HIGH-PROTEIN RICE FLOURS[1]

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ABSTRACT

High-protein flours have been prepared by two types of commercial machinery from both normal and high-protein rice. One process, consisting of fine-grinding and air-classification, furnished 8 to 10% of the kernels as flour with about 75% higher-protein, intermediate fractions, and 75 to 80% residual flour with slightly less protein than the original. Protein content was highest in the finest particles and decreased with increasing particle size. Fat, ash, thiamine, riboflavin, and amylase activity were distributed in like manner. The second process was scouring off consecutive layers of milled rice in a continuous-flow abrasive cone mill similar to a rice-whitening cone. Flour from the outermost layers had about twice the original protein content of the whole kernels, and was obtained in 10 to 15% yield. The residue was chiefly whole kernels of slightly reduced size and protein content, with some broken kernels. Again, fat, ash, thiamine, riboflavin, and amylase activity followed the trend of protein content. Fine-grinding and air-classification of flours obtained by abrasive milling further concentrated protein in the finest-particle fractions.

Rice protein has been reported (1,2) as among the best cereal proteins from a nutritional standpoint. If the protein content of rice foods could be raised, nutritional benefits would accrue to large segments of the world's population.

Breeding, fertilization, and other studies of cultural practices now in progress are proving that the protein content of rice can be raised. Rice varieties which normally contain 6 to 7% protein have been grown with 9 to 11% protein (3,4; see also Table II). Selection and breeding studies are promising new rices with over 10% protein.

With the hope of obtaining rice foods relatively high in protein from available rice, preparation has been undertaken of rice fractions as flours high in protein. These flours are of interest for such foods as cereal milks, gruels, or porridges of high protein content for infants. The United Nations Children's Fund desires high-protein rice foods for augmenting protein-deficient diets in rice-eating countries.

One process, fine-grinding and air-classification, is being used commercially in the wheat industry (5,6,7). In this process high-protein

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material concentrates in the finer-particle fractions. Preliminary experiments on rice flour have been reported by Stringfellow, Pfeifer, and Griffin (8).

A second method is abrasive removal or scouring of flour from the outer layers of milled rice. A protein gradient decreasing from the outer to the inner layers of the kernel was reported by Subrahmanyan, Sreenivasan, and Das Gupta in 1938 (9). Little and Dawson (10) showed, by histological studies, that the protein is concentrated in the outer layers. Primo and co-workers (11) reported at the First International Congress on Food Science in London, September 1962, that the layers removed successively from rice kernels had high but decreasing protein contents. They emphasized the possibilities of preparing high-nitrogen rice flours by milling off outer layers of the grain. Very recently Hogan and co-workers (12) reported laboratory-scale removal of high-protein flours from brown and milled rice by use of a novel abrasive device.

The present report compares results of using the two processes to obtain rice flour with enhanced protein content. The distribution of some other nutritionally important components was also investigated. The promising results led to preparation of enough rice flour for thorough evaluation of protein quality in animal feeding tests. These tests are being made by UNICEF.

Materials and Methods

Flours for Air-Classification. All flours were ground in the laboratory from California-grown rices. The pearl flour was from short-grain rice. High-nitrogen, single-variety flours were prepared from Caloro, Calrose, and Colusa rice grown in 1961 at the Biggs Rice Station especially for these tests. The rices received three applications of fertilizer (each 80 lb. nitrogen per acre).

Rice for Abrasion Milling. A supply of commercially milled No. 1 California Calrose was purchased. Laboratory-milled samples of the three high-nitrogen varieties were also scoured. Colusa rice for preparing a large sample of high-protein flour for protein-evaluation feeding tests was grown at Biggs in 1963 especially for this preparation, with 120 lb. of nitrogen per acre, applied in two treatments.

Milling. All paddy rice was hulled with a McGill sheller according to official methods (13). The Calrose for scouring had been milled commercially, as mentioned above. The large supply of Colusa used in preparing flour for feeding tests was slightly undermilled in an Engelberg huller.

Air-Classification. Milled rice was ground in a Brabender Quadriplex mill and reground to fine particles in a laboratory-scale Pillsbury hurricane grinder at 10,000 r.p.m. (peripheral rotor speed about 18,000 ft. per min.). Air-classification was performed with a Walther Staubtechnik machine, which effects separations by a cycloning action. The finest-particle fraction was separated in the first pass. The coarser portion was again passed through at the same setting to ensure complete separation. Then, controls were set for a slightly coarser cut, and a second fraction was prepared by two passes as before. This process was repeated with size of control openings increasing, to yield increasingly coarse fractions of flour.

Abrasive Milling. In a CeCoCo Model D rice-whitening or barley-pearling machine of Japanese manufacture, the rice passes between a horizontal rotating abrasive cone and a concentric slotted screen. The flour formed escapes through the screen and is collected. About 5 kg. of rice is required for batch testing, and the machine operates readily on continuous throughput.

Analyses. Nitrogen, determined by the Kjeldahl method, was multiplied by 5.95 to calculate crude protein.

Moisture was determined by the 130°C. air-oven method; ash by heating overnight at 550°C.; and fat by overnight extraction with ethyl ether in a Soxhlet apparatus. These three methods are official AOAC procedures (14; secs. 13.002, 13.006, and 13.018 respectively).

Thiamine and riboflavin were determined by the thiochrome and short fluorometric methods, respectively, of AACC official procedures (15).

Alpha-amylases were extracted with phosphate buffer at pH 7, and beta-amylases at pH 4.6 according to Giri and Sreenivasan (16), and determined by a modified Bernfeld dinitrosalicylic acid procedure (17). The modification was incubation for 10 min. at 30°C. instead of 3 min. at 20°C. Amylase activities are given as mg. of maltose per g. of protein.

Particle sizes were measured electronically with a Coulter Counter which had been precalibrated over the size range used.

Results and Discussion

Air-Classification. Table I shows the extensive segregation of flour turbomilled from pearl rice. Fraction 1, with the smallest particles, had almost twice as much protein as the feed. Subsequent fractions of increasing particle sizes had consistently less protein until nearly half the flour had been separated. The residue, which had about the same protein as the feed, was composed of unsegregated coarse particles much the same as regularly milled flour.

TABLE I
PROTEIN DISTRIBUTION IN AIR-CLASSIFIED CALIFORNIA PEARL[a] RICE FLOUR
(Percentages on dry basis)

MATERIAL	TURBOMILLED ONCE		TURBOMILLED TWICE	
	Weight	Protein	Weight	Protein
	%	%	%	%
Feed	100	5.8	100	5.9
Fraction				
1	6.7	11.2	4.9	8.2
2	3.8	7.1	3.0	7.0
3	1.4	6.2	2.0	6.1
4	2.1	5.6	1.7	5.4
5	2.4	5.1	2.4	5.1
6	2.7	4.8	2.8	4.8
7	17.6	4.0	26.2	3.9
Coarse residue	51.6	5.6	54.8	6.8

[a] Caloro and/or Colusa variety.

The results agree with those of Stringfellow, Pfeifer, and Griffin (8) in showing that the largest fraction of small-particle material was the cut containing the least protein. However, their largest fraction was an intermediate one and ours (fraction 7) was next to the coarse residue.

The variation probably reflects that our flour was a finer-particle material and more cuts were taken in the smallest-particle range. That our fine-grinding was more effective is demonstrated by a redistribution in our air-classification of 15.3% of the total protein compared to 7.5% in theirs.

A second fine-grinding reduced rather than improved the separation. This reduction may result from increased starch damage. It may well be that regrinding the coarse residue would yield additional high-protein fractions. Only in the first three fractions had protein increased, again in agreement with Stringfellow and co-workers (8). Accordingly, in subsequent air-classification of flour from three single rice varieties with high initial protein content, only three cuts and a coarse residue were taken.

The results of air-classification of three single rice varieties (Table II) made it abundantly clear that all measured constituents were concentrated along with protein, and that the fractions of increasing particle size became increasingly higher starch concentrates up to the unsegregated residue. This distribution of constituents is in agreement with, and extends the findings of, previous workers on rice (8) and other cereal flours (18).

Abrasion Milling. Removal from whole rice kernels of material beyond the bran and polish layers by a McGill miller or an Engelberg huller was not successful. These machines remove outer layers chiefly

TABLE II
AIR-CLASSIFICATION OF FLOUR FROM THREE CALIFORNIA RICE VARIETIES[a]
(All values on dry weight basis)

Fraction of Material	Weight	Particle Size, MMD[b]	Composition: Protein	Composition: Ash	Composition: Fat	Composition: Thiamine	Composition: Riboflavin	Amylase Activity: Alpha-	Amylase Activity: Beta-
	% of total	*μ*	*%*	*%*	*%*	*μg./g.*	*μg./g.*	*mg. maltose*	*mg. maltose*
				Variety: Caloro					
Flour	100	9.8	9.3	0.51	0.70	1.5	0.51	17.4	34.1
Fr. 1	8.3	4.2	16.7	1.26	1.77	3.1	1.3	57.9	58.6
Fr. 2	4.7	5.4	10.7	1.06	1.21	2.2	1.4	42.9	56.3
Fr. 3	3.6	7.2	9.4	0.93	1.11	2.3	1.5	33.7	52.5
Fr. 4	82.9	14.1	8.0	0.49	0.49	0.60	0.56	34.6	32.1
				Variety: Calrose					
Flour	100	12.0	9.2	0.68	1.00	1.9	0.22	21.1	27.4
Fr. 1	8.0	4.8	16.2	1.84	2.67	4.9	0.78	52.4	67.7
Fr. 2	5.0	6.2	11.7	1.31	1.91	3.8	0.55	45.3	59.6
Fr. 3	3.8	8.3	9.0	0.92	1.77	3.0	0.59	38.8	51.5
Fr. 4	81.5	19.8	8.5	0.49	0.79	0.83	0.25	26.5	26.0
				Variety: Colusa					
Flour	100	19.5[c]	9.4	0.52	0.48	0.93	0.37	11.1	27.3
Fr. 1	9.3	7.5	16.9	1.53	0.71	3.4	0.55	46.0	54.1
Fr. 2	4.9	. . .	10.9	1.29	1.27	2.2	0.47	35.7	46.3
Fr. 3	3.7	. . .	9.0	1.06	1.13	2.1	0.47	32.6	41.1
Fr. 4	78.9	. . .	8.5	0.47	0.55	0.31	0.44	21.5	23.3

[a] Turbomilled once.
[b] Mass median diameter in microns. This is the point at which 50% by weight is undersize.
[c] When turbomilled twice, the particle sizes of the fractions are comparable with those of the other two varieties: 13.6, 5.4, 7.3, 9.7, and 20.1 μ respectively.

by abrading the grains against each other. After the milled rice stage is reached, abrasion becomes poor and increased pressure only increases breakage. A more effective source of abrasion is required.

The type of rice whitener or barley pearler in which an abrasive cone rotates within a stationary concentric screen is satisfactory. The light pressure upon the rice passing between the cone and screen, and the adjustable space between cone and screen, permit operators to choose conditions that will scour peripheral material from the rice with little breakage. The process scours only a little off each kernel. The number of passes determines the total amount removed.

In the CeCoCo machine a commercial Calrose white rice (6% protein, dry basis) gave first fractions, from the outermost layers, with more than double the original protein content of the whole kernel. Table III shows that the successive layers removed from the rice had high but decreasing protein content, and the residual grains contained less protein than the original whole kernels.

TABLE III

CHARACTERISTICS OF FRACTIONS ABRADED FROM COMMERCIAL MILLED CALROSE RICE
(All values on dry weight basis)

MATERIAL	PORTION OF TOTAL WEIGHT	COMPOSITION					AMYLASES	
		Protein	Fat	Ash	Thiamine	Riboflavin	Alpha-	Beta-
	%	%	%	%	μg./g.	μg./g.	*mg. maltose*	*mg. maltose*
Feed	100	6.0	0.67	0.50	0.74	0.37	4.1	7.3[a]
Fr. 1	4.2	13.7	5.91	3.60	4.2	2.3	24.4	45.8
Fr. 2	2.6	12.8	3.55	2.11	4.3	1.6	21.6	34.5
Fr. 3	1.7	11.8	2.17	1.32	3.8	1.0	14.6	33.0
Fr. 4	1.4	11.0	1.75	1.02	2.7	0.69	10.9	29.9
Fr. 5	1.4	10.6	1.43	0.86	2.2	0.65	6.3	29.0
Fr. 6	1.2	10.4	1.20	0.81	1.8	0.60	5.2	25.8
Residue	84.7	5.2	0.24	0.29	0.07	0.26	3.5	6.4

[a] Particle sizes of original feed and residue are comparable with each other but not with the finer flour of the six fractions. This accounts to some degree for the differences in magnitude of values.

All other measured constituents also decreased progressively as successive layers were scoured from the grain. Accordingly, the residual core of the grain had a higher starch concentration. Primo and co-workers have shown that the fat (19) as well as the protein (11) is concentrated in the outer layers. They also showed (20) that kernels remaining after successive peripheral layers had been removed gave increasingly greater Brabender viscosities. Hinton (21) and Hinton and Shaw (22) reported thiamine and nicotinic acid much higher in the outer than in the central portion of endosperm of dissected rice. Simpson has shown (23) fluorimetrically that thiamine, and to a lesser extent riboflavin, concentrates in outer layers of the endosperm. The agreement of the present data with these results demonstrates that

TABLE IV

ABRASIVE MILLING OF HIGH-NITROGEN CALORO RICE
(All values on dry weight basis)

MATERIAL	A. HEAD RICE ONLY[a]		B. HEAD RICE + BROKENS + CHALKY	
	Weight, Portion of Total	Protein	Weight, Portion of Total	Protein
	%	%	%	%
Feed	100	9.6	100	9.6
Fraction				
1	3.1	16.7	3.8	15.5
2	2.1	17.2	2.6	15.5
3	1.9	16.8	2.3	14.8
4	1.6	16.2	1.8	14.8
5	1.6	14.9	1.6	14.1
6	1.3	15.5	..	...
7	1.2	14.8	..	...

[a] Most of the broken and chalky kernels were removed in a Hart-Carter Dockage Tester.

commercial processing equipment can concentrate these nutritive constituents.

Scouring high-protein milled rice in the same equipment yielded a similar concentration of protein in the flour from the outer layers. (Table IV). It remains to be determined whether the lower proportional increase of protein results from varietal difference or less-than-optimal machine setting. Dilution of the protein content by chalky grains and broken kernel fractions is clear.

This protein gradient in successive layers resembled that in air-classified flours, as did the distribution of other components. This raised the question of whether or not air-classification of flour obtained by abrasion would give additional protein concentration. The data in Table V show that it would: the protein content of the finest-particle flour was increased 3.1 to 4.4% over that of the feed. About 25% of the air-classified flour had more protein.

TABLE V

AIR-CLASSIFICATION OF FLOUR ABRADED FROM HIGH-NITROGEN CALORO RICE
(All values on dry weight basis)

Material	A. Head Rice Only,[a] Not Defatted		B. Head Rice + Brokens + Chalky[b]			
			Not Defatted		Defatted[c]	
	Weight, Portion of Total	Protein	Weight, Portion of Total	Protein	Weight, Portion of Total	Protein
	%	%	%	%	%	%
Feed	100	15.5	100	15.2	100	14.3
Fraction						
1	16.0	19.9	15.2	18.3	10.7	16.1
2	11.3	18.6	9.8	17.0	9.2	17.0
3	6.2	17.1	6.3	15.5	6.0	16.0
4	63.9	12.8	65.6	12.4	73.4	12.3

[a] Seven fractions of Table IV-A combined. Turbomilled flour contained 2.60% fat.
[b] First four fractions of Table IV-B combined. Turbomilled flour contained 3.40% fat.
[c] Defatted by percolation with ethyl ether. Lower protein content results from proportionally greater use of high-protein fractions for analyses before recombination.

The 3.4% fat in the flour scoured from the heads-plus-brokens rice was also fractionated, with the finest flour fraction containing 5.5% fat and the coarse residue, 2.4%. Reclassification after combination of the fractions and removal of most of the fat separated protein less efficiently than the original method. Removal of the fat seems unnecessary and undesirable for concentration of the protein. The effect of the fat content on storage stability is still to be determined.

Semicontinuous Scouring. A larger, semicontinuous flour preparation was also undertaken. A 425-lb. lot of undermilled Colusa rice with

7.6% protein (dry basis) was fed through the machine in two continuous batches. A total of five passes gave the products listed below.

Material	*Weight* % *dry basis*	*Protein Content* % *dry basis*
Feed	100	7.6
Fraction		
1	4.4	15.5
2	3.9	13.9
3	1.8	13.2
4	2.2	12.3
5	1.8	11.8
Residue	85.1	6.4

Feed material contained 6% brokens and residue contained 17%. The first two fractions were blended to give 34 lb. of flour with 15.0% protein (dry basis).

Comparison of Processes. In general, the two processes yield similar fractions. Only particle-size distribution differs. Of course, the residual materials from the processes differ markedly – in one case flour, in the other, whole and broken kernels.

Rice flour can be ground from broken kernels, which have a lower market value than head rice. The flour must then be turbomilled before air-classification. After removal of high-protein fine fractions the residual material is flour, which has a relatively small market. Because rice is usually eaten as whole-kernel grain, the flour-milling process does not enter the economic picture in the same fashion as in wheat milling where flour is the major product.

In comparison, abrasive scouring of flour from outer layers of the white rice kernel leaves mostly whole-grain rice. The scouring of a thin layer from the kernels can be considered an extension of the regular milling process. If only a few percent were abraded from the rice, the general composition of the residual grain would not change greatly and only a small amount of breakage would occur. It would cost little more than the usual rice-milling processes. The operation would provide a small amount of high-protein specialty food and a correspondingly reduced amount of milled rice still suitable for use in all mixed diets. If high-protein rice were the starting material, the rice remaining after scouring could well be more nutritious than some low-protein rices now on the market.

The abrasion process appears to be the more attractive of the two and promises highly nutritious specialty foods, not only for export but for our domestic market. Their development as infant and geriatric foods could become important to rice utilization.

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