Protein Concentrates and Prime Starch from Wheat Flours

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ABSTRACT

Five wheat flours, three milled from high-protein hard wheats and two from low-protein soft wheats, were developed into doughs, dispersed in water, and fractionated by centrifugation for 15 min at 1,500 × *g* at room temperature for a total of 0.5–1 hr. The fractions included a low-protein (0.6–0.8%) prime starch, one or two gluten fractions containing up to 67.0% protein (N × 5.7, dmb), tailings, insoluble fibers, and water solubles. The protein-rich fractions contained up to 5.4 times the protein contents of the original flours. Total prime starch yields were up to 70% of total dry matter recovered. Protein recoveries in the protein concentrates were up to 88%. The total water load in the fractionation process was as low as 2.0 times the flour weight. This article describes a closed system that produces a concentrate high in protein and prime starch.

Cereal Chem. 70(6):701–706

The processes for production of vital gluten can be grouped grossly in two types: 1) the Martin system, in which a dough is developed before separation into gluten, starch, and water solubles (WS), basically by a washing-out process; and 2) the batter system, in which wheat flour dispersions are fractionated by centrifugal separation with decanters or hydrocyclones (Fellers 1973, Godon et al 1983, Kempf and Röhrmann 1989, Meuser et al 1989). The main disadvantages of the Martin system are a large amount of water used (up to 10 m^3 per ton of flour), a heavy waste water load (up to 5–8 m^3 per ton of flour), and somewhat impaired functional properties (lower vitality, water absorption, and rate of hydration) (Sarkki 1980). In some batter systems (i.e., the Raisio), the total amounts of water used and waste water loads are claimed to be 3 and 2 m^3 per ton of flour, respectively. The practical, engineering and technological advantages and limitations of the batter separation systems have been the subject of much controversy (Barr 1989, Zwitserloot 1989), and the claims of low water consumption have been challenged.

In addition to the large water requirement, waste water load, and high energy requirements of the Martin system, the starch is admixed with pentosans that may adversely affect functional breadmaking properties (Meuser et al 1989). In the batter system (unlike the dough system), it is possible to obtain a high yield of a pure, large-granule A starch and a B starch fraction in which the small granules are admixed with pentosans. There is a good market and use for both fractions if they can be separated at high resolution and yield.

A process was patented (Wallace 1981) for the fractionation of wheat flour into starch (to be used in the production of fermentable sugars) and into a second, protein-enriched fraction (as a result of starch removal). The concept was evaluated by Pao-Wen et al (1983), who used three separation methods: the Fellers (1973) slurry method at high speed, the conventional Martin method, and a soft-dough method (hand-washing of a dough) (Shogren et al 1969). The protein contents in dry products from the slurry, Martin, and soft-dough fractionation methods were: 2.8 and 31.8%, 3.9 and 23.7%, and 6.0 and 20.0% in the starch fractions and protein-enriched fractions, respectively. Increases in the protein-enriched fractions ranged from 1.6 to 2.5 times that of the flour; the protein levels in the so-called prime starch fractions were prohibitive, especially for production of modified starches, certain industrial uses, and hydrolysis to monosaccharides.

The process we developed is based on a combination of dough development, sequential slurrying, and centrifugation at moderately low speeds. It is basically a closed system, all fractions of which can be utilized. A small amount of processing water is required. The objective was to produce a high-quality protein concentrate and prime starch by a combination of simple and rapid techniques. Further objectives were to design a system in which the yields are high and water requirements and waste water loads are low.

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MATERIALS AND METHODS

Flours

Five flours were used: three were milled from hard wheats and two from soft wheats. All were milled commercially or experimentally on a Bühler laboratory mill. Two batches each of both soft and hard wheat commercially milled flours (from the same mill and with a similar grist and approximately the same milling extraction) were obtained. The protein contents of the two hard wheat and the two soft wheat flours were the same within experimental error.

Moisture content, protein, ash, and free lipids (extracted with petroleum ether) of the flour were determined according to standard procedures (AACC 1983). Mixogram mixing time and water absorption were determined according to Finney and Shogren (1972). Alveograph parameters were determined according to Addo et al (1990). Amylograph parameters on 65 g of flour (14% mb) in 450 ml of water were determined according to Shuey and Tipples (1980). For some of the fractionation experiments, defatted flours were prepared by exhaustive extraction with chloroform, which is a more effective extractant for free lipids than petroleum ether and presumably does not impair breadmaking potential (MacRitchie 1985). For defatting, 300 g of flour was shaken three times (20 min each) with 600 ml of chloroform and filtered (Whatman no. 1 paper) between extractions. The defatted flour was spread on a tray under a hood and allowed to evaporate until no solvent odor was detected.

Fractionation

This study included three series of experiments, differing in time and the amount of water used for fractionation. Experiments in the first series required 1 hr for fractionation and were carried out on undefatted and defatted flour, each fractionated by water or salt solution as described below.

The flours (200 g, moisture-free basis, as is or defatted) were mixed into a dough in a mixer (National Mfg., Lincoln, NE) at 60% absorption (hard wheat flours) or 55% absorption (soft wheat flours) at 110 rpm for 2.5 min with either water or a 1% NaCl solution. The dough was kept at 15°C for 40 min in 200 ml of water or 1% NaCl. The combined dough and water or 1% NaCl solution was transferred to a blender with enough liquid to make the total 500 ml (including that used in dough mixing and soaking). The total weight was 700 g (200 g of flour and 500 ml of liquid). The dough was dispersed by vigorous (high-speed) blending (Osterizer, J. Oster Mfg., Milwaukee, WI) for 3 min and then centrifuging for 15 min at 2,500 rpm (1,500 × *g*). Those conditions were established after a series of preliminary investigations conducted on the original (nondefatted) flour. Six layers were separated manually from the bottom to the top of the centrifuge tube (Fig. 1). The bottom layer (*a*), containing

pure starch, was well-separated from a layer of insoluble fiber IF (*b*), the thickness of which depended on the flour type (hard or soft) and extraction rate. Next was a well-developed and easy-to-peel major, protein-rich second layer (*c*), and tailings starch (*d*), which could be washed out from the top of the protein layer (*c*) by a water or 1% NaCl stream. Finally, there were the WS (*e*) and the minor, top protein-rich, first layer (*f*).

In this article, proteins in fractions *c* and *f* are identified as first and second gluten layers, respectively, on the basis of solubility and electrophoretic studies (*unpublished data*). The fractions were protein-rich, but they did not meet the requirements of *Codex Alimentarius* (FAO 1987) for commercial gluten. The term *gluten* is used here to simplify presentation and discussion.

Fractions *b–f* were frozen and freeze-dried; fraction *a* was air-dried on trays at room temperature (about 21°C). Using a grinder (Udy Corp., Fort Collins, CO), fractions were ground once (fractions *a*, *b*, and *d*) or twice (fractions *c* and *f*) to pass a sieve with 0.25-mm, round openings. Fraction *e* was hand-ground in a mortar. All fractionation experiments were done seven to 10 times, using methods described by Czuchajowska and Pomeranz (1990, 1991), to obtain sufficient amounts of material for determining composition, physical and rheological characteristics, and end-use properties (*unpublished data*).

The next two series of experiments were intended to reduce the processing time and the amount of water in the system. In one series of experiments (conducted on two commercially milled flours from hard and soft wheats), the 40-min relaxation time was omitted. In the second series (conducted on four flours), relaxation was omitted and the flour-to-water ratio was reduced from 1:2.5 to 1:2.0. The flours in the third series were two laboratory-milled hard wheats and the two commercially milled wheats (hard and soft).

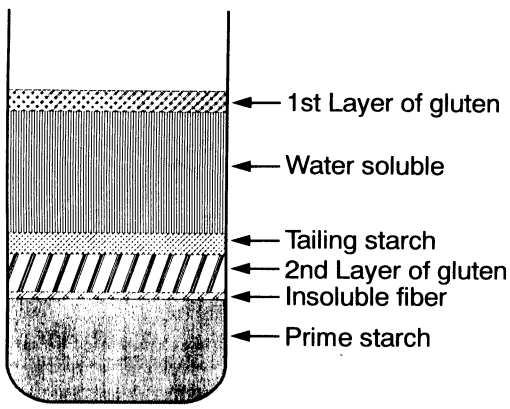

Fig. 1. Schematic presentation of layers obtained from fractionation.

The net result of the changes was a reduced amount of water and shortening of the process from about 1 hr to about 0.5 hr.

RESULTS

Flour Characteristics

Some compositional and rheological characteristics of flours are described in Table I. The hard wheat flours were higher in protein than the soft wheat flours; there were no consistent differences in ash or lipids. Mixing times, water absorption, and alveograph *P* and *W* values of the hard wheat flours were higher than the corresponding values of the soft wheat flours. The low-peak amylograph viscosity of the commercial hard wheat flour indicates that it probably was supplemented by malt.

Series 1 Experiments

Yields, protein, and ash (moisture-free basis) of fractions separated from the four flours (as is or defatted) with water or extracted with a 1% NaCl solution are given in Tables II–V. Yields of prime starch, as expected, were higher from the low-protein soft wheat flours than they were from the high-protein hard wheat flours. Defatting generally reduced the yields of prime starch. The use of a 1% NaCl solution instead of water had no consistent effect on yields of prime starch. Yields of tailings starch were higher from fractionation of hard wheat flours than they were from soft wheat flours. Defatting, or use of a 1% NaCl solution, generally produced higher amounts of tailings starch than nondefatted or water-separated fractions. The increase in yield of separated tailings in a 1% NaCl solution was due to high mineral (salt) contents. Similarly, the yields of WS and IF were affected by salt content. There was no consistent difference in yields of WS or IF among fractions isolated from hard wheat or soft wheat flours; defatting the flours increased the yields of WS and decreased the yields of IF.

Two protein-rich layers were formed: a minor one on top of the centrifuge tube (first gluten layer) and a major one between the tailings starch and IF (second gluten layer) (Figs. 1 and 2). No (or a small amount) first gluten layer was formed in dough separation from nondefatted flour with a 1% NaCl solution. As expected, the high-protein hard wheat flours produced larger amounts of gluten-rich layers than did the low-protein soft wheat flours.

In nondefatted flours, the yield of second gluten layer was higher than that of first gluten layer (Fig. 2A and B). In defatted flours (Fig. 2C and D), especially from hard wheats, the opposite was correct. Those yields must be evaluated, however, in the context of: the protein contents of those layers (Table II–V); total protein recovery (Table VI); and the presence of one versus two layers and their ease of separation. While the main objective was to obtain a gluten concentrate with a high protein content, a low

TABLE I
Some Compositional[a] and Physical Characteristics of Flours

Flour Types	Protein (N × 5.7) (%)	Ash (%)	Free Lipids (%)	Mixogram		Alveogram				Amylogram	
				Mixing Time (min)	Water Absorption (%)	*P*	*L*	*W*	*P/L*	Peak Temp. (°C)	Peak Viscosity (BU)
Laboratory-milled hard red spring wheat[b]	14.2	0.48	0.79	4:00	68.0	77	108	317	0.71	88.5	280
Laboratory-milled hard white spring[c] (cv. Klassic)	11.8	0.33	0.86	6:45	65.0	80	146	454	0.55	84.0	1,100
Commercial hard wheat	12.6	0.44	1.13	3:45	68.0	68	128	302	0.52	84.0	120
Laboratory-milled soft wheat[b]	9.5	0.43	1.24	1:50	58.0	43	123	116	0.35	89.3	800
Commercial soft wheat	8.9	0.48	1.02	3:00	57.0	44	98	117	0.45	89.3	450

[a] Expressed on a 14% moisture basis.
[b] 72% extraction.
[c] 60% extraction.

protein content in the starch was of equally great significance, especially as starch is the main flour component.

Protein concentrations in the prime starch fractions ranged from 0.6 to 0.8% and were not consistently affected by flour source or treatment (Tables II–V). Protein in the IF fractions ranged from 1.7 to 6.7% (mean 3.2%). The wide range probably reflects the ease or difficulty of separating the fraction from the neighboring low-protein starch and high-protein second gluten layer.

Similar considerations are probably valid, in part at least, for the tailings starch fraction, with a protein range of 5.6–34.8% (mean 14.0%). The mean protein in the tailings starch fraction was higher in doughs from soft wheat flours (17.8%) than in those from hard wheat flours (10.2%), which is a reflection of the better separation of the higher protein flours. Protein was higher in tailings from flours separated in 1% NaCl (mean 19.6%) than in water (8.4%) and higher in tailings from nondefatted flours (17.8%) than from defatted flours (10.2%). Apparently, a 1% salt solution softened the interphase between the second gluten layer and the tailings starch layer (Fig. 2B), which made separation of the two layers difficult. This was especially pronounced in soft wheat flours. The WS fractions were a consistent and rich

TABLE II
Yield, Protein, and Ash of Dough Fractions Obtained from a Laboratory-Milled Hard Wheat Flour[a]

	Nondefatted						Defatted					
	Water			1% NaCl Solution			Water			1% NaCl Solution		
Fractions	Yield	Protein[b]	Ash	Yield	Protein	Ash	Yield	Protein	Ash	Yield	Protein	Ash
First gluten layer	7.1	61.3	0.7	1.7	58.2	2.9	18.4	59.0	0.7	20.6	53.3	2.7
Water solubles	3.6	21.1	...	4.8	18.8	...	3.9	19.5	...	5.9	17.9	...
Tailings starch	5.0	7.5	1.1	4.0	20.5	21.4	6.9	7.1	1.0	6.2	8.0	15.0
Second gluten layer	21.8	47.4	0.6	22.6	54.2	2.5	11.3	33.2	0.5	8.9	30.0	2.1
Insoluble fiber	1.6	2.2	0.3	4.4	2.2	1.2	1.2	6.7	0.4	2.0	3.1	1.4
Prime starch	60.9	0.7	0.2	62.5	0.7	0.7	58.3	0.8	0.3	56.4	0.8	0.9

[a]%, expressed on a moisture free basis.
[b]N × 5.7.

TABLE III
Yield, Protein, and Ash of Dough Fractions Obtained from a Commercially Blended Hard Wheat Flour[a]

	Nondefatted						Defatted					
	Water			1% NaCl Solution			Water			1% NaCl Solution		
Fractions	Yield	Protein[b]	Ash	Yield	Protein	Ash	Yield	Protein	Ash	Yield	Protein	Ash
First gluten layer	3.1	61.2	0.7	0	...	...	17.9	54.6	0.6	20.3	49.5	2.0
Water solubles	4.3	17.5	...	5.5	17.1	...	4.4	16.9	...	5.7	16.3	...
Tailings starch	6.2	6.9	1.1	4.7	18.2	18.2	9.7	6.1	0.8	8.6	7.1	9.6
Second gluten layer	21.7	50.5	0.7	21.6	54.2	2.5	10.6	35.2	0.5	8.0	25.5	1.6
Insoluble fiber	2.9	2.6	0.4	5.9	1.7	1.2	0.9	3.1	...	3.7	3.4	1.1
Prime starch	61.8	0.6	0.2	62.3	0.7	0.7	56.5	0.8	0.2	53.7	0.8	0.7

[a]%, expressed on a moisture free basis.
[b]N × 5.7.

TABLE IV
Yield, Protein, and Ash of Dough Fractions Obtained from Laboratory-Milled Soft Wheat Flour[a]

	Nondefatted						Defatted					
	Water			1% NaCl Solution			Water			1% NaCl Solution		
Fractions	Yield	Protein[b]	Ash	Yield	Protein	Ash	Yield	Protein	Ash	Yield	Protein	Ash
First gluten layer	3.2	56.4	0.8	0	...	...	10.1	48.0	0.7	6.6	47.7	1.7
Water solubles	3.6	21.3	...	5.1	19.1	...	4.4	20.4	...	5.5	18.8	...
Tailings starch	3.5	11.6	1.2	2.8	29.5	19.1	6.7	5.6	0.9	3.9	14.9	8.9
Second gluten layer	13.6	52.9	0.8	15.4	52.2	2.8	13.2	36.2	0.6	12.5	40.5	1.9
Insoluble fiber	2.7	5.1	0.4	3.9	2.4	1.2	0.8	2.8	...	3.2	4.7	1.2
Prime starch	73.4	0.6	0.2	72.8	0.7	0.7	64.8	0.7	0.2	68.3	0.7	0.7

[a]%, expressed on a moisture free basis.
[b]N × 5.7.

TABLE V
Yield, Protein, and Ash of Dough Fractions Obtained from Commercially Blended Soft Wheat Flour[a]

	Nondefatted						Defatted					
	Water			1% NaCl Solution			Water			1% NaCl Solution		
Fractions	Yield	Protein[b]	Ash	Yield	Protein	Ash	Yield	Protein	Ash	Yield	Protein	Ash
First gluten layer	1.8	54.6	0.7	0	...	...	5.6	51.8	0.6	5.3	54.4	1.8
Water solubles	3.7	18.3	...	4.8	16.5	...	4.2	17.8	...	5.8	16.7	...
Tailings starch	3.0	13.7	1.8	3.8	34.8	18.1	5.3	8.8	1.2	3.2	23.7	10.9
Second gluten layer	12.8	57.8	0.8	13.2	54.4	3.4	12.3	44.9	0.6	9.9	48.6	2.7
Insoluble fiber	3.6	4.1	0.5	6.3	1.9	1.2	2.1	2.3	0.4	3.4	3.7	1.2
Prime starch	75.1	0.7	0.2	71.9	0.7	0.7	70.5	0.6	0.2	72.1	0.7	0.6

[a]%, expressed on a moisture free basis.
[b]N × 5.7.

source of protein (range: 16.3–21.3, mean 18.4%, dmb). WS from nondefatted flours contained more protein (mean 18.7%) than did WS from defatted flours (18.0%); WS from flours separated with water (19.1%) contained more protein than did WS from flours separated with 1% NaCl (17.7%).

The highest protein concentrations were recorded in the first gluten layers; they ranged from 47.7 to 61.3% (mean 54.6%). Mean protein was higher in the first gluten layer of high-protein flour doughs (56.7%) than it was in low-protein flour doughs (52.2%). Neither defatting nor replacing water with a 1% NaCl solution increased the protein content of the first gluten layer. The second gluten layer varied widely in protein content (25.5–57.8%); defatting, consistently lowered the protein content. Replacing water with a 1% NaCl solution increased the protein content of the gluten layer from nondefatted hard wheat flours but not from soft wheat flours.

As stated before, the yields of layers and distribution of protein in those layers should also be evaluated from the standpoint of protein (as a percentage of that in the flour) recovered in the gluten layers. The results are summarized in Table VI. Total flour protein recoveries were higher in fractionated high-protein hard wheat flours (mean 87.5%) than they were in low-protein soft wheat flours (80.2%). The difference reflects, in part at least, differences in WS proteins among the flours. In no case did replacing water with a 1% NaCl solution improve the total recovery. Defatting generally improved total recovery in the gluten fractions. The improvement in recovery was accompanied, however, by the formation of a large, relatively low-protein fraction (Tables II–V). It is therefore debatable to what extent this improvement in yield is an actual processing and marketing benefit. Increasing the dough mixing time to 10 min, the dough dispersion time to 5 min, or the centrifugation speed to 2,000 × *g* did not improve yields or quality of fractions (*unpublished data*).

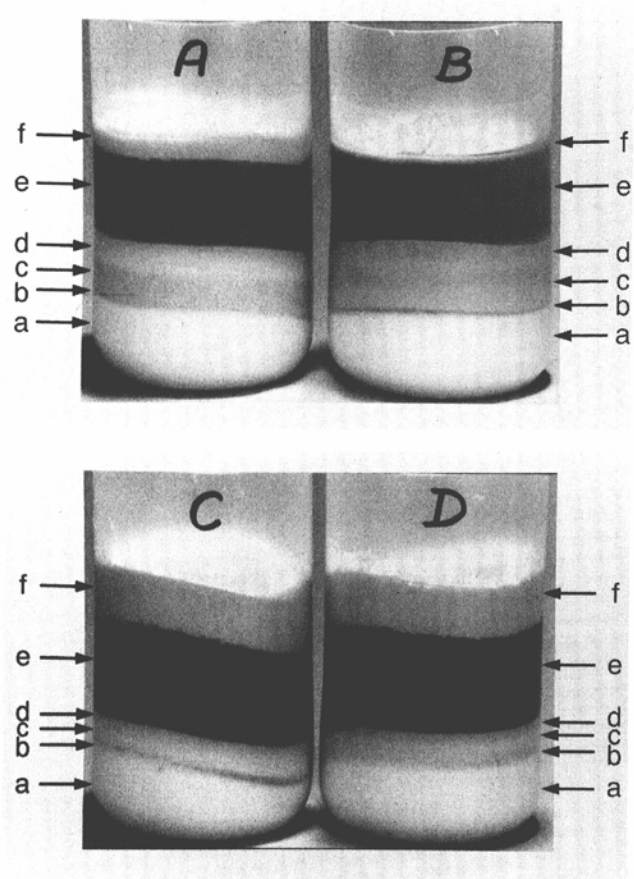

Fig. 2. Layers obtained after fractionation of laboratory-milled hard wheat flour using extraction with water (**A**) and extraction with 1% NaCl (**B**). Layers obtained after extraction of defatted flour with water (**C**) and extraction of defatted flour with 1% NaCl (**D**). From bottom to top: **a,** prime starch; **b,** insoluble fiber; **c,** major (second) gluten layer; **d,** tailing starch; **e,** water solubles; **f,** minor (first) gluten layer.

Series 2 and 3 Experiments

The data for the effects that a) eliminating relaxation and b) reducing the amount of water plus eliminating relaxation has on yield and on protein content are summarized in Tables VII

TABLE VI
Recovery of Protein (% of flour) in Gluten-Rich Fractions

Flour	Gluten Layer		Combined
	First	Second	
Hard wheat, laboratory-milled			
As is			
Water	26.7	63.4	90.1
1% NaCl	6.5	79.5	86.0
Defatted			
Water	66.2	22.8	89.0
1% NaCl	70.0	16.9	86.9
Hard wheat, commercial			
As is			
Water	13.1	75.5	88.6
1% NaCl	0	84.6	84.6
Defatted			
Water	65.7	25.1	90.8
1% NaCl	71.0	14.3	85.3
Soft wheat, laboratory-milled			
As is			
Water	9.8	73.1	82.9
1% NaCl	0	72.7	72.7
Defatted			
Water	28.7	54.5	83.2
1% NaCl	28.5	47.9	76.4
Soft wheat, commercial			
As is			
Water	16.6	66.7	83.3
1% NaCl	0	77.2	77.2
Defatted			
Water	43.9	43.5	87.4
1% NaCl	30.1	48.5	78.6

TABLE VII
Effect of Eliminating Relaxation on Yield of Fractions and Protein Contents[a] from Commercial Wheat Flours

Fraction	Hard Wheat				Soft Wheat			
	Yield, %		Protein, %		Yield, %		Protein, %	
	Relaxed	Not Relaxed	Relaxed	Not Relaxed	Relaxed	Not Relaxed	Relaxed	Not Relaxed
First gluten layer	2.5 A	5.9 B	58.6 A	60.4 A	2.2 B	4.5 A	54.8 A	57.1 A
Water solubles	3.9 A	3.8 A	20.4 B	21.5 A	3.9 A	4.0 A	20.1 B	21.3 A
Tailings starch	4.1 B	5.6 A	8.6 A	7.7 A	3.4 A	3.7 A	12.1 A	10.1 B
Second gluten layer	22.0 A	19.6 B	52.2 A	46.9 B	15.4 A	14.6 B	55.4 A	50.1 B
Insoluble fiber	4.5 A	4.0 A	3.6 A	2.4 A	4.9 A	4.8 A	4.7 A	4.3 A
Prime starch	63.0 A	60.9 A	0.8 A	0.7 A	70.0 A	68.3 A	0.7 A	0.7 A

[a]Values with different letters for the same flour and the same determination between relaxed and not relaxed material are significantly different at the 5% level.

TABLE VIII
Effect of Eliminating Relaxation and Reducing Water-to-Flour Ratio on Percentages of Yields of Fractions and Protein Contents

	Commercial Flour				Laboratory-Milled Flour			
	Hard		Soft		Hard Red Spring		Hard White Spring	
Fraction	Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein
First gluten layer	1.9	67.0	1.8	66.9	10.2	60.3	1.1	66.2
Water solubles	3.1	20.2	3.2	21.1	2.3	22.0	2.3	25.5
Tailings starch	5.6	9.5	3.5	19.0	5.9	14.2	3.2	12.9
Second gluten layer	24.2	48.1	15.6	52.5	22.4	37.6	19.7	57.7
Insoluble fiber	4.2	2.1	4.5	4.1	...	...	2.0	1.1
Prime starch	60.0	0.8	71.7	0.7	59.2	0.7	71.8	0.6

TABLE IX
Wet Weight and Dry Weight (grams per 100 g of flour) of Fractions from Separation of Flours by Water

	Hard Wheat				Soft Wheat			
	Laboratory-Milled		Commercially Milled		Laboratory-Milled		Commercially Milled	
Fraction	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.
First gluten layer	15.1	6.8	10.9	3.1	8.6	3.2	6.2	1.8
Water solubles	116.0	3.4	120.5	4.2	146.1	3.6	132.9	3.7
Tailing starch	40.1	4.8	41.3	6.1	22.4	3.4	35.9	3.0
Second gluten layer	65.8	20.9	60.2	21.5	34.0	13.4	37.2	12.7
Insoluble fiber	2.3	1.5	5.0	2.9	8.7	2.7	7.2	3.6
Prime starch	97.9	58.3	96.4	61.1	121.1	72.6	123.9	74.4
Total	337.7	95.7	334.2	98.9	340.9	98.9	343.4	99.2

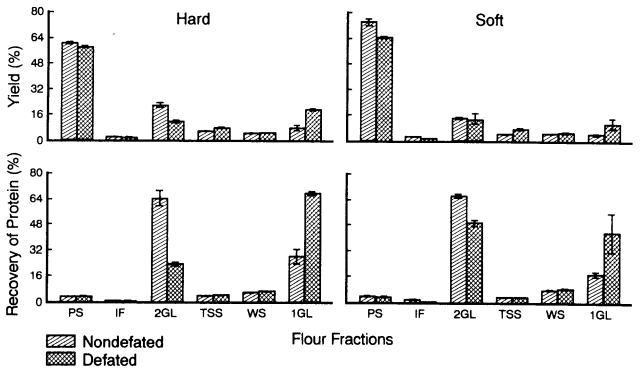

Fig. 3. Effect of flour defatting on yield and protein recovery in layers obtained during fractionation of laboratory-milled hard and soft wheat flours. PS = prime starch, IF = insoluble fiber, 2GL = major (second) gluten layer, TSS = tailings starch, WS = water solubles, 1GL = minor (first) gluten layer.

and VIII, respectively. The data in these two tables were obtained from fractionating the second batches of the two commercial flours.

A comparison of the yield and protein content of the fractions of hard wheat flour obtained with and without relaxation is shown in Table VIII. Under both conditions, most of the protein was recovered in two layers. Elimination of relaxation significantly increased the yield of the first layer, at the expense of the second layer. Yield of prime starch was unaffected. Dough relaxation did not affect the general fractionation patterns, total protein recovery, or protein contents of the starch fraction. However, eliminating relaxation lowered the protein content in the second gluten layer.

Neither relaxation nor reduction of total water impaired the layering and ease of separation of the layers. On the average, 90% of the flour dry matter was recovered by the prime starch and gluten layers. In three of the four flours, the yield of the first gluten layer was only 1.1–1.9%; a predominant part of the protein was recovered in the second gluten layer. The laboratory-milled HRS wheat flour was an exception; the yield of the first gluten layer was as high as 10.2% (Table VIII), had the highest absorption (68%), and had an unusual pattern of hydration. It behaved like a wet dough throughout the mixing and absorbed water until the end of development.

The hard white spring wheat (cv. Klassic) flour produced only 1.1% of the first gluten layer; it had the highest protein (57.7%) in the second gluten layer and the lowest protein in the prime starch (0.56%). Total protein recoveries by the protein-rich layers for all flours ranged from 81.6 to 90.8%, an excellent result for a short and simple procedure. The prime starch contained about 3% of the total protein.

Distribution of Water

The final consideration, with regard to the proposed method of flour fractionation, concerns the amounts of water that must be evaporated to produce a dry, storable product when desired. This is of particular significance for the removal of water in the WS fraction.

The distribution of water in fractions from separation of the four flours in an aqueous system, in which the ratio of water to flour was 2.5 to 1, is summarized in Table IX. Ranges and means of dry matter (percentage basis calculated from data in Table IX) in the fractions are: first gluten layer, 29.03–40.40% (mean 33.77); WS, 2.46–3.49% (2.92); tailings, 8.36–15.18% (9.75); second gluten layer, 31.76–39.41% (35.26); IF, 31.03–65.22% (51.06); and starch, 59.55–63.38% (60.73). The dry matter in the combined fractions was 28.34–29.59%; average for the four flours was 28.96% compared to the calculated value of 28.57%. Thus, the two main fractions, prime starch and gluten, contained, on the average, 39.3 and 65.5% water, respectively. The IF fraction is dry and the tailings fraction binds a large amount of water. Although the WS fraction contains as much as 97% water, its dry matter content is higher than that in the WS fractions from high-water-load fractionation techniques.

The reduction of the ratio of water to flour from 2.5:1 to 2.0:1 significantly lowered (by 30–38%) the amount of the WS fraction, but it did not affect the other fractions. Reduction of the WS fraction is of particular interest because of the energy required to remove water from this layer.

DISCUSSION AND CONCLUSIONS

Both low-protein soft wheat and high-protein hard wheat flours can be used for fractionation. The protein contents of the prime starch (yields of up to 70% of dry matter recovered) were 0.6–0.8%.

The gluten-rich fraction contained up to 5.4 times the protein of the original flours. The yields of products (fractions) and protein recoveries in those fractions for the two laboratory-milled flours are depicted graphically in Figure 3.

Some of the products of fractionation can be used (without drying) as part of a system for production of baked goods that require high gluten levels (such as hearth-baked bread, specialty breads, and high-fiber breads) or for general low-protein flour enrichment. In addition, part of the system (i.e., the prime starch) can be used for production of baked products that require low protein levels (such as cookies, cakes, confectionery, etc.). The use of the fractionation products in the combined plant could reduce substantially the energy cost and better retain the functional properties of gluten proteins. Those properties could be further enhanced by interaction-incorporation of additives (emulsifiers). The WS fraction could be used for feed, microbiological processing, pharmaceuticals, or general industrial purposes.

We were gratified to find that the best (most effective and simplest) method for fractionation was obtained for the water extraction. A somewhat better separation was obtained when a 0.5% NaCl (rather than a 1% NaCl) solution was used, but both were inferior to water alone, especially in soft wheat flours (*data not reported here*). Defatting the flour before fractionation resulted in large changes in separation results, but the effects on biochemical and physico-chemical characteristics, and especially breadmaking potential, were basically deleterious (*to be reported elsewhere*) and are, therefore, of limited practical value.

Note that omitting dough relaxation did not impair the recovery of proteins in gluten layers or the yield and the purity of prime starch. Reducing the amount of water in the system still resulted in a good fractionation, while it substantially decreased the WS layer. The gluten fractions recovered from 80–90% of the total proteins of the flour.

Finally, our fast and simple laboratory technique seems to have potential for fractionation on a large scale. It could also assist the gluten industry at large, which uses a plethora of fractionation techniques to screen flours for production of gluten or protein concentrates. In the latter case, our technique can serve as a tool to evaluate the suitability of a flour for industrial separation into gluten and prime starch.

ACKNOWLEDGMENT

We gratefully acknowledge the financial support of the Washington Wheat Commission.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 08-01, approved April 1961, revised October 1981; Method 30-25, approved April 1961, revised October 1976, October 1981, October 1991; Method 44-15A, approved October 1975, revised October 1981; Method 46-11A, approved October 1976, revised October 1982, September 1985. The Association: St. Paul, MN.

ADDO, K., COAHRAN, D. R., and POMERANZ, Y. 1990. A new parameter related to loaf volume based on the first derivative of the alveograph curve. Cereal Chem. 67:64.

BARR, D. J. 1989. The engineering of a modern wheat starch process. Pages 502-508 in: Wheat is Unique. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

CZUCHAJOWSKA, Z., and POMERANZ, Y. 1990. Quest for a universal test of commercial gluten quality for breadmaking. Cereal Foods World 35:458.

CZUCHAJOWSKA, Z., and POMERANZ, Y. 1991. Evaluation of vital dry gluten composition and functionality in breadmaking by near-infrared reflectance spectroscopy. Cereal Foods World 36:439.

FAO. 1987. Codex Alimentarius. CX 5/90.2. CL 1987/33-VP. Food and Agriculture Organization: Rome.

FELLERS, D. A. 1973. Fractionation of wheat into major components. Pages 207-228 in: Industrial Uses of Cereals. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

FINNEY, K. F., and SHOGREN, M. D. 1972. A ten-gram mixograph for determining and predicting functional properties of wheat flours. Baker's Dig. 46(2):32.

GODON, B., LeBLANC, M.-P., and POPINEAU, Y. 1983. A small scale device for wheat gluten separation. Qual. Plant. Plant Foods Hum. Nutr. 33:161.

KEMPF, W., and RÖHRMANN, C. 1989. Process for the industrial production of wheat starch from whole wheat. Pages 521-540 in: Wheat is Unique. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

MacRITCHIE, F. 1985. Studies of the methodology for fractionation and reconstitution of wheat flour. J. Cereal Sci. 3:221.

MEUSER, F., ALTHOFF, F., and HUSTER, H. 1989. Developments in the extraction of starch and gluten from wheat flour and wheat kernels. Pages 479-500 in: Wheat is Unique. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

PAO-WEN, SEIB, P. A., HOSENEY, R. C., and LIANG, Y. T. 1983. Breadmaking integrated with wet-processing of wheat flour. Milling & Baking News March 8, 1983. BD-10-15, 20.

POMERANZ, Y. 1961. "Peeling" of wheat kernels. Cereal Science Today 6:76.

SARKKI, M.-L. 1979. Wheat gluten. Pages 155-169 in: Cereals for Food and Beverages. G. F. Inglett and L. Munck, eds. Academic Press: New York.

SHOGREN, M. D., FINNEY, K. F., and HOSENEY, R. C. 1969. Functional (breadmaking) and biochemical properties of wheat flour components. I. Solubilizing gluten and flour protein. Cereal Chem. 46:93.

SHUEY, W. C., and TIPPLES, K. H. 1980. The Amylograph Handbook. Pages 12-24. Am. Assoc. Cereal Chem.: St. Paul, MN.

WALLACE, L. C. 1981. U.S. Patent 4,248,896 (cited in Pao-Wen et al 1983).

ZWITSERLOOT, W. R. M. 1989. Production of wheat starch and gluten: Historical review and development into a new approach. Pages 509-520 in: Wheat is Unique. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

[Received January 5, 1993. Accepted August 25, 1993.]