Proso Millets. Milling Characteristics, Proximate Compositions, Nutritive Value of Flours

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ABSTRACT

The milling characteristics, proximate compositions, and nutritive value of proso millets (*Panicum miliaceum*) are discussed. The millets were successfully dehulled with a barley pearler before the grains were ground into flour. The millets could also be milled in a Quadrumat Jr. mill without being dehulled. Conditioning of the millets before milling was unnecessary. Milling yields decreased with increasing levels of grain moisture. Comilling of wheat and nondehulled proso millets in a Quadrumat Jr. mill was feasible. Compared with wheat flour, the millet flours were high in ash and crude fat and as high or higher in nitrogen, depending on the flour extraction. Proso millet flours were very low in lysine (0.79–1.14 g/100 g of protein). Comparison of in vitro proteolysis of wheat and millet flours indicated that the protein in wheat flour was more readily hydrolyzed than was the protein in millet flours. Nitrogen solubilities were considerably lower in millet flours than in wheat flour.

The term "millet" is used for several small seeded annual grasses that are of minor importance in the Western world but a staple in the diets of African and Asiatic people. Millets can be cultivated in a wide range of soils and climates and are of special importance in semiarid regions because of their short growing seasons (Schery 1963). Five millets are common. *Setaria italica* includes cultivars such as Hungarian grass, White Wonder, and Siberian, foxtail, and German millets. The species supposedly originated in India but is principally cultivated today in the Near East and China. *Pennisetum glaucum* or *P. typhoideum* is known as pearl or cattail millet. It is used extensively in the southeastern United States as a forage crop. In Egypt and tropical Asia, it is cultivated as a cereal food. *Eleusine coracana,* known as finger millet, ragi, birds-foot millet, and African millet, is cultivated in India and Africa for both grain and forage. *Echinochloa frumentacea,* known as barnyard millet or billion dollar grass, is a seed and forage millet grown in parts of the United States. Other species of *Echinochloa* are grown for food in tropical Africa and South America (Hinze 1972, Matz 1959). *Panicum miliaceum,* also known as proso millet, hershey, broom corn, or hog millet, is planted in some African countries as a food crop. It is the only species of economic importance in the United States at present. Many farmers in eastern Colorado and western Nebraska are including proso in three-year and five-year rotation systems. Proso planted after wheat in a wheat-proso-fallow rotation is an excellent way to control or at least reduce infestation of annual weeds (Nelson and Daigger 1975).

Proso millet is used in feeding rations, as bird seeds, and also as human food (Hinze 1972). Suggested food applications of dehulled proso millet in the United States include a puffed or cooked breakfast cereal or replacement for up to 30% of wheat flour in certain baked products and other household recipes (Hinze 1972).

Very little research has been conducted with millets, especially proso millet, compared with other cereal grains. In this article, the milling characteristics, proximate composition, and nutritional value of flours from proso millet are discussed.

MATERIALS AND METHODS

Sample Identification

This study included the standard red proso variety Turghai and the white seeded proso millet Cope, which has just been released by the Colorado State University Agricultrual Experiment Station. Yields of this new variety have been excellent, compared with other varieties grown in eastern Colorado. Seeds were made first available in 1979. Both varieties were grown at the Colorado State University Experiment Farm in Springfield, CO, in 1977. A wheat variety, Chris, was also included in the study to permit comparisons between wheat and the proso millets.

Dehulling and Milling of Grains

Dehulling. Millets were dehulled successfully in a barley pearler in which the normal screen was replaced with a very fine mesh screen (0.5-mm diameter openings). The hulls were separated from the seeds by winnowing. A hammermill was then used to grind the seeds into a whole grain flour.

Quadrumat Jr. Milling. In an attempt to simplify the milling procedure, samples of the Cope and Turghai varieties of proso millet were also milled in a Quadrumat Jr. mill without prior

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dehulling. The grains, 7.6 and 8.1% moisture, respectively, were milled initially without tempering and then after tempering to 12, 13, 14, and 15% moisture for 24 hr. Bran, high-grade, and low-grade flours were collected. Milling yields were determined and compared with those for the wheat variety Chris (initial moisture 8.0%), tempered to the same moisture levels as the millets.

In a second milling series, the millet samples, without dehulling, were first heated for 1 hr at 80°C to make removal of the hulls easier and possibly also to improve the baking performance of the millet flour. The millets were heated in 9 × 13 in. cake pans in a bread oven. They were turned every 10 min. After being heated, samples were tempered to 12, 13, 14, and 15% moisture for 24 hr before being milled in the Quadrumat Jr. mill.

Comilling of Grains. Millet flours cannot fully replace wheat flours in bakery applications, as was shown by Awadalla (1974), Badi et al (1976), and Badi and Hoseney (1976). A 20–30% wheat flour substitution level appears to be the maximum. To avoid having to mill wheat and millet separately before blending the flours in proper proportions for bakery applications, the possibility of comilling the two grains in one milling operation was investigated. The blends of grains that were milled contained 5, 10, 20, or 30% millets. Each blend was tempered to 12, 13, 14, and 15% moisture for 24 hr. The millets were not dehulled before milling. Milling yields were determined.

Proximate Analyses

Milling fractions were analyzed for moisture, crude fat, ash, nitrogen, and crude fiber by AACC approved methods 44-15A, 30-10, 08-01, 46-11, and 32-15, respectively (AACC 1969).

Color Measurement

The color of all milling fractions was determined with a Hunter color difference meter. The color standard was L = 94.6, a = −0.6, and b = 0.1.

Amino Acid Analyses

Samples containing approximately 10–15 mg of protein were weighed directly in 16 × 150 mm glass culture tubes. Exactly 10 ml of 3N *p*-toluenesulfonic acid (Liu and Chang 1971) containing norleucine as an internal standard was added, and the tubes were capped with polypropylene caps. The tubes were placed in an enclosed boiling water bath for 31 hr of hydrolysis. Each sample was cooled, transferred to a 25-ml volumetric flask, neutralized with NaOH, diluted witn pH 2.2 buffer, and frozen until analyzed.

Each sample was thawed and ultrafiltered through a 0.2 mμ cellulose acetate membrane immediately before application to the ion-exchange column. Samples (185 μl) were applied to the long and short columns of a Beckman 120C automatic amino acid analyzer and eluted according to the Beckman 2-hr hydrolyzate procedure.

Recoveries of amino acids were corrected for mechanical losses with norleucine (Walsh and Brown 1962) and calculated to 100% on a protein basis (N × 6.25).

In Vitro Digestibility

The initial rate of in vitro proteolysis was determined by Sheffner's method (1963) on samples of the wheat flour and the flours of the two millet varieties. Based on the protein content, samples were weighed so as to contain 2 mg of nitrogen per milliliter. After the samples were suspended in distilled water (40 ml), the pH was adjusted to 7.0. Samples were then permitted to rehydrate for 1 hr at 5°C.

The rehydrated samples were incubated at 37°C in a water bath, and 3 ml of lyophilized trypsin (twice crystallized) at a concentration of 40 mg/ml was added. Changes in pH were determined at 1-min intervals for 10 min.

Nitrogen Solubility

The nitrogen solubility of the wheat flour and the two millet flours were determined by a modification of the method of Saunders et al (1974). Approximately 0.2 g of each sample was suspended in 9 ml of distilled water. The pH of the samples was then adjusted to a range between 2 and 10, using 0.01, 0.1, and 1 *N* HCl and 0.01, 0.1, and 1 *N* NaOH solutions. The samples were shaken in a water bath at 25°C for 60 min. The sample volume was made to 10 ml and the sample centrifuged at 6,000 rpm for 15 min at 25°C, followed by filtering through Whatman No. 2 filter paper. Five milliliters of the supernatant was used for determining the nitrogen solubility in each sample. Nitrogen was determined by the micro-Kjeldahl method.

RESULTS AND DISCUSSION

Dehulling of Grains

Wheat milling technology is not always applicable to millets, as shown in studies with unspecified varieties conducted in Senegal and the Sudan (Perten 1976). These were probably varieties of *E. coracana*, which is most often cultivated in the area. Better yield and flours of lighter color were obtained by separate decortication of the grain before grinding on an attrition mill or hammermill. A Palyi-Hansen horizontal debranner was recently developed for dehulling and dry debranning of grains that need gentle abrasion. It has been used successfully with millets (Rasper 1976).

In this study, a barley pearler was used to remove the hulls of millets. Dehulling is necessary because the hulls contain a very high percentage of silica. All but about 1% of the hulls were removed from grains of the cultivar Cope, and all but about 5% from Turghai. The flours produced in a hammermill were considered satisfactory in color. Flour from the cultivar Cope had a Hunter color L value of 77.6 and that from the variety Turghai an L value of 72.3. These flours, which represent 100% extractions, were slightly darker than those of lower extractions produced in the Quadrumat Jr. mill. The L value for wheat flour was 86.9.

Milling with Quadrumat Jr.

Although dehulling of millets before grinding or milling was possible with a barley pearler, accomplishing both dehulling and milling in one operation would be advantageous, and that was found to be possible with the Quadrumat Jr. mill. This does not necessarily disagree with Perten's observations (1976) because different varieties of millets are involved. The varieties milled in this study have a protruding germ, not well protected by adjacent layers, which should make removal of the germ relatively

TABLE I
Milling Yields and Colors of Flours

Tempered to % Moisture	Chris			Cope			Turghai		
	Flour Yield[a]	L	ΔE[b]	Flour Yield[a,c]	L	ΔE[b]	Flour Yield[a,c]	L	ΔE[b]
As is	65.6	83.6	14.8	87.3	77.5	25.6	78.4	75.6	25.8
12	73.3	86.9	12.1	79.7	80.8	25.7	74.2	78.0	23.9
13	68.8	···	···	78.5	80.9	25.8	73.8	78.8	23.5
14	67.9	87.8	11.4	75.7	82.0	25.2	67.1	74.6	24.4
15	66.6	88.0	11.4	77.5	81.2	24.7	67.5	76.3	24.2

[a] High grade flour.
[b] ΔE = total color difference = $\sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$
[c] Flour yields of millets are based on the weight of the nondehulled grains.

easy and produce flours with relatively low lipid contents.

Table I shows the milling yields and color values of the high grade flours obtained in the Quadrumat Jr. with Chris wheat and the millet varieties Cope and Turghai tempered to different moisture contents before milling. Flour yield of the wheat variety Chris increased as the grain was tempered to 12% moisture. The "as is" moisture content was only 8%. Flour yields decreased as grain was milled at moisture contents above 12%. As flour extraction decreased, the color of the flour became lighter, as indicated by higher Hunter L values and lower color difference (ΔE) values.

Millet variety Cope produced a high grade flour extraction of 87.3% and the variety Turghai an extraction of 78.4% when milled without tempering. The moisture contents of the nondehulled grains were 7.6 and 8.1%, respectively. Quadrumat Jr. milling removed the hulls effectively. Hulls represented 11.8% of the grains. The color of the millet flours was darker than that of the wheat flour, as indicated by lower L values. Flour color became lighter with decreased flour extractions. The lighter color is a definite advantage. Yield, however, is more important in developing countries than a light color. Tempering of millets to 12–15% moisture levels produced no advantage. Flour yields decreased as moisture content of the grains at milling increased.

Badi et al (1976) reported a total flour extraction of 57.9% for pearl millet milled in a Quadrumat Jr. mill. Yields of flour were higher in this study with cultivars of proso millet.

TABLE II
CoMilling of Grains

Blend Composition Wheat (%)	Blend Composition Millet (%)	Moisture at Milling[a] (%)	High Grade Flour (%)	Low Grade Flour (%)	Bran (%)	Color of High Grade Flour (L)
100	0	13.0	73.4	7.2	19.4	86.9
95	5	as is	74.0	8.2	17.8	84.6
		12.0	72.4	7.2	20.4	87.0
		13.0	71.2	7.0	21.8	···
		14.0	70.0	7.1	22.9	88.0
		15.0	68.2	7.4	24.4	88.1
90	10	as is	74.6	7.0	18.4	83.8
		12.0	72.0	8.0	20.0	86.9
		13.0	72.6	8.0	19.4	87.3
		14.0	70.8	8.4	20.8	86.5
		15.0	70.2	8.0	19.8	87.2
80	20	as is	72.2	9.0	18.8	84.3
		12.0	71.0	8.8	20.2	86.3
		13.0	70.0	8.0	22.0	86.7
		14.0	71.6	9.0	19.4	86.3
		15.0	69.4	8.6	22.0	85.4
70	30	as is	74.4	8.2	17.4	83.1
		12.0	73.2	7.6	19.2	84.6
		13.0	71.2	7.0	20.8	85.8
		14.0	71.4	7.6	21.0	85.3
		15.0	68.0	8.0	24.0	85.8

[a]"As is" indicates that the grain blend was milled without tempering.

Comilling Wheat and Millet

The results of comilling Chris wheat and Cope millet in a Quadrumat Jr. mill are shown in Table II. The yield of high grade flour was highest when the grain blend was milled without tempering, regardless of the level of millet in the blend. High grade flour yields decreased as the moisture level increased. These flour yields and the colors of these flours were expected from the values obtained when the grains were milled separately (Table I). The lightness in color of the flours and the total ΔE between samples and the color standard differed very little between the wheat flour and the blends of wheat and millet flours even with 30% millets in the blend. These results indicate that comilling wheat and proso millets in a Quadrumat Jr. mill without prior dehulling and conditioning of the grains is feasible, saving time and energy. Work by Crabtree and Dendy (1976, 1979) showed that comilling of Canadian hard wheat and millets in a relatively large mill such as the Buhler mill is possible after conditioning the grains individually to 16% moisture.

Proximate Compositions

The proximate compositions of the wheat flour, the high grade millet flours, and the millet bran fractions are presented in Table III. Compared with the mineral contents of wheat, corn, and sorghum, that of millets is high (Burton et al 1972). Ash values of whole grain millets range from 2.6 to 3.9% for cultivars of *E. coracana, P. typhoideum, S. italica,* and *P. miliaceum* (Burton et al 1972, Carr 1961, Joseph et al 1959, Kurien 1967). The scientific literature contains little information about the mineral composition of millets and how it is affected by factors such as soil growing conditions, water supply, and varietal differences.

As expected, the ash values of the high grade flours of both millet varieties were considerably higher than that of the wheat flour. Ash values decreased as flour extraction rates decreased. The ash values of the bran fractions are very high because the silica content of the hulls is high.

Frequent references to the need to preserve whole grain millet and millet flours in airtight containers in order to minimize rancidity serve as a reminder of the high lipid content of millets (Gast and Adrian 1967). Various authors report lipid contents ranging from 3.0 to 6.5% for whole grain millets (Freeman and Bocan 1973, Jellum and Powell 1971, Pruthi and Bhatia 1970),

TABLE III
Proximate Composition of Flours and Bran Samples[a]

Grain Variety	Tempered to Moisture[b] (%)	High Grade Flour Yield[c] (%)	Bran Yield (%)	Flour Ash (%)	Flour Nitrogen (%)	Flour Crude Fat (%)	Bran Ash (%)	Bran Nitrogen (%)	Bran Crude Fat (%)
Chris	13	73.4	19.4	0.55	2.17	1.03	···	···	···
Turghai	as is	78.4	20.1	1.86	2.53	3.64	···	···	···
Cope	as is	87.3	19.8	1.60	2.32	3.48	15.1	0.98	3.89
	12	79.7	22.1	1.14	2.25	2.24	14.6	1.39	6.19
	13	78.5	24.6	1.00	2.16	1.83	14.0	1.42	6.97
	14	75.7	27.3	0.84	2.14	1.56	12.9	1.90	10.74
	15	77.5	27.1	0.78	2.18	1.81	11.9	1.93	11.04
Cope (Heated 1 hr at 80°C before milling)	as is	77.6	19.6	1.42	2.35	2.71	15.1	1.05	5.34
	12	74.8	20.5	1.28	2.29	2.04	···	···	···
	15	69.8	23.4	0.73	2.14	1.41	12.1	1.92	12.74

[a]14% moisture basis.
[b]"As is" indicates that the grain was milled without tempering.
[c]Flour yields of millets are based on the weight of the nondehulled grains.

TABLE IV
Amino Acid Composition of Wheat and Millet Flours[a]

Amino	Flours								Bran	
Acid	Wheat	Turghai	Cope	Cope	Cope	Cope	Cope[b]	Cope[b]	Cope	Cope[b]
Lysine	1.98	1.14	1.01	0.92	0.80	0.69	0.94	0.79	3.94	3.42
Histidine	1.89	1.97	1.85	1.87	1.81	1.78	1.71	1.80	1.92	2.19
Ammonia	4.69	3.25	3.35	3.38	3.41	3.31	3.30	3.40	2.91	3.29
Arginine	2.52	2.06	1.24	1.05	1.79	1.85	1.54	1.45	6.07	4.29
Aspartic acid	4.23	6.13	6.08	6.04	5.83	5.82	6.04	5.86	11.02	10.32
Threonine	2.47	2.37	2.55	2.47	2.51	2.36	2.37	2.37	3.92	3.76
Serine	5.39	7.07	6.86	7.04	7.54	7.13	7.95	7.00	6.31	7.26
Glutamic acid	35.63	24.60	24.64	26.01	24.67	25.47	25.08	25.47	18.18	19.92
Proline	14.81	9.72	9.04	8.77	8.87	9.53	9.34	9.88	8.03	6.63
Half cystine	0.60	0.27	0.31	0.33	0.25	0.31	0.25	0.14	0.55	0.30
Glycine	3.30	1.87	1.90	1.82	1.98	1.59	1.80	1.76	4.99	4.74
Alanine	2.65	12.22	12.40	12.38	12.39	12.45	12.33	12.24	9.29	10.06
Valine	2.94	3.20	3.40	3.33	3.33	3.24	3.17	3.23	3.97	3.88
Methionine	1.55	1.76	2.03	1.95	2.03	1.98	1.88	1.92	1.44	1.61
Isoleucine	2.26	2.41	2.59	2.54	2.56	2.49	2.44	2.47	2.43	2.38
Leucine	6.40	12.33	12.34	12.43	12.56	12.55	12.30	12.63	8.21	8.86
Tyrosine	2.20	2.75	3.09	2.80	2.70	2.61	2.66	2.57	2.60	2.54
Phenylalanine	4.51	4.87	5.30	4.89	4.96	4.82	4.90	5.03	4.21	4.55
Extraction (%)	73.3	78.4	87.3	79.7	78.5	77.5	77.6	69.8	19.8	19.6
Protein (%) (N × 5.7)	13.56	15.81	14.50	14.06	13.50	13.62	14.69	13.38	6.12	6.56
Moisture (%)	6.56	9.80	8.50	9.48	9.85	10.24	6.37	11.40	6.71	5.06
Recovery (Kjeldahl N basis)	96.5	105.5	98.9	110.0	108.0	110.6	108.4	105.7	74.8	68.6
Norleucine (internal std.) recovery	96.7	101.0	98.0	94.7	98.0	96.3	95.7	96.8	86.9	99.4

[a]In grams of amino acids per 100 g of protein corrected to 100% recovery protein basis.
[b]Grain heated before conditioning and milling.

which are higher than those of wheat, corn, rice, or sorghum. In this study, the crude fat contents of the high grade flours of the millet cultivars Cope and Turghai were higher than that of the wheat flour. The crude fat values of the flours decreased and those of the bran fractions increased with lower flour extraction rates.

Because cereal grains contribute approximately 70% of the calories in the diets of people in developing countries, protein studies are nutritionally important. Protein in millets varies from 5.6 to 14.8% (Burton et al 1972: Doesthale et al 1970, 1971; Lorenz and Hinze 1976) for species of *E. coracana* and *P. typhoideum*. In this study, nitrogen contents of the high grade flours milled from the two proso millets without previous conditioning are higher than that of the wheat flour. Nitrogen contents decreased with lower flour extraction rates.

Heating the millet samples to 80°C for 1 hr before tempering and milling did no appreciably affect the proximate composition of the flours and bran fractions, compared with flours at comparable flour extraction rates milled from grains that did not receive this heat treatment. Flour yields decreased with increased moisture levels and were lower than those of millets not receiving heat treatment. Because flour yields are important, especially in the developing countries, heating the grains before milling is not recommended.

Amino Acid Compositions

Amino acid compositions of wheat and millet flours and millet bran are given in Table IV. Amino acid recoveries ranged from 98.9 to 110.6% for millet flours. Millet bran, because of its high lipid content and nitrogenous but nonproteinaceous components, gave lower recoveries—74.8 and 68.6%. The wheat control gave a 96.5% total recovery.

The Cope millet tempering series, which resulted in a decrease in flour extraction with increasing moisture levels, showed trends in the lysine and leucine recoveries and to a lesser extent in the tyrosine recoveries. Lysine and leucine trends are opposite, indicating a shift in the relative amounts of prolamine to the other proteins, as is commonly observed in corn (*Zea mays* L.). This parallels the decreasing flour yields and suggests that the higher lysine value is due to more nutritionally superior aleurone protein being obtained at high flour extraction rates. The tyrosine values support this trend also.

TABLE V
Percent Nitrogen Solubilities of Wheat and Millet Flours[a] at Various pH Values

pH	Wheat (Chris)	Millet (Turghai)	Millet (Cope)	Millet (Cope)[b]
2.0	66.91	8.38	10.87	11.03
2.25	62.44	···	···	10.87
4.0	60.41	5.18	8.98	9.44
5.0	52.81	6.38	6.67	6.15
6.0	23.23	9.30	8.23	9.87
8.0	24.01	11.43	10.00	10.16
10.0	51.70	15.95	11.59	13.74

[a]Wheat tempered to 13% moisture; millets milled without conditioning.
[b]Grains heated at 80°C for 1 hr before tempering and milling.

In general, the basic amino acid content is low in these proso millets. Amino acid compositions of foxtail millets and proso millets reported by Taira (1968) and Jones et al (1970) are very similar to those reported here. Badi et al (1976) reported considerably higher values for most of the essential amino acids, especially lysine, in one variety of pearl millet.

The amino acids in proso millets do not complement those in wheat.

Nitrogen Solubilities

The percentages of nitrogen in the wheat flour and millet flours solubilized at various pH values are presented in Table V. Compared with those of wheat flour, nitrogen solubilities of the millet flours were extremely low and changed only slightly due to changes in pH. The isoelectric point of the wheat protein was at about pH 6.0, which agrees with reported values (Saunders et al 1974, Wu and Sexson 1975). The isoelectric point of the millet protein was between pH 4.0 and 5.0. Heating the millets before tempering and milling changed the nitrogen solubility only slightly.

In Vitro Proteolysis

The results of in vitro proteolysis of the wheat and millet flours are illustrated in Fig. 1. In all samples, most of the proteolysis occurred in the first few minutes and then remained constant, but the wheat flour was more easily hydrolyzed than the millet flours,

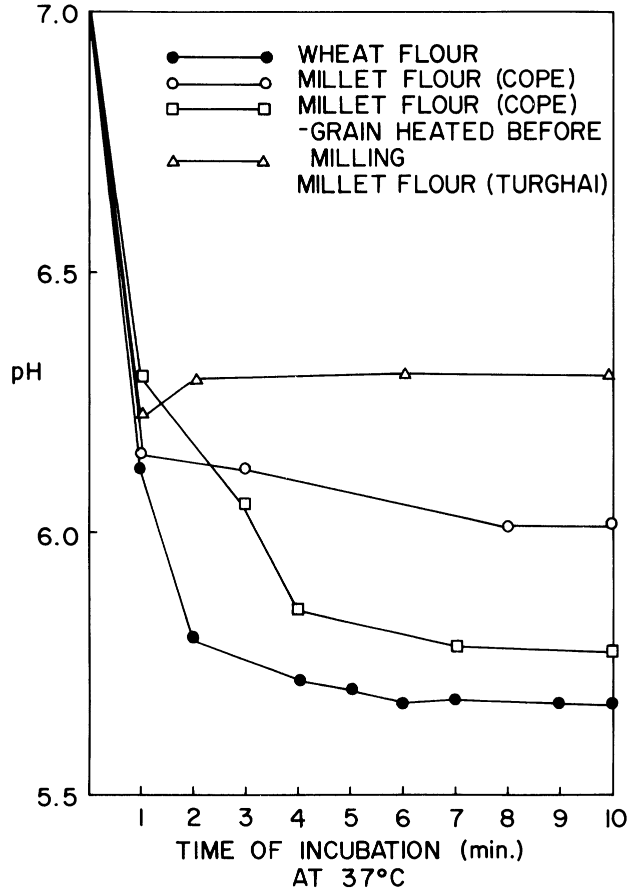

Fig. 1. Trypsin hydrolysis rates of wheat and millet flours (wheat tempered to 13% moisture before milling; millets milled without conditioning).

as indicated by lower pH values after 2–10 min incubation at 37°C. Protein in flour from the millet variety Cope was more readily hydrolyzed than that in flour from the variety Turghai. Heating the grain before tempering and milling increased the rate of proteolysis. Increased rates of proteolysis of high protein additives due to heating were reported previously (Maga et al 1973). Heating makes the protein more susceptible to hydrolysis, perhaps because of structural changes or because it acts on the lipids and carbohydrates that could have been binding a portion of the protein.

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