharkof wheat.

Portion	Pearled Weight gm.	Difference From Unpicked Portion gm.
Unpicked wheat	15.70	
Yellowberry portion	15.23	-0.47
Dark vitreous portion	15.77	0.07

There was at least one significant difference (0.25 gram as shown in Table 7) between the means for the dark vitreous kernels and the yellowberry kernels of the same sample of wheat.

<u>The Effect of Hardness.</u> A series of samples was composited which represented samples from 100 percent hard kernels to 100 percent soft kernels. The results obtained on this series of samples are given in Table 9.

Table 9. Pearled weights of samples containing various percentages of hard and soft kernels.

Sample	Hard Kernels %	Soft Kernels %	Pearled Weight gm.	Number of Significant Differences from 100% Hard Kernels
10H	100	0	14.21	0
9H	95	5	14.01	1
8H	90	10	13.21	3
7H	85	15	13.14	3
6H	80	20	13.10	3
5H	75	25	13.45	2
4H	70	30	12.83	4
3H	65	35	12.58	5
2H	60	40	13.26	3
1H	55	45	12.45	5
0	50	50	11.85	7
1S	45	55	12.22	6
2S	40	60	11.59	8
3S	35	65	11.36	9
4S	30	70	11.22	9
5S	25	75	11.11	10
6S	20	80	10.90	10
7S	15	85	10.41	12
8S	10	90	10.30	12
9S	5	95	10.58	11
10S	0	100	10.22	12

It is very evident that the pearling test was able to reveal differences in the hardness of the wheat sample. This is shown by the fact that there was a distinct ranking of the samples by the pearled weight that was in complete agreement with the percentage of hard and soft kernels present in the samples.

Correlation Coefficients. Statistical correlations, calculated by the methods of Snedecor (1938, p. 123-141) are presented in Table 10. It should be noted that the pearled weight was correlated very closely with both the pearling time and the hardness of the sample. However, the regression of the time on the pearled weight was four times as great as the regression of the hardness on the pearled weight. In other words, the pearling test was much more sensitive to variations in length of pearling time than it was to variations in the hardness of the sample.

Table 10. Correlation coefficients for various factors affecting the pearled weight of wheat.

Factors Correlated With Pearled Weight	Coefficient of Correlation r	Coefficient of Regression b	P=
Pearling Time (Hard Wheat)	0.91	1.65	0.01
Pearling Time (Soft Wheat)	0.96	3.06	0.01
% Hard Kernels in Sample	0.95	0.41	0.01

<u>Summary of Pearling Work.</u> A hard and a soft wheat were used to determine an optimum length of time for pearling and to determine the errors of replications that might be expected. The differences in means required for significance were 0.25 gram for hard wheat and 0.29 gram for soft wheat.

The pearling test was able to detect differences in hardness of a wheat sample because of the presence of yellowberries. In an experiment designed to determine the ability to reveal differences in kernel hardness by making up a series of samples containing various percentage of soft kernels there was a range of 12 significant differences between the completely hard and the completely soft samples. The pearling test was found to be much more sensitive to differences in the length of the pearling time than it was to differences in the hardness of the sample.

Determination of Tempering Requirements

The determination of tempering requirements for preparing wheat for research milling is a problem in accuracy rather than speed.

Bailey (1927) pointed out that there are three factors involved in the tempering process: the amount of water that is added, the temperature of the wheat and the length of the tempering period. Many millers have recognized these factors through long experience with wheat crops of varying characteristics. As this viewpoint seemed to be fundamental it was used as a starting point in the development of a method to determine the amount of water required to temper wheat, provided the effects of temperature and time were held constant.

Experimental Procedure. After preliminary experimentation the following procedure was adopted to determine the moisture requirements for tempering wheat:

1. Five 100-gram sub-samples were weighed and tempered to 13½, 14, 14½, 15 and 15½ percent moisture.
2. The time of temper was allowed to vary from 16 to 24 hours and the samples were kept at 70° F.
3. These sub-samples were milled through the breaks of a Buhler experimental mill with the rolls set the following distances apart: 1st Break, 0.019 inch; 2nd Break, 0.002 inch; and the 3rd Break, 0.0015 inch.

4. The middlings from each sub-sample were collected and a 50-gram portion was sifted over a stack of the following sieves: 40, 50, 60, and 70 GG, and a 10 XX.
5. After sifting for one minute in a Rotomatic sifter the overs of each cloth and the throughs of the 10 XX sieve were weighed on a balance sensitive to 0.01 gram.

To aid in selecting the best sub-sample the weights obtained were converted to an "index of tempering" by the following method:

1. The weight over the 40 GG was multiplied by 3
2. The weight over the 50 GG was multiplied by 3
3. The weight over the 60 GG was multiplied by 2
4. The weight over the 70 GG was multiplied by 1
5. The weight over the 10 XX was multiplied by -1
6. The weight through the 10 XX was multiplied by -2
7. These numerical products were added algebraically to obtain the "index of tempering."

The multipliers used in the calculations shown above were selected to emphasize the type of middlings or other milling products desired.

Since the coarser fractions (overs of 40 and 50 GG) were of better quality they were multiplied by 3. The next best fraction (over 60 GG) was multiplied by 2, and finally (over 70 GG) by 1. The less desirable fraction over the 10 XX was multiplied by -1 and the throughs of the 10 XX by -2. An addition of these mathematical products would indicate that the sub-samples with the higher indexes of tempering were in better condition for milling in that they contained the largest amount of coarse middlings with the least amount of break flour. This allowed more opportunity to produce a gradual reduction of the middlings during the milling process.

Reproducibility of Results. In order to test the reliability of this method of determining moisture requirements an experiment was designed in such a manner that it would be possible to compare the reproducibility of the selection of the optimum moisture content for tempering the samples. A group of nine samples of different wheats was subjected to the determination of the tempering requirements. Later a second determination was made on each of the samples. The data obtained are tabulated in Table 11.

Table 11. Reproducibility of the determination of moisture requirements for tempering wheat.

Sample No.	Moisture Content Required For Tempering		
	1st Trial %	2nd Trial %	Average %
801	15.6	16.2	15.9
802	15.0	14.6	14.8
803	14.5	15.1	14.8
804	15.3	15.3	15.3
805	15.5	14.5	15.0
806	14.1	14.5	14.3
807	15.0	15.0	15.0
808	15.8	15.4	15.6
809	15.5	16.1	15.8

It will be noticed that there were some variations between the two replications of each sample. However, the accuracy was such that any one value probably would differ from the real value by more than plus or minus 0.5 percent in only eight out of 100 trials.

The statistical reasons for the accuracy of the prediction just made are beyond the scope of this thesis. It is sufficient to say that the accuracy of such predictions is directly affected by the number of original observations included in the calculation. A complete discussion of this relationship is given by Fisher (1936) on pages 42 to 80.

Method of Preparing and of Milling Samples

Cleaning and Scouring. While the cleanliness of a sample is important as far as a commercial evaluation is concerned, it is obvious that research work should eliminate the effect of such variations upon the final results obtained. Therefore, all samples were cleaned and scoured with an experimental cleaner and scourer as soon as they were received.

Test Weight. To avoid the errors introduced by variable amounts of scouring on different samples the test weights were determined on the samples after cleaning but before scouring. The test weights as recorded were the equivalent of dockage-free test weights.

Weighing and Tempering of Samples. The samples, weighed from the cleaned, scoured wheat, were 2000 grams or even multiples whenever possible. This allowed the use of a chart which gave the amount of water required to temper 2000 grams of wheat from the original moisture contents (in the range of 7 to 12 percent) to the final moisture content as had been previously determined by the methods outlined in this thesis. The water was added to the wheat and it was mixed by hand.

After being thoroughly mixed the dampened wheat was transferred to a water-tight can and moved to the mill room. The tempering time was 16 to 24 hours depending on what time of the day the samples were milled. That is, all the samples to be milled the following day were tempered at about 4 P. M. the previous afternoon. Just previous to milling a light second temper was added to condition the bran for milling.

Atmospheric Control of Mill Room. The room in which the milling was done was completely air-conditioned and automatically controlled to maintain a previously adjusted temperature and relative humidity. The milling reported in this thesis was done with the room controlled at 70° F. and 50 percent relative humidity. These conditions were selected because they represented a compromise between what was comfortable for both summer and winter conditioning. In addition, this temperature and humidity allowed the mills to operate within the range of best results as judged by the way the samples handled on the mills.

Mills and Flow-sheets. Most of the milling reported in this thesis was done on a Buhler laboratory mill. However, some of the tests were made with the Allis experimental mill. The flow-sheets used with these mills are shown in figures 1 and 2 on plate I. The mills were set to give a straight grade flour as nearly like that obtainable from a commercial mill as was possible. As each sample represented a somewhat different problem the mills were set for each sample so that it might be milled under optimum conditions.

Data Collected. Generally, the only milling data taken was the weight of the flour obtained and the weight of the bran and the shorts. With some of the samples the wheat was weighed just before milling. In a few instances the roll settings on the Buhler mill were recorded in an effort to determine if it would be necessary to adjust the mill for each sample.

Sampling Methods. After milling the wheat the flour was thoroughly mixed before sampling. To determine the effect of mixing on the results a short experiment was performed on one of the samples milled.

EXPLANATION OF PLATE I

Fig. 1. The flow sheet of the Allis mill.

Fig. 2. The flow sheet of the Buhler mill.

Plate I

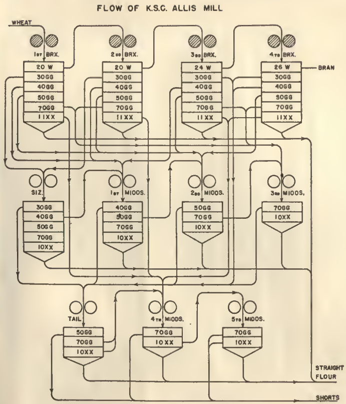

Fig. 1. Flow sheet of the Allis-Chalmers mill.

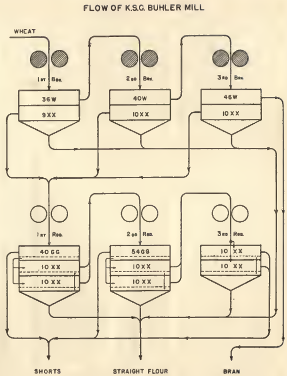

Fig. 2. Flow sheet of the Buhler mill.

Since the protein content of the different portions of the wheat kernel varies so much it was thought that the protein content of the flour would be a good criterion as to whether or not the flour was receiving ample mixing. A series of samples was collected from the Buhler mill at various times during the milling process. The results of the protein determinations on these samples are given in Table 12.

Table 12. Protein content of various products from a sample of Kharkof wheat milled on a Buhler mill.

Product	Protein Percentage (15 % m.b.)
Wheat	15.2
Break Flour	14.7
Middlings Flour	14.2
Straight Flour (unmixed)	14.4
Straight Flour (mixed once)	14.5
Straight Flour (mixed twice)	14.5
Bran	17.3
Shorts	17.1

It is evident from Table 12 that the flour was rather uniform as it came from the mill and that one thorough mixing was sufficient to give a representative sample for chemical analysis.

Baking Methods. The baking work reported in this thesis was done by Mr. Karl Finney of the Hard Winter Wheat Quality Laboratory. All flours were stored three weeks at 70° F. and placed in cold storage at 40° F. until baked. Each sample was baked in duplicate and the data reported herein are the average of the two replications.

The following formula was used:

Ingredient	Percentage based on flour
Flour	100.0
Water	Variable
Sugar	6.0
Salt	1.5
Yeast	2.0
Shortening	3.0
Dry Skim-milk	4.0
Potassium Bromate	0.003

The loaves baked on any one day were obtained from a 200 gram dough divided into two equal parts after being given an optimum mix in a Swanson-Working mixer. The fermentation time was three hours (105 minutes to the first punch, 50 minutes to the second punch, and 25 minutes to the pan). The proof time was 55 minutes at 86° F. and the baking time was 25 minutes at 425° F. The loaf volumes were measured immediately after baking and the inside characteristics were judged the following morning. All data given are the averages of at least two bakes. Experience in the laboratory has shown that it requires approximately 25 cc. to be a significant difference.

THE EVALUATION OF MILLING QUALITY

In the present study it is considered that milling quality should mean, among other things: a large yield of flour, uniform tempering requirements, a high percentage of the wheat protein recovered in the flour, uniform kernel hardness, and a low ash in the flour in relation to the ash in the wheat. As the ultimate evaluation probably will be made by commercial usage the commercial miller's viewpoint is adapted to evaluating milling quality in small wheat samples.

As a basis of illustrating the importance of these various factors the following assumption has been made: In a mill of 500 barrels capacity a close record is kept of the wheat ground and the yields obtained from it. Table 13 presents illustrative figures on three samples of wheat. These are theoretical but not unlike what one would normally find. It has been assumed that the wheat was worth $1.00 a bushel with a premium of 2 cents per bushel for each percent of protein above 12 percent and that mill feed was worth $20.00 a ton. In the discussion of the various factors affecting milling quality this basic assumption will be used to illustrate the importance the miller must attach to them.

Table 13. Assumed data for purposes of illustrating factors of milling quality.

Sample	Flour Extraction Percentage	Wheat Yield 5/	Percent Protein in Wheat	Percent Protein in Flour	Percent Ash in Wheat	Percent Ash in Flour	Feed Recovery Percentage
A	70.0	4:40	14.0	12.0	1.80	0.44	30.0
B	68.5	4:46	13.0	12.0	1.80	0.44	31.5
C	70.0	4:40	13.0	12.0	1.80	0.38	30.0

5/ Bushels and pounds of wheat required to produce a barrel of flour.

Flour Yields

The importance of good flour yields can be illustrated by the comparison of samples A and B from Table 13. In this case it has required six more pounds of wheat to produce a barrel of flour from wheat B. With wheat worth $1.00 a bushel this is equivelent to an increased cost of production of ten cents a barrel. That these differences are real and not just apparent is shown by Table 14 in which are tabulated the flour extractions obtained on a group of uniform samples.

Table 14. Comparative cost of milling a group of samples of No. 1 Hard Winter Wheat.

Sample No.	Market Grade 6/	Test Weight (Lb.per Bu.)	Flour Extraction Percent	Wheat Yield 5/	Cost of Wheat Per Barrel of Flour 7/
39607	1 H. W.	60.9	73.7	4:27	$4.45
39616	"	60.5	71.9	4:32	4.53
39634	"	60.2	71.4	4.34	4.57
39604	"	60.6	70.7	4.37	4.62
39610	"	60.7	70.1	4:40	4.67
39648	"	62.2	67.9	4:49	4.82
39645	"	61.7	66.0	4:57	4.95

5/ Bushels and pounds of wheat required to produce a barrel of flour.
6/ As graded by Federal Grain Supervisors.
7/ Assuming that wheat was worth $1.00 per bushel.

If the costs shown in Table 14 were multiplied by 500 there would be differences in the cost of wheat for a 500 barrel mill as much as $250.00 per day.

Protein Recovery

Samples A and C, of Table 13, are good illustrations of how a poor quality wheat could cost a mill money because protein premiums were necessary. Each bushel of wheat A that was ground would have cost two cents extra because of the protein yet the protein content of the flour was the same as that milled from wheat C. If 500 barrels of flour were made this would amount to approximately $45.00 difference per day. The formula for expressing this factor is as follows:

$$\text{Protein Recovery \%} = \frac{\text{Flour Protein \%}}{\text{Wheat Protein \%}} \times 100.$$

For the purpose of calculating the protein recovery percentage both the wheat and flour protein percentages are expressed on the 15 percent moisture basis. This is contrary to most laboratories in that they usually express the wheat protein on the "as received" moisture basis. In other words, they do not correct for the moisture content of the wheat as compared to the moisture content of the flour.

Ash Recovery

The percentage of ash recovery is important in that it allows the miller a chance to determine whether high ash in his flour was due to the wheat or due to other factors, which may not have been controlled.

To eliminate the effect of moisture content the ash percentages of both the wheat and the flour are expressed on the 15 percent moisture basis. The formula for calculating the ash recovery percentage is:

$$\text{Ash Recovery } \% = \frac{\text{Flour Ash } \%}{\text{Wheat Ash } \%} \times 100.$$

Single Figure or "Milling Value"

If all these factors are considered together their combined effect is to give a summary of the components of milling quality. Some of these factors are more important than others so they have been weighted in accordance with their relative importance. In this thesis the following formula was used to calculate the "milling value":

$$\text{"Milling Value"} = \text{Flour Ext.}\% + 0.5 \text{ Feed Recovery } \% + 0.2 \text{ Protein Recovery } \% - 0.1 \text{ Ash Recovery } \%$$

The factors included in this formula were selected because experience has shown that they are components of milling quality. A preliminary study of a series of replicates of a wheat sample furnished data so that the coefficients of each of the factors could be selected statistically. The desirability of this procedure was that it assisted the development of a formula that was logical yet accurate.

That this formula is accurate in practice will be shown later in the third part of this thesis where the results of an experiment to test the reliability of these methods have been recorded.

For the wheats in Table 13 the "milling values" are: A, 99.2; B, 99.5; and C, 100.4. If this method of calculating milling value is sound fundamentally it should reflect the monetary value of these wheats under the conditions assumed for Table 13. Table 15 gives a calculation of the net cost of materials for a barrel of flour for each of the three wheats of Table 13.

It is apparent from Table 15 that the "milling value" did rank these wheats in their respective order as measured in dollars and cents. In addition the "milling value" does not require any assumption as to prices and no information other than that obtained in the laboratory.

Table 15. Cost of material for one barrel of flour.

Wheat	Cost of Wheat	Cost of Protein Premium	Credit for Feed	Net Cost
A	$4.67	$0.18	$0.84	$4.05
B	4.77	0.09	0.86	3.96
C	4.67	0.09	0.84	3.93

The Calculation of Flour Extractions

There have been many ways of calculating and expressing flour extractions or yields. In general the term "extraction" is used to indicate the percentage of wheat that is recovered as flour. The "wheat yield" or "yield" is usually taken to mean the bushels and pounds of wheat required to produce a barrel of flour. The work in this thesis has referred to both of these terms. The important thing to know in any case is the method of calculating the flour extraction and, indirectly, the wheat yield.

As Milled Flour Extractions. Perhaps the most common method of calculating flour extractions is the "as milled" basis. This method takes no consideration of the moisture content of either the wheat or flour and is calculated by the formula:

$$\text{Flour Extraction Percentage} = \frac{\text{Weight of Flour}}{\text{Weight of Wheat}} \times 100.$$

Flour Extraction on 15 Percent Moisture Basis. This flour extraction figure is based on the "as milled" extraction . However, in this method of calculating flour extraction the weight of both the wheat and the flour are corrected to the 15 percent moisture basis before the percentage is figured. (This is the same as the "dry matter" basis of calculating flour extractions.)

The formula for calculating the flour extraction percentage on the 15 percent moisture basis was:

$$\text{Flour Extraction Percentage(15\%m.b.)} = \frac{\text{Weight of flour at 15 percent moisture}}{\text{Weight of wheat at 15 percent moisture}}$$

This method of figuring flour extraction eliminated the variations due to differences in the original moisture content of the wheat, in the tempering procedure and in the atmospheric conditions of the mill-room.

Flour Extraction Based on Total Products. This method is based on a common commercial practice of figuring the flour extraction on the basis of the total amount of products made. In a commercial mill the only method available is often this one. The weights of the flour and feed are taken from the packers and the extraction is then figured by the formula:

$$\text{Flour Extraction \%}\ (\text{basis total products}) = \frac{\text{Weight of Flour}}{\text{Weight of Flour} + \text{Feed}} \times 100.$$

For laboratory purposes this formula was used except that the various products were weighed off the mill. This method allowed a little correction for the moisture content of the wheat and flour but it did not fully correct all the weights to a constant moisture basis.

Kansas Milling Company Method. Another method of calculating flour extractions has been proposed by Mr. L. E. Leatherock.[8/] This method is essentially the same as the total products method except for the manner in which the weight of the flour is obtained. The weight of the flour in this method is not obtained by weighing but is secured by subtracting the weight of the feed from the weight of the wheat milled.

8/ Private communication dated January 12, 1940.

Generally no correction is made for the moisture content of the feed or the wheat, but it is possible to use any of the previously outlined methods in connection with this one. Apparently the outstanding thing about this method is the fact that is permits one to obtain experimental flour extractions that are nearly identical with commercial extractions obtained from the same wheat. Another advantage of this method is that it eliminates variations due to loss of flour or due to hang-ups of the flour that might be overlooked in cleaning out the mill.

TESTING THE RELIABILITY OF LABORATORY TECHNIQUES AND METHODS OF EVALUATING MILLING QUALITY

As a final test of the reliability of the techniques and methods of evaluating milling quality an experiment was designed in such a manner that these factors could be investigated when the milling was done by each of two millers on both the Buhler and the Allis mills. For this work a series of six common varieties of hard red winter wheat were chosen. Each of these were sub-divided into 18 samples. The general scheme of the experiment was that each miller milled on each mill on each of three days. Since the Buhler mill is more rapid twelve samples (two of each of the six varieties) were milled on it each day while six samples (one of each of the six varieties) were milled on the Allis mill.

The samples were all milled under code so that the millers had no knowledge of which variety they were handling. The order of the samples in milling was such as to eliminate as far as possible the effect of time of day. The baking was done by Mr. K. F. Finney of the Hard Winter Wheat Quality Laboratory by the methods previously outlined in this thesis.

The original data on all samples are tabulated in Tables 16 to 21 inclusive.

Flour Extractions

The flour extractions of this set of samples were calculated by each of the four methods previously discussed (pages 42-45) and are presented in Tables 22, 23, 24 and 25.

As Milled Flour Extractions. The most noticeable thing about the "as milled" flour extractions is the difference in the level of the extractions obtained on the Buhler mill as compared with those on the Allis mill. The standard error of replication of the Allis mill was somewhat higher also.

Flour Extractions on 15 Percent Moisture Basis. The main difference between this and the "as milled" flour extraction was in the level of their means. The extractions obtained with this method were about two percent lower than those obtained on the "as milled" basis. There were still the same differences in the level of the extractions obtained on the two mills.

Table 16. Original data obtained on samples of Kharkof wheat milled on two mills by two millers. (2000 gram samples were milled)

Sample No.	Flour Obtained gm.	Feed Recovered gm.	Flour Moisture %	Flour Ash 10/ %	Flour Protein 10/ %	Loaf Volume cc.	Grain Texture Score
			Miller A on Allis mill				
206 9/	1050	420	13.4	0.440	15.03	1002	47.5
404 9/	1368	645	13.3	0.436	15.41	954	47.8
602 9/	1070	460	13.7	0.472	15.38	943	47.2
			Miller B on Allis mill				
101	1297	728	13.3	0.413	15.00	991	46.9
305	1372	639	13.2	0.446	15.25	940	47.1
503	1376	658	13.2	0.409	15.19	973	47.2
			Miller A on Buhler mill				
107	1502	524	13.2	0.523	15.64	916	47.2
118	1500	573	13.5	0.493	14.93	947	47.1
311	1480	591	13.5	0.488	15.72	957	46.9
316	1486	583	13.4	0.476	15.00	994	46.3
509	1480	560	13.4	0.480	15.71	940	47.8
514	1472	594	13.5	0.486	15.77	932	46.9
			Miller B on Buhler mill				
212	1458	591	13.3	0.480	14.87	944	47.2
217	1457	590	13.2	0.474	14.87	929	46.6
410	1448	593	13.2	0.470	15.68	925	47.2
415	1484	565	13.0	0.497	15.46	918	47.8
608	1475	563	12.9	0.521	15.80	901	46.3
613	1490	561	12.6	0.502	15.79	981	47.2

9/ Only 1500 grams were milled.
10/ 15 percent moisture basis.

Table 17. Original data obtained on samples of Blackhull wheat milled on two mills by two millers. (2000 gram samples were milled)

Sample No.	Flour Obtained gm.	Feed Recovered gm.	Flour Moisture %	Flour Ash[10] %	Flour Protein[10] %	Loaf Volume cc.	Grain Texture Score
			Miller A on Allis mill				
201[9]	1060	470	13.2	0.466	15.31	998	47.2
405[9]	1390	628	12.8	0.434	15.30	957	45.8
603[9]	1033	496	13.5	0.438	15.48	986	47.2
			Miller B on Allis mill				
102	1294	697	13.2	0.405	15.15	979	47.5
306	1333	628	12.8	0.413	14.93	983	47.2
504	1390	647	13.6	0.397	14.99	990	47.2
			Miller A on Buhler mill				
108	1450	622	13.2	0.466	15.57	975	46.6
113	1434	607	13.6	0.466	15.91	964	45.9
312	1440	608	13.5	0.466	14.76	980	46.6
317	1440	600	13.5	0.476	14.99	1012	45.7
515	1426	619	13.5	0.462	14.72	982	46.9
510	1470	600	13.4	0.456	14.87	947	46.9
			Miller B on Buhler mill				
207	1505	589	13.5	0.490	14.88	982	46.9
218	1446	611	13.2	0.472	14.89	992	45.7
411	1454	622	13.3	0.454	14.99	976	46.6
416	1435	590	13.1	0.454	14.99	938	47.2
609	1460	607	13.4	0.471	15.53	969	46.3
614	1437	593	13.2	0.479	15.47	1018	46.6

9/ Only 1500 grams were milled.
10/ 15 percent moisture basis.

Table 18. Original data obtained on samples of Oro wheat milled on two mills by two millers. (2000 gram samples were milled)

Sample No.	Flour Obtained gm.	Feed Recovered gm.	Flour Moisture %	Flour Ash [10] %	Flour Protein [10] %	Loaf Volume cc.	Grain Texture Score
			Miller A on Allis mill				
202 [9]	1074	460	13.9	0.466	14.98	1103	47.8
406	1390	628	13.5	0.458	15.21	1074	48.1
604 [9]	1060	499	13.7	0.449	14.99	1080	48.1
			Miller B on Allis mill				
103	1341	600	13.1	0.450	14.71	1092	47.8
301	1450	652	14.1	0.454	15.16	1073	47.5
505	1422	671	13.4	0.446	15.09	1118	48.7
			Miller A on Buhler mill				
109	1440	625	13.1	0.486	15.37	1103	47.5
114	1440	638	13.9	0.484	15.46	1078	47.2
307	1464	578	14.2	0.513	15.54	1052	47.2
318	1460	609	13.6	0.490	15.55	1110	47.5
511	1450	630	13.7	0.464	15.33	1070	47.2
516	1460	645	13.9	0.476	14.84	1092	47.2
			Miller B on Buhler mill				
208	1432	632	13.4	0.472	15.42	1108	48.1
213	1424	601	13.9	0.482	14.89	1083	47.8
412	1420	648	13.6	0.450	15.39	1087	47.2
417	1468	622	13.7	0.472	15.36	1049	46.9
610	1438	616	13.4	0.472	15.48	1105	47.8
615	1461	610	13.4	0.499	15.58	1090	48.1

9/ Only 1500 grams were milled.
10/ 15 percent moisture basis.

Table 19. Original data obtained on samples of Cheyenne wheat milled on two mills by two millers. (2000 gram samples were milled)

Sample No.	Flour Obtained gm.	Feed Recovered gm.	Flour Moisture %	Flour Ash [10] %	Flour Protein [10] %	Loaf Volume cc.	Grain Texture Score
			Miller A on Allis mill				
203 [9]	1065	452	14.2	0.462	14.87	987	46.8
401	1424	592	14.0	0.436	14.66	970	48.1
605 [9]	1087	429	13.3	0.482	14.66	970	45.8
			Miller B on Allis mill				
104	1380	630	13.2	0.432	14.45	1004	48.1
302	1402	636	13.7	0.417	14.65	992	47.7
506	1424	630	13.5	0.417	14.80	1009	48.7
			Miller A on Buhler mill				
110	1518	558	13.3	0.484	15.19	1002	48.1
115	1492	562	13.4	0.478	15.08	1007	48.7
308	1532	530	13.9	0.495	15.23	964	46.4
313	1481	543	13.8	0.474	15.24	1029	47.1
512	1504	536	13.6	0.495	15.21	975	47.1
517	1506	550	13.5	0.468	15.09	1020	48.4
			Miller B on Buhler mill				
209	1504	541	13.4	0.468	14.77	1018	48.1
214	1520	587	13.6	0.468	14.99	1003	46.5
407	1538	543	13.7	0.493	15.09	979	47.8
418	1522	559	13.5	0.474	14.50	1024	48.1
611	1534	527	13.3	0.510	14.78	1005	47.8
616	1521	545	13.0	0.453	14.89	1013	46.8

9/ Only 1500 grams were milled.
10/ 15 percent moisture basis.

Table 20. Original data obtained on samples of Nebred wheat milled on two mills by two millers. (2000 gram samples were milled)

Sample No.	Flour Obtained gm.	Feed Recovered gm.	Flour Moisture %	Flour Ash[10] %	Flour Protein[10] %	Loaf Volume	Grain Texture Score
			Miller A on Allis mill				
204[9]	1056	452	13.8	0.415	15.36	1234	46.9
402	1412	622	14.0	0.430	15.60	1196	45.7
606[9]	1040	490	13.4	0.414	15.50	1174	46.6
			Miller B on Allis mill				
105	1398	665	13.2	0.391	15.22	1192	45.7
303	1362	681	13.2	0.391	15.48	1168	46.6
501	1402	563	13.5	0.407	15.52	1208	46.9
			Miller A on Buhler mill				
111	1430	600	13.6	0.448	14.94	1215	46.9
116	1488	598	13.5	0.480	14.82	1170	46.9
309	1490	565	13.7	0.468	15.76	1174	46.0
314	1496	606	13.7	0.452	15.72	1198	45.4
507	1480	576	13.3	0.456	15.38	1182	46.9
518	1470	584	13.3	0.446	15.41	1180	47.2
			Miller B on Buhler mill				
210	1462	604	13.2	0.464	15.62	1200	46.3
215	1440	619	13.3	0.442	15.18	1171	45.7
408	1448	600	13.1	0.444	15.18	1172	46.0
413	1442	579	13.0	0.442	15.23	1194	47.5
612	1454	614	13.2	0.451	15.15	1204	46.0
617	1444	594	13.0	0.441	15.02	12.05	46.6

9/ Only 1500 grams were milled.
10/ 15 percent moisture basis.

Table 21. Original data obtained on samples of Chiefkan wheat milled on two mills by two millers. (2000 gram samples were milled)

Sample No.	Flour Obtained gm.	Feed Recovered gm.	Flour Moisture %	Flour Ash [10] %	Flour Protein [10] %	Loaf Volume cc.	Grain Texture Score
			Miller A on Allis mill				
205 [9]	1092	420	13.9	0.474	14.81	814	44.6
403 [9]	1456	576	13.3	0.472	14.74	774	43.7
601	1075	556	14.5	0.453	14.62	791	44.0
			Miller B on Allis mill				
106	1402	769	13.3	0.438	14.84	810	45.6
304	1401	658	13.0	0.460	14.95	788	44.3
502	1414	654	13.6	0.425	14.82	795	45.0
			Miller A on Buhler mill				
112	1544	557	13.6	0.501	15.21	799	45.0
117	1512	542	13.6	0.493	15.04	787	45.2
310	1526	554	13.8	0.493	15.16	794	44.3
315	1534	512	13.7	0.484	15.09	798	44.0
508	1578	522	13.7	0.542	15.13	779	43.4
513	1548	515	13.6	0.523	15.13	767	43.7
			Miller B on Buhler mill				
211	1496	580	13.3	0.472	15.00	783	44.6
216	1498	586	13.7	0.470	15.01	787	44.3
409	1490	624	13.2	0.474	15.02	805	43.3
414	1504	575	13.5	0.476	15.18	778	44.3
607	1516	546	13.1	0.494	14.80	745	44.0
618	1520	534	13.1	0.483	14.76	789	43.7

[9] Only 1500 grams were milled.
[10] 15 percent moisture basis.

Table 22. Percent flour extractions of six varieties of hard red winter wheat milled on the Buhler and the Allis mills by two millers and calculated on the "as milled" basis.

Variety	Buhler Mill Miller A	Buhler Mill Miller B	Buhler Mill Av.	Allis Mill Miller A	Allis Mill Miller B	Allis Mill Av.
Kharkof	74.3	73.4	73.9	69.9	67.5	68.7
Blackhull	72.2	72.8	72.6	69.7	67.0	68.4
Oro	72.6	72.0	72.3	70.6	70.2	70.4
Cheyenne	75.3	76.2	75.8	71.6	70.1	70.8
Nebred	73.8	72.4	73.1	70.1	69.4	69.7
Chiefkan	77.0	75.2	76.1	72.4	70.1	71.3
Average	74.2	73.7	74.0	70.7	69.0	69.9
Range	4.8	4.2	4.5	2.7	3.2	2.9
Standard Error[11]	0.83	0.77	0.79	0.81	1.58	1.23

[11] $S=\sqrt{\frac{\Sigma x^2}{n-1}}$

Table 23. Percent extractions of six varieties of hard red winter wheats milled on the Buhler and the Allis mills by two millers and calculated on the 15 percent moisture basis.

Variety	Buhler Mill Miller A	Buhler Mill Miller B	Buhler Mill Av.	Allis Mill Miller A	Allis Mill Miller B	Allis Mill Av.
Kharkof	72.3	71.7	72.0	67.9	65.7	66.8
Blackhull	70.1	70.9	70.5	68.0	65.2	66.6
Oro	70.5	70.1	70.3	68.6	68.3	68.5
Cheyenne	73.1	74.1	73.6	69.4	68.3	68.8
Nebred	71.3	70.3	70.8	67.6	67.2	67.4
Chiefkan	74.5	73.0	73.8	69.9	68.1	69.0
Average	72.0	71.7	71.8	68.6	67.1	67.9
Range	4.4	4.0	3.5	2.3	3.1	2.2
Standard Error[11]	0.82	0.77	0.79	0.86	1.47	1.19

11/ $s = \sqrt{\frac{\Sigma x^2}{n-1}}$

Table 24. Percent flour extractions of six varieties of hard red winter wheats milled on the Buhler and the Allis mills by two millers and calculated on the basis of total products.

Variety	Buhler Mill Miller A	Buhler Mill Miller B	Buhler Mill Av.	Allis Mill Miller A	Allis Mill Miller B	Allis Mill Av.
Kharkof	72.3	71.8	72.1	69.8	66.6	68.2
Blackhull	70.3	70.7	70.5	68.5	67.1	67.8
Oro	70.1	69.9	70.0	69.0	68.7	68.9
Cheyenne	73.4	73.5	73.5	70.8	68.9	69.9
Nebred	71.7	70.7	71.2	69.1	68.6	68.9
Chiefkan	74.3	72.4	73.4	69.9	67.0	68.5
Average	72.0	71.5	71.8	69.5	67.8	68.7
Range	4.2	3.6	3.5	2.3	2.3	2.1
Standard Error[11]	0.74	0.75	0.75	1.48	1.47	1.47

[11] $S = \sqrt{\frac{\Sigma x^2}{n-1}}$

Table 25. Percent flour extractions of six varieties of hard red winter wheats milled on the Buhler and the Allis mills by two millers and calculated by the Kansas Milling Company method.

Variety	Buhler Mill Miller			Allis Mill Miller		
	A	B	Av.	A	B	Av.
Kharkof	76.9	76.1	76.5	76.6	72.8	74.7
Blackhull	75.5	75.6	75.5	74.7	73.7	74.2
Oro	75.4	75.4	75.4	75.5	74.9	75.2
Cheyenne	78.5	78.2	78.4	77.4	75.6	76.5
Nebred	76.6	75.8	76.2	75.9	75.3	75.6
Chiefkan	79.4	77.2	78.3	75.9	72.7	74.3
Average	77.1	76.4	76.7	76.0	74.2	75.1
Range	4.0	2.8	3.0	2.7	2.8	2.3
Standard[11] Error	0.85	0.83	0.84	1.87	1.90	1.86

[11] $s = \sqrt{\frac{\Sigma x^2}{n-1}}$

Flour Extractions Based on Total Products. The results obtained with this method of calculation were nearly identical with those expressed on the 15 percent moisture basis. The only difference of importance was in the error of replication for the samples milled by one of the millers on the Allis mill which was much higher than when the extractions were expressed on the 15 percent moisture basis.

Kansas Milling Company Method. There were two outstanding things about the flour extractions calculated by this method. The actual level of the extractions were higher by this method and there were smaller differences between the two mills. The Buhler mill gave an average extraction 1.6 percent higher than that obtained on the Allis mill.

The reason for the higher extractions was that all the mechanical and evaporative losses were eliminated in calculating the extractions as these losses were assumed to be in the flour. In spite of the removal of these sources of error, the standard error of replication was higher than by other methods of calculation.

Summary of Tests of Flour Extractions. The more Tables 22, 23, 24 and 25 are studied the more evident it becomes that the relative rankings of the varieties would have been the same regardless of which method of calculation had been used. It is evident, too, that the Buhler mill tended to give higher extractions than the Allis mill. Assuming that the quality of the flour is as good as that obtained from the Allis mill (this will be shown to be true later) the use of the Buhler mill would be more desirable for general laboratory usage.

"Milling Value"

The "milling value" of the samples of the six varieties, as milled by the two millers on both mills, were calculated by the formula given on page 40 of this thesis. The flour extractions substituted into this formula were calculated by the Kansas Milling Company method. These "milling values" are tabulated in Table 26.

One of the striking things about the "milling value" of these various millings was the little difference between the samples milled on the two mills. The only difference discernible in the results from the two mills was in the standard error of replication which was somewhat higher on the Allis mill.

Table 26. Milling Value of six varieties of hard red winter wheat milled on the Buhler and the Allis mills by two millers and calculated on the basis of flour yields figured by the Kansas Milling Company method.

Variety	Buhler Mill Miller A	Buhler Mill Miller B	Buhler Mill Av.	Allis Mill Miller A	Allis Mill Miller B	Allis Mill Av.
Kharkof	107.2	106.6	106.9	108.0	106.1	107.0
Blackhull	106.4	106.4	106.4	107.2	106.7	106.9
Oro	107.0	107.0	107.0	107.3	106.8	107.1
Cheyenne	108.5	107.8	108.1	108.0	107.4	107.7
Nebred	107.1	106.7	106.9	108.0	107.6	107.8
Chiefkan	109.0	107.4	108.2	107.1	105.7	106.4
Average	107.5	107.0	107.3	107.6	106.7	107.2
Range	2.6	1.4	1.8	0.9	1.9	1.4
Standard[11] Error	0.69	0.50	0.62	1.09	1.26	1.16

[11] $S = \sqrt{\frac{\Sigma x^2}{n-1}}$

The mean of all samples of each variety was used to calculate a standard error of replication of the "milling value" which included the effect of both miller and mills. This error was 1.0 units. That this error of replication was rather low is shown by the fact that the error of replication of the flour extractions used in the calculation of the "milling values" was over one percent.

Flour Protein

The protein contents of the flours milled by the two millers on both mills are tabulated in Table 27. The only differences of importance were in the errors of replication for the Buhler mill which were twice as large as those for the Allis mill. The protein contents of the Allis flours tended to be lower but there was not enough difference to be significant.

Flour Ash

The ash contents of the various flours are presented in Table 28.

Table 27. Protein content of flour milled from six varieties of hard red winter wheat on the Buhler and Allis mills by two millers.

Variety	Wheat Protein	Buhler Mill Miller			Allis Mill Miller		
		A	B	Av.	A	B	Av.
Kharkof	16.12	15.46	15.41	15.44	15.27	15.15	15.21
L..ckhull	15.92	15.13	15.14	15.13	15.36	15.02	15.19
Oro	15.92	15.35	15.35	15.35	15.06	14.99	15.02
Cheyenne	15.53	15.17	14.84	15.00	14.77	14.63	14.70
Nebred	16.12	15.34	15.23	15.28	15.49	15.41	15.45
Chiefkan	15.53	15.13	14.96	15.04	14.72	14.87	14.79
Average	15.82	15.26	15.16	15.21	15.11	15.01	15.06
Range	0.59	0.33	0.57	0.40	0.77	0.78	0.75
Standard Error[11]		0.32	0.25	0.29	0.11	0.14	0.12

[11] $S = \sqrt{\frac{\Sigma x^2}{n-1}}$

Table 28. Ash content of flour milled from six varieties of hard red winter wheat on the Buhler and Allis mills by two millers.

Variety	Percent Ash (15 percent moisture basis)					
	Buhler Mill			Allis Mill		
	Miller			Miller		
	A	B	Av.	A	B	Av.
Kharkof	0.491	0.491	0.491	0.449	0.423	0.436
Blackhull	0.465	0.470	0.467	0.446	0.405	0.426
Oro	0.486	0.476	0.481	0.458	0.450	0.454
Cheyenne	0.482	0.478	0.480	0.460	0.422	0.441
Nebred	0.458	0.447	0.453	0.420	0.396	0.408
Chiefkan	0.506	0.480	0.493	0.466	0.441	0.454
Average	0.481	0.474	0.478	0.450	0.423	0.436
Range	0.048	0.043	0.040	0.046	0.054	0.046
Standard[1] Error	0.014	0.014	0.014	0.013	0.010	0.011

1/ $S = \sqrt{\frac{\Sigma x^2}{n-1}}$

It is very evident that the flours from the Buhler mill were significantly higher in ash than those from the Allis mill. That this was no accident is shown by the fact that in every published test of these two mills the flours from the Buhler mill are invariably higher in ash. This should not be taken as a necessary impairment of the baking quality of the flour as it will be shown that the baking quality of the Buhler flours was equal that from the Allis mill. Apparently the high ash was due to the short system flow where the breaking must, of necessity, be more severe and the reduction of middlings more rapid. The higher ash was also partially due to the somewhat higher flour extractions.

Baking Quality of Flour

For the purposes of this thesis the principal measures of baking quality have been assumed to be loaf volume and grain-texture scores. It is recognized that there are other measures but a fuller evaluation and discussion of baking quality is beyond the scope of this thesis.

Loaf Volumes. The loaf volumes of the bread baked from the various flours have been tabulated in Table 29. A study of this table reveals very clearly that the only differences in loaf volume are those due to variety. There were no differences of significance between the flours milled by either miller or on either mill.

Grain-Texture Scores. The grain-texture scores used in this thesis are combined measure of the grain of the bread and the texture of the crumb, both of which were judged by the baker. The part of this score which represented the crumb grain was calculated by the formula:

Grain component = Grain score x 0.3

The texture component is obtained from the following table:

Texture	Texture Component
VG	22
VG	20
G	18
G	16
F	14
F	12
P	10
P	8
VP	6
VP	4

Example: Grain 80; texture VG; grain-texture score = 0.3 x 80 = 24 plus 20 (from table) = 44.

Table 29. Loaf Volumes of six varieties of hard red winter wheat milled on the Buhler and Allis mills by two millers.

Variety	Buhler Mill Miller A	Buhler Mill Miller B	Buhler Mill Av.	Allis Mill Miller A	Allis Mill Miller B	Allis Mill Av.
Kharkof	948	933	940	966	968	967
Blackhull	977	979	940	980	984	982
Oro	1085	1087	1086	1086	1094	1090
Cheyenne	1000	1007	1003	969	1002	985
Nebred	1187	1191	1189	1201	1189	1195
Chiefkan	787	781	784	793	798	795
Average	997	996	997	1000	1003	1002
Range	400	410	405	408	391	400
Standard Error[11]	19.3	19.9	19.5	19.8	14.6	17.2

[11] $S = \sqrt{\frac{\Sigma x^2}{n-1}}$

The grain-texture scores are given in Table 30. It is evident that there were but little differences in this value for any of the samples within a variety. The only differences of importance were those due to variety.

One is led to speculate as to what might have been the results if a lean formula had been used in the baking. It is quite commonly agreed that with a lean formula the baking results are dependent upon the differences in diastatic activity of flour. This, of course, implies that the differences in diastatic activity are important.

That a rich formula (eliminating the effects of variations in diastatic activity) is the correct one to use cannot be argued here. It is sufficient to say that approximately 90 percent of the commercial bread produced in the United States is produced with a formula similar to that used in this work. The data presented, of course, leads to the conclusion that either mill produces acceptable flour for studying the baking quality of wheat. However, since the quality of the flour is the same, but the quantity of flour and the number of samples milled per day are greater from the Buhler mill it follows that the Buhler mill would be more desirable for routine laboratory use.

Table 30. Grain-texture scores of six varieties of hard red winter wheat milled on the Buhler and the Allis mills by two millers.

Varieties	Buhler Mill Miller A	Buhler Mill Miller B..	Buhler Mill Av.	Allis Mill Miller A	Allis Mill Miller B	Allis Mill Av.
Kharkof	47.0	47.1	47.1	47.5	47.1	47.3
Blackhull	46.4	46.6	46.5	46.7	47.5	47.0
Oro	47.3	47.6	47.5	48.0	48.0	48.0
Cheyenne	47.6	47.5	47.6	46.9	48.2	47.5
Nebred	46.6	46.4	46.5	46.4	46.4	46.4
Chiefkan	44.3	44.0	44.2	44.1	44.9	44.5
Average	46.5	46.5	46.5	46.6	47.0	46.8
Range	3.3	3.6	3.4	3.9	3.3	3.5
Standard Error[11]	5.77	5.27	5.48	5.64	4.23	4.91

11/ $s = \sqrt{\frac{\Sigma x^2}{n-1}}$

Summary of Baking Quality. The data collected in this experiment showed little or no effect of either the mill or miller on baking quality as measured by loaf volume and grain-texture scores. There was a tendency for the loaf volumes of the flours from the Allis mill to run 5 or 10 cc. higher than those from the Buhler mill but these differences were not great enough to be significant, either statistically or practically.

CONCLUSIONS

The technique of measuring kernel hardness proposed by Taylor, Bayles and Fifield (1939) was modified and studied to determine the reproducibility of results. It was found that a difference of 0.25 gram in the weight of pearled hard wheat and 0.29 gram in the weight of pearled soft wheat was required to be significant. It was also found that the pearling test was much more sensitive to differences in the length of pearling time than it was to differences in kernel hardness.

A study was made of the efficiency of mixing the flour after milling before taking a sample for chemical analysis. It was found that a thorough mixing by hand was sufficient to secure accurate chemical analysis of the flour.

A method for the evaluation of milling quality of wheat was presented and substantiated by a theoretical calculation of the monetary value of these various factors. It was concluded that the following factors are of importance: flour extraction, uniform kernel hardness, uniform tempering requirements, a high protein recovery and a low ash recovery.

A single figure method of calculating "milling value" was proposed and it was shown that the method was accurate and logical in that it ranked the wheats in the proper order as far as monetary value is concerned.

Four methods of calculating flour extractions were discussed and it was concluded that they are all nearly equal in reliability and value.

From a study of the reproducibility of milling results on the Buhler and the Allis experimental mills, it was concluded that the Buhler mill gave slightly higher yields of flour of approximately the same quality, as measured by a baking test, and that the effect of operation by different millers was practically negligible.

It is recognized that more extensive investigations need to be made in this field, but it is hoped that the work reported in this thesis may help to point the direction that further research in experimental milling should take.

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