Changes in Milling Properties of Newly Harvested Hard Wheat During Storage[1]

E. S. POSNER[2] and C. W. DEYOE[3]

Cereal Chem. 63(5):451–456

ABSTRACT

The milling quality of newly harvested wheat is of interest to the miller because changes in flour quality and milling characteristics may occur during wheat storage. Small-scale milling experiments with hard red winter (HRW) wheat defined the changes that occur in milling and baking performance during the sweating period. These changes were examined by milling freshly harvested wheats both individually and in blends with HRW and hard red spring wheats from the previous crop year. Wide fluctuations in milling characteristics were observed resulting from storage of freshly harvested wheat. Results obtained from milling two consecutive crops of HRW wheat showed during the first five months an increase in flour extraction of 2–5%, sizing production of 2–3%, and average flour particle size about 11 μm. Statistical methods to fit a model for the milling characteristics revealed that flour quality characteristics did not react linearly with changes in the mill stocks. Regression procedures were used to determine relationships between technological evaluations of wheat and calculated milling values. The cost of storage time above 14 weeks exceeded the additional monetary benefits gained through improved milling results.

The term "in the sweat" is used to describe the occurrence of free moisture or "sweat" on the grain after harvest when the wheat is stacked before threshing. In a broader sense, grain elevator operators and millers use sweating to define the moisture changes that occur for an undefined period between the time wheat is threshed or combined and the time it reaches the mill.

One question that arises for operative millers each year is when to start milling the newly harvested wheat. Many technical, logistic, and economic factors influence the miller's decision at the time new wheat arrives at the mill. Millers incorporate the newly harvested wheat into the mill mix in several ways. Some millers store the wheat for two to three months before it is used; others incorporate it immediately. It is accepted in the industry that 5–15% new wheat may be added to the old wheat mix. Gradually increasing the proportion of the new wheat in the blend reduces major changes in flour milling.

Swanson (1931, 1946) stated that the problem of new wheat in the mill mix is ameliorated by the usual holdover from a previous crop. During the first few weeks or months after harvest, milling and baking qualities are improved. Thereafter, the changes are very small and the wheat maintains its quality for a long period. The lower the moisture and the temperature, the slower the rate of change.

Bice et al (1945) reported an increase in percentage of particles below 11 μm during storage up to three weeks after harvest.

Bailey (1925) attributed the intensity of respiration in wheat during storage after harvest to shape and size. Shriveled wheat kernels respired more than plump wheat kernels, probably a result of the larger proportion of germ in a unit volume of shriveled wheat.

Fitz (1910) showed improvement with time in water absorption and bread volume in wheat milled 4, 18, and 57 days after it was threshed at harvest and stored in a bin. Wheat stacked for 57 days, then threshed and milled, showed an improvement in water absorption, bread volume, and color. Stockham (1920) milled and baked hard red spring wheat over a period of nine years. There was a significant increase in baking strength during the first year, little change during the subsequent year, and a decrease after six years.

According to Shellenberger (1939), there is no change in water absorption and little change in loaf volume during the storage process. Flour yield increased from 60.9 to 62.2% and flour ash from 0.42 to 0.44%.

According to Pomeranz (1982) immature wheat grains are vitreous, and as maturation proceeds some grains remain vitreous while others become mealy. During roller milling, the endosperm cells of vitreous hard wheat kernels tend to shatter rather than powder while the breakage of both starch granules and protein matrix occurs. The miller is interested in total and patent flour extraction, flour particle size, and sizing characteristics during milling. According to Pelshenke (1958) there is a close correlation ($r = 0.959$) between sizing characteristics and grain structure. The above comments are bound to provoke the miller to study the changes in milling characteristics of the wheat during its storage after harvest.

The purpose of this study was to document the changes that take place in wheat during the sweating period immediately after harvest and how these changes affect milling and baking performance.

MATERIALS AND METHODS

The study was conducted in two parts with wheat from two consecutive hard red winter (HRW) crops. In the first year (part I) observations of the newly harvested wheat were complimented with evaluation of its performance in blends with old wheat. This approach simulated an accepted commercial practice. In the second year (part II), quality changes in the newly harvested wheat were studied according to a predesigned, statistical approach based on results of the first year. During both parts of the study, the

[1]Contribution 86-101-J, Department of Grain Science and Industry, Kansas Agricultural Experiment Station, Manhattan 66506. Mention of firm names or trade products does not imply that they are endorsed or recommended by the Agricultural Experiment Station over other firms or similar products not mentioned.

[2]Instructor, Department of Grain Science and Industry, Kansas State University, Manhattan 66506.

[3]Professor, Department of Grain Science and Industry, Kansas State University.

wheats were stored at a relative humidity of 68% and a temperature of 70° F. All milling experiments were conducted under the same controlled conditions (68% rh and 70° F).

In part I three wheat blends were milled: 1) 100% freshly harvested HRW wheat, variety Newton, from 1983 crop (A), 2) a blend of 50% HRW wheat from the 1982 crop and 50% A, and 3) a blend of 50% hard red spring (HRS) wheat from the 1982 crop and 50% A. The three blends were milled at five one-week intervals, at two two-week intervals, and at two three-week intervals for a total of nine milling experiments.

For part II, freshly harvested HRW wheat, a Newton, grown in 1984, was obtained. Duncan's (1975) multiple range test was used to determine the number of milling replicates in part II of the study. Duncan's formula δ / SE was used, where SE is the standard error

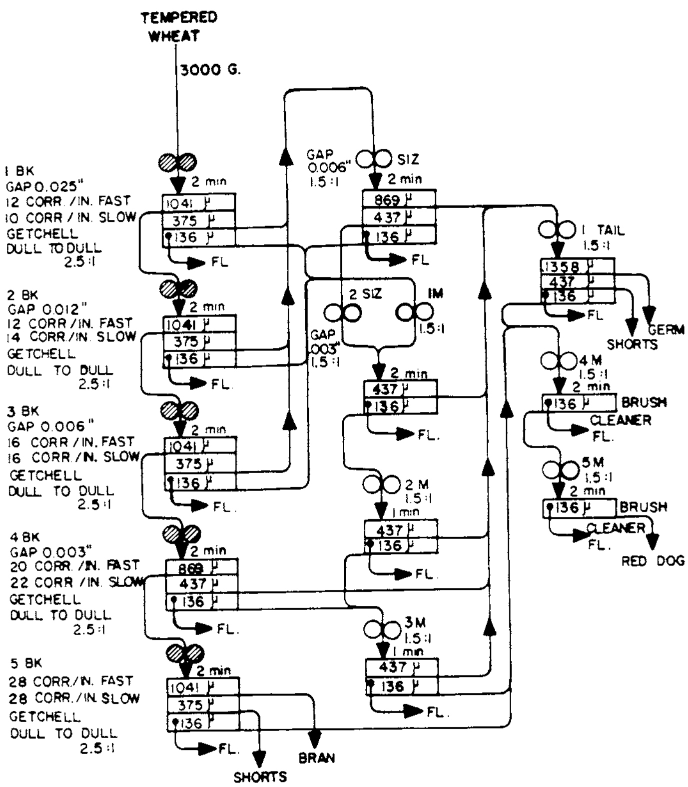

Fig. 1. The milling flow used in the study.

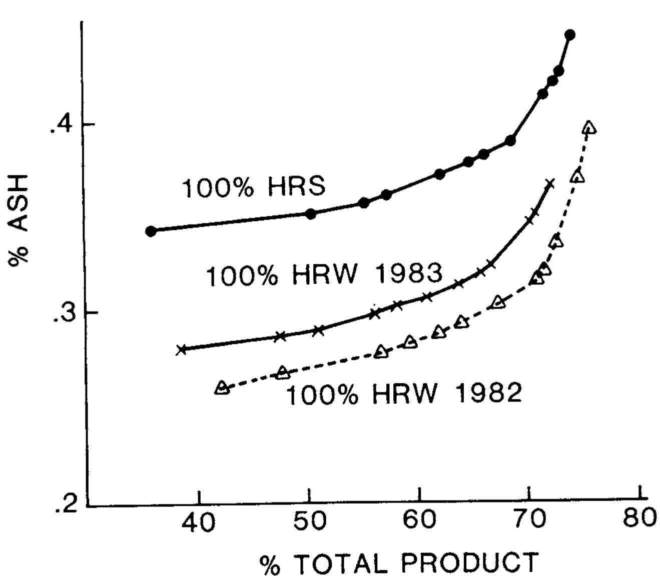

Fig. 2. Cumulative ash curves for the three original wheats for part I.

and δ is the mean difference. To establish results significant at the 5% level and relative efficiency of 95%, four milling replicates were performed every three weeks, starting one week after harvest.

The wheat samples were cleaned with a Carter dockage tester and scoured on a laboratory scourer. The wheat moisture was determined using a Motomco moisture tester; water was added to raise the moisture to 16%, and the wheat was tempered for 24 hr.

A batch-type milling process was used, consisting of roll stands with 9-in. diameter and 6-in. long rolls. Sieving was done on a multiple sieve, gyrating laboratory sifter. Figure 1 shows the flow used, consisting of five breaks, two sizings, five middlings, and one tailing. The number of corrugations, corrugation action, and gaps between the grinding rolls, the number of sieves, the mesh size of the sieves for each milling stage, and the sieving time (in minutes) are indicated for each stage. The weight of all intermediate streams and final products was recorded. Extraction rate was calculated for each milling experiment. Extraction was the percent of flours, bran, shorts, germ, and red-dog per 100 g of total product.

In part II, the flour of the replicates was combined to make up a composite of each stream in the flow, from which samples for ash and moisture determination were taken. A patent flour was a composite of the first, second, and third breaks, sizings, and the first, second, and third middlings.

Standard AACC methods (1983) were used to determine moisture, protein, ash, and gluten contents, and rheological (farinograph) characteristics. Flour granulation was measured using the Mine Safety Appliance (MSA)-Whitby size analysis laboratory method, AACC 50-10. Particle size indexes were determined using the Fisher sub-sieve sizer. Flour (1.44 g) was placed in the sample tube and packed to standard height; the average index was read using a porosity of 0.465.

Flour color was determined with the Agtron M-500; reflectance determinations were made by the dry method using discs no. 68 and 97 in the green mode.

Water absorption of patent flour was determined using a mixograph with a 10-g bowl, as reported by Finney and Shogren (1972).

Pup loaves were baked and scored as reported by Finney (1984). In part I loaves were baked once a week after milling, and again three weeks later. In part II they were baked once, 10 days after milling. In part II the baked breads were compared to controls baked from commercial flour of 12.2% protein, 0.47% ash, and 12.6% moisture.

RESULTS AND DISCUSSION

As stated by Swanson (1946), the practical miller tends to ameliorate changes in wheat quality by blending new wheat with wheat from the previous crop. This approach was used in part I. The results of tests performed on each of the three wheat samples, one week after harvest, are presented in Table I. Figure 2 shows cumulative ash curves of the three wheats. The highest ash curve was obtained from the HRS wheat and the lowest ash curve from the 1982 HRW wheat. The wheat used in part II had a protein

TABLE I
Wheat and Flour Characteristics (part I)

Characteristic	Hard Red Winter 1983	Hard Red Winter 1982	Hard Red Spring 1982
Wheat			
Moisture, %	10.2	9.9	11.1
Protein, % (14% mb)	10.3	12.1	13.6
Ash, % (14% mb)	1.63	1.53	1.64
Patent flour			
Ash, % (14% mb)	0.31	0.31	0.38
Farinograph water absorption, %	52	56	58
MTI (BU)[a]	20	20	20
Valorimeter	92	88	94
Loaf volume (cm^3)	790	740	918

[a] Brabender Units.

content of 13.0% and a test weight of 56.3 lb/bu. Table II shows the results of analysis of eight patent flours milled from the wheat in part II. The flour ash of the patent flour increased gradually without a significant change in protein content. The mean moisture content of the patent flour samples was 14.2% with a standard deviation of 0.6. This means that during milling in the air-conditioned, controlled environment, moisture losses were within an acceptable range. In commercial milling systems, a moisture loss of 1.5–2% is acceptable.

Flour granulation changed during the sweating period (Table II). Flour granulation was finer after harvest and increased in size as sweating proceeded. This might explain the use of open sifter cloths and reduction of mill loads to overcome difficulties encountered in the bolting of flours from newly harvested wheat in commercial mills. Apparently, during sweating there is an agglomeration of starch granules and interstitial protein in the wheat kernel endosperm. Immediately after harvest, adhesiveness between the flour components is weak but increases with time, which results in larger "chunks" of endosperm as sweating proceeds. The decrease in flour particle size after 19 weeks can be attributed to an increase in the extent of reduction during milling, as the chunks of endosperm continued to increase in size. The result of this trend could be an increase in starch damage and improved loaf characteristics as sweating proceeds.

Figures 3 and 4 show total flour extraction, sizing production, patent flour extraction, and farinograph water absorption for wheat and wheat blends milled during the two years. In Figure 3, first-week values are also shown for 100% HRW 1982 and 100% HRS 1982. For the freshly harvested wheat and both blends there were fluctuations in milling parameters at the beginning of the sweating period followed by well defined trends as time of storage increased. Figure 5 shows the increase in percent of break flour from part II during storage after harvest.

TABLE II
Patent Flour Analysis (part II)

Time After Harvest (weeks)	Moisture (%)	Fisher Sub-Sieve	MSA[a] Values	Agtron Color	Ash (14% mb) (%)	Protein (14% mb) (%)	Wet Gluten (%)
1	14.5	15.3	43.5	79.0	0.33	10.9	27.4
4	14.1	16.2	44.5	78.5	0.34	11.0	28.6
7	15.3	15.6	42.0	78.5	0.36	11.2	28.7
10	13.6	14.4	47.0	77.0	0.37	11.0	27.0
13	14.7	21.8	55.5	71.0	0.34	11.0	28.9
16	14.2	20.5	49.5	75.0	0.36	11.2	29.1
19	13.7	18.8	53.0	73.5	0.39	11.2	28.0
22	13.2	14.3	42.5	72.5	0.41	11.1	24.8

[a] MSA = Mine Safety Appliance.

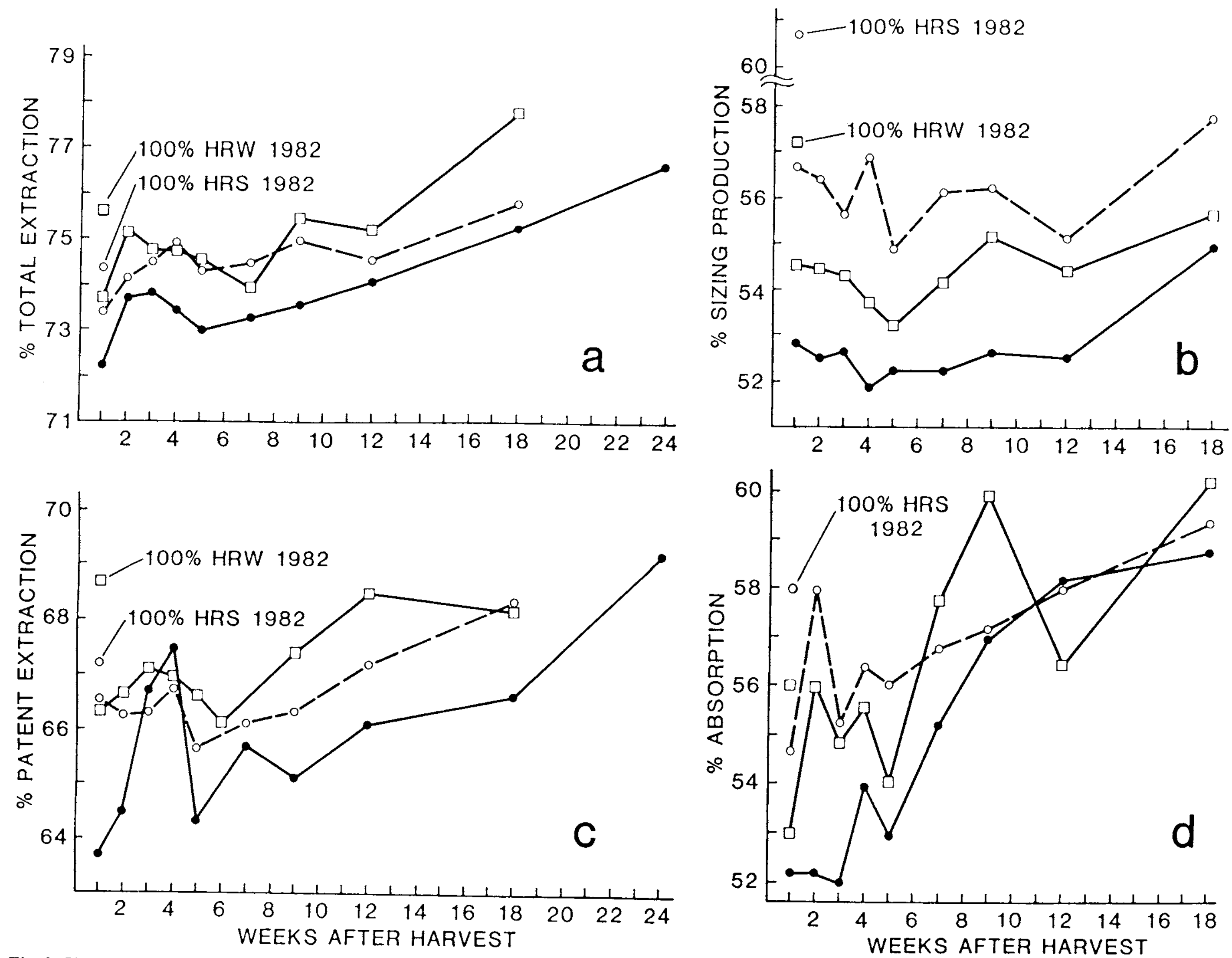

Fig. 3. Changes in milling and flour characteristics during wheat sweating, part I: **A,** total flour extraction; **B,** sizing production; **C,** patent flour production; and **D,** water absorption. ●—●, 100% hard red winter (HRW) wheat, 1983 crop. □—□, 50% HRW 1982 and 50% HRW 1983. o- -o 50% hard red spring and 50% HRW 1983.

In part I the flours were baked immediately after milling and three weeks later. No significant changes were found in water absorption, mixing time, or loaf volume. However, subjective scoring showed that three weeks of flour aging improved bread characteristics. The crust was less rough, and the internal grain was slightly more uniform. Similarly, storage of wheat before milling improved subjective bread characteristics. Subjective evaluation of bread appearance and color in part II indicated an improvement with grain storage.

Changes in loaf volume during storage from part II (Fig. 6) are similar to those observed by Shellenberger (1939). Loaf volume reached a peak at about 120 days after harvest and then decreased. The peak recorded in this study was 112 days. This was to be expected as every wheat goes through its typical sweating process after harvest. The length of sweating varies from one wheat to another.

Regression analysis (SAS 1982) was used to determine variations of the different milling technology parameters with time of storage. Values for total flour, patent, sizing, and all five breaks of flour production were used. The best fit for the data was a cubic model. The calculated R^2 values are shown in Table III. Analysis of variance indicated, however, some storage-time-dependent variations that could not be explained by the regression model. Some variables in experimental milling technology remain to be determined; they formed about 25% of the variability.

The experimental results of four milling replicates at each stage of the sweating process were analyzed using analysis of variance. The F values determined show significant differences in the milling characteristics with respect to time after harvest.

Correlation coefficients were determined for the experimental data. Table IV shows correlation coefficients of milling results. Only correlations significant at the 1 and 5% levels are shown. A significant correlation between break flour and wet gluten values indicates that, with time after harvest, an increased amount of

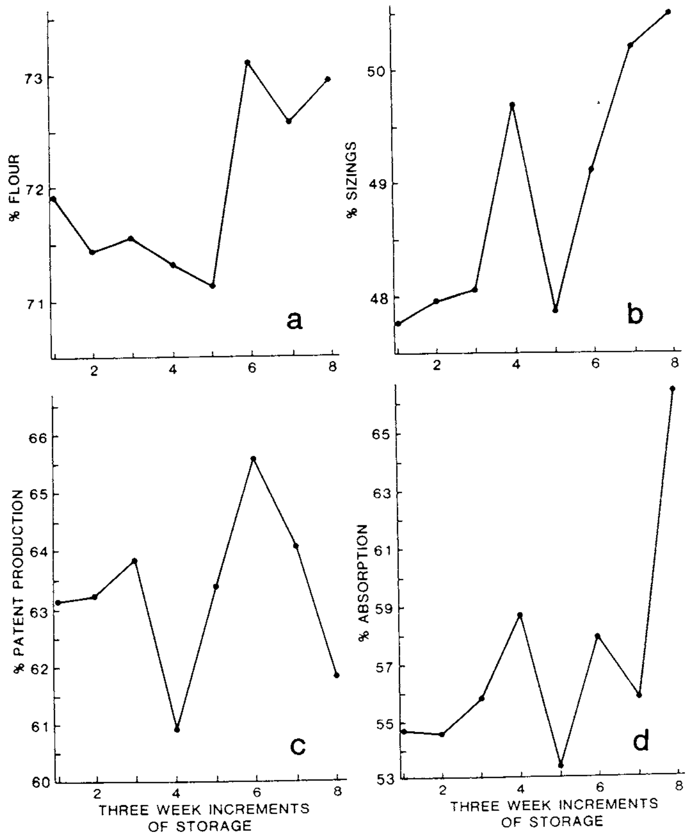

Fig. 4. Changes in milling and flour characteristics during wheat sweating, part II: **A,** total flour extraction; **B,** sizing production; **C,** patent flour production; and **D,** water absorption.

TABLE III

R^2 Values of Milling Characteristics as a Function of Time After Harvest

Milling Product	R^2 Value	Mean Yield (%)	SD	F values[a]
Total flour production	0.510	72.0	0.65	7.06
Sizing production	0.614	48.9	0.76	20.19
Total break flour production	0.624	11.3	0.70	7.30
Three break flour production	0.766	8.7	2.21	15.98
Four break flour production	0.756	10.5	0.44	14.27

[a] F values were all significant at the 1% level.

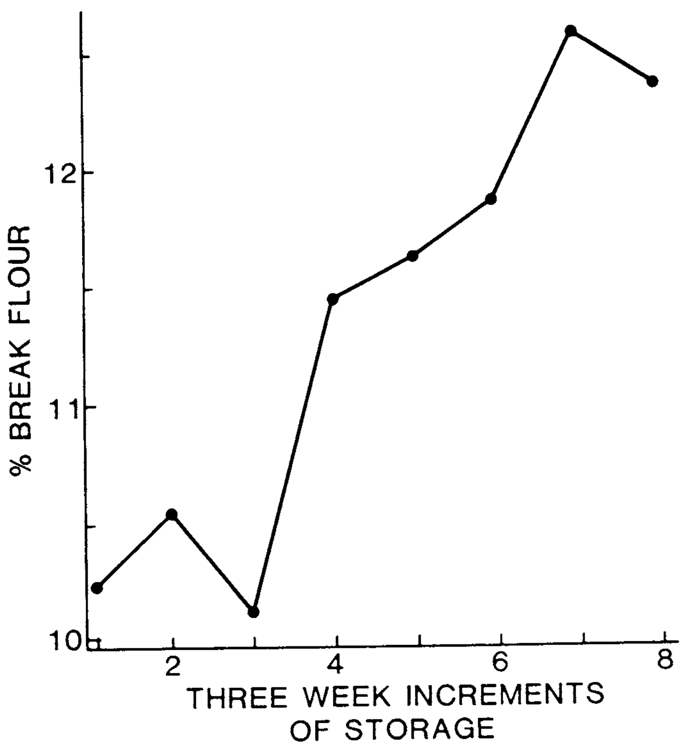

Fig. 5. Percent break flour produced, part II.

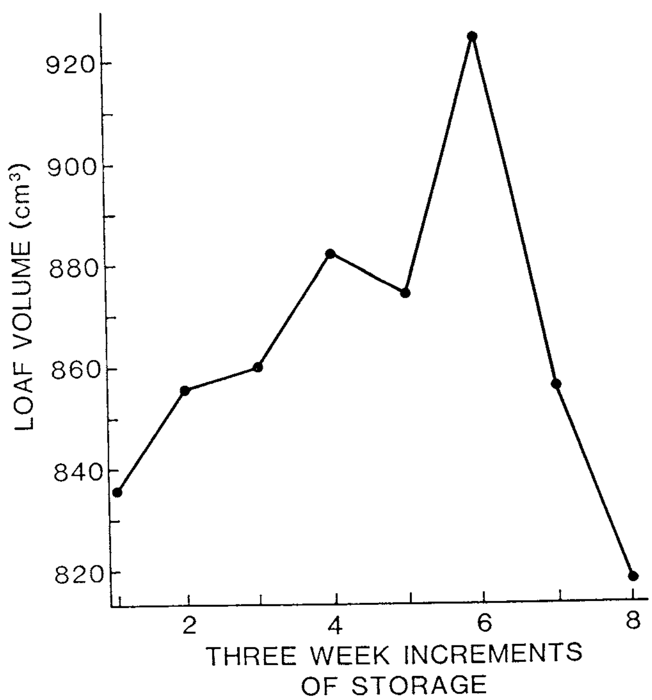

Fig. 6. Loaf volume of bread baked from flours, part II.

TABLE IV
Significant Correlation Coefficients of Milling Characteristics

Sizing Characteristics	Part	Sizing Production (part I)	Patent Production (part I)	Flour Production (part I)	Break Patent Production (part II)	Fisher Production (part II)	Sub-Sieve (part II)
Parent ash	II	...	...	...	0.736*[a]	...	...
Break flour ash	II	...	...	0.937**	0.838**	...	...
Total flour ash	II	...	...	0.895**	...	...	...
Break flour production	II	...	...	0.828*	...	...	...
Patent wet gluten	II	...	...	...	0.708*	0.707*	−0.869**
Sizing production	I	...	...	0.869**	...	...	...
Flour production	II	0.830*	0.728**	...	...	...	...
Flour production	II	...	...	0.728*	...	...	...
MSA particle size[b]	II	...	...	...	...	...	0.809*

[a]*, ** Two-tailed significant at 5 and 1% levels, respectively (n−2) df.
[b]MSA = Mine Safety Appliance.

gluten-containing proteins is extracted in the breaking system. It also suggests that with time, flour proteins making up the gluten undergo a maturation process.

A significant, positive correlation was found between sizing production and patent flour ash. Total flour extraction exhibited a significant positive relationship to patent flour ash and patent flour protein. A correlation of 0.809 between the results of the Fisher sub-sieve analyzer and the MSA method was determined (Table IV).

The HRW wheats for the two parts of the experiment differered. Still, significant correlations were found between the results from the two years in sizing and total flour production. In both years, total flour yields were significantly correlated to sizing production during milling.

Levels in sizing production of the newly harvested wheat during storage point to the need to exercise precaution in milling freshly harvested wheat. To balance the mill, break rolls should be adjusted for maximum sizing production. Newly corrugated rolls can help. This, however, may increase the amount of bran-contaminated sizings. Usage of ample amounts of air and finer reclothing of the purifiers would help remove bran from the sizings. Sizing rolls should be adjusted during this period for a light grind with minimal reduction for careful separation of endosperm from the attached bran.

Wet gluten was negatively correlated with farinograph absorption (r = −0.848, 0.01 level) and farinograph arrival (r = −0.773, 0.05 level) and was positively correlated with farinograph stability (r = 0.861, 0.01 level) and farinograph departure (r = 0.825, 0.05 level). Farinograph stability was found to be negatively correlated to farinograph absorption (r = −0.845, 0.01 level) and positively correlated to farinograph departure (r = 0.983, 0.01 level).

Milling value is an estimate of monetary value of the products derived from the milling operation. The percentages of patent and clear flours were determined by using the ash curves and the assigned maximum ash content for the patent flour. Factors affecting milling value are related to the milling performance of the wheat. On the same milling unit, for which variables such as mill setting and environmental conditions are held constant, milling different wheats will result in corresponding changes in percent of products produced, distribution of ash in flour streams, and the economic value of those wheats.

The cut-off point on the ash curves for patent flour was 0.35% ash; this was assigned a value of $10 per cwt. Flours on the ash curves above 0.35% ash were considered clear flour and were assigned a value of $8.00 per cwt. The feed was assigned a value of $5.00 per cwt.

In addition, the farmer and the miller must consider the cost of storage after harvest. An attempt was made in this study to develop an economical model for storage that would combine parameters relating to milling quality during sweating. The milling value (cwt basis) was converted to a 60 lb bushel milling value. A storage cost of 0.5 cents per bushel per week was subtracted from the calculated milling value to determine the net milling value. The net milling value was expressed in dollars per bushel. Using the SAS regression procedure (SAS 1982), intercepts and parameters were determined for a cubic model of net milling value versus time after harvest.

For part I, the equation relating length of storage in three week intervals (X) to net milling value (Y) was: $Y = 5.01357 + 0.00346X^3 - 0.04438X^2 + 0.14478X + \mathrm{U}$ with R^2 0.8288. For part II the equation was; $Y = 5.43857 - 0.00765X^3 + 0.09919X^2 - 0.40602X + \mathrm{U}$ with R^2 0.7253. The minimum and maximum times that wheat should be stored, with respect to storage cost, were determined by finding the derivative of the model equation and solving for $X1$ and $X2$ after equating it to zero. A minimum of six weeks and a maximum of 22 weeks of storage was allowed for sweating for the two wheats studied.

The optimum storage time for parts I and II was determined from the second derivative of the model equation. It was established that after about 14 weeks the increase in storage cost overrides benefits gained by further improvements in milling values.

The results emphasize the beneficial effects of blending freshly harvested wheat with old wheat to reduce fluctuations in the mill. It is left to the operative miller to make final decisions on blending ratios, as these will depend on several other factors, such as wheat availability, mill elevator storage capacity, and the price of wheat.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC. 7th ed. Methods 08-01, 44-19, 46-10, 50-10, and 54-21, approved April 1961. The Association, St. Paul, MN.

BAILEY, C. H. 1925. Pages 108-120 in: The chemistry of wheat and flour. The Chemical Catalog Co.: New York.

BICE, C. W., MACMASTERS, M. M., and HILBERT, G. E. 1945. Wheat starch properties in relation to grain maturity. Cereal Chem. 22:463.

DUNCAN, D. B. 1975. t Tests and intervals for comparisons suggested by the data. Biometrics 31:339.

FINNEY, K. F., and SHOGREN, M. D. 1972. A ten gram Mixograph for determining and predicting functional properties of wheat flour. Bakers Dig. 46: 2:32.

FINNEY, K. F. 1984. An optimized straight-dough, bread-making method after 44 years. Cereal Chem. 61:20.

FITZ, L. A. 1910. Handling wheat from field to mill. U.S. Bur. Plant Ind. Circ. 68.

PELSHENKE, P. F. 1958. Neue Methoden um die Mahltechnik in der Muehle zu kontrolliern. III Congr. Int. Ind. Ferment. Knokke, Le Zoute, Belgium.

POMERANZ, Y. 1982. Grain structure and end-use properties. Food Microstruct. 1:107.

SAS Institute. 1982. SAS User's Guide: Statistics. SAS Institute, Inc.: Cary, NC.
SHELLENBERGER, J. 1939. Variation in baking quality of wheat during storage. Cereal Chem. 25:676.
STOCKHAM, W. L. 1920. Some factors related to the quality of wheat and the strength of flour. North Dakota Agric. Exp. Sta. Bull. 139.
SWANSON, C. O. 1931. The story of a grain of wheat from reaper to roll. Assoc. of Oper. Millers Bull. 370.
SWANSON, C. O. 1946. Effects of rain on wheat during harvest. Agr. Exp. Stat., Kansas State University, Tech. Bull. 60.

[Received October 18, 1985. Revision received June 16, 1986. Accepted June 16. 1986.]