Air Classification of Flours from Wheats with Varying Hardness: Protein Shifts

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ABSTRACT

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Air classification of wheat flour (six hard red winter [HRW], four hard red spring [HRS], and four soft wheats [SW]) produced an ultrafine fraction with a protein content of 38–54% (N × 5.7, dry basis) in 0.3–1.5% yield and a fine fraction (<15 μm) with protein content of 21–30% in 11–25% yield. Brule, a HRW wheat with both hard and semihard kernels, produced a <15-μm fraction with the highest protein content (30%) and yield (16%) of all HRW wheats studied. The ultrafine and <15-μm fractions may have commercial potential as a protein concentrate. HRS wheat, HRW wheat, and SW classes differed in protein content of the 24- to 30-μm fraction, protein shift, and ratio of protein content of the <15-μm or 24- to 30-μm fractions to protein content of the flour.

Air classification is an effective method to separate flour into fractions of different particle size. The finest fraction (<15 μm) has a protein content considerably higher than that of the starting wheat flour. Normal soft wheat (SW) flour has a good protein shift after air classification (Peplinski et al 1964), but the starting flour is generally low in protein. Protein shift is a calculated value for comparing protein displacement in air classification. It equals the sum of the protein shifted into the high-protein fractions and out of the low-protein fractions as a percentage of the total protein in the starting flour (Gracza 1959). Normal hard wheat flour has a protein content higher than that of SW, but protein shift upon air classification is usually less than that of SW flour (Stringfellow and Peplinski 1964, Peplinski et al 1965). However, a high-protein SW flour gave a substantial protein shift after air classification (Wu and Stringfellow 1979).

Changes in breeding strategies, such as releasing varieties with multiple biotypes and crossing hard and soft wheats, make traditional differences between hard and soft wheats less clear. For example, Arkan is a hard red winter (HRW) wheat derived from a cross between hard and soft wheats (Martin et al 1983). Also, Brule is a HRW wheat but has soft parents in its pedigree and contains both hard and semihard kernels (Schmidt et al 1983). Traditional visual classification criteria of kernel size, shape, and color may be unable to categorize such wheats as hard or soft.

The objectives of this study were 1) to examine the suitability of wheat varieties such as Arkan and Brule to yield protein concentrates by air classification of flour and 2) to relate yield and protein content of air-classified flour fractions to wheat hardness and to distinguish differences between hard red spring (HRS), HRW, and SW.

MATERIALS AND METHODS

Wheats

Arthur, Hart, and Ruler were soft red winter (SRW) wheats grown in Ohio in 1984. Daws, a soft white winter (SWW) wheat, was grown in Washington in 1981. Arkan, Centurk 78, Newton, and Sage were HRW wheats grown in Kansas in 1984. Brule and Scout 66 were HRW wheats from Nebraska (1987) and Kansas (1986), respectively. Len and Wheaton were HRS wheats from North Dakota (1988) and Minnesota (1988), respectively. Samples of Marshall, a HRS wheat, were grown in Minnesota and North Dakota in 1988. All wheats were clean and sound on arrival and were stored at 1°C. The wheats chosen are current varieties and include a softer-than-usual HRW wheat (Brule) and harder-than-usual SWW wheat (Daws).

Milling

SW were tempered to 14% moisture overnight and then to 14.5% for 0.5 hr before milling on a Buhler pneumatic laboratory flour mill (Uzwil, Switzerland) in constant laboratory conditions of 25°C and 48% rh. Hard wheats were tempered to 15.5% moisture overnight and then to 16.0% for 0.5 hr before Buhler-milling. Flour consisted of the combined break and reduction flour fractions. Flours from Buhler-milling were ground three times in an Alpine 160Z laboratory pin mill (Augsburg, Germany) at 14,000 rpm before air classification.

Air Classification

A Pillsbury laboratory air classifier (Minneapolis, MN) was used to separate flour into five fractions. Four passes of material through the air classifier adjusted to 15, 18, 24, and 30 μm cutpoints produced five fractions (<15, 15–18, 18–24, 24–30, and >30 μm). Each coarse fraction was used for the subsequent air classification step. In addition to these five fractions, a small amount of ultrafine material was collected from the air filter bag of the air classifier.

Near-Infrared Reflectance Hardness

A Pacific Scientific 6250 near-infrared reflectance (NIR) spectrophotometer (Silver Springs, MD) was used to determine hardness according to AACC Method 39-70A (1983). The instrument was calibrated with 10 standard wheats from the Federal Grain Inspection Service. Wheats were ground in a Udy cyclone mill (Fort Collins, CO) with a 1-mm screen. The best fit equation was hardness $= -274.14 - 1{,}152.08\ [\log (1/R)]_{1{,}680} + 1{,}546.24\ [\log (1/R)]_{2{,}230}$, where subscripts are wavelengths in nanometers of measured reflectance (R). The same formula and procedure then were used to obtain hardness values for other wheats.

Analyses

Moisture of wheat for milling was determined in triplicate by a Brabender Moisture/Volatiles Tester, type SAS (Hackensack, NJ) at 130°C for 30 min after the wheat was cracked in an Enterprise model 00 grain mill (Philadelphia, PA). Protein, in triplicate, and starch damage were determined by AACC approved methods 46-13 and 76-30A, respectively (1983); crude protein was calculated from Kjeldahl N × 5.7. Moisture of flour was determined in duplicate by heating samples in an air oven at 100°C to constant weight. Statistical correlations are Pearson's coefficients with probability values representing the probability of a zero coefficient.

RESULTS AND DISCUSSION

Starch Damage of Flour and Air-Classified Flour Fractions

Two HRS wheats, two HRW wheats, and two SW (generally the hardest and softest in each class based on NIR measurements) were chosen for starch damage measurements of flour and air-

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classified flour fractions (Table I). Flours from the Buhler pneumatic laboratory flour mill had starch damages of 0.7–3.1%. When the flours were ground three times at 14,000 rpm in a pin mill and then air-classified, starch damage decreased with increasing particle size of each wheat flour fraction, in general. Starch damage values in Table I were not excessive and were lower than the values reported by Sosulski et al (1988) for fifth break and first middlings flours and their reground fractions.

Yield, Protein Content, and Protein Shift of Air-Classified Flour Fractions

Earlier studies with the same air classifier showed that the mass median diameters of air-classified fractions from SRW and HRW wheat flours that were reground three times at 14,000 rpm before air classification agreed within 1 μm for the first seven corresponding fractions from an eight-part air classification (Pfeifer and Griffin 1960). Also, mass median diameters of air-classified fractions from SRW, HRW, and HRS wheat flours agreed within 1 μm for the first six corresponding fractions from an eight-part air classification (Pfeifer and Griffin 1960).

Table II presents yield and protein contents of all air-classified fractions. Protein contents were highest in fine fractions and were exceptionally high (38–54%) in the minor (0.3–1.5%) ultrafine "bag fractions." For the air-classified fractions, protein shifts without bag fraction (Table II) were 0.8–4.1 percentage points lower than corresponding values including the bag fraction (not shown). Since the bag fraction had very high protein content compared with that of the starting flour, inclusion of bag fraction in the calculation would result in a higher protein shift value than that without the bag fraction. The highest protein content of all fractions was 54% for the Arthur bag fraction, and the lowest protein content was 3% for the Ruler 24- to 30-μm fraction.

TABLE I
Starch Damage (%) of Flour and Air-Classified Flour Fractions

Flour Fractions	Len	Marshall (MN)	Sage	Brule	Daws	Ruler
Flour[a]	2.5	2.6	3.1	0.7	1.8	1.6
<15 μm	13.7	15.9	12.3	8.0	7.1	6.1
15–18 μm	10.9	13.7	11.8	5.3	6.4	4.1
18–24 μm	7.9	8.0	8.4	2.9	3.1	2.2
24–30 μm	5.9	6.1	7.2	2.2	3.1	1.9
>30 μm	3.8	4.7	6.4	2.8	3.1	2.1

[a] Flour from Buhler mill. The flour was ground three times at 14,000 rpm in a pin mill before air classification.

Protein shift values from previous studies include 58–68% for four-part fractionation (<13-, 13- to 16-, 16- to 40-, and >40-μm fractions) and 81–86% for eight-part fractionation (<13- and >40-μm fractions plus six intermediate fractions) of six SRW wheat flours; 50–56% for four-part fractionation and 71–80% for eight-part fractionation of three SWW wheat flours (Peplinski et al 1964); 20–34% for four-part fractionation and 36–60% for eight-part fractionation of five HRW wheat flours (Stringfellow and Peplinski 1964); and 9–12% for four-part fractionation and 24–29% for eight-part fractionation of four HRS wheat flours (Peplinski et al 1965). Our protein shift values in Table II from five-part fractionation compared favorably with those from previous studies. Since all wheats in Table II differ from those in previous studies, it appeared that the current wheat varieties studied here responded better to air classification (had higher protein shift) than the earlier varieties.

Except for bag fractions, Brule's <15-μm fraction had the highest protein content among all wheats and the highest yield among all HRW wheat flours (Table II), although the protein content of the original Brule flour was near the average value of HRW wheat flours and below the protein contents of HRS flours.

For wheats within each class, yields, protein contents of each fraction, and protein shifts were generally similar (Table II). Brule, however, differed greatly from the other HRW varieties in the low protein content of its 15- to 18-μm fraction, the high yield of its 18- to 24-μm fraction, the low yields of its 24- to 30-μm and >30-μm fractions, and its high protein shift. Newton, having hardness comparable to that of Brule according to NIR measurement, had the highest yield of the 18- to 24-μm fraction, the lowest yields of the 24- to 30-μm and >30-μm fractions, and the highest protein shift among HRW wheats excluding Brule.

Air classification data reveal several class-specific features. Yield of the <15-μm fraction differentiated HRW (11.1–15.5%) from HRS (17.9–24.6%) wheats (Table II). Yields of the 15- to 18-μm and 24- to 30-μm fractions distinguished SW (15.7–16.5 and 17.1–19.4%, respectively) from HRS wheats (12.9–14.9 and 8.0–12.3%, respectively). Protein contents of the 18- to 24-μm fractions, >30-μm fractions, and flour from SW (3.7–5.1, 3.7–5.0, and 8.7–10.7%, respectively) differed from those of hard wheats (6.4–10.7, 8.6–15.5, and 11.1–16.3%, respectively). Protein content of the 24- to 30-μm fraction and protein shift without bag fraction for SW (3.3–4.2 and 64.1–77.0%, respectively), HRW wheats (7.2–10.2 and 36.8–56.0%, respectively) and HRS wheats (12.0–15.8 and 27.9–36.5%, respectively) distinguished one class of wheat from another.

Air classification results also correlated with hardness. The yield

TABLE II
Yield, Protein Content, and Protein Shift of Air-Classified Flour Fractions (% dry basis)

Wheat, Class[a]	NIR Hardness[b]	Bag		<15 μm		15–18 μm		18–24 μm		24–30 μm		>30 μm		Flour Protein	Protein Shift
		Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein		
Newton, HRW	44	1.5	38.0	13.9	25.7	16.7	15.7	43.2	8.0	17.3	7.2	7.3	8.6	12.5	44.8
Centurk 78, HRW	56	1.4[c]	48.2	14.4	23.8	16.8	14.4	38.7	7.0	19.7	7.5	9.1	9.5	11.1	44.0
Sage, HRW	67	0.8	47.0	11.1	29.6	12.2	18.6	35.0	9.4	22.4	10.2	18.5	12.3	14.8	37.4
Arkan, HRW	60	0.3	49.2	11.5	27.0	13.2	17.0	35.2	8.7	22.4	9.2	17.4	11.1	12.4	36.8
Scout 66, HRW	51	1.5	48.6	11.9	23.1	13.9	14.5	32.5	7.5	24.0	7.7	16.2	9.1	12.3	39.4
Brule, HRW	46	0.7	50.2	15.5	30.3	14.0	10.3	58.5	6.4	7.2	9.6	4.1	14.4	13.2	56.0
Wheaton, HRS	68	1.1	41.6	21.5	20.6	14.9	12.1	39.5	9.1	12.3	12.4	10.8	12.9	13.7	27.9
Len, HRS	70	1.2	46.9	24.6	23.0	12.9	12.9	43.4	10.7	8.8	15.8	9.2	15.5	16.3	28.8
Marshall (MN), HRS	62	1.1	40.0	20.5	23.2	13.1	12.4	50.9	8.8	8.0	12.0	6.5	13.0	13.6	35.2
Marshall (ND), HRS	62	1.1	49.4	17.9	27.0	13.2	13.9	51.3	9.2	8.5	12.7	8.1	14.3	14.6	36.5
Hart, SRW	18	1.0	45.4	15.3	26.5	16.2	14.6	42.6	4.3	18.2	3.8	6.8	4.0	10.7	70.6
Arthur, SRW	26	0.6	53.9	16.5	25.9	15.7	13.4	44.0	5.1	17.1	4.2	6.2	5.0	10.3	65.6
Ruler, SRW	12	0.7	50.5	17.0	25.3	16.5	13.7	40.7	3.7	18.5	3.3	6.6	3.7	9.5	77.0
Daws, SWW	31	0.3	44.7	15.3	20.9	16.0	11.6	40.1	4.1	19.4	3.6	9.0	4.5	8.7	64.1

[a] HRW = hard red winter, HRS = hard red spring, SWW = soft white winter, and SRW = soft red winter.

[b] Near-infrared reflectance hardness.

[c] The yield of Centurk 78 bag fraction was estimated from the weight actually recovered from the bag and the average of weight recovered from bag divided by increase in bag weight after air classification from Sage and Arkan.

of the 15- to 18-μm fraction; protein contents of the 18- to 24-, 24- to 30-, and >30-μm fractions; and protein shift without bag fraction correlated significantly ($P < 0.01$) with NIR hardness (Table III).

Ratio of Protein Contents in Air-Classified Fractions and Flour

Since protein contents of the flour differed both within and between classes of wheat, we normalized protein contents of wheat flours by dividing protein contents of the air-classified fraction by protein content of flour (Table IV). Ratios varied from 34% for Ruler's 24- to 30-μm fraction to 530% for Ruler's bag fraction. Such extreme ratios are characteristic of SW, which also have high protein shifts (Table II).

Results for Brule differ from those of other HRW varieties. Brule has a low ratio for the 15- to 18-μm and 18- to 24-μm fractions, and high ratios for the <15- and >30-μm fractions. All wheats had higher protein contents for their bag fraction and their <15-μm fraction and lower protein contents for the 18- to 24- and 24- to 30-μm fractions than those of the original flour.

TABLE III
Correlation Coefficients of Yields and Protein Contents of Air-Classified Fractions

Fraction	Correlation Coefficient[a]	Protein Content Ratio[b]
Bag		−0.810**
Yield[c]	0.319	
Protein content	−0.268	
<15 μ		−0.873**
Yield	0.216	
Protein content	−0.072	
15–18 μm		−0.605*
Yield	−0.713**	
Protein content	0.165	
18–24 μm		0.925**
Yield	−0.03	
Protein content	0.949**	
24–30 μm		0.941**
Yield	−0.287	
Protein content	0.905**	
>30 μm		0.881**
Yield	0.468	
Protein content	0.898**	
Protein shift without bag	−0.974**	

[a] Versus hardness by near-infrared reflectance. * = Significant at 0.05, ** = significant at 0.01.
[b] Air-classified fraction to original flour.
[c] Yields and protein contents in percent dry basis.

Ratios of air-classified fraction protein content to flour protein content differentiated HRS wheats from SW for the 15- to 18-μm fraction (79–94 and 130–144%, respectively), for the 18- to 24-μm fraction (62–67 and 39–49%, respectively), and for the >30-μm fraction (94–97 and 37–52%, respectively) (Table IV). Ratios of the <15-μm and 24- to 30-μm fractions distinguished SW (240–265 and 34–41%, respectively), HRW wheats (189–232 and 58–74%, respectively), and HRS wheats (141–184 and 87–97%, respectively).

Ratios of protein content (air-classified fraction to flour) also correlated with NIR hardness for the 15- to 18-μm fraction ($P < 0.05$) and for the <15-, 18- to 24-, 24- to 30-, and >30-μm fractions and the bag fractions ($P < 0.01$) (Table III).

CONCLUSIONS

The ultrafine bag fraction obtained from air classification increased the protein shift by up to 4% (Table II). Although yield of this fraction was small, it had a very high protein content (up to 54%). At present, industrial air classifiers cannot collect this bag fraction. This would be desirable in future industrial air classifiers.

The <15-μm fractions from air classification had 11–25% yield and 21–30% protein contents (Table II). This fraction and the bag fraction could be combined to produce a protein concentrate to increase protein content of food products. Remaining fractions could be used for bread flours, cake or cookie flours, or other uses.

Brule, a problem HRW wheat with both hard and semihard kernels, had the highest yield and protein content for its <15-μm fraction of all HRW wheats studied. Among the HRW wheats examined in this work, Brule appears most desirable for protein concentrate production by air classification. The higher protein shift value for Brule compared with other hard wheats was probably a result of soft wheat parents in its pedigree.

It was of particular interest that wheat classes differed in air classification response. Protein content of the 24- to 30-μm fraction, protein shift without the bag fraction, ratio of <15-μm fraction protein content to flour protein content, and ratio of 24- to 30-μm fraction protein content to flour protein content differentiated HRW wheats, HRS wheats, and SW. While several methods (Cutler and Brinson 1935, Williams 1979, Obuchowski and Bushuk 1980, Miller et al 1982, Sampson et al 1983) differentiate hard and soft wheats, this was one of the first observations of a true apparent difference between HRS and HRW wheats. Inclusion of a softer-than-usual HRW wheat (Brule) and a harder-than-usual SWW wheat (Daws) in our study gave us more confidence that the results obtained may hold true for a larger number of wheats, but further studies are needed to test this observation.

TABLE IV
Ratio (%) of Protein Contents in Air-Classified Fractions and Flour

Wheat, Class[a]	Fraction in μm <15	15–18	18–24	24–30	>30	Bag Fraction
Newton, HRW	206	125	64	58	68	303
Centurk 78, HRW	215	130	63	68	86	437
Sage, HRW	207	130	66	71	86	328
Arkan, HRW	211	137	70	74	89	396
Scout 66, HRW	189	119	61	63	75	395
Brule, HRW	232	79	49	73	110	383
Wheaton, HRS	151	88	67	91	94	304
Len, HRS	141	79	66	97	95	275
Marshall (ND), HRS	184	94	62	87	97	337
Marshall (MN), HRS	170	91	64	88	95	293
Hart, SRW	249	137	40	35	37	427
Arthur, SRW	251	130	49	40	49	523
Ruler, SRW	265	144	39	34	39	530
Daws, SWW	240	133	47	41	52	515

[a] HRW = hard red winter, HRS = hard red spring, SRW = soft red winter, and SWW = soft white winter.

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LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 39-70A, approved October 1986, revised November 1987 and November 1989; Method 46-13, approved October 1976, reviewed October 1982, revised October 1986; Method 76-30A, approved May 1969, revised November 1972, October 1982, and October 1984. The Association: St. Paul, MN.

CUTLER, G. H., and BRINSON, G. A. 1935. The granulation of whole wheat meal and a method of expressing it numerically. Cereal Chem. 12:120.

GRACZA, R. 1959. The subsieve-size fractions of a soft wheat flour produced by air classification. Cereal Chem. 36:465.

MARTIN, T. J., BOCKUS, W. W., BROWDER, L. E., FINNEY, K. F., HATCHETT, J. H., and WETZEL, D. L. 1983. Registration of Arkan wheat. Crop Sci. 23:1221.

MILLER, B. S., AFEWORK, S., POMERANZ, Y., BRUINSMA, B. L., and BOOTH, G. D. 1982. Measuring the hardness of wheat. Cereal Foods World 27:61.

OBUCHOWSKI, W., and BUSHUK, W. 1980. Wheat hardness: Comparison of methods of its evaluation. Cereal Chem. 57:421.

PEPLINSKI, A. J., STRINGFELLOW, A. C., and GRIFFIN, E. L., Jr. 1964. Air classification of Indiana, Ohio, and Michigan soft wheat flours. Northwest. Miller 271(2):10.

PEPLINSKI, A. J., STRINGFELLOW, A. C., and GRIFFIN, E. L. Jr. 1965. Air classification response of durum and hard red spring wheat flours. Northwest. Miller 272(5):34.

PFEIFER, V. F., and GRIFFIN, E. L., Jr. 1960. Fractionation of soft and hard wheat flours by fine grinding and air classification. Am. Miller Process. 88(2):14.

SAMPSON, D. R., FLYNN, D. W., and JUI, P. 1983. Genetic studies on kernel hardness in wheat using grinding time and near infrared reflectance spectroscopy. Can. J. Plant Sci. 63:825.

SCHMIDT, J. W., JOHNSON, V. A., MATTERN, P. J., DREIER, A. F., McVEY, D. V., and HATCHETT, J. H. 1983. Registration of Brule wheat. Crop Sci. 23:1223.

SOSULSKI, F. W., NOWAKOWSKI, D. M., and REICHERT, R. D. 1988. Effects of attrition milling on air classification properties of hard wheat flours. Starch/Staerke 40:100.

STRINGFELLOW, A. C., and PEPLINSKI, A. J. 1964. Air classification of Kansas hard red winter wheat flours. Northwest. Miller 270(6):19.

WILLIAMS, P. C. 1979. Screening wheat for protein and hardness by near infrared reflectance spectroscopy. Cereal Chem. 56:169.

WU, Y. V., and STRINGFELLOW, A. C. 1979. Protein concentrate from air classification of high-protein soft wheat flours. J. Food Sci. 44:453.

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