Effect of fiber in sorghum on nitrogen digestibility[1-3]

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ABSTRACT Digestibility measurements were carried out on a population of 12 Cameroonians whose habitual diet, deficient in animal products, is based on consumption of sorghum meal which supplies between 2.4 and 4.2 g of crude fiber per 100 g of dry matter. Over an 11-day period, the 12 subjects received successive diets of 3.3, 4.8, and 5.4 g of crude fiber per 100 g of dry matter. The increase in fiber intake resulted in a significant rise in quantity of fecal matter excreted, including nitrogen and formic insoluble substances. On the other hand, the highest urinary nitrogen losses were obtained from the diet least rich in fiber. The apparent digestibility of nitrogen dropped from 65.4 to 60.5% and then further to 56.9%. The apparent digestibility of nitrogen of the diet least rich in fiber differed significantly from those of the other two diets. The subjects under study did not benefit from an adaptive physiology which would enable them to reduce digestive nitrogen losses. Intestinal disappearance of crude fiber augmented significantly and then stabilized when switching from the diet least rich in fiber to the two others, i.e., from 15.1 to 19.9 g/day and then 19.8 g/day. This population was distinguished by its ability to breakdown large quantities of fiber and to reduce urinary nitrogen loss when fecal nitrogen output rises. Apparent nitrogen balances remained positive. *Am. J. Clin. Nutr.* 34: 2454–2459, 1981.

KEY WORDS Crude fiber, sorghum, nitrogen disgestibility, crude fiber digestibility, nitrogen retention, Cameroonian population

Introduction

As a result of the observations and epidemiological studies conducted by Cleave (1) and by Burkitt and Trowell (2), a series of recent works has noted a fiber deficiency in Western diets. This deprivation may help to explain the etiology of such nutritional and digestive disorders as diverticulosis and cardiovascular diseases (3–6). A fiber-enriched diet may thus constitute a simple therapeutic solution to colonic pathology. It is also a means of increasing satiety and decreasing obesity, since fiber may affect the digestibility of other nutrients (7). Indeed, excessive food fiber results in waste of nitrogen, energy, and minerals (8).

This led us to investigate Cameroonian populations whose static nutritional patterns have for generations involved high fiber intake. This is the case for groups who subsist essentially on cereals such as millet and sorghum, for which traditional food-processing technology permits no more than crude milling (9). For these rural groups, cereals are the main source of proteins and are of intermediate biological value. The question arises as to whether the combination of high fiber intake and weak levels of mediocre quality protein promotes protein-energy deficiency or whether such populations have developed an adaptive physiology which restrains the nitrogen loss that habitually occurs with excess dietary fiber.

This hypothesis has been tested by studying digestibility in a group of individuals who traditionally consume imperfectly ground grain meal.

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Methods

Subjects

The survey took place in Maroua, in the Diamare subdivision of Northern Cameroon, at the end of the dry season (May to June). Twelve adult Cameroonian volunteers aged 19 to 25 yr participated in this experiment. The basis of their daily diet consists of a sorghum *boule* prepared from meal which has been refined to a certain extent. (The term *boule* denotes a flour-based dish, which is cooked in water until it attains a doughy consistency.)

Initial clinical examinations revealed no evidence of disease, and parasites were systematically eliminated at the beginning of the experiment by administering six 100-mg tablets of Vermox (mebendazole) over 3 consecutive days. Mean weight and height averaged 57.7 kg and 171.1 cm, with ranges of ± 4.6 kg and ± 5.7 cm (SD). The population averaged 14% below Harvard reference values (10) for weight for height criteria.

Diet

Regimens were designed so as to ensure that each individual received 45 kcal (0.19 MJ)/kg of body weight every day, with 80% from grains and the remaining 20% from a meat sauce whose composition was set in accordance with local eating habits and held constant throughout the experiment. The protein intake of 1.1 g of which the net protein utilization (NPU) approximated 0.50 (11)/kg of body weight corresponds to the safe level (12). Dietary components appear in **Table 1**. The caloric values of these foods are taken from FAO tables (13). The daily ration was split into two meals, served at noon and at 7 PM in accordance with local custom.

Three types of regimens (A, B, and C) were tested, varying only in terms of the amount of processing of the sorghum meal employed in preparation of the *boule.*

Type A. This was a diet based on hulled sorghum meal produced by intensive pounding with a large pestle. Such meal contains 2.4 g crude fiber per 100 g dry matter, bringing the crude fiber content of the diet to 3.3% (**Table 2**). In fact, compared to industrial flours, this manually prepared meal falls somewhere between a brownish-gray wheat flour extracted at 85% and a fully-ground wheat flour (14).

Type B. This was a diet based on whole grain sorghum meal. A brief pounding removes the chaff, leaving the peripheral layers affixed to the seeds. This meal contains 4.2 g crude fiber per 100 g dry matter, for an overall dietary content of 4.8%. Types A and B represent the two traditional methods of meal preparation encountered in the northern province.

Type C. This was a diet surcharged with byproducts of the milling process. The debris of the husks collected during processing of the meal of diet A are added to whole grain sorghum meal in a proportion of 15 to 100 (and represent 13% of the total). The chemical composition of the chaff and husks is presented in Table 2. The crude fiber content of the meal mixture is 5.0% of the dry matter, while that of this regimen is 5.4%.

All three kinds of flour were prepared with the same mill. The three diets were tested in sequence. A 5-day adaptation period preceded the 6-day test period, which was divided into two phases of 3 days each. This procedure enabled verification of the replicability of the measures with each individual. Each subject's weight was maintained during the course of the experiment, and drinking water was freely distributed.

TABLE 1
Composition of diet for a 60-kg body weight man

Ingredients*	g/2700 kcal	kcal/day	MJ/day
Sorghum flour	630	2160	9.03
Zebu meat, cooked	59.4	102	0.43
Onions, fresh	18.9	8	0.03
Peppers, fruit, dried	3.8	13.5	0.06
Baobab, leaves, dried	25.5	71.5	0.30
Cottonseed oil	38.5	345	1.44
Common salt (NaCl)	7.7		
Chemical analysis			
Energy		2700 kcal	11.29 MJ
Protein (N × 6.25)		66.2 g	
Fat		64.2 g	
Energy (%) from			
Protein		9.8	
Fat		21.4	
Carbohydrate		68.8	

* Edible portion.

TABLE 2
Dietary levels of crude fiber in the diets*

Diet A	3.3%
Diet B	4.8%
Diet C†	5.4%

* Expressed in grams of formic insoluble per 100 g of dry matter.

† Chemical analysis of middings used to increase the level of crude fiber in regimen C, percentage wet matter: water 10.3, protein 7.0, fat 5.2, formic insoluble 7.9.

Specimen collection

Subjects were ambulant in a dwelling house, their only exercise being walking, playing cards, or other sedentary games. Collections of urine were taken each day and preserved by the addition of 0.25% of a 10% solution of thymol in isopropanol before freezing. Daily creatinine excretion was measured in order to check that the entire urinary output had been collected. All feces were collected during each phase of the experiment. One gram of carmine was used as a marker at the beginning and at the end of each period. Feces were sprinkled superficialy with ethanol before being frozen. The apparent nitrogen balances are calculated, excluding cutaneous and other minor N losses.

Analytical methods

For water content: dessication in a drying-room at 105°C until attaining constant mass.

For total nitrogen content: in accordance with the Kjeldahl's method (15) after sulfuric mineralization in presence of a selenium catalyst. Nitrogen-protide conversion coefficient = 6.25.

For total lipid content: extraction by means of petroleume ether in a Soxhlet apparatus for 10 h without preliminary hydrolysis.

For crude fiber content: Guillemet and Jacquot's technique (16). This method enables an approximation of the sum cellulose + liguin + some generants of furfural, and gives results comparable with the quantities of crude fiber as determined by methods accepted by A.O.A.C. (15).

For creatinine content: in accordance with Husdan and Rapoport's method (17).

Statistical analysis

Student's test was employed for the statistical analysis of most results, and Mann and Witney's U-test was used for non-Gaussian distributions. Correlation coefficients were performed according to Snedecor (18). Significance is given for $P < 0.05$.

Results

Urinary excretion of creatinine and nitrogen

The mean daily creatinine remained constant throughout the experiment (**Table 3**). Highest mean urinary nitrogen losses were noted with diet A; these losses tapered off slightly for the two regimens richer in crude fiber. Individual nitrogen balances were positive in all but three cases and declined when the subjects switched from diet A to diets B and C.

Emission of fecal matter

Quantity of fresh fecal matter augmented rapidly with increasing crude fiber dietary content (**Table 4**). Dry matter output followed an identical pattern, as fecal degree of humidity underwent no significant variation with dietary modifications (**Table 5**). No significant correlation was found between fecal water content and fecal formic insoluble content ($r = -0.15$, $df = 70$). On the other hand, the correlation between quantities of crude fiber ingested and amounts of dry fecal matter emitted is highly significant ($r = 0.81$, $p < 0.001$).

Highest fecal nitrogen losses occured with diet C, which does not differ significantly from diet B in this respect. However, it may be noted that the feces emitted after ingestion of diet A were richest in protides. Quantities of crude fiber ingested and those of total fecal

TABLE 3
Changes in urinary creatinine, urinary nitrogen, and nitrogen retention of 12 Cameroonians fed three levels of crude fiber

Subject	Creatinine (mg/kg body wt/day)			Nitrogen (g/day)			Nitrogen retention (g/day)		
	Diet A	Diet B	Diet C	Diet A	Diet B	Diet C	Diet A	Diet B	Diet C
1	22	25	26	5.81	5.36	5.75	1.55	−0.48	0.16
2	25	26	23	6.35	5.58	4.51	1.84	0.43	0.86
3	21	19	21	3.44	3.26	3.45	3.41	2.82	2.16
4	22	24	22	4.65	4.80	3.54	2.21	0.58	2.79
5	24	25	21	5.69	4.60	4.36	2.04	1.32	1.43
6	26	23	21	7.63	5.10	5.58	0.97	1.43	1.04
7	16	21	22	4.63	5.27	5.58	1.61	1.28	0.01
8	22	22	22	4.48	4.97	4.73	2.44	2.32	2.06
9	24	23	23	6.31	5.45	5.99	0.74	0.63	−0.19
10	20	19	18	5.42	5.06	4.41	2.52	1.82	2.38
11	26	21	24	7.21	4.68	6.27	1.68	3.06	1.00
12	22	23	22	4.33	3.79	5.35	3.27	2.43	−0.44
Mean*	22.5^{a}	22.6^{a}	22.1^{a}	5.50^{a}	4.83^{b}	4.96^{ab}	2.02^{a}	1.47^{a}	1.11^{b}
± SD	2.8	2.3	1.9	1.25	0.69	0.93	0.81	1.07	1.08

* For each parameter mean values with no common superscript are significantly different (level of significance $p < 0.05$).

TABLE 4
Daily amounts of total solids, nitrogen, and crude fiber in feces of 12 Cameroonians fed three levels of crude fiber

Fecal component (g/day)	Diet A	Diet B	Diet C
Wet matter	211.6 ± 86.0^{a}	295.3 ± 94.4^{b}	355.5 ± 110.4^{c}
Dry matter	52.7 ± 11.5^{a}	69.7 ± 16.7^{b}	87.1 ± 20.5^{c}
Nitrogen	4.02 ± 0.92^{a}	4.13 ± 0.84^{ab}	4.73 ± 1.35^{b}
Crude fiber	5.77 ± 1.93^{a}	9.76 ± 3.63^{b}	12.84 ± 5.08^{b}

* Mean value ± SD. For each parameter mean values with no common superscript are significantly different (level of significance $p < 0.05$).

TABLE 5
Percentage of water, protein, and crude fiber in feces of 12 Cameroonians fed three levels of crude fibers*

Fecal component (percentage wet matter)	Diet A	Diet B	Diet C
Water	73.43 ± 4.67[a]	75.80 ± 2.62[b]	74.89 ± 2.47[ab]
Crude fiber	2.80 ± 0.39[a]	3.28 ± 0.44[b]	3.53 ± 0.56[b]
Protein	12.62 ± 2.41[a]	9.09 ± 1.47[b]	8.44 ± 1.36[b]
Protein (% dry matter)	47.46 ± 3.39[a]	37.40 ± 2.99[b]	33.56 ± 4.31[c]

* Mean value ± SD. For each parameter mean values with no common superscript are significantly different (level of significance $p < 0.05$).

TABLE 6
Apparent digestibility of dry matter, nitrogen, and crude fiber of 12 Cameroonians fed three levels of crude fiber

Digestibility*	Diet A	Diet B	Diet C
Dry matter	91.64 ± 1.42[a]	88.83 ± 2.25[b]	85.69 ± 2.12[c]
Nitrogen	65.36 ± 6.38[a]	60.45 ± 7.18[b]	56.86 ± 8.07[b]
Crude fiber	72.48 ± 8.69[a]	67.36 ± 11.07[ab]	61.24 ± 13.35[b]

* Mean value ± SD. For each parameter mean values with no common superscript are significantly different (level of significance $p < 0.05$).

nitrogen correlate strongly ($r = 0.57$, $p < 0.001$). Finally, quantities of crude fiber ingested correlated closely with formic insoluble substances found in the feces. ($r = 0.73$, $p < 0.001$).

Effects on apparent digestibility utilization

Digestibility of dry matter decreases significantly with each augmentation of crude fiber content (**Table 6**). This also holds true for nitrogen digestibility, which drops to a very low level in the fiber-surcharged diet. Calculation of true nitrogen digestibilities, using an arbitrary endogenous fecal excretion of 12 mg/kg of body weight (12) in the absence of other data relating to the population under investigation, yields very low numerical values. Amount of crude fiber ingested and nitrogen digestibility correlate strongly ($r = -0.60$, $p < 0.001$). However, nitrogen balances are not correlated with fiber intake ($r = -0.11$, ddl = 70).

Breakdown of formic insoluble substances

The mean quantity of formic insoluble substances which disappeared increased significantly when diets were switched from hulled to whole meal: 15.10 g ± 2.41 for the hulled-meal diet and 19.85 ± 3.30 for the whole-meal diet. It seems that the overload of husks and chaff is not accompanied by increased digestion of formic insoluble substances; it remains, on the average, at 19.75 g ± 4.33. Correlation between quantities of formic insoluble substances ingested and amounts broken down is significant ($r = 0.61$, $p < 0.001$).

Fecal and urinary nitrogen

A negative correlation exists between fecal and urinary nitrogen ($r = -0.27$, $p < 0.02$).

Discussion

Effects of increased crude fiber intake are clearly apparent in the quantity of fecal matter produced. Also, digestibility of dry matter in the diet diminishes very rapidly, the depressive effect of crude fiber on digestibility being particulary marked when passing from diet B to C. Thus the addition of 1.5 g and then of 2.1 g crude fiber to the hulled diet is followed by a drop of 2.81, then of 5.95 points, of the digestibility of dry matter; the additional 0.6 g causing a 3.14 point decrease in digestibility.

Fecal degree of humidity and formic insoluble content are little affected by dietary modifications. On the other hand, the fecal protide concentration tends to diminish, indicating that fecal dry matter loss is proportionally more important than protide loss when changing from a fiber-poor to a fiber-rich diet.

During the experiment, we noted reduced nitrogen digestibility, even for diet A which was poorest in fiber content. Consequently our results appear weak in comparison with those obtained elsewhere under similar conditions. Farrell et al. (19) found apparent nitrogen digestibilities in Australian men of 89.7 and 87.6% for daily diets of 33 and 53 g of NDF (neutral detergent fiber), produced from wheat bran. Similarly, Macrae et al. (20), using a fully ground wheat flour, mentions a protide digestibility of 85.7%.

The subjects studied behaved normally when exposed to the first fiber overload and exhibited no signs of a particular adaptation to a fiber-rich diet. One may note, however, that the quantities of nitrogen obsorbed in diets B and C are almost identical (6.3 and 6.2 g/day) the amounts ingested were, respectively, 10.4 and 10.9 g/day.

Several phenomena may have contributed to the fecal wastage observed. Reduced absorption by the small intestine can be provoked merely by the presence of fibers, which behave like a trap. Increased fiber intake may also be accompanied by corresponding rises in endogenous losses including desquamation. Such an hypothesis is similar to that revived by Walker (21), wherein fecal nutrients losses associated with fiber-rich diets are of endogenous rather than dietary origin. Thus it is probable that diminishing capacity of the digestive tract, linked to the individual's overall nutritional status, combines with the fiber specific effects. During the course of the study, all 12 subjects were in good health. We had no precise information on their previous nutritional status. However, an old (though not outdated) study demonstrates that the usual feeding patterns of the population from which our subjects were drawn is characterized by seasonal variations, during which large deficiencies are registered in animal proteins and in vitamins—vitamin A, vitamin C, riboflavin (9). In addition, we were also able to verify the widespread incidence of intestinal parasites (threadworm and ankylostoma).

Despite the drop in nitrogen digestibility provoked by increasing the intake level of fiber, nitrogen balances remained positive. Such a reduction of excreted urinary nitrogen has already been observed by Nicol and Phillips (22) in a sample population of low-income Nigerians.

In our study, the diets provide 22, 32, and 36 g crude fiber for a man weighing 60 kg. These intakes correspond to those observed for other rural African cereal-consuming populations. Lubbe's studies (23) indicate an average intake of 24.8 g of crude fiber. On the other hand, these values are much higher than those which characterize British and American dietary patterns, respectively 4 to 8 and 8 to 11 g of crude fiber as defined by the Weende method (24, 25).

Quantities of broken down formic insoluble substances increase markedly when switching from the hulled grain to the wholegrain diet. However, the second surcharge is not followed by an augmentation of the amount digested. This last observation is probably linked to the different glucidic properties of the middings utilized, wherein cellulose and lignin were more prevalent.

One may note, however, the important quantities broken down, certainly facilitated by a particular fecal microflora well adapted to the hight fiber content of the diet. Comparison with other studies reveals that non-African populations are much less capable of digesting fiber, even ingested in smaller quantities. Thus Holloway et al. (26) record a 38% digestibility coefficient for New Zealanders consuming 9.4 g cellulose and lignin. Southgate and Durnin (27) find that for cellulose intakes of less than 9 g by 22-yr-old European males the digestive utilization does not exceed 26%. Finally, Farrell et al. (19) note a 61.7% digestibility for a larger (32 g) intake of acid detergent fiber in a population of Australian men (19).

In view of the ability of fecal-colonic flora to break down increased quantities of crude fiber it would have been interesting to know the amounts of nitrogen, ammonia, and other nitrogenous gases excreted.

The sample population which we have examined thus exhibits normal behavior in terms of fecal nitrogen losses subsequent to ingestion of crude fiber-rich diets, as no evidence of compensatory mechanisms could be found. However, this group is marked by its ability to break down fairly large quantities of crude fiber and to reduce urinary nitrogen losses when the nitrogen balance is near equilibrium.

Yet the digestibility measurements that we have taken, which reveal high fecal nitrogen losses, do not enable us to distinguish between the respective roles of fiber-induced effects and those due to a diminution of digestive capacity, resulting from an alteration of the mucous membrane, itself caused by nutritive deficiency.

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