Nutritional Attributes of a Sweet Corn Fibrous Residue[†]

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A sweet corn fibrous byproduct with 72.7% neutral detergent fiber (NDF) was chemically and nutritionally characterized. The fiber components were hemicellulose, 67.9%; cellulose, 31.4%; and lignin, 0.7%. For nutritonal evaluation, diets with 1.1% (group A), 5.7% (group B), and 11.5% (group C) corn fiber were used. Increasing fiber content decreased apparent protein digestibility ($P < 0.05$). However, the fiber content did not affect significantly the apparent biological value and the net protein utilization. Body weight gain decreased significantly ($P < 0.05$) in group C as compared to group A. Protein efficiency ratio, diet consumption, and diet efficiency ratio were similar among the three groups. The mean value for fiber digestibility was 47%. In another experiment the effect on the iron, calcium, zinc, and magnesium absorption by rats was tested. Increasing NDF from 1.2% to 13.1% caused a decrease of iron, calcium, zinc, and magnesium apparent absorption by 50%, 26%, 22%, and 10%, respectively.

INTRODUCTION

Dietary fiber is one of the constituents of foods that has been progressively excluded from human diets as more industrialized and refined foods are consumed. Concurrently, during several decades, nutritionists have placed very low value on food fiber, considering it dispensible in the diet. However, epidemiological findings have suggested positive correlations between low-fiber diets and incidence of degenerative diseases related to the digestive tract and circulatory system such as diverticular disease, atherosclerosis, and colon cancer (Burkitt, 1973; Creasey, 1985; Schneeman, 1986). Besides, it is known that dietary fiber aids the regulation of intestinal functions partly due to its water-holding capacity, causing the fecal material to become more moist and softer. The dietary fiber also affects intestinal transit time by stimulating peristaltic movements (Kay, 1982). On the other hand, the fiber components can bind organic and metal ions, causing loss of nutrients in the feces (Yu and Miller, 1981; Roehrig, 1988).

A fibrous residue has been obtained as a byproduct in the processing of a high-lysine sweet corn developed at the University of Campinas in an attempt to solve nutritional problems in the country. In this paper some physical properties and the chemical composition of this material, as well as some of its nutritional effects on rats, are reported. This residue, after characterization, could be indicated as a source of fiber in human foods.

MATERIALS AND METHODS

Fibrous Residue. The fibrous residue was a byproduct obtained in the dehydration of sweet corn pulp as indicated in Figure 1. Kernels were initially ground and transformed into a porridge by forcing them through a horizontal pulper (Westinghouse Model Life-Time T), which removed the coarser particles that were approximately 20% (w/w) of the ground kernels. These particles, which contained most of the kernel pericarp and part of the germ and accompanying soluble solids, were submitted to several washings with tap water to remove excess starch and to concentrate the fibrous fraction. The resulting insoluble residue, named fibrous residue, was dried in a hot air dryer at 60 °C for 16 h, ground in a hammer mill, and stored at 20 ± 2 °C in polyethylene bags for further investigation.

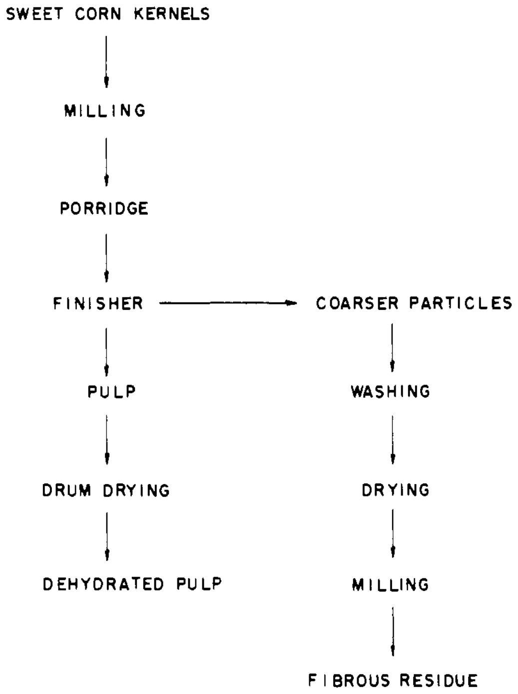

Figure 1. Flow sheet for the preparation of dehydrated sweet corn pulp and the fibrous residue.

Particle Size Distribution. The fibrous residue (200 g) was submitted to granulometry determination in a Produtest agitator equipped with 14, 28, 35, 48, and 65 mesh sieves for 20 min. The material retained in each sieve was weighed and the percentage of each fraction calculated.

Apparent Density. The apparent density of the fibrous residue was measured by determining the weight of material contained in a 100-mL volume (Parrot and Thrall, 1978). The material was added on a graduate cylinder with minimal shaking to assure complete filling.

Hydration Capacity. The hydration capacity of the fibrous residue was determined by the procedure of Quinn and Paton (1979). For this purpose, samples containing 5 g of the fibrous residue were weighed into a 50-mL centrifuge tube. Measured

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Table I. Composition of Diets Used in the Biological Assays

	expt 1			expt 2	
component	A	B	C	D	E
protein (%N × 6.25)[a]	20.4	20.7	20.0	20.4	20.3
corn oil[b]	10.0	10.0	10.0	10.0	10.0
vitamin mixture[c]	2.0	2.0	2.0	2.0	2.0
salt mixture[d]	5.0	5.0	5.0	5.0	5.0
neutral detergent fiber	1.1	5.7	11.5	1.2	13.1
carbohydrate mixture[e] [starch/sucrose 75:25 (w/w), to complete 100% in all diets]					

[a] Determined on the diet (source: casein plus fibrous residue); casein from Commercial Caetano Angelo Croce, Uruguay. [b] Mazola corn oil, food grade, São Paulo, Brazil. [c] Vitamin mixture (US Biochemical Corp., Cleveland, OH) in grams per kilogram of mixture: α-tocopherol (1000 IU/g), 5.0; L-ascorbic acid, 45.0; choline chloride, 75.0; D-calcium pantothenate, 3.0; inositol, 5.0; menadione, 2.25; niacin, 4.5; p-aminobenzoic acid, 5.0; pyridoxine hydrochloride, 1.0; riboflavin, 1.0; thiamin hydrochloride, 1.0; vitamin A acetate 900 000 units; calciferol (D_2), 100 000 units; biotin, 0.020; folic acid, 0.090; vitamin B_{12}, 0.00135. [d] Rogers and Harper's Salt Mixture (US Biochemical) as percentage of mineral mixture: ammonium molybdate·$4H_2O$, 0.003; calcium carbonate, 29.29; calcium phosphate·$2H_2O$, 0.430; cupric sulfate, 0.156; ferric citrate·$6H_2O$, 0.623; magnesium sulfate·$7H_2O$, 9.980; manganese sulfate·H_2O, 0.121; potassium iodide, 0.0005; potassium phosphate, 34.310; sodium chloride, 25.06; sodium selenite·$5H_2O$, 0.002; zinc chloride, 0.020. [e] Maizena, food grade cornstarch, Refinações de Milho, São Paulo, Brazil. Sucrose, food grade, Açúcar União, São Paulo, Brazil.

volumes of distilled water were added and the contents then vigorously mixed by spatula for 2 min. The tubes were centrifuged for 20 min at 1400g. The volumes of water added to the two adjacent tubes, one with and one without supernatant, were divided by the dry sample weight to obtain the hydration capacity of the fibrous residue.

Chemical Determinations. Moisture, ash, and total lipid contents of the fibrous residue were each determined by AOAC (1975) procedures. Protein (%N × 6.25) was determined by the micro-Kjeldahl method (AACC, 1976). The fiber content of the fibrous residue was determined by the methods of neutral detergent fiber (NDF) (Van Soest and Wine, 1967) and acid detergent fiber (ADF) (Van Soest, 1963). The lignin content was determined according to the method of Van Soest (1963). Cellulose content was estimated by subtracting lignin from the ADF, and the hemicellulose content was estimated by subtracting the ADF from the NDF (Kelsay, 1978). Neutral detergent fiber (NDF) content of the diets was determined by the modified NDF procedure described by McQueen and Nicholson (1979). A preliminary treatment with α-amylase from *Bacillus licheniformes* was applied for hydrolysis of the starch. The fiber content of the feces was determined by the NDF method (Van Soest and Wine, 1967). Calcium and magnesium were determined by a titrimetric procedure with EDTA and iron and zinc by atomic absorption spectrometry, each according to AOAC (1975) procedures.

Biological Assays. Biological assays were performed in two experiments. In experiment 1, 24 male weanling rats of the Wistar strain, obtained from Escola Paulista de Medicina, São Paulo, Brazil, aged 21 days and weighing 38–42 g, were randomly distributed in three groups and then collectively housed in wire-bottomed cages (8 rats/cage) under conditions of 12 h light/12 h dark daily, at 23 ± 1 °C. Diet and water were offered ad libitum. The composition of diets is given in Table I. The animals' weight, food intake, and feces excretion of each group were monitored every 4 days during the initial 24 days. After this period, the rats were transferred to individual metabolic cages and maintained under the same environment and feeding plan for an additional 4 days. Feces and urine were then collected individually for this last period. The feces collected were dried, weighed, ground, and stored at −18 °C. The urine was collected in flasks containing 20 mL of H_2SO_4 20% and then diluted at 100 mL with distilled water and stored at 4 °C prior to analysis. Urinary, fecal, and dietary nitrogen contents were determined by the micro-Kjeldahl procedure (AACC, 1976). These results were used for calculations of absorbed nitrogen, nitrogen balance, protein biological value, net protein utilization, and protein digestibility (apparents). Digestibility of the fiber was estimated on the basis of fiber intake and excretion in the feces.

Table II. Percent Distribution of Particle Size in the Fibrous Residue

mesh	sieve,[a] mm	fraction, %
14	1.19	0.4
28	0.59	43.1
35	0.42	28.1
45	0.297	9.5
65	0.21	10.5
bottom		8.4

[a] These values indicate sieve diameter. The percentages represent the fractions of the fibrous residue retained by the various sieves.

Table III. Chemical Composition of the Fibrous Residue

component	%	component	%
moisture	7.3	neutral detergent fiber (NDF)	72.7
crude protein (%N × 6.25)	6.1	hemicellulose	67.9
ash	0.9	cellulose	31.4
total lipids	2.5	lignin	0.7
		acid detergent fiber (ADF)	23.3

Experiment 2 had a duration of 15 days (diets D and E). Groups of five weanling male Wistar rats, aged 21 days and weighing 39–43 g, from Escola Paulista de Medicina, were randomly allotted individually to stainless steel metabolic cages. The first 10 days were for adaptation, and in the remaining 5 days feces were collected for individual rats. Due to insufficient amount of feces produced by individual rats, feces from each group (D and E) were mixed in a composite sample, dried, and ground and then stored in a freezer (−18 °C) for subsequent analysis. The diet consumption was measured during the last period. Apparent absorption of iron, zinc, calcium, and magnesium was calculated on the basis of the intake and fecal excretion of the mineral elements for each group (D and E).

Statistical Analysis. The results of the first experiment were treated by analysis of variance followed by the Tukey's range test. The weight gain of the rats, in experiment 1, was expressed by growth curves, which were obtained by adjustment using the method of minimum square (Cochran and Cox, 1957).

RESULTS AND DISCUSSION

The particle size distribution of the fibrous residue used is shown in Table II. Over 70% of solids were retained in sieves of 0.59–0.42 mm (28–35 mesh). The apparent density of the fibrous material was 0.44 g/mL, and the hydration capacity was in the range 5.2–5.4 mL of water/g of sample. The particle size distribution is reported because it may influence the digestibility and the functional properties of the fiber. Also, the hydration capacity seems to depend on the nature of the fibrous material and the particle size (Roehrig, 1988).

The chemical composition as well as the main components of the fibrous residue is given in Table III. The material contained 6.1% and 2.5% of protein and lipids, respectively, probably associated with the germ fraction. The content of neutral detergent fiber was 72.7%, and it was composed mainly of hemicellulose (67.9%) and cellulose (31.4%). Lignin content was very low (0.7%). According to Sosulski and Cadden (1982), hemicellulose and lignin are the most chemically active components of the cell walls, being responsible for interactions with other dietary components and for decreasing bioavailability of nutrients. Therefore, since the lignin content of the fibrous residue is very low, hemicellulose could be considered responsible for the nutritional effects observed in this study.

The rate of growth as a function of time, for rats fed diets A–C, is shown in Figure 2. There was a significant

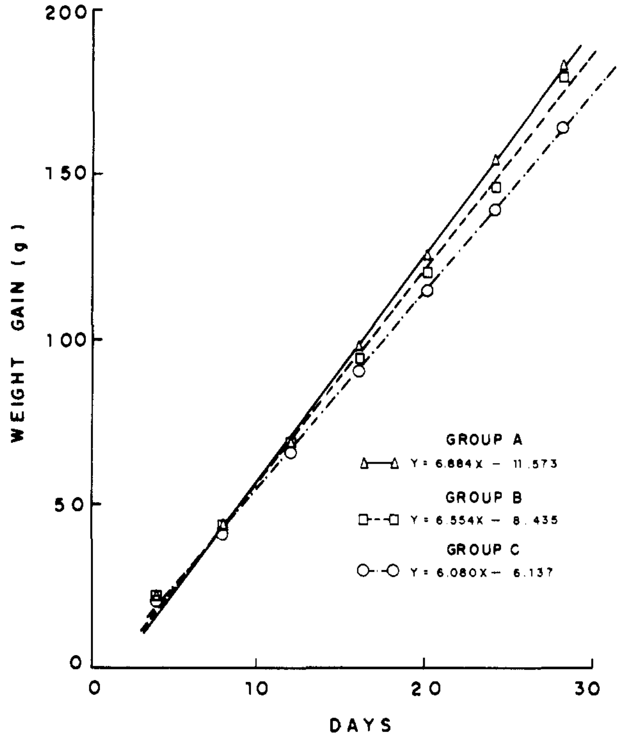

Figure 2. Average accumulated weight gain and regression equation for three experimental groups of Wistar rats fed diets containing sweet corn fibrous residue to furnish (A) 1.1%, (B) 5.7%, and (C) 11.5% neutral detergent fiber.

difference in weight gain with time ($P < 0.05$) between diets A and C. During the feeding experiment of 28 days of duration (experiment 1) the average ad libitum diet consumption (rat/day) was 13.6, 13.3, and 13.2 g and the average feces production (rat/day) was 0.57, 1.02, and 1.77 g for diets A, B, and C, respectively. It becomes evident that increasing the fibrous residue content in the diet increased feces production by the rats (211% between diets A and C) without increase in food intake. These results also suggest that the difference in weight gain between diets A and C was due to the fiber content of the diets and not to differences in diet consumption. Keim and Kies (1979) observed a decrease in weight gain of mice with increasing consumption of cellulose and lignin; however, they found an increased growth by increasing hemicellulose in the diet. The authors suggested that the mice could use hemicellulose as a source of energy. Nevertheless, it cannot be established from our experiments whether the Wistar rat can use hemicellulose for weight gain.

Results of the NDF determination in the diets and rat feces permitted the calculation of the apparent fiber digestibility of 41%, 52%, and 51% for diets A, B, and C, respectively, with a mean of 47%. These results suggest that the rats digested the fibrous residue in the fiber-rich diets to the same extent, independently of concentration. Nyman and Asp (1982), using rats as experimental animals, reported a fiber digestibility of 37% for wheat bran. According to Anderson and Chen (1979) fiber digestibility depends on its chemical structure, on the intestinal microflora, and on the time of residence in the colon.

Table IV shows the results of nitrogen balance, apparent protein biological value, net protein utilization, and apparent protein digestibility for rats on diets A–C. Increasing fiber content in the diets did not affect significantly ($P < 0.05$) nitrogen intake, but it increased significantly ($P < 0.05$) fecal nitrogen excretion. Consequently, apparent protein digestibility decreased with increasing fiber consumption. A similar effect on protein digestibility was observed by Keim and Kies (1979) and Nomani et al. (1979) using other types of dietary fiber. The results presented in Table IV also show that increasing fibrous residue intake did not affect significantly ($P < 0.05$) the nitrogen balance. Similarly, Yu and Miller (1981) reported that a daily ingestion of 15 g of wheat bran did not affect the nitrogen balance in rats. No statistical difference ($P < 0.05$) was found in apparent protein biological value as well as in net protein utilization for the three different diets. The results show that while nitrogen loss into feces is increased by increasing the fibrous residue, it has no effect on the efficiency of protein utilization. However, these results leave open the question of whether protein utilization would be modified when dietary protein is limited. For instance, Nyman and Asp (1982), using diets containing 10% casein, reported a decrease of 7% in the biological value for a diet with 10% wheat bran as compared to a fiber-free diet.

Table IV. Nitrogen Balance, Protein Digestibility, Protein Biological Value, and Net Protein Utilization (Apparents) for Three Groups of Rats Fed Diets Containing 1.1% (A), 5.7% (B), and 11.5% (C) Fibrous Residue[a]

	expt group[b]		
determination	A	B	C
ingested N, g/4 days	2.30 ± 0.20[a]	2.40 ± 0.28[a]	2.18 ± 0.19[a]
N absorbed, g/4 days	2.19 ± 0.19[a]	2.22 ± 0.25[a]	1.97 ± 0.18[a]
fecal N, g/4 days	0.12 ± 0.01[a]	0.18 ± 0.06[a]	0.21 ± 0.03[b]
urinary N, g/4 days	0.53 ± 0.08[a]	0.54 ± 0.16[a]	0.43 ± 0.08[a]
N balance, g/4 days	1.66 ± 0.19[a]	1.68 ± 0.12[a]	1.54 ± 0.11[a]
app protein biol value, %	75.6 ± 3.8[a]	76.1 ± 4.5[a]	78.1 ± 2.4[a]
net protein utiln, %	71.8 ± 3.6[a]	70.4 ± 5.2[a]	70.4 ± 2.1[a]
app protein digest., %	95.0 ± 0.3[a]	92.5 ± 2.1[b]	90.2 ± 1.1[c]

[a] Determined as neutral detergent fiber. [b] Means ± SD, $n = 8$. Values with different superscripts in the horizontal lines are significantly different ($P < 0.05$).

Table V. Effects of Fibrous Residue on Mineral Apparent Absorption for Rats on Diets Containing 1.2% (D) and 13.1% (E) Dietary Fiber[a]

		exptl group	
mineral	distribution	D	E
iron	ingested, mg/5 days	5.14	5.11
	excreted in feces, mg/5 days	2.81	3.96
	apparently absorbed, %	45.3	22.5
zinc	ingested, mg/5 days	1.46	1.50
	excreted in feces, mg/5 days	0.59	0.80
	apparently absorbed, %	59.6	46.7
calcium	ingested, mg/5 days	324.0	371.2
	excreted in feces, mg/5 days	149.9	224.7
	apparently absorbed, %	53.7	39.5
magnesium	ingested, mg/5 days	106.8	124.4
	excreted in feces, mg/5 days	18.7	32.5
	apparently absorbed, %	82.5	73.9

[a] Determined as neutral detergent fiber. Duplicate determinations in a pooled composite sample from each group.

The average protein efficiency ratio (PER) was 2.36, 2.33, and 2.23 and the average diet efficiency ratio (weight gain/diet intake) was 0.48, 0.48, and 0.45 for diets A, B, and C, respectively. Although the PER and the diet efficiency ratio suggest no influence of the fibrous residue on rat growth, there was a significant ($P < 0.05$) decrease in the rate of growth between diets containing 1.1% and 11.5% NDF (Figure 2).

In a second experiment (experiment 2 in Table I) the influence of the fibrous residue on the apparent absorption of various minerals was studied. The results are shown in Table V. When the neutral detergent fiber was increased from 1.2% (diet D) to 13.1% (diet E), a decrease in apparent absorption of 50.3%, 26.4%, 21.6%, and 10.4% was observed for iron, calcium, zinc, and magnesium, respectively. Kelsay (1978) and Reinhold et al. (1976) suggested that high dietary fiber content increases fecal excretion of iron, calcium, and magnesium, and Fairwheather-Tait (1982) found that increasing wheat bran fiber content in the diet from 0.4% to 7.2% caused a decrease in iron absorption by the rat of 47.3%. On the other hand, Sandstead et al. (1978) did not observe any detrimental effect on iron absorption by humans consuming diets containing 26 g of wheat bran and 26 g of corn bran for a period of 28–30 days.

Reyes et al. (1989) studied the effect of the corn fibrous residue used in this work on the rat intestinal transit time. At a concentration of 5% in the diet the fibrous material reduced the intestinal transit time by 50%. Also, an application of the corn fibrous residue in human food was studied by incorporation into cookies, which were tested for effectiveness in preventing or ameliorating chronic intestinal constipation. The study was conducted with volunteers at the University of Campinas Clinical Hospital, and the results have been submitted for publication (Sevá-Pereira et al., 1990).

Because of the reported importance of dietary fiber in the regulation of intestinal functions and prevention of degenerative diseases, as well as demonstrated interference of certain types of fiber with bioavailability of nutrients in the diet, more studies are necessary to critically evaluate the level and the kinds of fiber which are more desirable in the diet. This concern is of particular importance for human populations that are marginally undernourished or relying essentially on vegetable diets.

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Registry No. Hemicellulose, 9034-32-6; cellulose, 9004-34-6; lignin, 9005-53-2; nitrogen, 7727-37-9; iron, 7439-89-6; calcium, 7440-70-2; zinc, 7440-66-6; magnesium, 7439-95-4.