Experimental Milling of Soft Wheat Cultivars and Breeding Lines[1]

W. T. YAMAZAKI and L. C. ANDREWS[2]

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ABSTRACT

A four-stand Allis Chalmers experimental mill was modified to improve precision in milling soft wheat and was then used to compare three milling procedures. A six-break, variable-roll, variable reduction-pass system was found to be best suited to accommodate the diverse types of soft wheat cultivars and breeding lines. A milling characteristic termed endosperm separation index, which appeared to be a measure of ease of separation of endosperm and bran, was found to be associated with yield of straight-grade flour.

Soft wheat breeders are developing new lines they hope are superior to present cultivars in agronomic characteristics such as increased yield, greater disease resistance, earlier maturity, and shorter straw. These characteristics are evident in the field, and line selection for further development can be made on the basis of plant performance (Patterson and Allan 1981). However, processing quality, including quality for milling and baking, which is also inherited and is important in the utilization of the crop, is not as readily evaluated and must be determined by laboratory tests (Bode 1959).

Flour from soft wheat in the United States, especially that grown in the East, is not used domestically for bread or pasta products but rather for cookies, cakes, crackers, pretzels, and similar products, collectively termed flour confectionery products. Breeding lines being developed for eventual release to farmers in the region are, therefore, evaluated for processing quality using criteria and procedures that differ markedly from those for hard or durum wheats (Finney and Yamazaki 1967).

The science of soft wheat breeding has advanced steadily in recent decades. More and more exotic plants are being used as parents in crosses in an effort to expand the germ plasm resource for agronomic attributes. In the course of these introductions, genes have been included that influence the quality characteristics of progenies as well. Current physiocochemical and baking tests appear adequate for testing baking quality. However, evaluation of breeding lines for millability does not appear to have reached a similar stage of development.

At the Soft Wheat Quality Laboratory, experimentally milled flours from breeding lines are evaluated for quality by comparing their performances against that of a flour milled from a commercial cultivar grown under the same environmental conditions as the test lines. This comparative type of evaluation is necessary because a given cultivar will vary somewhat in absolute milling and baking quality depending on location of growth and crop year, although the relative cultivar rankings will normally be retained. We have often encountered situations in which the standard or commercial cultivar mills under a fixed procedure to give a straight-grade flour yield of 76.5% with an ash content of 0.41%, whereas a test line gives a flour yield of only 73.3% with an ash content of only 0.35%. Can such flours be compared for baking quality on an equal basis? Would the test line have milled to yield a flour of quality equal to that of the standard if the mill had been adjusted to accommodate the wheat? What would have been its yield if that had been done? Flour quality is expressed here in terms of ash content, in a manner analogous to those of Shellenberger and Ward (1967) for hard red winter wheat and of Shuey et al (1971) for hard red spring wheat.

We initiated an inquiry into soft wheat milling in general and into inherited milling attributes in particular. We considered the Allis-Chalmers laboratory mill to be best suited for research in milling because of its flexibility in adjusting roll speed, stock feed rate, sifting time, screen mesh size, number and flow of passes, and a number of other variables.

Our objectives in this experiment were threefold. First, we wished to modify the Allis-Chalmers mill to make reproducible millings in which the resulting flours would reflect accurately, through their quantity and quality, any changes in mill set-up, differences in wheat type, or variations in wheat treatment. Second, we wanted to develop a procedure that would give a high yield of straight-grade flour of uniform ash level (or ash level within a narrow range) from wheats available in only limited quantities but differing widely in grain attributes, so that we could make flour baking quality comparisons on an equitable basis. Third, we wished to find a milling characteristic that would provide a clue to the reasons for differences in milling response so that we could direct further milling research into productive channels. This article presents results obtained in pursuance of these objectives.

MATERIALS AND METHODS

The Allis-Chalmers Mill

The four-stand mill (referred to here as the Allis mill) consisted of three break-roll and one smooth-roll stands. The break rolls, with 14, 20, and 24 Nordyke E corrugations per inch, respectively, and rotating dull to dull, had recently been commercially recorrugated. The smooth rolls had also been dressed. The mill was extensively modified before this study by minimizing roll play, improving replicability, and minimizing roll heating to stabilize its operation.

In this modification, the feed gate for each stand was replaced by a vibratory feeder to regulate and control feed rate. The feeder and metal-lined hopper with hinged cover were completely enclosed to minimize dust loss. The flat belt pulleys were replaced by V-belt sheaves and hubs to obtain more positive drive and eliminate slippage. The conversion necessitated the installation of two power shafts, each with a motor, to effect the counter rotation of the rolls. The Babbit bearings on the mill roll cradles were replaced by self-aligning roller bearings on the shafts to reduce frictional heating of the rolls. The mill roll shafts (57.2 mm in diameter) were machined to accommodate the bearings, but a shoulder was left between the bearing and roll to eliminate shaft bending. Extreme care was exercised in the machining of the shafts to minimize total indicator readout (TIR). Milling was performed on a 50-hp Monarch machine lathe with the stock held by a four-jaw chuck. Frequent gauging during milling preserved maximum concentricity throughout the machining process. Careful and repeated tests for roll concentricity with bearings mounted on V-blocks indicated that the TIR for the break rolls were 76, 20, and 13 μm, for the first, second, and third stands, respectively. The TIR

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[2]Research chemist and biological technician, respectively, Soft Wheat Quality Laboratory, North Central Region, ARS-USDA, Ohio Agricultural Research and Development Center, Wooster 44691.

for the reduction roll was 5 μm.

The lever controlling the position of the fast roll for each stand was extended to four times its original length and the roll position gauged by means of a needle on the lever traveling over a roll distance indicator that had been calibrated using feeler gauges on the rolls. Play in the positioning of the lever had previously been minimized by fabricating new eccentric cams governing roll positions and reaming eccentric receptables for closer fit. Eccentrics for the first two stands were milled in the normal manner, but for the third stand, they were milled such that a lever needle travel of 38 mm corresponded to a change in roll distance of only 25 μm. This restricted the range of roll distance on the stand but made possible finer positioning of the rolls. Other changes included the fabrication of closer fitting eccentric cams for the fast roll cradles and of bolts on caps holding the roll bearings on the cradles, the milling of cradles and caps to accommodate the bearings, the fabrication and installation of leather and cloth seals to prevent flour loss at the shafts, and the rewiring of the sifter boxes through timing switches so that they could be operated independently of the mill.

TABLE I
Typical Room Conditions and Roll Temperatures for the Milling of Six Samples

	Start of Day	After Sample 1	After Sample 2	End of Day
Room condition				
Temperature (°C)	23.3	21.7	22.8	21.7
Relative humidity (%)	54	52	51	52
Mill roll temperature (°C)				
First break stand				
Fast roll	RT[a]			28.8
Slow roll	RT			28.2
Second break stand				
Fast roll	RT[a]			30.2
Slow roll	RT			27.8
Third break stand				
Fast roll	RT			27.2
Slow roll	RT			26.9
Reduction stand				
Fast roll	RT			30.5
Slow roll	RT			28.3

[a] Room temperature.

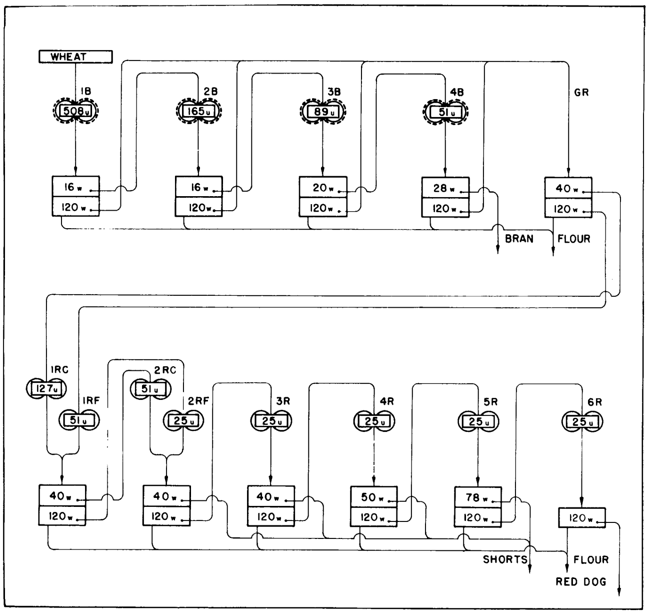

Fig. 1. Mill flow for four-break, six-reduction system for soft wheat on Allis-Chalmers laboratory experimental mill. **B** = break, **GR** = grader, **R** = reduction, **RC** = reduction (coarse stock), **RF** = reduction (fine stock), **w** = wire screen with indicated meshes per inch.

As the Allis mill is presently operated, two persons perform the milling, one on the break side and the other on the reduction. All stock and classified material weights are recorded for each pass in each milling. The flour streams are blended in a MacLellan or Patterson-Kelley blender. Five or six millings, each of 2,000–2,500 g, are made per day. The milling time for a sample is estimated to be about 2 hr. Because the stock and other materials are exposed to the atmosphere for an extended period, wheat is normally tempered to about 15.3%. We lose a small quantity of moisture during tempering (which is carried out in a tumbler) and during two passes through a scourer after tempering.

All millings are performed in a room with controlled temperature and humidity. Ambient conditions range from about 21 to 23°C and 50–60% rh. Typical room conditions and roll temperatures for the milling of six samples are given in Table I.

Wheats

Several soft wheat samples, some considered to be typical of the wheat class and others thought to be of poor milling quality, were used in the preliminary phases of the experiment. All were selected on the basis of normal kernel appearance, absence of shriveling, and freedom from foreign matter. Kernel texture, measured by particle size index (PSI), was determined by grinding 20 g of grain in a Labconco grinder previously calibrated with grains of known texture, followed by sieving 15 g for 30 sec on a Tyler screen with 425-μm openings that was mounted on a Rotomatic sifter base, weighing the meal passing through the screen, and converting the weight to percent. Ash content was determined by AACC method 08-01 at a temperature of 555°C, moisture by the Motomco method (method 44-11), and grain protein content by grinding and analyzing for nitrogen with method 46-12 but substituting potasium sulfate for mercuric oxide in the oxidizing mixture (AACC 1979).

Cleaned wheats for milling were scoured through a Forster scourer modified to facilitate removal of shriveled grain, then tempered for at least 16 hr before milling. Samples were then scoured again before milling to further remove dust and loose epidermal tissue. Flour yield was calculated on a recovery basis.

The milling technique adopted as the result of this study was applied to more than 770 individual samples and composites representing breeders' entries following the 1977–1980 harvests. A number of wheats were milled in duplicate to produce sufficient flour for cake-baking tests.

Milling Methods

Three milling methods were evaluated for flour yield and quality. The first was a four-break six-reduction system, a procedure used in our laboratory for many years. It was essentially a short-flow fixed-roll system (Fig. 1) and is referred to in this paper as the four-break system. The second and third methods, basically quite similar to each other, were six-break multiple reduction-pass systems. In the fixed system, the second of the three millings evaluated, all break roll settings as well as the number of reduction passes were fixed. This procedure is called the six-break fixed-roll system. In the third method, break-roll settings were adjusted to scalp weights, and the number of reduction passes could be varied according to the cumulative flour yield data (Fig. 2). It is designated in this paper as the six-break variable-roll system.

In the six-break fixed-roll system, the first-break pass was made with a roll distance of 890 μm on the first break stand. The next four break passes were made on the second break stand with roll settings of 267, 133, 92, and 83 μm, respectively, and the last break pass was made on the third break stand at a roll distance of 51 μm. Other passes consisted of seven reductions, a sizing pass through the third break stand, and two low-grade passes, all at fixed roll settings.

In the six-break variable-roll system, adjustments were made in roll settings of the third, fourth, and fifth break passes in accordance with the quantity of stock on the scalp screen of the preceding break pass, to produce about 9.0% bran (by weight, over the 74-mesh Durloy screen). However, this optimum bran weight was not obtained from all wheats.

The roll settings and screen arrangement for reduction passes under this system were the same as those under the fixed-roll system, except that the number of reduction and low-grade passes could be increased. Yield from wheats difficult to mill could thus be increased to a desirable level without increasing flour ash content excessively. The cumulative flour weight, the weight of stock, and the appearance of flour streams served as guides in determining the need for more passes. The system was intended primarily to increase flour yield for those wheats (mostly breeding lines) that tended toward high bran weight or low flour yield with low ash content. Although not shown in the figure, minor adjustments in screen mesh size were made in certain millings at the end of the variable-roll system to expedite the milling. Although poor-milling wheats could be identified without this somewhat elaborate experimental milling technique, the high desirability for flour of nearly equivalent ash level from all wheats for later testing mandated such a milling procedure.

Endosperm Separation Index

Endosperm separation index (ESI) is defined as the approximate quantity of endosperm remaining attached to the bran and bran pieces after break and first reduction passes. It is computed by combining the weights of bran, of materials over the 32-, 43-, and 54-mesh screens following the third, fourth, and fifth break passes, respectively, and of materials over the 40-mesh screen following the first reduction pass (Fig. 2). Independent determinations[3] showed that these materials accounted for more than 94% of the neutral detergent fiber in wheat grain. The nominal wheat bran and germ content value (17% of the grain) is subtracted from the combined weight of these bran-rich materials (expressed as percent of wheat), and the difference is the endosperm separation index. A wheat with a lower value is considered to have properties that more readily separate endosperm from bran than do those of a wheat with a higher value, and is thus considered more amenable to good milling.

[3] Unpublished data, Soft Wheat Quality Laboratory, Wooster, OH.

RESULTS AND DISCUSSION

Wheat, milling, and flour data for representative pure variety grains milled by the procedures are presented in Table II. Paha is a club wheat exhibiting high flour yield; Frankenmuth is an Eastern soft white wheat; and Fairfield is an old soft red winter wheat that resists giving good flour yield. Arthur is a contemporary cultivar and a typical representative of soft red winters in milling properties. Purkof is an old semihard red winter no longer being grown. Oasis is a present day cultivar that has been variable in milling response, occasionally giving low yield. The PSI data exemplify the range of and variability in kernel texture encountered among soft wheats. The values in the table are in contrast to a PSI range of 24–29% for hard red winter wheats and values of more than 50% for the softest soft wheats.

The four-break milling method gave low flour yield with lower ash and protein contents than those of flour obtained by the six-break procedures. The differences in yield and ash contents in flours by the four-break and six-break procedures is further exemplified by data in Table III for breeders' entries submitted to our laboratory over several crop years.

Although the majority of soft wheats gave similar yield and ash contents, whether milled by the six-break fixed-roll or variable-roll methods, some samples responded differently to the two procedures. Yield and ash data are given in Table IV for some of

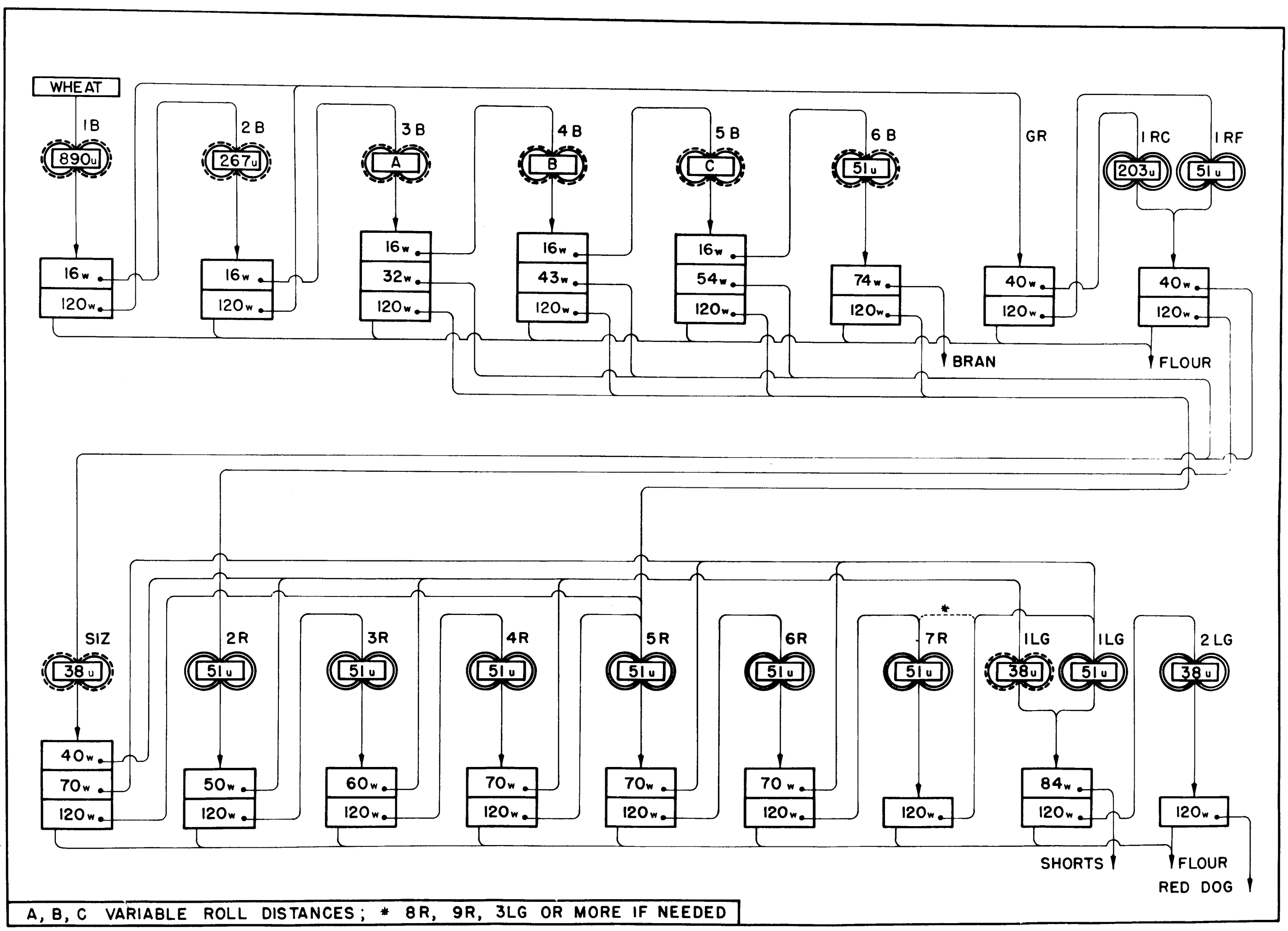

Fig. 2. Mill flow for six-break, seven-reduction plus sizing and low-grade pass system for soft wheat on Allis-Chalmers laboratory experimental mill. **B** = break, **GR** = grader, **R** = reduction, **RC** = reduction (coarse stock), **RF** = reduction (fine stock), **SIZ** = sizing, **LG** = low grade, **w** = wire screen with indicated meshes per inch.

TABLE II
Wheat, Milling, and Flour Analytical Data for Representative Wheats Milled by Three Methods on Allis-Chalmers Mill

	Wheat				Milling			Flour		
Cultivar	Moisture (%)	Ash[a] (%)	Protein[a] (%)	Particle Size Index (%)	Method[b]	Break Flour Yield[c] (%)	Yield[c] (%)	Moisture (%)	Ash[a] (%)	Protein[a] (%)
Paha	11.7	1.37	9.08	35.3	Short	29.2	75.3	13.8	0.360	7.53
					Fixed	26.2	78.0	13.4	0.387	7.79
					Variable	27.0	77.8	13.2	0.388	7.76
Frankenmuth	12.4	1.48	11.62	42.1	Short	34.1	73.9	13.9	0.380	10.03
					Fixed	31.4	76.2	13.7	0.421	10.24
					Variable	31.7	76.7	13.5	0.421	10.27
Fairfield	11.2	1.73	10.36	42.8	Short	34.5	70.9	13.9	0.360	8.92
					Fixed	31.4	72.5	13.7	0.400	9.14
					Variable	32.1	72.6	13.5	0.402	9.17
Arthur	11.4	1.88	12.29	39.7	Short	30.2	74.6	13.9	0.403	11.23
					Fixed	27.5	75.0	14.0	0.416	11.44
					Variable	28.2	75.4	13.5	0.420	11.44
Purkof	11.4	1.67	10.79	29.3	Short	25.6	72.9	14.4	0.382	9.65
					Fixed	22.5	75.5	13.6	0.402	9.81
					Variable	22.4	75.3	13.4	0.399	9.72
Oasis	11.0	1.64	13.64	38.3	Shot	30.4	69.8	14.2	0.394	12.14
					Fixed	27.9	72.3	13.7	0.436	12.47
					Variable	27.3	72.2	13.6	0.427	12.44
Mean values					Short	30.67	72.90	14.0	0.380	9.95
					Fixed	27.82	74.92	13.7	0.410	10.15
					Variable	28.12	75.00	13.5	0.410	10.13

[a] Data on 14% moisture basis.
[b] Short = four-break, six-reduction method; fixed = six-break, seven-reduction with fixed roll setting and fixed number of reduction passes; variable = similar to fixed method but with variable break roll setting and variable number of reduction passes.
[c] Yield on recovery basis.

TABLE III
Mean Flour Yield and Ash Values for Soft Wheats Milled by Four-Break System (1971–1974 Crops) and by Six-Break Variable-Roll System (1977–1979 Crops)

Milling Method	Crop Year	No. of Entries	Mean Flour Yield (%)	Mean Flour Ash (%)
Four-break	1971	69	72.98	0.390
	1972	103	71.27	0.390
	1974	95	72.79	0.387
Six-break	1977	90	76.05	0.398
	1978	52	76.15	0.396
	1979	117	75.87	0.395

these entries milled by the two methods. In spite of adjustments in break roll settings allowed by the variable-roll procedure, break flour yields did not often vary greatly. However, yields were improved by the variable-roll method over those of the fixed-roll procedure for some samples (Table IV), and the ash levels were often brought closer to levels obtained in the majority of samples we have milled. For 105 soft wheats milled in duplicate in 1977–1979, the standard deviation and least significant difference ($P = 0.05$) for a variable-roll single milling were 0.19 and 0.53%, respectively. These values compared with a standard deviation and least significant difference ($P = 0.05$) of 0.65 and 1.84%, respectively, for 119 millings in duplicate by the four-break procedure in 1971, 1972, and 1974.

The ash content of 142 entries milled in 1974 by the four-break method averaged 0.391%, with a standard deviation of the distribution of 0.0257%. For 237 entries of the 1979 crop, milled by the six-break variable-roll procedure, the mean ash content was 0.398%, but the standard deviation of the distribution was only 0.0190%. The data, although not strictly comparable, were all from

TABLE IV
Break and Straight-Grade Flour Yields and Ash Contents for Soft Wheats Milled by the Six-Break Fixed-Roll and Variable-Roll Procedures

		Yield		
Cultivar	Milling Method	Break Flour (%)	Straight Grade Flour (%)	Flour Ash[a] (%)
McNair 3271	Fixed-roll	34.1	72.2	0.360
	Variable-roll	33.9	74.4	0.409
S-78	Fixed-roll	30.8	72.2	0.399
	Variable-roll	30.6	74.0	0.424
Omega 78	Fixed-roll	30.2	74.2	0.375
	Variable-roll	30.3	76.2	0.422
Holley	Fixed-roll	31.1	74.2	0.378
	Variable-rolls	31.3	75.4	0.391
Ruler	Fixed-roll	33.3	73.5	0.390
	Variable-roll	33.8	75.1	0.412

[a] 14% moisture basis.

soft wheat millings and indicated that flours milled by the latter technique were more nearly uniform in quality than those by the former procedure. We did not have enough samples to mill by both fixed-roll and variable-roll procedures to enable us to make a statistical study of their ash content distributions, but on the basis of examples in Table IV and other (unreported) data, flours milled by the variable-roll method seem to have slightly lower standard deviation of the distribution for ash content than those milled by the fixed-roll method.

Among the more than 600 soft wheats grown over the crop years 1978–1980 and submitted by breeders from all parts of eastern

TABLE V
Cultivar Mean Straight-Grade Flour Yield and Endosperm Separation Index for Soft Wheats, 1978–1980 Crop Years

Cultivar or Line	Subclass	No. of Entries	Straight-Grade Flour Yield (%)	Endosperm Separation Index (%)
Argee	Red	3	78.83 ± 0.72	7.77 ± 0.70
Tecumseh	White	7	77.90 ± 0.37	9.40 ± 0.29
Caldwell	Red	6	76.93 ± 1.23	10.07 ± 0.32
Houser	White	5	76.94 ± 0.44	9.62 ± 0.45
Frankenmuth	White	7	76.79 ± 0.29	10.24 ± 0.53
Yorkstar	White	10	76.72 ± 0.92	9.90 ± 0.81
Genesee	White	9	76.69 ± 0.86	10.24 ± 0.68
Arthur	Red	13	76.66 ± 0.60	10.69 ± 0.55
Augusta	White	8	76.61 ± 0.48	9.93 ± 0.57
Monon	Red	6	76.58 ± 1.23	11.18 ± 0.60
Il 71-5241	Red	3	76.43 ± 0.50	11.40 ± 0.36
Wis X839-1	Red	4	76.23 ± 0.83	9.78 ± 0.49
Il 72-2219-1	Red	4	76.15 ± 0.30	10.43 ± 0.34
Ionia	White	6	76.15 ± 0.11	11.05 ± 0.51
Sullivan	Red	10	75.85 ± 0.47	11.52 ± 0.64
Roland	Red	8	75.76 ± 1.03	11.00 ± 0.70
Fredrick	White	8	75.76 ± 1.19	11.30 ± 0.99
Coker 747	Red	4	75.65 ± 0.21	11.05 ± 1.79
NC 74-36	Red	3	75.60 ± 0.27	9.87 ± 0.38
Arthur 71	Red	7	75.56 ± 0.76	11.70 ± 0.78
OH 112	Red	4	75.53 ± 0.26	12.50 ± 0.66
Wis X1017-2-1	Red	4	75.38 ± 0.25	11.73 ± 0.59
Abe	Red	13	75.18 ± 0.63	11.78 ± 0.66
Oasis	Red	17	75.09 ± 1.06	11.96 ± 0.89
Doublecrop	Red	7	75.04 ± 1.59	12.96 ± 1.61
Beau	Red	9	74.99 ± 0.50	12.90 ± 0.84
T 76-2051	Red	7	74.91 ± 0.67	12.07 ± 0.43
Coker 76-22	Red	4	74.80 ± 1.02	11.68 ± 0.13
Omega 78	Red	10	74.76 ± 1.05	12.76 ± 0.79
Ruler	Red	9	74.61 ± 1.13	13.59 ± 0.81
Hart	Red	9	74.53 ± 1.19	12.50 ± 0.71
Titan	Red	12	74.51 ± 0.75	12.33 ± 0.51
S-76	Red	9	74.40 ± 0.54	12.17 ± 0.49
McNair 1813	Red	6	74.32 ± 1.67	12.12 ± 0.96
S-78	Red	7	74.31 ± 0.56	13.46 ± 0.45
Holley	Red	4	73.48 ± 1.78	14.13 ± 0.67
McNair 1003	Red	4	72.35 ± 1.25	15.08 ± 0.57
Pooled standard deviation (%)			1.363	1.456
Error mean square (%)			0.789	0.535
Least significant difference ($P = 0.05$)			1.421	1.013

United States were 37 cultivars and breeding lines for which at least three millings were made. Mean varietal straight-grade flour yield and ESI data for these cultivars and lines are presented in Table V. The least significant differences for flour yield and ESI provide bases for determining the extent of differences among cultivars in these properties. Analyses of variance for yield, ESI, flour ash, and bran yield (Table VI) showed that both yield and ESI were definitely varietal properties and therefore heritable.

A high order of association existed between flour yield and ESI. For the 604 individual millings of entries in 1978–1980, the correlation coefficient was −0.823, and for the varietal means listed in Table V, this value was −0.92, both very highly significant values. This association was demonstrated in spite of environmental variables such as location of growth, crop year, and protein content, which could affect either flour yield or ESI, or both.

The analyses of variance for bran yield and flour ash content (Table VI) indicated significant varietal effects, but the relationships appeared to be of a lower order than for yield or ESI.

In summary, we believe that we achieved our first stated objective by making modifications in the Allis mill that reduced replication variability for yield as shown by the least significant difference values. We gained the second objective by developing the six-break variable-roll system with break roll settings determined by scalp weight and a variable number of reduction passes to increase yield while controlling ash content. The procedure allows us to mill experimental wheats with widely differing milling properties to yield flour of approximately equal quality (from the ash content standpoint), which can be evaluated for baking quality on a more uniform basis than flours by the other two methods that we evaluated. The third objective was gained with the finding of a milling value that correlated highly with flour yield and appeared to be associated with the ease of bran-endosperm separation, a major consideration in estimating the milling value of soft wheat cultivars and breeding lines. The ESI value may be calculated before milling has been completed; hence it is at least partially independent of flour yield and quality. It is also unrelated to kernel texture or temper level (within reasonable limits) but appears to be associated with inherent wheat properties, ie, to be a varietal trait. The stock from which the ESI value is derived can be isolated during milling and therefore is attractive material for further study of factors contributing to millability.

TABLE VI
Analyses of Variance for Straight-Grade Flour Yield, Endosperm Separation Index, Flour Ash Content, and Bran Yield of Allis-Milled Soft Wheats, 1978–1980 Crops

Characteristic	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Straight-grade flour yield	Total	265	492.000		
	Cultivar	36	311.250	8.646	10.95
	Remainder	229	180.750	0.789	
Endosperm separation index	Total	265	561.594		
	Cultivar	36	439.125	12.198	22.81
	Remainder	229	122.469	0.535	
Flour ash content	Total	265	0.091858		
	Cultivar	36	0.025841	0.000718	2.49
	Remainder	229	0.066017	0.000288	
Bran yield	Total	265	148.219		
	Cultivar	36	42.554	1.182	2.56
	Remainder	229	105.664	0.461	

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