PROTEIN CONCENTRATES BY DRY MILLING OF WHEAT MILLFEEDS[1]

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ABSTRACT

Milling and sifting wheat millfeeds gave flours high in protein, low in fiber, and suitable for use in food products. Coarse bran, fine bran, and shorts, at various moisture levels (3 to 17%), were milled three times on the reduction rolls of a Brabender Quadrumat Senior flour mill. The flour fractions, which were sifted out after each milling, were analyzed for protein, fat, starch, total sugars, ash, pentosans, and fiber. Flour yields were highest from shorts and lowest from coarse bran. Compared to the millfeeds, the flour fractions were considerably richer in protein and starch and slightly higher in total sugars and fat but lower in fiber, pentosan, and ash. Coarse bran, fine bran, and shorts, when recombined in proportions similar to plant output, gave considerably less flour than that of the separately milled components. Flour yields were greatest at the lower moisture levels (3 to 7%), but substantially higher levels of protein and starch and lower levels of fiber, pentosan, and ash were obtained at 9 to 11% moisture. Yields of flour at higher moisture levels (13 to 17%) were lowest and, though fiber was further reduced slightly, protein content was also reduced.

Considerable interest, of late, has been displayed in the upgrading and conversion of wheat millfeeds to products of greater stature, value, and market stability (1,2). Since millfeeds contain substantial quantities of good-quality protein (3), it seems natural to tie in the problem of millfeed upgrading with the emphasis on increasing the world supply of protein-rich foods. The objective in the present work has been

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to process millfeeds to produce high-protein, low-fiber products suitable for use in foods for man.

In milling wheat for production of flour, it is generally recognized that as the percent flour extracted increases, protein content of the flour increases (4,5). The reason is associated with the protein anatomy of the wheat kernel and the mechanical properties of the various tissues at the moisture content of the wheat during milling.

Hinton (6), working with a soft wheat of 8% protein, found the following protein concentrations in dissected wheat: pericarp plus testa, 4%; aleurone, 18%; outer endosperm, 12.5%; middle endosperm, 8%; innermost endosperm, 6%. Other workers (5,7,8) have also observed this phenomenon.

In the milling of wheat, the separation of starchy endosperm is not perfect; and some of the outer starchy endosperm adheres to the bran particles (bran includes aleurone). Because this outer endosperm has a high protein content, further milling produces a flour of higher protein concentration than the flour produced from the relatively more easily separated inner endosperm. In addition, if milling is carried still further, the high-protein aleurone cells will be broken down, causing release of their contents and thereby augmenting the production of a flour high in protein but with considerably more ash, fiber, pentosan, and fat (9).

From the information available, it appeared that milling of millfeeds should provide a simple method of producing flour fractions high in protein and low in fiber.

Some 5 million tons of millfeeds containing about 800,000 tons of good-quality protein are produced in the United States each year. A 30% recovery of these millfeeds would provide enough food to feed each resident of New York City one pound of product each day for a year. When one considers the world production of millfeeds, the amount of additional food that would be available for the world from this source is indeed impressive.

Materials and Methods

Millfeeds. A Montana hard red spring wheat blend was commercially milled to yield the products described in Table I.

Values for starch may be somewhat low for samples with high pentosan content, because the levorotatory effect of pentosans in the calcium chloride extraction solution diminishes the total dextrorotatory effect contributed by the starch (10).

Moisture Adjustment. A quantity of coarse bran (CB) was thoroughly mixed to provide a uniform sample. It was then divided into

TABLE I
PROXIMATE CHEMICAL COMPOSITION OF A HRS WHEAT AND ITS MILLING PRODUCTS (DRY BASIS)

	HRS WHEAT	COARSE BRAN	FINE BRAN	SHORTS	FEED MIDDLINGS	STRAIGHT-RUN FLOUR
	%	%	%	%	%	%
Protein (N × 5.7)	18.3	19.2	20.6	20.9	19.5	17.8
Fiber	2.5	12.6	10.5	8.5	4.4	0.3
Fat	1.9	5.5	6.3	6.9	4.4	1.0
Ash	1.9	6.9	6.2	5.2	3.3	0.6
Total sugars	2.9	6.1	7.1	7.3	5.7	2.3
Starch	58.8	5.8[a]	10.0[a]	15.9[a]	37.7[a]	74.5
Pentosans	6.6	27.1	24.5	19.7	12.6	1.7
Undetermined	7.1	16.8	14.8	15.6	12.4	1.8
Percent of whole wheat	100.0	10.4	6.3	8.4	2.4	72.5

[a] Values may be somewhat low (1–2%) because of levorotatory effect of high pentosan content.

a number of approximately 1,000-g. batches and each batch was placed in a can. The same process was used for fine bran (FB), shorts (SH), and a combination (mix) of CB, FB, and SH in the proportions (similar to commercial plant output) of 42:25:33 respectively.

The 1,000-g. batches were adjusted to the desired moisture levels as follows: A vacuum dryer operated at room temperature was used to reduce moisture. To increase moisture, a fine mist was sprayed onto the material during mixing. Each sample was then replaced in the can and allowed to equilibrate 24 hr. or more. Samples were made up at 3, 5, 7, 9, 11, 13, 15, and 17% moisture. Moistures were adjusted to within ± 0.2%.

Milling Procedure. A millfeed sample at a particular moisture level was divided into two 500-g. samples. The corrugated, differential-speed reduction rolls and sifting system of a Brabender Quadrumat Senior flour mill were used for milling and sifting. The first 500-g. sample was used to condition the mill. The material was fed by hand at the maximum practicable rate. After the last of the material was fed, the sifting system was allowed to run 8 min. additional to clear the screens. This was done in all subsequent millings. All the conditioning fractions were discarded. Next, the second 500-g. sample was fed to the reduction rolls in the same manner. Two products were produced, a flour (through 7xx bolting cloth) and a coarse residue. The coarse residue was then remilled to yield a second milling flour and a coarse residue. This coarse residue was again remilled to yield a third milling flour and the final coarse residue. All samples were weighed and placed in airtight containers. The total weight of products collected agreed in all cases within 10 g. of the 500 g. of starting sample.

The use of feed middlings in the system described resulted in no fractionation; therefore, further work with this millfeed fraction was omitted.

Analytical. Moisture and nitrogen were run on all samples of flour and coarse residue. Analyses for fiber, fat, ash, total sugars as glucose, starch, and pentosan were run on the flours produced from 5-, 9-, and 13%-moisture samples. Starch was determined by the polarimetric method of Clendenning (10), pentosans by the method of Adams and Castagne (11), and nitrogen, fat, ash, fiber, and total sugars as glucose (invertase converted) by the Official Methods of Analysis of the AOAC (12). Moisture was determined by the hot-air-oven method at 130°C. for 1 hr. All composition and yield results are on a moisture-free basis.

Results and Discussion

Flour Yields. Table II presents the yields of flour obtained from the various millfeeds at the different moisture levels investigated. Generally, yields were highest at lowest moisture level of the millfeed before milling, though the increase in yield below 7% moisture was small. Of particular interest in the case of coarse bran (CB), fine bran (FB), and shorts (SH) was the sharp increase in flour yield as moisture levels were reduced from 11 to 9%. This suggests some critical point or zone of increasing friability.

Comparing the different millfeeds, one readily notes that SH yielded more flour than FB and FB more than CB, as might be expected from their respective original starch contents (Table I). The magnitude of difference at any one moisture level was such that FB yielded about 0.75 as much flour as SH, and CB 0.6 as much.

Factors affecting yield were the type of millfeed, moisture content of the millfeed before milling, and the number of millings. Another probable factor not considered here is the type of mill and rolls.

One surprising observation was that the mix (CB, FB, SH) tended to give flour yields approximating that of CB, whereas the predicted yields based on the weighted averages of the components indicated a flour yield more closely approximating that of FB or slightly higher. Therefore, particle-size distribution of the millfeed must be added to the list of factors affecting flour yield.

Protein Distribution. Table III gives the protein content of the flours described in Table II. As expected, the protein contents of the flours were higher than that of the standard white flour (Table I) and, in fact, were considerably higher than that of the millfeed itself. The protein content varied with the moisture content of the millfeed before milling. The range of protein content for flours from SH was 23.6 to

TABLE II

Yields of Flour from Millfeeds at Various Moisture Levels[a]

Moisture before Milling	Shorts				Fine Bran				Coarse Bran				Mix			
	1	2	3	T	1	2	3	T	1	2	3	T	1	2	3	T
%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
3	35.1	12.0	6.4	53.5	25.4	11.1	5.3	41.8	19.2	8.0	5.0	32.2				
5	34.3	12.6	7.3	54.2	23.3	8.2	5.2	36.7	19.5	6.4	4.6	30.5	19.5	7.4	4.8	31.7
7	32.4	11.5	6.7	50.6	23.6	8.2	4.8	36.6	20.6	6.2	3.5	30.3				
9	31.9	10.7	6.2	48.8	21.1	7.9	4.7	33.7	17.7	6.1	4.1	27.9	17.2	7.0	4.0	28.2
11	21.8	6.9	5.8	34.5	13.8	7.0	4.8	25.6	10.7	4.5	4.2	19.4				
13	16.1	9.4	7.0	32.5	13.3	6.4	5.8	25.5	9.0	6.7	3.2	18.9	12.1	5.4	4.4	21.9
15	12.2	6.2	5.3	23.7	10.5	4.9	3.3	18.7	8.9	4.3	2.6	15.8				
17	9.8	5.8	4.4	20.0	7.8	3.7	3.6	15.1								

[a] Legend: 1 = 1st milling; 2 = 2nd milling; 3 = 3rd milling; T = total flour yield of all millings. Mix = 42% coarse bran, 25% fine bran, 33% shorts.

TABLE III

Protein Content of Flours from Millfeeds at Various Moisture Levels

Moisture before Milling	Shorts				Fine Bran				Coarse Bran				Mix			
	1	2	3	T	1	2	3	T	1	2	3	T	1	2	3	T
%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
3	24.9	24.1	22.4	24.4	27.1	24.9	22.8	25.9	28.6	26.2	23.0	27.1				
5	25.0	23.6	22.5	24.3	28.5	26.4	24.7	27.5	28.9	26.4	21.5	27.3	27.7	26.1	24.6	26.8
7	25.4	24.2	22.6	24.8	29.2	27.0	24.6	28.1	27.8	26.5	27.0	27.5				
9	26.2	24.3	22.7	25.3	29.6	27.5	25.8	28.6	29.5	27.1	25.4	28.4	28.6	27.4	26.0	28.0
11	26.2	26.8	26.7	26.4	30.1	30.3	26.2	29.4	32.1	31.5	31.0	31.7				
13	25.1	26.4	25.8	25.6	29.3	31.0	30.8	30.0	32.6	32.8	33.1	32.7	28.1	28.9	29.2	28.5
15	23.8	24.5	22.2	23.6	29.0	30.1	30.8	29.9	31.8	32.6	33.4	32.2				
17	23.8	23.6	24.2	23.8	29.4	28.9	29.1	29.2								

[a] Legend: 1 = 1st milling; 2 = 2nd milling; 3 = 3rd milling; T = total flour yield of all millings. Mix = 42% coarse bran, 25% fine bran, 33% shorts.

26.4%, with a maximum level at 9 to 11% moisture. For FB the range was 25.9 to 30.1%, with a maximum level at 11 to 13% moisture. CB displayed a range of 27.1 to 32.7%, with a maximum at 13% moisture.

The greatest concentration of protein occurred with CB and the least with SH. A comparison of the protein content of a millfeed with the maximum protein content of the flour from that millfeed shows that there was a 70% increase in protein content of the flour from CB, a 46% increase for FB, and a 26% increase for SH.

As a result of the concentration of protein, protein yields (percentage of millfeed protein recovered in the flours) were somewhat higher than flour yields. Figure 1 depicts the protein yields obtained from SH

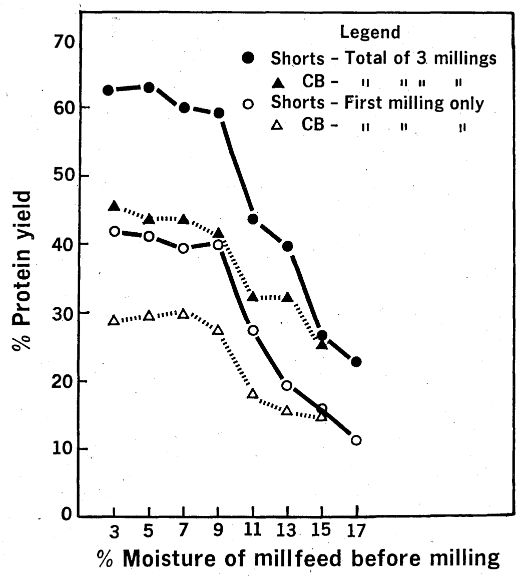

Fig. 1. Yield of protein in flour fractions produced by milling shorts and coarse bran at various moisture levels.

and CB at the various moisture levels. Protein yields are shown for one milling as well as the cumulative yields from three millings. FB protein yields were intermediate.

Fiber and Other Components. An aspect as important as protein concentration is fiber reduction, if the product is to have use in human foods. Table IV lists the analytical data on crude fiber, pentosan, ash, crude fat, total sugars as glucose, and starch on a number of the flours milled. The flours produced from each of the millfeeds were substantially reduced in fiber and pentosan content and somewhat reduced in

TABLE IV
EFFECT OF MILLFEED MOISTURE CONTENT ON COMPOSITION (OTHER THAN PROTEIN) OF THE FLOURS PRODUCED

MILLING No.	MOISTURE OF MILLFEED BEFORE MILLING								
	Shorts			Fine Bran			Coarse Bran		
	5	9	13	5	9	13	5	9	13
	%	%	%	%	%	%	%	%	%
				Fiber					
1	3.3	2.5	2.4	3.5	3.2	3.4	4.7	5.3	2.8
2	5.2	4.5	2.7	5.5	4.7	3.1	7.0	5.4	3.1
3	7.6	5.7	3.4	6.6	6.1	4.2	8.3	6.9	3.8
T	4.3	3.3	2.7	4.4	4.0	3.5	5.7	5.6	3.1
				Pentosan					
1	8.0	8.0	4.8	8.0	6.5	6.0	9.4	7.7	4.8
2	11.2	10.4	6.5	8.8	9.7	5.5	15.7	7.7	5.3
3	15.4	14.3	7.2	12.5	12.5	6.8	18.8	10.7	8.0
T	9.7	9.3	5.8	8.8	8.1	6.1	12.1	8.1	5.5
				Ash					
1	4.1	4.2	3.6	4.4	4.5	4.1	4.9	5.2	4.1
2	4.3	4.3	4.3	4.8	4.7	4.5	5.6	5.3	6.4
3	4.8	4.5	4.6	5.1	5.2	5.1	6.1	6.0	5.2
T	4.2	4.3	4.0	4.6	4.6	4.4	5.2	5.3	5.1
				Fat					
1	7.1	7.2	6.3	7.4	7.6	6.4	5.6	6.0	4.8
2	6.8	6.9	7.4	7.1	6.9	7.4	5.5	5.5	5.2
3	6.7	6.6	7.7	6.6	6.6	8.2	5.6	5.6	5.9
T	7.0	7.1	6.9	7.2	7.3	7.1	5.6	5.8	5.1
				Total Sugars					
1	9.4	9.9	7.5	11.4	10.2	8.4	8.0	9.1	6.1
2	8.4	6.3	9.3	9.3	9.2	10.0	7.3	7.6	6.8
3	7.9	7.9	10.0	8.4	8.4	11.4	6.6	7.0	8.8
T	9.0	8.9	8.6	10.5	10.3	9.5	7.6	8.5	6.8
				Starch					
1	30.3	32.7	41.3	27.5	28.3	33.0	25.4	25.8	35.0
2	23.1	25.0	33.6	20.6	22.1	27.5	18.5	22.1	32.9
3	18.1	21.0	28.4	12.5	18.0	21.6	13.9	17.3	26.2
T	27.0	29.5	36.3	23.8	25.4	29.0	22.2	23.7	32.8

[a] Legend: 1 = 1st milling; 2 = 2nd milling; 3 = 3rd milling; T = total flour of all millings.

ash. Starch was increased greatly in all the flours; generally, total sugars were increased moderately and fat slightly.

Figure 2 shows how the composition of SH flours (first milling; milled at various moisture levels) compares with that of the original SH (Table I). Fiber, pentosan, and ash contents decreased as moisture content of SH increased (3 to 17%), whereas starch content increased. On the other hand, protein, fat, and total sugars tended to go through an optimum or peak condition. These peaks did not occur at the same moisture level; thus for SH, the protein peak appeared between 9 and

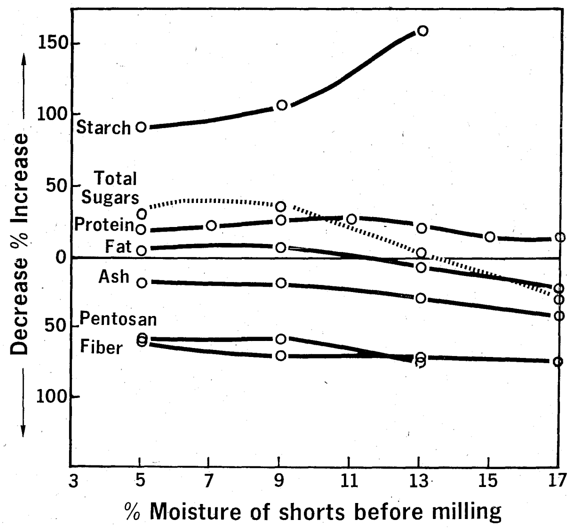

Fig. 2. Change in proximate composition of shorts flours (first milling) from that of the original shorts.

11% moisture, while the fat and total sugar peaks were somewhat lower, at 7 to 9% moisture. These peaks must occur because of a preferential rate of breakdown of the tissues high in these components at the particular moisture level.

From the standpoint of change in composition of the millfeed flours with change in milling conditions and from the standpoint of desirable product composition, fiber, protein, and starch are important components. Pentosan also varies greatly, but the analytical procedure is tedious. Furthermore, the trend in pentosan results is adequately described by the fiber results. Ash, which is a widely used quality indicator for white flours, has little value in differentiating between the various millfeed flours, which were all comparatively high in ash.

Figure 3 shows how fiber, protein, starch content, and yield of flour from the first milling of SH differed at various moisture levels. Figure 4 gives the same information for the combined flours from three millings of SH. As can be seen, both yield and fiber increased as moisture of the millfeed before milling decreased. If one sets a maximum fiber level tolerable in the flour product, one can then determine the possible yield and its predicted protein and starch content. For example, the maximum fiber level allowed in defatted soybean flour is 3.8% on a dry basis (13). At this fiber level, under the best conditions, possible yields of millfeed flours were approximately: CB, 20%, FB, 30%; SH, 40–50%.

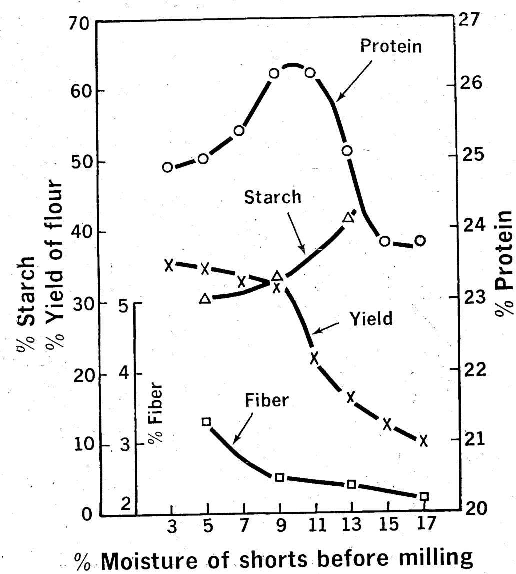

Fig. 3. Effect of moisture content of shorts on fiber, protein, starch, and yield of flour (first milling).

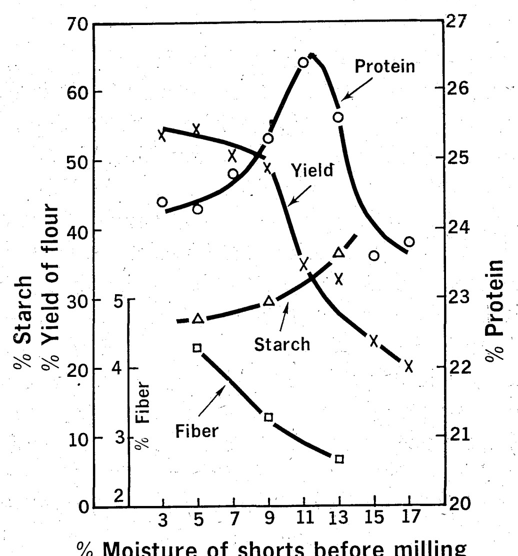

Fig. 4. Effect of moisture content of shorts on fiber, protein, starch, and yield of flour (total of three millings).

Figure 5 shows how the fiber content of flours varied with flour yield for SH and CB milled at three different moisture levels, 5, 9, and 13%. It is apparent that there was an advantage in milling SH at 9% moisture over 5% moisture with respect to the fiber content of the

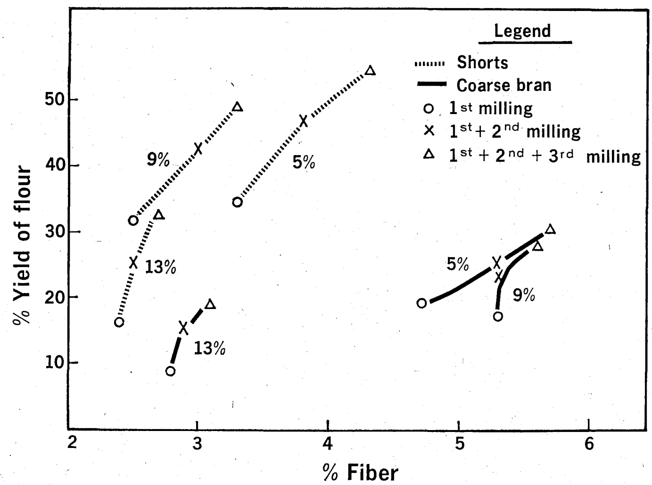

Fig. 5. Relation between fiber content and yield of flour for shorts and coarse bran at different moisture levels.

resulting flours of comparable yield. A similar situation existed for FB. This was not true for CB where the 5- and 9%-moisture CB yielded flour with approximately the same high fiber content, whereas the 13% moisture CB yielded flours with considerably lower fiber.

The difference between CB and SH or FB, in this respect, is probably due to the fact that CB contains a larger portion of the pericarp tissues which become brittle below 13% moisture, whereas SH and FB contain more aleurone and germ tissues which are more pliable by virtue of their fat content (9). These tissues must apparently be drier (less than 9% moisture) before the cell walls and other fibrous materials become sufficiently brittle to be broken down to flour.

The starch contents of the flours obtained in this study (Table IV, Figs. 3 and 4) were used as indicators of the amount of starchy endosperm contained in them. It was calculated that 1% starch represented approximately 1.55% starchy endosperm. Since the millfeed flours ran from 22 to 41% starch, the range of starchy endosperm in these flours was estimated at 34 to 64%. It can be seen, therefore, that the contribution of bran components is substantial, indicating a highly nutritious material, particularly from the standpoint of protein and certain vitamins and minerals which are known to be concentrated in the aleurone layer (5,9,14). Amino acid analyses, protein efficiency ratio evaluations, and other nutritional characteristics are being studied and will be reported at a later date.

An observation made in the course of this study was the fact that the millfeed flours (through 7xx bolting cloth) could be further fractionated by a simple sifting operation. The new fractions were found to differ very substantially in composition. These shifts in composition indicate increased flexibility in the ability to "tailor-make" millfeed flours of certain compositional characteristics. Additional work is being carried out and will be reported later.

Acknowledgment

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