Studies on Weaning Diets in Nigeria. I. Carbohydrate Sources

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ABSTRACT

Ogi is a fermented cereal porridge and a popular weaning, breakfast, and convalescent food in Nigeria. It is made from sorghum in the northern part of the country, where sorghum is cultivated abundantly, and from maize in the heavy rain belt of the south. In this study, *ogi* was made from white and yellow maize and from white and red sorghum and compared with other carbohydrate sources in a simulated weaning diet. The yield of *ogi* was 66.0-75.9%, and the protein content was 7.53-9.28%, compared with 8.05% for breadfruit and 1.05% for cassava starch. Reducing sugar was 2.85% in breadfruit and 0.03-0.08% in the others. White sorghum *ogi* contained the highest energy (4.07 kcal/g) and the lowest ash (0.32%), whereas cassava starch contained the lowest energy (3.38 kcal/g) and the highest ash (3.91%). Fat content was 5.5% in maize *ogi*, 2.97% in sorghum *ogi*, and 1.92% in breadfruit. Processing grains into *ogi* reduced the tannin content by 64-100% and phytate by 72-93%. Cyanide was not detected in sorghum *ogi* or cassava starch. In the rat bioassay, feed intake was highest (78.3 g) in a red sorghum *ogi*-casein diet (13% protein level) and lowest in a corn starch diet (59.4 g). Weight gain, protein efficiency ratio, and net protein ratio values were highest in the cassava diet (25.2, 2.6, and 3.9 g, respectively), followed by breadfruit and corn starch; the lowest values were recorded with a white sorghum *ogi* diet (weight gain 9.5 g, protein efficiency ration 1.0, and net protein ratio 2.2). Protein digestibility was high (93.0-97.1%) for all diets. In vitro starch digestibility was highest in corn starch, followed by breadfruit, and lowest in white sorghum and yellow maize *ogi*. Using a first-order kinetics equation, breadfruit had the highest initial rate of starch hydrolysis ($t_{1/2}$ for 19.4 min), followed by corn starch (26.1 min); the lowest was for white sorghum *ogi* (109.7 min). The bioassay results were therefore explained in terms of starch digestibility and gastric emptying.

Ogi, a fermented cereal porridge, is a popular weaning, breakfast, and convalescent food in Nigeria. It is made from sorghum (*Sorghum bicolor* L. Moench) grains in northern Nigeria, where sorghum is cultivated abundantly, and—more predominantly—from maize in the heavy rain belt of the south.

In both parts of the country, *ogi* is traditionally produced only from the red, "bird-proof" variety of sorghum because it is believed to be more nutritious; it is even added to maize to enhance the nutritional value of the *ogi* product. Both yellow and white varieties of maize are processed to *ogi.* Osuntogun et al (1989) showed that red sorghum (variety SRN 484) contains a higher level of tannin (2.9% catechin equivalent) and total polyphenol (2.7% tannic acid equivalent) than the white variety, which contains tannin in the range of 0.25-0.67% catechin equivalent and polyphenols in the range of 0.32-0.68% tannic acid equivalent. Hagerman and Butler (1978), Reichert et al (1980), Osuntogun (1984), and Osuntogun et al (1987) showed that tannin can combine with proteins, thereby exhibiting a deleterious effect on the nutritional value of food products through enzymatic inhibition, poor digestibility, and absorption (Glick and Joslyn 1970). Indeed, at a level above 2%, tannin can be lethal.

Literature abounds on the traditional and improved production techniques of *ogi* (Banigo and Muller 1972; Banigo et al 1974, Banigo and Adeyemi 1975, Akingbala et al 1981a, 1981b). However, to our knowledge, not much work has been done on the effect of fermentation and *ogi* production on the level of antinutritional components (tannin, phytate, cyanide) of grains, the nutritional value of the different varieties of grain, or the comparative chemical and nutritional analysis of *ogi* and other unconventional sources of carbohydrate in a weaning diet. These parameters are important to the successful development of an inexpensive weaning diet that is available from a local source.

With this in mind, we investigated the production of *ogi* from white and red sorghum and white and yellow maize, the effect of processing on the tannin, phytate, and reducing sugar levels, and the rate of carbohydrate hydrolysis. We also compared the nutritional value of these *ogi* varieties with those of corn starch, cassava starch, and breadfruit by rat bioassay.

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MATERIALS AND METHODS

White sorghum grain variety SSV3 and red variety SRN484 were obtained from the Institute of Agricultural Research, Ahmadu Bello University, Zaria, Nigeria. White and yellow varieties of maize were from the local market; corn starch and casein were from the Nutritional Biochemicals Company (Cleveland, OH); and cassava starch was a preproduction sample from Nimetco Starch Company Limited, Ibadan. Breadfruit from the local market was peeled, oven-dried at 50°C, and milled to a fine powder.

Production of *Ogi*

Each variety of cereal grain (1.5 kg) was steeped in 3 L of tap water at room temperature for four days. The steep water was decanted, and the fermented grain was washed with clean fresh water and wet milled. The bran was removed by sieving, and the remaining solid matter—the *ogi*—was allowed to settle. The water was decanted, and the *ogi* was further drained of water and air-dried for 24 hr and in the oven at 50°C for 48 hr. The dry powder was milled and was kept in a desiccator at room temperature until needed.

The crude protein of the samples was analyzed by the micro-Kjeldahl method (AOAC 1975) and calculated as N $\times$ 6.25. Ash was determined by the AOAC (1975) method. Total energy was determined by the bomb calorimetry method (AOAC 1975), using benzoic acid as the standard. Phytate was determined by the method of Harland and Oberleas (1986). Tannin was extracted with 1% HCl in methanol for 1 hr and determined by the vanillin-HCl method of Price and Butler (1977). Screening for cyanide was done according to the method of Feigl and Anger (1966).

Determination of In Vitro Starch Hydrolysis

In vitro starch hydrolysis was determined essentially according to Singh et al (1982). Of each sample, 0.25 g was added to 10 ml of 0.2M of phosphate buffer (pH 6.9). Then 5 ml of a mixture of 20 mg of pancreatic amylase (sigma-type VIA) in 50 ml of phosphate buffer was added. The mixture was shaken and incubated at 37°C. The mixture was allowed to settle for 3 min before 1-ml aliquots were withdrawn at intervals and added to 2 ml of dinitrosalicylic acid reagent (1% dinitrosalicylic acid, 0.2% phenol, 0.1% sodium hydrosulfite, and 1% NaOH, according to Miller 1959). The mixture was shaken and heated in boiling water for 5 min, diluted to 25 ml, and the absorbance read at 550 nm against a blank containing buffer, enzyme, and dinitrosalicylic acid reagent.

Total reducing sugar was extracted with 80% ethanol; the alcohol was evaporated; and the extract was diluted. Aliquots

TABLE I

Composition of Weaning Diets Based on White and Yellow Maize, White and Red Sorghum *Ogi*, Corn and Cassava Starch, and Breadfruit

	Diet							
Ingredient	Protein Free	Corn Starch	White Maize	Yellow Maize	White Sorghum	Red Sorghum	Cassava	Breadfruit
Starch	85.00	68.10	75.60	77.50	75.60	75.50	69.00	75.90
Casein	···	16.90	8.40	7.50	9.40	9.50	16.00	9.10
Nonnutritive cellulose	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Salt mix[a]	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Vitamin mix[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Palm oil	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
% Protein	···	13.00	13.04	13.01	13.06	13.01	13.04	13.07

[a]Jones and Foster (Nutritional Biochemicals Corporation, Cleveland, OH).
[b]ICN Nutritional Biochemicals, Cleveland, OH.

TABLE II

Crude Protein (N × 6.25) Content (Mean Yield and Cost Analysis) of Whole Grain, *Ogi*, Bran, Breadfruit, and Cassava Starch[a]

Sample	Whole Grain (%)	*Ogi* (%)	Bran (%)	Mean Yield of *Ogi* (%)	Cost (₦/kg)[b]
White maize	10.33	8.58	8.05	75.9	2.1
Yellow maize	10.68	9.28	8.40	70.4	2.9
White sorghum	8.93	7.70	8.40	66.0	3.3
Red sorghum	9.10	7.53	8.23	68.1	3.3
Breadfruit	8.05	···	···	···	0.83
Cassava starch	1.05	···	···	···	2.00

[a]Mean value of at least two determinations (db).
[b]₦ = Nigerian naira; ₦1 = $0.14.

were added to 5 ml of dinitrosalicylic acid reagent and treated as above.

Bioassay

Ogi and other carbohydrate sources were gelatinized at 80°C for 30 min. The composition of the simulated weaning diets is shown in Table I. Protein was fed at 13% because the samples contained various levels of protein, and the aim was to compare the samples as primary sources of carbohydrate. In addition, this would represent the practice of the middle-income class in developing countries like Nigeria. Casein was used as the reference protein with corn starch as the control for the carbohydrate source. Albino rats of the wistar strain (age, 20–30 days; weight, 38–42 g) were obtained from the Faculty of Pharmacy colony. The animals were individually housed in metal cages and were given food and water ad libitum. The rats were acclimatized to the new environment for three days, were starved for 24 hr, and were fed the test diets for 21 days. Five rats per treatment were used. Other procedures used in the bioassay were as outlined previously (Adewusi and Oke 1985).

RESULTS AND DISCUSSION

Whole grain and *ogi* from the yellow maize had the highest crude protein (CP) content (10.68 and 9.28%, respectively), followed by those from white maize (10.33 and 8.58%, respectively) (Table II). In sorghum samples, the whole grain of red sorghum had a CP content of 9.10%, compared with 8.93% for the white variety. *Ogi* from the white variety, however, contained a slightly higher CP level: 7.70%, compared with 7.53% for the red sorghum. Akingbala et al (1981a) reported CP content ranging from 8.1 to 11.4% for seven sorghum varieties. The CP of *ogi* from those varieties, and the Nigerian samples ranged from 9.5 to 5.9%. The CP content of the bran was 8.05 and 8.40% for white and yellow maize, respectively, compared with 8.40 and 8.23% for white and red sorghum, respectively, which is well below the 13.9–19.9% quoted by Akingbala et al (1981a).

Milling generally affects the distribution of CP between *ogi* and bran, but according to the present practice in Nigeria, the grains are finely milled in such a way that sieving would no longer be necessary, and the *ogi* is taken as such. This would definitely result in increased protein intake for the consumers, since most of the grain protein would still be present in the *ogi* (except for what is leached during steeping and in the wash water).

The mean yield of *ogi* was highest from white maize (75.9%) followed by yellow maize (70.4%) but was still better than the mean yield from sorghum (68.1 and 66.0% for red and white sorghum varieties, respectively). A mean yield of 78–82% was reported for maize *ogi* by Akinrele (1970), while 68.4–79.0% was reported for *ogi* by Akingbala et al (1981a) from seven sorghum varieties.

The cost of *ogi* from both white and red sorghum was highest—₦3.3/kg of dry weight-while *ogi* from yellow and white maize was ₦2.9 and ₦2.1/kg, respectively. This reflects the cost of the grains plus the fact that sorghum grains are not produced in the southern part of Nigeria and would therefore involve additional freight costs. Production of cassava starch with 1.05% CP costs about ₦2.00—less than any form of *ogi*. (The price of cassava starch has recently risen to ₦6.00/kg in the open market due to demand for cassava-based diets.) Cassava generally has a low CP content but has the advantage of easy cultivation and adaptation to many ecological locations. Therefore, it would be very abundant and available to the weaning-food industry.

By far the cheapest source of carbohydrate is breadfruit (about ₦0.83/kg of dry weight). The breadfruit used in this study contained 8.05% CP, which is comparable to the 8.0% obtained by Omole et al (1978). In the course of this study we encountered a breadfruit with 5.8% CP. Whether this variation is statistically significant due to species differences and/or location is being investigated.

The reducing sugar content (Table III) was highest in breadfruit (2.85%), followed by cassava starch (0.08%), *ogi* from white and yellow maize (0.07 and 0.06%, respectively), and white and red sorghum (0.04 and 0.03%, respectively). The reducing sugar content is generally low and would be a good attribute, since both traditional and modern methods of preparing weaning foods involve heat processing. Heat has been known to adversely affect amino acid availability through the Maillard reaction and other protein interactions, and this effect is aggravated by the presence of reducing sugars (Knipfel et al 1975, Warmbier et al 1977, Adewusi and Oke 1984). Ether extract, or percent fat, was high in *ogi* from white and yellow maize (5.49 and 5.46%, respectively) (Table III), which is comparable to the value obtained by Akinrele (1970) and about double the fat content of white and red sorghum *ogi* (2.96 and 2.98%, respectively). Akingbala et al (1981a) reported 1.6–3.1% fat for *ogi* prepared in the laboratory from sorghum cultivars and 1.1–1.5% for *ogi* traditionally made in Nigeria.

Breadfruit had the lowest fat content (1.92%) (Table III). However, this was about the same level as the 2% obtained previously in this laboratory (Omole et al 1978). Total energy was highest in white sorghum *ogi* (4.07 kcal/g), followed by yellow maize *ogi* (4.02 kcal/g). Both of these samples contained very low ash content (0.32 and 0.38% for white sorghum and yellow maize *ogi*, respectively) and may well contain more carbohydrate in addition to the high fat content of yellow maize *ogi*. Breadfruit, white maize *ogi*, and red sorghum *ogi* contained 3.78, 3.76, and

3.53 kcal/g, respectively. Cassava starch had a lower energy content (3.38 kcal/g) than the commercial corn starch (3.62 kcal/g).

Although cassava starch had the lowest total energy, it contained the highest ash content (3.91%) (Table III). Ash content of the *ogi* samples was generally low (red sorghum 0.77%, yellow maize 0.38%, white maize 0.34%, and white sorghum 0.32%). Akingbala et al (1981a) reported a 0.3–1.0% range of ash for *ogi* from seven sorghum cultivars and observed that more than 50% of the mineral in sorghum had leached into the steep and wash water. Oke (1967) and Akinrele (1970) also observed that most minerals in maize were lost during processing into *ogi*. In our study, the lowest ash content was recorded for corn starch (0.11%), showing that virtually all minerals are removed during industrial processing.

Two antinutritional factors, tannin and phytate, were present in whole grains (Table IV). Tannin content was very high in red sorghum grains (25.68 mg/g of catechin equivalent). Osuntogun et al (1989) reported a value of 29.2 mg/g for the same variety planted in 1985 and 1986. However, tannin levels were low in the other grains (yellow maize 1.75 mg, white maize and white sorghum 1.25 mg/g catechin equivalent). Osuntogun et al (1989) reported 2.5–6.7 mg/g of catechin equivalent for 14 cultivars of sorghum of varying color. Akingbala et al (1981a) reported 3.91 and 3.02 mg/g for CA 615 and NK 300 sorghum cultivars but only traces of tannin for five other varieties investigated. In our study, breadfruit and cassava starch contained negligible amounts of tannin (0.63 mg/g each of catechin equivalent).

High tannin content could reduce digestibility and food value expected from the analytical compositions (Jambunathan and Mertz 1973) and could even be deleterious to health (Osuntogun 1984). This would make red sorghum unsuitable for human and animal consumption. However, the extractable tannin content was reduced by 85% during processing to *ogi*. The tannin content of yellow maize was also reduced to 0.63 mg/g (64% reduction), while the tannin content of both white maize and white sorghum grains were reduced to nondetectable levels in their *ogi* products.

TABLE III
Reducing Sugar, Ether Extract, Total Energy, and Ash Contents of *Ogi*, Breadfruit, Corn, and Cassava Starch[a]

Sample	Reducing Sugar (%)	Ether Extract (%)	Energy (kcal/g)	Ash (%)
White maize *ogi*	0.07	5.49	3.76	0.34
Yellow maize *ogi*	0.06	5.46	4.02	0.38
White sorghum *ogi*	0.04	2.96	4.07	0.32
Red sorghum *ogi*	0.03	2.98	3.53	0.77
Breadfruit	2.85	1.92	3.78	0.65
Cassava starch	0.08	N.D.[b]	3.38	3.91
Corn starch	N.D.	N.D.	3.62	0.11

[a]Mean value of at least two determinations.
[b]N.D. = Not determined.

In a similar experiment, Akingbala et al (1981a) reported a 60–70% reduction in the tannin content of the whole grains of two sorghum cultivars during *ogi* production but cautioned that a reduction in assayable tannin is not always a true index of nutritional quality, as observed by Price et al (1978).

In the whole grains, the phytate level was highest in the red sorghum (2.66 mg/g, dry weight), followed by yellow maize (1.86 mg/g), and was very low in white maize (0.32 mg/g) and white sorghum (0.36 mg/g) (Table IV). Breadfruit contained a negligible amount of phytate (0.09 mg/g), and none was detected in cassava starch. Processing the whole grain into *ogi* reduced the phytate content by 72, 88, 89, and 93% in white maize, yellow maize, white sorghum, and red sorghum, respectively. Oke (1967) had also observed that phytin phosphorus was reduced drastically during steeping and fermentation of maize.

In the rat bioassay (Table V), feed intake was highest in animals that were fed a red sorghum *ogi*-casein diet (78.3 g). However, this was not significantly different from the intake of animals fed the breadfruit-casein, white sorghum *ogi*-casein, and cassava-casein diets (76.6, 75.5, and 74.8 g, respectively). Animals fed *ogi* from yellow and white maize consumed less but about the same level of diet (68.6 and 64.9 g, respectively). The lowest feed intake was by animals on the corn starch diet (59.4 g).

The reason for the different intake levels is not immediately apparent, but a crucial factor could be the palatability of the different diets. The presence of condensed tannins was probably responsible for maintaining the 5.6 pH level of the steep water and an apparent reduction in fermentation, leading to less production of acid (Daiber 1975, Akingbala et al 1981b). This phenomenon would make the red sorghum *ogi* less sour and thus more palatable to the animals than the other *ogi* products, in which the pH level would decrease further after 72 hr, resulting in increased fermentation, acid production, and souring. Breadfruit contained the highest reducing sugar (Table III) and possibly the highest disaccharides, thus imparting a sweet taste to the diet. This could be responsible for the high feed intake of the rats fed the breadfruit-casein diet.

Another factor could be the high rate of breadfruit starch digestibility (discussed later). The lowest feed intake by animals on the corn starch diet could also be attributed to the palatability factor. Weight gain was highest for rats on the cassava starch diet (25.2 g) but was not significantly better than the weight gain of animals on the breadfruit diet (23.3 g) (Table V). Animals on the corn starch diet gained 16.9 g, while animals on white maize, yellow maize, and red sorghum *ogi* gained 14.9, 14.8, and 14.2 g, respectively. The smallest weight gain was recorded for animals on the white sorghum *ogi*-casein diet (9.5 g)—less than half the value obtained for cassava starch and breadfruit diets and about half that for corn starch. Feed intake could not account for this phenomenon, since feed intake of animals on this diet was high (second highest). The highest protein efficiency ratio (PER) was recorded for animals on the cassava starch-casein diet (2.6), higher but not significantly better than those of animals on the breadfruit (2.4) and corn starch (2.3) diets.

TABLE IV
Tannin and Phytate Contents of Whole Grains, *Ogi*, Breadfruit, and Cassava Starch[a]

Sample	Tannin[b] (mg/g of catechin equivalent) Whole Grain	Tannin *Ogi*	Tannin Reduction (%)	Phytate[c] (mg/g, dry weight) Whole Grain	Phytate *Ogi*	Phytate Reduction (%)
White maize	1.25	N.D.[d]	100	0.32	0.09	72
Yellow maize	1.75	0.63	64	1.86	0.23	88
White sorghum	1.25	···	100	0.36	0.04	89
Red sorghum	25.68	3.75	85	2.66	0.18	93
Breadfruit	0.63	···	···	0.09	···	···
Cassava starch	0.63	···	···	N.D.	···	···

[a]Mean value of at least two determinations.
[b]Tannin was determined by the vanillin-HCl method of Price and Butler (1977).
[c]Phytate was determined by the method of Harland and Oberleas (1986).
[d]N.D. = Not detected.

TABLE V
Rat Bioassay: Comparison of Weaning Diets (Mean ± SD, Five Rats per Treatment)[a]

Diet Treatment	Feed Intake (g)	Weight Gain (g)	Protein Efficiency Ratio	Net Protein Ratio	True Digestibility
Corn starch	59.4 ± 2.9 a	16.9 ± 2.7 a	2.3 ± 0.2 a	3.8 ± 0.3 a	93.2 ± 1.7 a
Casein and					
Yellow maize *ogi*	68.6 ± 3.5 b	14.8 ± 1.3 b	1.7 ± 0.1 b	3.0 ± 0.1 b	93.9 ± 0.7 a
White maize *ogi*	64.9 ± 5.9 ab	14.9 ± 2.9 ab	1.8 ± 0.1 b	3.3 ± 0.3 b	93.0 ± 2.0 a
Red sorghum *ogi*	75.3 ± 4.4 c	14.2 ± 1.4 b	1.4 ± 0.2 c	2.6 ± 0.2 c	93.2 ± 1.8 a
White sorghum *ogi*	75.5 ± 1.9 c	9.5 ± 1.8 c	1.0 ± 0.2 d	2.2 ± 0.2 d	93.2 ± 1.1 a
Cassava starch	74.8 ± 1.4 c	25.2 ± 3.7 d	2.6 ± 0.4 a	3.9 ± 0.3 a	95.9 ± 1.2 b
Breadfruit	76.6 ± 0.4 c	23.3 ± 2.5 d	2.4 ± 0.3 a	3.6 ± 0.2 a	97.1 ± 0.2 b

[a] Figures followed by the same letters in the same column are not significantly different at the 95% confidence level.

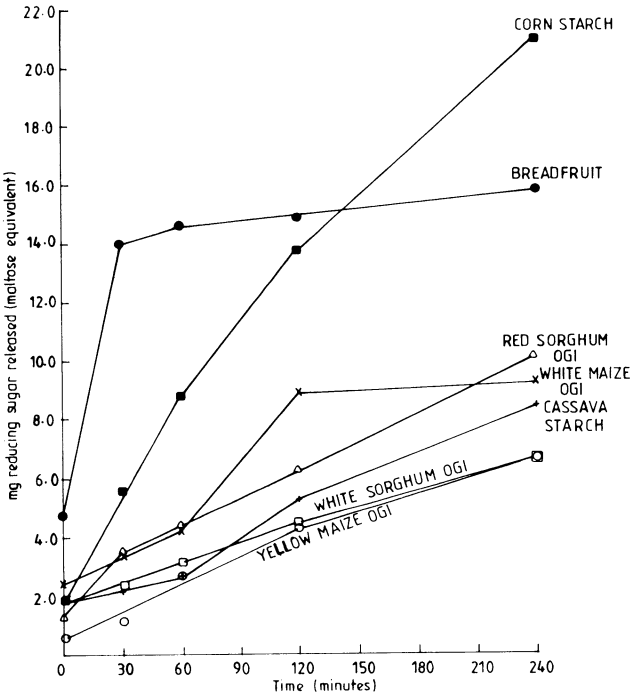

Fig. 1. In vitro starch digestibility of *ogi*, corn and cassava starch, and breadfruit over time.

TABLE VI
Rate Constant and Half-Life Values of Starch Hydrolysis in Different Sources[a]

Sample	t_1	t_0	t	k	$t_{1/2}$
White maize *ogi*	60	0	60	0.0092	75.3
	120	60	60	0.0055	126.0
	240	120	120	0.0033	210.0
Yellow maize *ogi*	120	0	120	0.0165	42.1
	240	120	120	0.0035	198.0
White sorghum *ogi*	120	0	120	0.0063	109.7
	240	120	120	0.0062	111.0
Red sorghum *ogi*	30	0	30	0.0343	20.2
	240	30	180	0.0061	113.1
Breadfruit	30	0	30	0.0357	19.4
	60	30	30	0.0013	529.0
	240	60	180	0.0005	1480.8
Cassava starch	60	0	60	0.0061	113.1
	120	60	60	0.0118	58.7
	240	120	120	0.0038	180.9
Corn starch	60	0	60	0.0265	26.1
	120	60	60	0.0076	91.6
	240	120	120	0.0034	204.6

[a] First order kinetics equation $2.303 \log {}_{n}o\, kt$ and $t_{1/2} = 0.693/k$, where n_o is the size of the product — reducing sugar (in maltose equivalent) at time t, n is the size of the product — reducing sugar (in maltose equivalent) at time interval t, k is the rate constant, t is the experimental period under consideration ($t_1 - t_0$), and $t_{1/2}$ is half-life.

In an earlier experiment, the highest PER was found with breadfruit (2.81), followed by cocoyam (2.79). The lowest PER was recorded with cassava (2.21), when six tropical root crops and fruits were fed to rats at the 30% level. The low PER obtained for cassava was attributed to the presence of cyanide, which led to high levels of plasma urea and thiocyanate (Omole et al 1978). Cassava starch and sorghum *ogi* used in this experiment contained no detectable cyanide, as confirmed by the Feigl-Anger paper test. The highest PER recorded for the cassava-casein diet could be due to the superior protein value of casein, but this could not solely account for the result obtained. True digestibility was slightly higher than for most feeds (except breadfruit diet) and cassava had a high ash content, which might include some essential ions.

In our study, the PER obtained for breadfruit with 9.1% casein was 2.4. This is not statistically different from the PER of cassava and corn starch diets, which contain 16 and 16.9% casein, respectively) and would indicate that breadfruit is a very good source of protein, comparable to casein. Indeed, the amino acid profile of breadfruit (FAO 1970) shows that its protein is better than that of egg with respect to isoleucine, phenylalanine, threonine, tryptophan, and valine. The yellow and white maize *ogi*-casein diets had about the same PER value (1.7 and 1.8, respectively). The 1.8 PER value for the white maize diet could be attributed to the slightly higher casein content of yellow maize. The red sorghum *ogi*-casein diet had a PER of 1.4, which is significantly lower than that of the maize *ogi* diet, despite the fact that the sorghum *ogi* diet had a higher casein content. This result could be attributed to the tannin (measurable content 3.75 mg/g) and phytate content (0.18 mg/g) in the red sorghum *ogi*. The lowest PER (1.0) was recorded for the white sorghum *ogi*. This could not be accounted for by the presence of tannin or phytate. Furthermore, the white sorghum *ogi* contained the highest total energy content (4.07 kcal/g) and the lowest ash content (0.32%). The major reason could be the digestibility of either the starch or protein content of the diet. The protein digestibility for all the diets was generally high (between 93.0 and 97.1%). Therefore, the poor performance by animals on the white sorghum *ogi* diet could not be due to poor digestion of protein. Values for net protein ratio generally followed the results for the PER results.

In an effort to elucidate the problem of the low PER value for white sorghum *ogi*, an in vitro hydrolysis of the starch sources was performed. The highest reducing sugar level (maltose equivalent) was recorded for corn starch incubated with pancreatic amylase, followed very closely by breadfruit (Fig. 1). The other samples—red sorghum *ogi*, white maize *ogi*, and cassava starch—produced intermediate levels of reducing sugar. White sorghum and yellow maize *ogi* gave the least in vitro starch digestibility. Susceptibility of a carbohydrate source to α-amylase attack and therefore digestion is subject to many factors, including the extent of damage to starch granules (the greater the damage, the more susceptible the starch is to amylolytic attack [Akingbala et al 1981b], starch gelatinization, amylase-amylopectin ratio, starch-lipid complexes, starch-protein interactions, retrogradation, and enzyme inhibitors [Asp 1989]). It has also been suggested that a proportion of the starch in cooked foods could become resistant to α-amylase hydrolysis in vitro and could therefore be fermented in the ileum (Faulks et al 1989).

A first-order kinetics equation (Rosenthal and Nasset 1958) used on the starch hydrolysis in vitro indicated that the half-life of corn starch within the first 60 min was 26.1 min (Table VI), showing a high level of starch digestion. The half-life of breadfruit starch hydrolysis was 19.4 min in the first 30 min. This is the highest rate of hydrolysis, indicating the presence of low molecular weight dextrins in breadfruit. The possibility that breadfruit may contain an appreciable amount of α-amylase cannot be ruled out, considering its high rate of deterioration after harvest. The high rate of breadfruit starch hydrolysis is, however, consistent with the high feed intake by animals fed breadfruit and the concensus that breadfruit in any form is a light diet.

The cassava starch diet had the highest PER, but the intermediate rate of hydrolysis $t_{1/2}$ was 113.1 min in the first 60 min and 58.7 min in the next 60 min. Starch from white and yellow maize and red sorghum had fairly high in vitro digestibility ($t_{1/2}$ 75.3, 42.1, and min, respectively, during the first 60 min). This again would be consistent with the intermediate PER values observed. White sorghum *ogi* starch had a low in vitro digestibility, with a half-life of 109.7 in the first 120 min and 111.0 min in the next 120 min. This low rate of hydrolysis may lead to conditions similar to those of hypoglycemia, whereby proteins would be used as an energy source. However, it is important to point out that the rate of starch hydrolysis would not be the sole determinant of PER and food quality. Protein quality is a major factor, as is the rate of gastric emptying, which is determined by the carbohydrate source. A high rate of gastric emptying would lead to a reduced rate of carbohydrate and protein digestion and absorption (Rosenthal and Nasset 1958, Porter and Rolls, 1971).

LITERATURE CITED

ADEWUSI, S. R. A., and OKE, O. L. 1984. Lysine in cassava based diets. I. A note on the effect of heat on digestibility and available lysine. Food Chem. 15:261-268.

ADEWUSI, S. R. A., and OKE, O. L. 1985. Lysine in cassava based diets. II. The nutritional evaluation of acetylated casein in maize meal, corn starch and cassava based diets. Food Chem. 16:25-36.

AKINGBALA, J. O., ROONEY, L. W., and FAUBION, J. M. 1981a. A laboratory procedure for the preparation of ogi, a Nigerian fermented food. J. Food Sci. 46:1523-1526.

AKINGBALA, J. O., ROONEY, L. W., and FAUBION, J. M. 1981b. Physical, chemical and sensory evaluation of ogi from sorghum of differing kernel characteristics. J. Food Sci. 46:1532-1536.

AKINRELE, I. A. 1970. Fermentation studies on maize during the preparation of a traditional African starch cake food. J. Sci. Food Agric. 21:619-622.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. 1975. Official Methods of Analysis, 12th ed. The Association: Washington, DC.

ASP, N.-G. 1989. Bioavailability of food carbohydrates as related to analytical methods. Pages 301-309 in: Nutrient Availability: Chemical and Biological Aspects. D. Southgate, I. Johnson, and C. R. Fenwick, eds. The Royal Society of Chemistry: Cambridge, England.

BANIGO, E. O. I., and ADEYEMI, A. I. 1975. A comparative study of the commercial practice of traditional ogi manufacture using high-lysine (opaque-2) corn and normal corn. Page 402 in: Proceedings of the 10th International Congress of Nutrition. International Union of Nutritional Sciences: Kyoto, Japan.

BANIGO, E. O. I., and MULLER, H. C. 1972. Manufacture of ogi (a Nigerian porridge): Comparative evaluation of corn, sorghum and millet. Can. Inst. Food Sci. 5:217.

BANIGO, E. O. I., DE MAN, J. M., and DUITSCHAEVER, C. O. 1974. Utilization of high-lysine corn for the manufacture of ogi, using a new improved processing system. Cereal Chem. 51:559-561.

DAIBER, K. H. 1975. Enzyme inhibition by polyphenols of sorghum grain and malt. J. Sci. Food Agric. 26:1399-1411.

FAO. 1970. Amino acid content of foods and biological data on proteins. FAO Nutr. Meet. Rep. Ser. 24. Food and Nutrition Organization of the U.N.: Rome.

FAULKS, R. M., SOUTHON, S., and LIVESEY, G. 1989. The utilization of α-amylase resistant corn and pea starches in the rat. Pages 319-321 in: Nutrient Availability: Chemical and Biological Aspects. D. Southgate, I. Johnson, and C. R. Fenwick, eds. The Royal Society of Chemistry: Cambridge, England.

FEIGL, F., and ANGER, V. 1966. Replacement of benzidine by copper ethylacetoacetate and tetra base as a spot test reagent for hydrogen cyanide and cyanogen. Analyst 91:282-284.

GLICK, Z., and JOSLYN, M. A. 1970. Effect of tannic acid and related compounds on the absorption and utilization of proteins in rats. J. Nutr. 100:516-518.

HAGERMAN, A. E., and BUTLER, L. G. 1978. Protein precipitation method for the quantitative determination of tannins. J. Agric. Food Chem. 26:809-812.

HARLAND, B. F., and OBERLEAS, D. 1986. Anion exchange method for determination of phytate in foods. Collaborative study. J. Assoc. Off. Anal. Chem. 69:667-670.

JAMBUNATHAN, R., and MERTZ, E. T. 1973. Relation between tannin levels, rat growth and distribution of proteins in sorghum J. Agric. Food Chem. 21:692-699.

KNIPFEL, J. E., BOTTING, H. G., and McLAUGHLAN, J. M. 1975. Nutritional quality of several proteins as affected by heating in the presence of carbohydrate. Pages 375-391 in: Protein-Nutritional Quality of Foods and Feeds. Part 2. H. Friedman, ed. Marcel Dekker: New York.

MILLER, G. L. 1959. Use of dinitrosalicylic acid reagent for determination of reducing sugar. Anal. Chem. 51:126-129.

OKE, O. L. 1967. Chemical studies on the Nigerian foodstuff (ogi). Food Technol. 21:202-205.

OMOLE, T. A., ADEWUSI, S. R. A., ADEYEMO, A., and OKE, O. L. 1978. The nutritive value of tropical fruit and root crops. Nutr. Rep. Int. 17: 575-580.

OSUNTOGUN, B. A. 1984. Chemical identification of polyphenols in plants and their effects on protein metabolism. Ph.D. dissertation. Obafemi Awolowo University, Ile-Ife, Nigeria.

OSUNTOGUN, B. A., ADEWUSI, S. R. A., TELEK, L., and OKE, O. L. 1987. The effect of tannin content on the nutritive value of some leaf protein concentrates. Human Nutr. Food Sci. Nutr. 41F:41-46.

OSUNTOGUN, B. A., ADEWUSI, S. R. A., OGUNDIWIN, J. O., and NWASIKE, C. C. 1989. Effect of cultivar, steeping and malting on tannin, total polyphenol and cyanide content of Nigerian sorghum. Cereal Chem. 66:87-89.

PORTER, J. W. G., and ROLLS, B. A. 1971. Some aspects of the digestion of proteins. Proc. Nutr. Soc. 30:17-24.

PRICE, M. L., and BUTLER, L. G. 1977. Rapid visual estimation and spectrophotometric determination of tannin content of sorghum grains. J. Agric. Food Chem. 25:1268-1273.

PRICE, M. L., BUTLER, L. C., ROGLER, J. C., and FEATHERSTON, W. R. 1978. Detoxification of high tannin sorghum grain. Nutr. Rep. Int. 17:229-236.

REICHERT, R. D., FLEMING, S. E., and SCHWAB, D. J. 1980. Tannin deactivation and nutritional improvement of sorghum by anaerobic storage, H_2O, HCl-, or NaOH-treated grain. J. Agric. Food Chem. 28:824-829.

ROSENTHAL, S., and NASSET, E. S. 1958. Gastric emptying and intestinal absorption of carbohydrate and protein as influenced by the nature of the test meal. J. Nutr. 66:91-103.

SINGH, U., KHERDEKAR, M. S., and JAMBUNATHAN, R. 1982. Studies on desi and kabuli chickpea (*Cicer arietinum* L.) cultivars. The levels of amylase inhibitors, levels of oligosaccharides and in vitro starch digestibility J. Food Sci. 47:510-512.

WARMBIER, H. C., SCHNICKELS, R. A., and LABUZA, T. P. 1977. Nonenzymatic browning kinetics in an intermediate moisture model system: Effect of glucose to lysine ratio J. Food Sci. 41:981-983.

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