Air Classification of Pin-Milled Break and Middling Flours from Hard Red Spring Wheat

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ABSTRACT

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Two passes through a commercial pin mill doubled starch damage and increased the degree of particle size reduction (<45 μm diameter) to 94% for fifth break flour and to 95% for first middling flour, based on image analysis. Air classification of the twice-milled break flour yielded over 30% of high-protein fraction (28.2% protein, 45.9% starch, 14.0% moisture basis) and 54% of a medium-protein fraction (13.8% protein, 0.40% ash). The twice pin-milled middlings were air classified into 24% of high- (25.0% protein), 22% medium- (12.0% protein), and 54% low- (5.9% protein, 77.4% starch) protein fractions. The two high-protein fractions substituted for gluten at an equal protein basis in bread formulations that contained 15 ppm potassium bromate. The medium-protein fraction from air classification of fifth break flour did not adversely affect loaf volumes and bread scores when blended with patent and bakers' flour at nine and 15%, respectively, in formulations containing 15 ppm potassium bromate.

Jones et al (1959) determined that air classification cuts of English wheat flours at 17 and 35 μm particle size diameters would yield a fine fraction (< 17 μm) of high protein content, intermediate particles (17–35 μm) representing a low-protein fraction (LPF) composed largely of starch granules, and larger fragments of endosperm cells (>35 μm). Fluid energy and pinned disk mills were used to regrind the soft and hard wheat flours so the medium protein fraction (MPF) represented only 0–12% of the total flour. In the present study, "degree of reduction" is defined as the proportion of roller- or pin-milled flour that is less than 45 μm diameter and potentially air-classifiable into fine and intermediate fractions.

Stringfellow et al (1964) pin milled and air classified patent flours from two hard red winter (HRW) wheat varieties and obtained yields of up to 14.0% of high-protein fraction (HPF) containing 25.2% protein. Bean et al (1969a) blended HPF from five HRW varieties with low-protein base flours at replacement levels of 20–30% and found that loaf volumes and farinograph curves of the blends were strongly influenced by the characteristics of the HPF parent flour. HPF from strong gluten varieties enhanced loaf volumes of the blends, and only weak gluten varieties gave LPF that was suitable for cookie and cake applications (Bean et al 1969b).

Tipples and Kilborn (1968) found that pin milling of hard red spring (HRS) wheat flours increased starch damage, baking absorption, and bread yield in short-time breadmaking systems. There was little advantage in pin milling flour for the long bulk fermentation baking systems, but the reduction in particle size had no adverse effects on bread characteristics. MacArthur and D'Appolonia (1976, 1977) reported that HPF from pin-milled and air-classified HRS flours contained mainly small starch granules and much of the lipid, pentosans, ash, reducing and nonreducing sugars from the original flours. Compared to the LPF and pin-milled flour, HPF had the highest starch damage, water binding capacity, Brabender pasting temperature, and peak height but the lowest setback values.

Hayashi et al (1976) air classified three pin-milled flour streams (2B, 1M, 3M) from four HRS wheat varieties (Red River 68, Chris, Era, Pitic 62) and found that incorporation of HPF into flour blends did not improve baking quality. Generally, the best bread, cake, and cookie scores were obtained with blends containing LPF.

In a similar investigation of eight flour streams from Era and Red River 68, water absorptions in the HPF fractions were very high, but the MPF fractions gave the strongest rheological properties (Dick et al 1977). Blends of the various air-classified flour streams showed that variety had a marked influence on rheological properties. Acceptable baking quality was not achieved except when fractions of a strong baking wheat, Waldron, were included in the blends (Dick et al 1979).

Protein shift is a quantitative measure of the degree to which protein is concentrated from the parent flour into the fines fraction (Gracza 1959). Certain air classifiers are sensitive to flour moisture content at narrow vane settings, and protein shift has been greatly enhanced by reducing moisture contents to as low as 4 or 5% (Kent 1965, Tyler 1982). Most investigators appear to have pin milled and air classified the flours at 13.5–15.0% moisture, as obtained from the roller mill, and protein shifts as low as 5.7% for break flours and 9.4% for middling flours have been reported (Dick et al 1977).

The objective of the present investigation was to determine the potential for pin milling and air classification of Canadian HRS

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wheats which, by grade definition (Canadian Grain Commission 1985), are composed of varieties equal in breadmaking quality to Marquis. This study reports the effects of regrinding fifth break (5B) and first middling (1M) flours with laboratory and commercial pin mills on starch damage and particle size distribution as monitored by image analysis. The two pin-milled flours were air classified at five progressively wider vane settings, and the six fractions were subjected to chemical analysis. Selected air-classified fractions were evaluated for gluten strength on the mixograph and in bread formulations. The 5B and 1M flours used in the study were predried to 8% moisture before pin milling and air classification as, below 8% moisture, static effects rendered the fines difficult to handle.

MATERIALS AND METHODS

Flour

Flour was milled from an equal blend of Canada Western Red Spring no. 1 and no. 2 wheat grown in central Saskatchewan in 1984. During the period of flour sampling at the mill, the wheats were blended to contain about 13.2% protein on a 14.0% moisture basis before milling. Samples of flour used in this study were those produced from 5B and 1M rolls. The samples were collected over a period of two months and each flour stream was bulked and blended. Before further processing, both flours were equilibrated to 8.2 ± 0.1% moisture by natural air-drying in the plant.

Mills

The above blend of HRS wheat was tempered for 8 hr to 16.0% moisture content and roller milled on a commercial flour mill at a flow rate of 250 kg/min, based on 16.0% moisture. Corrugations of the 5B rolls were 11.6 cuts/cm and the differential roll speed was 2.5:1. The corresponding values for the reduction rolls which produced the 1M stream were 12.6 and 2:1, respectively. The roll action in both cases was dull to dull. The final siftings of the 5B and 1M flours used in this study were through a 9XX sieve with the same aperture size, 153 × 153 μm.

The 5B and 1M flours were reground into subsieve size ranges by one or two passes through an Alpine 250 Contraplex CW pin mill (Alpine AG, Augsburg, FRG) with counter-rotating pins operated at 5,000 and 11,500 rpm, respectively (peripheral speed of both rotors = 240 m/sec). Feed gate openings of 15 and 22 mm, respectively, for the first and second millings were used for both streams, resulting in feed rates of 0.9 and 0.7 kg/min for the first and second millings. Samples of each flour were also milled one to four times on an Alpine 63C laboratory pin mill with counter-rotating pins operated at 17,000 rpm each (peripheral speed of both rotors = 37 m/sec) to assess the influence of additional milling on starch damage.

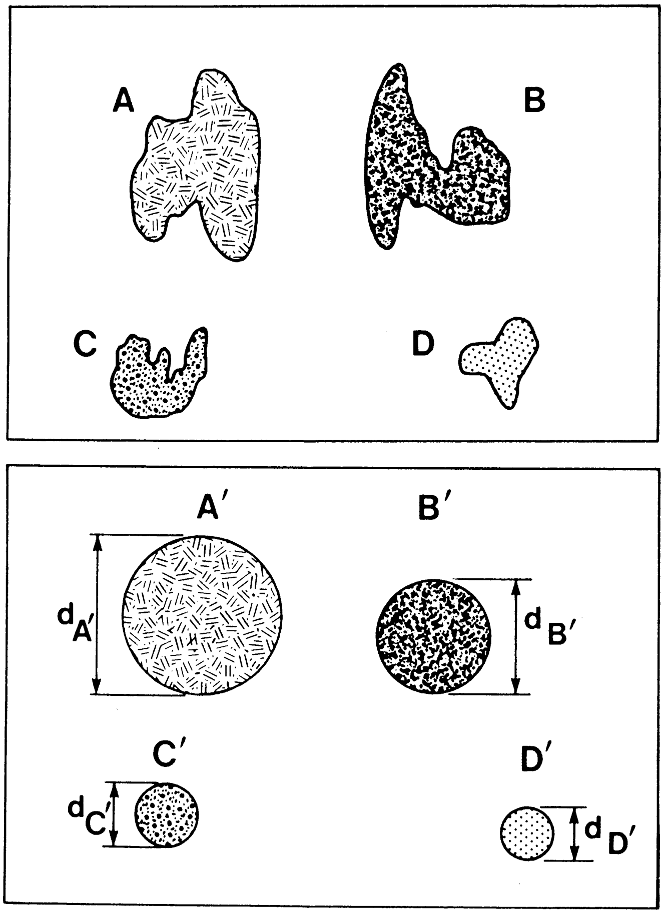

Fig. 1. Simulation of a microscopic field of view of wheat flour (top) and of an IBAS-Zeiss computer image analysis of the particles as circles with diameter, d (bottom).

Cryofreeze Milling

The 5B flour was twice milled on the laboratory pin mill at −195°C by immersion of the roller-milled flour in liquid nitrogen for 5 min. The flour and liquid nitrogen were then poured into the feed hopper for processing in the mill chamber at the normal rotor speed of 17,000 rpm. The process was repeated for the second milling.

Air Classifier

The roller- and pin-milled flours were air classified, using an Alpine 132MP air classifier (Alpine AG, Augsburg, FRG) set at a rotor speed of 11,000 rpm, into fine (less dense) and coarse (more dense) fractions. Each flour was initially classified at a narrow vane setting (VS) of 12, after which the coarse residues were reclassified progressively at wider settings of VS 16, 20, 26, and 34 so that the sum of the six fractions, including that greater than 34, constituted the whole flour. A feed gate opening of 7 mm was employed, resulting in feed rates of approximately 590 and 290 g/min for 5B and 1M flours, respectively.

Particle Size Determination

Mounts for light microscopy of the flours were made in immersion oil under cover glass for examination with a Carl Zeiss Jena microscope (Jena Instruments, Ltd., Jena, GDR). Photographs of the light microscope mounts (63× magnification) were analyzed for particle size distribution on an IBAS-Zeiss image analyzer equipped with a Kontron IBAS I (64K byte) microcomputer and IBAS II array processor (1M byte, 16 bit). IBAS software described by Caldwell and Germida (1985) was used for image processing and analysis. In each measurement a photograph of an optical micrometer was introduced for size calibration.

The parameters obtained were lengths and widths of the irregularly shaped flour particles, the diameter of a circle of equal area to the particle (Fig. 1), and the percentages of particles that occurred within the predetermined ranges of 15 μm for each parameter. The mass or volume (V) of particles within each diameter size range was calculated using the formula $V = 4.1888\, r^3$ where the radius (r) was taken as the average for the size range. The conversion of particle diameter classes into mass assumed the same density for each class. The air classifier operated on the principle of differential densities to obtain separations. Although not done in the present study, an appropriate correction factor should be applied when sufficient data on densities of air-classified fractions have been collected.

Chemical Analysis

Moisture (method 44-15A), lipid (method 30-10), ash (method 08-01), protein (method 46-12, N × 5.7), and crude fiber (method 32-10) were determined by AACC (1983) procedures. Starch content was determined by the enzymatic procedure of Fleming and Reichert (1980). Starch damage was measured by AACC (1983) method 76-30A. All data are reported on a 14.0% moisture basis.

The total dietary fiber content was analyzed by the gravimetric method of the AOAC (1984) (method 43.A14-43.A20) based on digestion of the sample with a heat-stable α-amylase, protease, and amyloglucosidase. The results were corrected for undigested protein (Kjeldahl N × 6.25) and ash (ignition at 525°C, 5 hr) associated with the fiber.

Breadmaking Quality Tests

Mixing properties of doughs made from soft wheat (SW) flour and SW-HPF blends were based on 35.0 g of flour (14.0% moisture basis) and constant water absorption of 65% (AACC method 54-40). In the blends, wheat gluten (Ogilvie Mills Ltd., Montreal, PQ) and HPF from 5B and 1M were mixed in proportions that provided flour blends with 14.0% protein content. Mixograph data are also provided on the HPF products alone, but using only 24.5 g of flour to retain the mixogram on the chart paper.

Baking performance was evaluated by the AACC (1983) straight-dough method 10-10A with and without 15 ppm potassium bromate. During baking, optimum water absorptions of the base flours were 57.8% for SW, 60.8% for Canadian Prairie Spring HY320, 59.5% for HRS patent, 60.3% for HRS bakers', and 61.8% for triticale. An additional 1% of water was added to the flour blends, which contained sufficient gluten or HPF from 5B and 1M to increase the protein content of each blend by two percentage units. The base flours were from commercial sources, the milling extraction percentages being about 72, 80, 75, 75, and 100% for SW, HY320, HRS patent, HRS bakers', and triticale, respectively.

An MPF from 5B was also evaluated at 0, 2.5, 5.3, and 8.8% replacement of HRS patent flour and 0, 7.0, 11.0, and 17.5% replacement of HRS bakers' flour at 0 and 15 ppm potassium bromate in the bread formulations.

RESULTS AND DISCUSSION

Flour Stream Analysis

The staff of the commercial flour mill maintain the flour yield at about 75.5% (as is basis) of the cleaned wheat. A listing of the various flour streams, their approximate production rates (basis total flour yield = 100%), and moisture content are provided in Table I. Break flours constituted 24%, reduction or middling flours 67%, and sizings and tailings 9% of the total flour production. The 1M and 2M flours accounted for nearly one-half of the total flour production in this mill.

TABLE I
Production Rates of Flour Streams in the Commercial Mill and Composition of Each Stream in Percent

Milling System and Flour Stream	Proportion of Total Flour	Moisture[a]	Protein[a,b]	Ash[b,c]
Break				
Pre-Break	0.7	15.1	18.3	0.70
1st Break	2.6	15.0	16.2	0.49
2nd Break	7.5	14.7	16.6	0.41
3rd Break	4.1	14.2	19.2	0.51
4th Break	1.9	14.2	20.4	0.74
5th Break	2.1	13.7	20.8	0.84
1st & 2nd Break cuts	2.5	15.0	16.4	0.42
3rd Break cuts	0.5	14.7	18.0	0.69
4th Break cuts	0.6	12.7	17.3	1.00
Break duster	1.1	13.8	19.9	1.16
Feed section	0.1	13.3	22.9	1.53
Sizing				
1st Sizing	0.4	13.8	15.6	0.50
2nd & 3rd Sizings	0.7	14.2	15.9	0.62
Tailings				
Quality	1.0	12.8	14.4	0.72
1st Tailings	0.8	13.0	15.0	0.75
2nd Tailings	0.7	12.6	13.7	0.81
Filter dust	5.8	13.0	15.3	0.62
Reduction				
Farina	6.3	14.3	11.5	0.33
1st Middlings	29.1	13.6	12.7	0.37
2nd Middlings	18.2	13.9	12.9	0.40
3rd Middlings	5.5	13.2	13.6	0.46
4th Middlings	2.8	12.6	13.0	0.48
5th Middlings	2.5	12.7	12.8	0.52
6th Middlings	1.4	12.3	13.8	0.88
Low grade	1.2	11.9	14.9	1.32

[a] Average SD = 0.1.
[b] Ash and protein reported on 14.0% moisture basis.
[c] Average SD = 0.01.

Moisture contents of the flour streams decreased from 15.1 to 11.9%, depending on the number of milling and sifting operations (Table I). At a 14.0% moisture basis, the protein contents of the flours (excluding the feed section) ranged from 11.5 to 20.8%, and ash contents varied from 0.33 to 1.32%. A major objective of flour milling has been to isolate the flours of the central endosperm from the outer endosperm layers. The center fractions, represented by 1M and 2M, contained only 0.37–0.40% ash and 12.7–12.9% protein. Flours from the outer portions of the endosperm included 3B, 4B, 5B, break duster (BD), and feed section (FS), which contained 0.51–1.53% ash and 19.2–22.9% protein.

Before selection of flour streams to represent the inner and outer endosperm, data from laboratory records were examined for variations in protein content. The 1M flour stream was selected because of the low average protein, from 11.5 to 12.5%, over the

TABLE II
Composition of Bulked Samples Selected from Roller-Milled 5B and 1M Flour Streams in Percent (14.0% Moisture Basis)

	5B Flour			1M Flour		
Constituent	Mean	SD[a]	SD[b]	Mean	SD[a]	SD[b]
Protein	19.9	0.5	0.2	12.1	0.2	0.1
Ash	0.93	0.07	0.02	0.39	0.02	0.01
Lipid	2.2	···	0.2	0.9	···	0.1
Crude fiber	0.28	···	0.04	0.15	···	0.03
Total dietary fiber	3.1	···	0.2	2.4	···	0.2
Starch	58.6	···	1.0	70.3	···	0.8
Starch damage	10.9	···	0.2	15.7	···	0.1

[a] $n = 72$ samples.
[b] $n = 4$ analyses.

TABLE III
Particle Size Range Based on Length, Width, Diameter, and Mass (Volume) of Roller-Milled 5B and 1M Flours

Class	Particle Size Range (μm)	Proportion of Particles Based on Length (%)	Width (%)	Diameter (%)	Composition of Flour by Mass[a] (%)
5B Flour					
1	0–15	17.9	36.0	29.5	0.3
2	16–30	29.3	29.8	32.3	3.2
3	31–45	17.5	13.5	15.3	6.8
4	46–60	12.2	11.5	9.6	12.2
5	61–75	6.8	4.9	6.2	16.6
6	76–90	5.0	2.3	3.6	17.2
7	91–105	3.9	1.1	1.8	14.0
8	106–120	2.1	0.4	1.0	12.0
9	121–135	1.7	0.2	0.4	5.9
10	136–150	1.2	0.1	0.2	4.1
11	151–165	0.8	0.1	0.1	2.5
12	>165	1.5	0.1	0.1	5.3
1M Flour					
1	0–15	32.4	52.6	45.9	0.3
2	16–30	30.3	26.7	30.3	2.8
3	31–45	15.1	7.4	9.5	3.8
4	46–60	7.7	5.1	4.5	5.3
5	61–75	3.4	3.0	3.1	7.7
6	76–90	2.5	1.9	2.3	10.5
7	91–105	2.4	1.4	1.5	11.2
8	106–120	1.3	0.8	1.1	11.7
9	121–135	1.0	0.5	0.7	11.8
10	136–150	1.3	0.3	0.5	9.9
11	151–165	0.7	0.2	0.2	6.9
12	>165	2.0	0.2	0.4	17.9

[a] Based on averaged diameters of particles in each size range.

TABLE IV

Effects of Roller Milling, Type and Number of Pin Millings, and Cryofreezing During Pin Milling on the Degree of Starch Damage in 5B and 1M Flours in Percent (14.0% moisture basis)

Flour Treatments	Roller Mill		Commercial Pin Mill		Laboratory Pin Mill[a]	
	5B	1M	5B	1M	5B	1M
Control	10.9 ± 0.2	15.7 ± 0.1	···	···	···	···
Pin milled						
1X[b]	···	···	16.0 ± 0.2	25.6 ± 0.3	16.3 ± 0.2	22.4 ± 0.1
2X	···	···	20.6 ± 0.4	30.5 ± 0.4	18.2 ± 0.4	27.3 ± 0.3
3X	···	···	···	···	18.4 ± 0.2	29.2 ± 0.4
4X	···	···	···	···	19.8 ± 0.2	30.1 ± 0.4
Cryofrozen 2X	···	···	···	···	16.5 ± 0.3	···

[a] For the laboratory experiment, LSD (0.05) = 0.3 for 5B and 0.5 for 1M at $n = 4$.

[b] 1X = Single pass, 2X = double pass, etc.

TABLE V

Distribution of Flour Particle Size Based on the Calculated Mass for Roller- and Pin-Milled 5B and 1M Flours

Particle Diameters (μm)	Proportion of the Total Flour Based on Mass				
	Roller Mill (%)	Commercial Pin Mill		Laboratory Pin Mill	
		1X (%)	2X (%)	2X (%)	2X + N[a] (%)
5B Flour					
0–15	0.3	16.0	21.2	26.7	24.1
16–30	3.2	41.9	51.6	51.9	52.5
31–45	6.8	21.9	21.6	20.5	13.2
46–60	12.2	13.5	2.5	0.8	8.2
61–75	16.6	6.6	3.1	0.0	2.0
76–90	17.2	0.0	0.0	0.0	0.0
91–105	14.0	0.0	0.0	0.0	0.0
>105	29.8	0.0	0.0	0.0	0.0
Degree of reduction[b]	10.3	79.9	94.4	99.2	89.8
No. of particles measured	10,078	10,028	10,004	10,045	10,101
1M Flour					
0–15	0.3	11.5	17.1	···	···
16–30	2.8	43.1	55.7	···	···
31–45	3.8	28.3	22.4	···	···
46–60	5.3	7.7	4.9	···	···
61–75	7.7	4.1	0.0	···	···
76–90	10.5	5.3	0.0	···	···
91–105	11.2	0.0	0.0	···	···
>105	58.3	0.0	0.0	···	···
Degree of reduction	6.9	83.0	95.1	···	···
No. of particles measured	10,098	10,110	10,056	···	···

[a] Pin milled with liquid nitrogen.

[b] Mass of particles with diameter <45 μm.

previous seven-year period. The 5B flour exhibited the highest protein content, although the yearly averages varied from 17.0% to nearly 21.0% between 1977 and 1984.

The 72 samples collected over a period of two months from the above flour streams were analyzed for protein and ash contents before bulking for later processing in pilot plant studies (Table II). For these samples of 5B and 1M, the average protein levels of 19.9 and 12.1% were lower, and ash levels of 0.93 and 0.39%, respectively, were higher than the protein and ash levels of the original flour streams (Table I). Variations among the samples in protein and ash contents were much greater in 5B than in 1M. In addition to the large difference in ash, concentrations of lipid and crude fiber were also two to three times greater in 5B than in 1M. However, 5B contained only 3.1% total dietary fiber compared with 2.4% in 1M. The difference in starch content between 5B and 1M was further evidence of characteristic differences in cell structure between the outer and inner endosperm. The higher proportion of protein and cell wall material in 5B was likely responsible, in part, for the lower degree of starch damage than in 1M flour.

Flour Particle Size

To characterize the distribution of particle size within each flour stream, the image analysis was programmed to compute the number of particles within 12 size ranges at 15 μm intervals from 0–15 to 165 μm (class 1–12, respectively). Counts were made separately for flour particle length, width, and diameter. The counts for the diameter size ranges were converted into flour mass (volume) using the average diameter of each class converted to the diameter of a circle of equal area.

The majority of particles in both flours had lengths of less than 75 μm and widths of less than 60 μm (Table III). One-half of the 1M flour particles had diameters of 0–15 μm, whereas those of 5B were more evenly distributed among the first three classes. When the equivalent diameters were converted into mass (volume), it became apparent that the large numbers of small particles constituted only a miniscule proportion of the total mass of the flours. In both flours, most of the particle mass was widely distributed among classes 4–12, in which at least one dimension exceeded 45 μm. Both flours had been bolted on 9XX sieves (153 ×153 μm), yet between 8% (5B) and 24% (1M) of the flour mass was composed of particles having at least one dimension greater than 150 μm.

Starch Damage

Increased water absorption and susceptibility to hydrolysis by amylolytic enzymes are the principal effects of starch damage (Williams 1969). High baking absorptions are preferred for the production of pan breads, because bread yield per unit flour weight can be increased without seriously affecting bread quality. Recently, Dexter et al (1985) showed that starch damage for HRS flours can be doubled over the level obtained during normal roller milling without adversely affecting pan bread quality. However, hearth breads could not tolerate the increased water absorption, and bread quality deteriorated in proportion to starch damage. In the present study the limit of starch damage considered acceptable for baking quality was set at approximately two times the value for roller-milled flour of the same class.

Starch damage in the roller-milled 5B and 1M flours was 10.9 and 15.7%, respectively, of the flours (Table II) and, when recalculated to a starch basis, the values became 18.6 and 22.3%, respectively, of the starch. The margin of difference between the two flours appeared quite large, and these differences increased with each pin milling (Table IV). The first pass through either pin mill increased starch damage in both roller-milled flours by 50%. The second pass raised the starch damage level another 40% in the commercial pin mill and 30% in the laboratory pin mill. Two additional passes through the laboratory mill resulted in only 1–10% increases in damaged starch. The total starch damage achieved with either mill was less than twice that found in roller-milled samples.

The greater degree of starch damage to middling flours is usually attributed to the more intensive roll action that is applied to middlings compared with break flours. Because even greater differences appeared in pin-milled flours, the effect was more likely associated with cell wall, starch granule, and protein differences between inner and outer endosperm. The central endosperm cells

TABLE VI
Yield and Composition of Fine Fractions and the Residual Coarse Fraction (>34) Obtained by Air Classification of Twice Pin-Milled Flour at Five Progressively-Wider Vane Settings in Percent (14.0% moisture basis)

Vane Setting/ Composition	Fraction Yield	Fraction Composition				Protein Shift	Starch Shift	Starch Damage	
		Protein	Starch	Ash	Lipid			In Flour	In Starch
5B Flour									
12	12.8	31.6	38.8	2.52	4.7	8.1	−4.5	17.9	46.7
16	9.8	28.4	46.8	1.94	3.5	4.6	−2.0	21.1	45.1
20	8.5	22.9	56.3	1.01	2.6	1.5	−0.4	22.6	40.1
26	27.6	14.8	65.1	0.46	1.6	−6.5	2.8	21.7	33.3
34	26.6	12.9	68.0	0.32	1.1	−8.9	4.0	20.1	29.6
>34	14.7	21.0	59.2	0.40	1.2	1.2	0.0	17.6	29.7
Total	100.0	···	···	···	···	30.8	13.7	···	···
Average SD	0.8	0.7	1.0	0.02	0.1	···	···	0.4	···
Compositional balance									
Original	···	19.9	58.6	0.93	2.2	···	···	20.6	35.2
Recovered	···	19.4	59.0	0.87	2.1	···	···	20.2	35.2
1M Flour									
12	24.0	25.0	51.9	0.77	1.2	26.8	−6.2	30.5	58.8
16	9.3	14.6	68.5	0.42	0.8	2.2	−0.2	33.8	49.3
20	4.9	12.2	70.8	0.38	0.7	0.2	0.1	33.4	47.2
26	8.0	8.6	74.4	0.37	0.6	−2.2	0.5	33.7	45.3
34	42.0	5.7	77.6	0.23	0.4	−21.7	4.6	31.2	40.2
>34	11.8	6.5	76.5	0.25	0.4	−5.3	1.1	28.6	37.4
Total	100.0	···	···	···	···	58.4	12.7	···	···
Average SD	0.6	0.4	0.7	0.01	0.1	···	···	0.3	···
Compositional balance									
Original	···	12.1	70.3	0.39	0.9	···	···	30.5	43.4
Recovered	···	11.8	69.9	0.40	0.7	···	···	31.3	45.9

TABLE VII
Yield and Composition of Fine Fractions and Residual Coarse Fraction (>34) Obtained by Air Classification of Twice Pin-Milled 5B Flour at Five Progressively-Wider Vane Settings Using Coarse Middlings as Carrier in Percent (14.0% moisture basis)

Vane Setting/ Composition	Fraction Yield	Protein	Ash	Protein Shift
12	21.0	30.6	2.36	11.7
16	12.6	23.5	1.26	2.5
20	12.4	18.4	0.70	−0.8
26	19.7	13.0	0.44	−6.7
34	20.6	12.4	0.34	−7.6
>34	13.7[a]	21.0[a]	0.40[a]	0.9
Total	100.00	···	···	30.2
Compositional balance				
Original		19.9	0.93	···
Recovered		19.7	0.95	···

[a] Calculated by subtracting carrier flour from the residual coarse fraction.

of wheat contain primarily large (15–40 μm diameter) and small (1–10 μm diameter) starch granules, whereas the high-protein outer cells contain starch granules that are of intermediate (6–15 μm diameter) size (Dengate and Meredith 1984). Presumably, the larger starch granules were more susceptible to damage during roller milling or impact grinding. This might also explain why the largest increases in starch damage occurred during the first pass through the pin mill for both flours. Increases in starch damage diminished progressively with each additional pass as the number of susceptible granules diminished (Table IV).

The experiment on cryofreezing during pin milling was designed to determine if degree of flour reduction could be enhanced without a marked increase in starch damage. Two passes of 5B flour in liquid nitrogen through the laboratory pin mill demonstrated a slightly lower degree of starch damage, 16.5%, compared with the control at 18.2% (Table IV).

Particle Size Distributions

The proportion of flour particles that had diameters equivalent to a circle of less than 45 μm diameter, potentially air-classifiable into high-or low-protein fractions, was designated as the degree of reduction in the present study (Kent 1965). The degree of reduction for the two roller-milled flours was only 7–10% (Table V). However, the first pass through the commercial pin mill (1X) decreased the proportion of flour particles greater than 105 μm from over 45% to 0% in each flour and increased the degree of reduction to 80%. The second pass through the pin mill (2X) eliminated all particles greater than 60 μm diameter in 1M and increased the degree of reduction to 95%. For twice pin-milled 5B, the degree of reduction was also 94%, and almost one-half of the flour was 16–30 μm in particle diameter. Kent and Evers (1969) reported that the degrees of reduction obtained by pin milling defatted subaleurone and inner endosperm were 25 and 52%, respectively. The mechanical resistance of the outer endosperm to particle size reduction was ascribed to the high protein-to-starch ratio and the intermediate size of the starch granules.

For both 5B and 1M flours, the first pin milling required much more energy than the second pass, in which the pin-milled flour flowed through the mill with comparative ease. Because the benefits of a second pin milling in reduction of particle size were substantial for each flour, and the increase in starch damage was within acceptable limits, two passes through the pin mill were adopted for the subsequent air classification studies. Two passes of 5B flour through the laboratory pin mill were more effective than the commercial mill runs in eliminating the large particles, and the degree of reduction was increased from 94.4 to 99.2% (Table V). The reason for the more efficient reduction in particle size was likely the slow feed rate used in the laboratory mill runs.

Cryogrinding

The objective of the cryogrinding experiment was to increase the degree of reduction of 5B flour, which resisted disintegration much more than 1M. However, the degree of reduction of flour pin milled under liquid nitrogen was only 20.0% (Table V). It appeared that cryogrinding decreased the degree of reduction without substantially minimizing the adverse effects on starch damage. Therefore, studies on cryogrinding were discontinued.

Air Classification of Pin-Milled Flours

The first two cuts of fines from pin-milled 5B, obtained at VS12 and VS16, were very high in protein content, 31.6 and 28.4%, respectively (Table VI). High yields of these fractions, 22.6%, resulted in a total protein shift of 12.7%. The two fractions also contained high concentrations of ash and lipid but less starch than the original flour, especially in the VS12 fraction. The VS20 fraction also contained more protein than the original flour, but the yield and protein shift were less marked. The VS26 and VS34 fractions, which constituted 54% of the total flour, were depleted in protein, ash, and lipid and were enriched in starch. Total protein and starch shifts in VS26 and VS34 fractions were −15.4 and 6.8%, respectively. The coarse fraction obtained from the last air classification (VS34) was slightly higher in protein content than the original flour but had only one-half the concentration of ash and lipid. Thus, each fraction, except possibly VS20, differed from the original flour in several chemical constituents.

As predicted by the particle size distributions (Table V), air classification more effectively separated protein of 1M flour than of 5B flour (Table VI). The 24.0% yield of fines separated from pin-milled 1M at VS12 provided a fraction with 25.0% protein, which represented a protein shift of 26.8%. Three subsequent cuts gave low yields of fines that contained progressively less protein, ash, and lipid but more starch. The final VS34 and VS >34 fractions constituted almost 54% of the total flour and had the lowest levels of protein, ash, and lipid but high starch contents. In the latter two fractions, the protein shift was −27.0% and the starch shift 5.7%.

TABLE VIII
Effects of Recommended Vane Settings on Percent Yield and Composition of Combined Fine and Coarse Fractions from Air-Classified 5B and 1M Flours Based on Data in Table VI (14.0% moisture basis)

Vane Setting	Fraction Yield	Fraction Composition				Starch Damage	Designation of Product
		Protein	Starch	Ash	Lipid		
5B Flour							
20 (Fines)	31.1	28.2	45.9	1.92	3.8	20.1	HPF/5B[a]
34 (Fines)	54.2	13.8	66.5	0.40	1.4	20.9	MPF/5B[b]
34 (Coarse)	14.7	21.0	59.2	0.40	1.2	17.6	HPF 2/5B
1M Flour							
12 (Fines)	24.0	25.0	51.9	0.77	1.2	30.5	HPF/1M
26 (Fines)	22.2	12.0	71.1	0.40	0.7	33.7	MPF/1M
26 (Coarse)	53.8	5.9	77.4	0.23	0.4	30.6	LPF/1M[c]

[a] HPF = High-protein fraction.
[b] MPF = Medium-protein fraction.
[c] LPF = Low-protein fraction.

TABLE IX
Effects of Supplementation with Gluten and High-Protein Fractions (HPF) from Air-Classified 5B and 1M Flours on Mixograph Parameters of Soft Wheat (SW)

Flour or Blend	Protein Content (%)	Time to Peak (sec)	Peak Height (cm)	Area Under Curve (cm^2)
SW flour	10.5	60	5.6	57.7
HPF/5B	28.2	140	8.0	88.2
HPF/1M	25.0	180	8.7	100.9
SW + gluten	14.0	80	6.3	67.5
SW + HPF/5B	14.0	90	6.1	65.0
SW + HPF/1M	14.1	80	7.0	78.7

Gracza (1959) introduced the concept of protein shift as a measure of the degree to which protein is concentrated or depleted relative to the parent flour. In the present study, the total protein shift was 30.8% for 5B and 58.4% for 1M flours. The same concept was applied to measure the degree to which starch was separated into the various fractions. Total starch shifts of 13.7% for 5B and 12.7% for 1M flours indicated that air classification was much less efficient in segregating starch in HRS wheats than in grain legumes (Tyler et al 1981).

Degrees of starch damage in each flour were fairly evenly distributed among the air-classified fractions, with the middle cuts having the highest values (Table VI). When calculated as a percentage of the starch in each air-classified fraction, the proportions of damaged starch increased with decreases in VS. It appeared that broken starch granules were being carried into the fines fractions, which would counterbalance the tendency for intact starch granules to separate into the coarse fractions. This might account for the low values for starch shift, especially in the 1M flour where starch damage was quite high.

The pin-milled 5B flour exhibited poor feeding and dispersal characteristics in the air classifier, which may result in a lower degree of protein shift. To alleviate the dispersion problem, the twice pin-milled 5B flour was blended with a coarse granular HRS flour in a ratio of 2.3:1 (w/w). During each stage of the air classification process, the carrier flour passed into the coarse fraction and was finally recovered at VS34. It was necessary to subtract the yield and composition of the dispersal agent from the coarse product obtained at VS34 (Table VII).

The dispersal agent was effective in increasing the yields of fines obtained at VS12, VS16, and VS20 (Table VII). Also, the protein shift for VS12 was increased from 8.1 (Table VI) to 11.7% (Table VII). However, use of the dispersant failed to increase the total positive protein shift between fractions.

It was concluded that more effective grinding was necessary to reduce the particle size of 5B flour to achieve a greater protein shift, and, thus, greater yields of high- and low-protein fractions.

Applications in Milling

Protein shift data were used as a guide to select the optimal VS for preparation of high-, medium-, and low-protein fractions from the two mill streams. For pin-milled 5B flour, a classifier cut at VS20 would yield 31% of HPF/5B containing 28.2% protein and only 45.9% starch (Table VIII). The major fraction of 5B would be the fines from a VS34 classification, which would be medium in protein and starch content. The coarse material from the VS34 cut represented a second high-protein fraction (HPF2) that was much lower in ash and lipid than the HPF/5B obtained at VS20.

For pin-milled 1M flour, it was apparent that a high-protein fraction (HPF/1M) should be separated at VS12 and the coarse residue reclassified at VS26 (Table VIII). The fines obtained at VS26 would provide an economic yield of a medium protein flour (MPF/1M), whereas the coarse fraction would give a very high yield of low-protein flour (5.9%), which was also characterized by low ash and lipid contents in association with a high starch level.

Whereas 5B flour only represented 2.1% of the total flour streams (Table I), other streams that have similar properties to 5B (3B, 4B, 4B cut, BD, and FS) account for about 10.6% of total flour production. Such streams have the lowest value among flour grades and may be discounted even further to dispose of stocks. Air classification could upgrade these flours substantially if the HPF could compete with gluten for certain market applications and if MPF could be blended into the high-quality bakery flours.

Many flour mills are maximizing production of patent flours, up to 60% of flour production. In HRS flour mills, the protein and ash levels of the additional increments of clears moving into patent grades has presented a serious quality problem. Reprocessing certain middling fractions into HPF, MPF, and LPF would provide greater flexibility in management of the protein, starch, and ash levels to suit market requirements.

Quality of Fractions

All air-classified fractions of 5B flour gave very strong mixograph curves, as was obtained for HPF/1M (Table IX). The

TABLE X
Influence of Supplementation with Gluten and High-Protein Fractions (HPF) from Air-Classified 5B and 1M Flours on Bread Loaf Volumes of Five Market Classes of Flour[a]

Flour Blends	Bromate Level (ppm)	Protein Content of Market Classes (%)					Average Volume Gain (%)
		SW	HY320	HRS Patent	HRS Bakers'	Triticale	
Flour protein content		10.5	11.9	11.8	13.7	14.5	
		Change in Loaf Volume					
Flour + gluten	0	3.3	2.7	5.1	2.7	8.5	4.5
Flour + HPF/5B	0	1.7	2.1	2.2	−3.4	11.9	2.9
Flour + HPF/1M	0	−1.7	−0.7	−2.2	−2.0	11.9	1.1
Average response		1.1	1.4	1.7	−0.9	10.8	
Average SD		0.2	0.1	0.2	0.1	0.5	
Flour	15	2.5	6.9	5.9	8.8	0.0	4.8
Flour + gluten	15	9.2	8.3	12.5	4.0	11.9	9.2
Flour + HPF/5B	15	6.7	11.0	9.6	6.1	15.2	9.7
Flour + HPF/1M	15	3.3	4.8	5.1	7.4	15.2	7.2
Average response		6.4	8.0	9.1	5.8	14.1	
Average SD		0.2	0.1	0.2	0.3	0.4	

[a] Results expressed as percentage increase over the no-bromate control.

TABLE XI
Influence of Medium-Protein Fraction (MPF) from Air-Classified 5B Flour on Bread Volume of HRS Patent and Bakers' Flour[a]

Flour Blends with MPF/5B	Flours Without Bromate		Flours with 15 ppm Bromate	
	Protein Content (%)	Volume Change (%)	Protein Content (%)	Volume Change (%)
Patent Flour				
Flour	11.8	0.0	11.8	2.8
Flour + 2.5%	11.9	4.3	11.9	6.4
Flour + 5.3%	11.9	4.3	11.9	7.8
Flour + 8.8%	12.0	4.3	12.0	8.6
Average SD		0.1		0.2
Bakers' Flour				
Flour	13.7	0.0	13.7	5.4
Flour + 7.0%	13.7	0.0	13.7	6.7
Flour + 11.0%	13.7	−4.9	13.7	2.4
Flour + 17.5%	13.7	−5.5	13.7	−2.4
Average SD		0.2		0.2

[a] Results expressed as percentage increase over the control.

blending strength of HPF/5B and HPF/1M were compared with gluten at equal levels of protein supplementation of a soft wheat flour. Compared to gluten, HPF/5B gave a higher peak with slightly lower area under the curve. HPF/1M gave a stronger mixograph curve than gluten or HPF/5B.

Five market classes of flour were supplemented with an additional two percentage units of protein from gluten, HPF/5B, and HPF/1M at zero and 15 ppm bromate levels in the formulation (Table X). Each flour responded positively to gluten supplementation, and the average loaf volume increase was 4.5% without bromate and 9.2% with bromate added. Without bromate, the loaf volume response to supplementation with HPF/5B averaged only 2.9%, but with bromate the average volume increase was 9.7%. HPF/1M depressed loaf volumes of wheat flours in the absence of bromate but quite satisfactory results were obtained when 15 ppm bromate was added. Triticale and HRS patent flour gave the best responses to protein supplementation, whereas the high-protein bakers' flour responded the least. In the presence of bromate, HPF/5B and HPF/1M appeared to be suitable gluten substitutes in bread formulations.

The potential for blending the major fraction, MPF/5B, into patent or bakers' flour streams was also investigated (Table XI). The replacement of 2.5, 5.3, and 8.8% of HRS patent flour with MPF/5B in bread formulations had positive effects on loaf volumes. Without bromate, the volumes increased 4.3%, and with 15 ppm bromate, the increases ranged from 6.4 to 8.6%. Without bromate, the bakers' flour tolerated a 7.0% blend of MPF/5B before volumes decreased, and with bromate, the level of tolerance was estimated to be at about the 15.0% replacement level.

It appeared that nearly all the products of the air classification of 5B flour could be utilized as value-added supplements or blends in the flour mill. It might not be economical to process the middlings flours in the same way unless important uses for the major LPF fraction are developed. Further studies on the functional properties of these fractions, and those obtained from other break streams, are currently underway.

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