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Nutritional Quality of Yam (*Dioscorea dumetorum* and *D rotundata*) Flours for Growing Rats

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Abstract: The digestibility and metabolism of diets based on flours prepared from raw, boiled or steamed tubers of the sweet yam (*Dioscorea dumetorum*) were evaluated in growing albino rats by the balance method in comparison with diets containing similar flours from the popular white yam (*D rotundata*). The results show that whatever their method of preparation, flours from *D dumetorum* promote higher growth rate and have higher nutritional value in the growing rat than corresponding *D rotundata* flours. This can be attributed to the good digestibility of *D dumetorum* starch which facilitates digestibility and absorption of nitrogen and other nutrients. Moisture–heat treatment of tubers before processing into flour improves the nutritional value, especially for *D rotundata*.

Key words: *Dioscorea dumetorum*, *D rotundata*, yam flours, diet, rat, nutritional evaluation, nitrogen, digestible carbohydrate, fibre, minerals.

INTRODUCTION

Of the eight yam species grown in the Cameroon, the popular white yam (*Dioscorea rotundata*) and the sweet yam (*D dumetorum*) are the most consumed. Whereas the former has a long shelf-life which does not affect its cooking and organoleptic qualities and can be available all year round, the latter is consumed exclusively during its limited harvest period because of a post-harvest hardening phenomenon which reduces storage durability.

The hardening of *D dumetorum* is a serious handicap and begins within 2–3 days after harvest. It is characterised by lignification of the yam tissue cell walls and a consequential increase in fibre content (mostly lignin and cellulose). Tubers become hardened and resistant to cooking and chewing (Lyonga *et al* 1973), thus making their consumption impossible. This limits the production of this yam and its commercialisation outside production zones. Generally, tubers are left in the soil and harvested as needed for food and are often boiled before selling in the market.

But for the hardening handicap, *D dumetorum* is the most nutritious of the eight yam species. It has a mean protein content of 9·6% (dry weight basis) compared with 8·2% for the water yam (*D alata*) and 7·0% for *D rotundata*. Analyses on several yam samples from our laboratory have shown that *D dumetorum* protein is well balanced in the essential amino acids (with a slight deficiency of lysine) and has an average chemical score of 93 against 86 for *D rotundata*, when compared with the FAO/WHO (1973) reference protein. *Dioscovea dumetorum* starch is as digestable as corn starch (Delpeuch and Favier 1980) and is made up of tiny polygonal or spherical granules (less than 10 μm) with a type A X-ray diffraction structure similar to that of cereals (Robin 1976).

Agronomically, *D dumetorum* is high-yielding with yields of 10 and 40 $t ha^{-1}$ recorded under traditional farming conditions and in agricultural stations, respectively (Lyonga and Ayuk-Takem 1979; Ngong-Nasah *et*

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al 1980). Unlike the other yams, staking is not necessary to maintain yields (Waitt 1963; Lyonga and Ambe 1985) and its tubers grow near the surface of the soil. This saves labour and allows for the mechanisation of harvest.

To make *D dumetorum* more useful as food, we have developed a scheme for processing it into instant flour with a long shelf-life and a chemical composition quite close to that of the fresh tubers (Treche *et al* 1983, 1984). The sensory qualities of the instant flour have been confirmed by an acceptability test in which it was compared to the raw yam flour and the World Food Programme wheat–soyabean flour, as fufu. Furthermore, the flour has been tried in cake-making, by replacing 30–40% of wheat flour, without any noticeable sensory change (Centre for Nutrition 1983).

The aim of this study was to evaluate the nutritional value of *D dumetorum* flours in comparison with similar flours prepared from *D rotundata*, as measured in growing rats.

MATERIALS AND METHODS

Diets

For each yam species three types of flours were used for formulating diets. They were prepared as follows (Treche *et al* 1983): peeling of tubers, cutting into thin slices of less than 3 mm thick, drying in an air convection oven, milling and sieving (raw flour); peeling, slicing, boiling in water for 30–45 min, drying, milling and sieving (boiled flour); peeling, slicing, steam-cooking for 5 min at 120°C, drying and milling (steamed flour). The chemical composition of each flour was determined including amino acids and some minerals (Table 1).

Diets were formulated to contain about 85% of yam flour and similar levels of energy and protein (Table 2). Mineral mixtures and vitamin mixtures were used to supplement diets taking into consideration the composition of the yam flours and rat requirements (Pawlak and Pion 1968). The casein-based control diet and the yam-based experimental diets were also supplemented with individual synthetic amino acids to meet rat requirements as indicated.

In all, eight diets were tested: a casein-based control diet, a protein-free diet and six yam-based diets containing each of the three aforementioned flours per yam species. The chemical composition of the diets are presented in Table 3. Each diet (powder form) was prepared in bulk and stored at 4°C in the dark. Weighed amounts were drawn daily and mixed with distilled water into a paste containing 40–50% dry matter before feeding to rats.

Animals and experimental design

Weanling albino rats of the Wistar strain were used. Due to a shortage of metabolic cages, the experiment was conducted in two batches at different times using two different sets of rats. The batch 1 assay was conducted with eight male rats for the casein-based diet and each of the boiled flour diets (*D dumetorum* and *D rotundata*) and with four rats for the protein-free diet. For the batch 2 assay, six rats (three males and three females) were assigned to the casein-based diet and each of the remaining yam-based diets (containing raw flour or steamed flour of either yam species) and four rats (two males and two females) for the protein-free diet (Table 4). Rats were divided into groups with similar average weights (70 ± 1 g) and growth rates and were housed in individual polyethylene metabolic cages in a room at about 22°C and 60% relative humidity and with a 12 h light/dark cycle.

Rats were fed the diets for 7 days (adaptation period) and then for further 10 days (experimental period) during which food intake was measured. They also received distilled water *ad libitum* and were weighed every 3 days of the experimental period to determine average daily weight gain or loss.

During the last 5 days of the experimental period, daily collections of the total urine and faeces of each rat were made separately, pooled together and frozen until analysis. A 0·5 ml sample of 4·8 M HCl was added to recipients before urine collection to prevent nitrogen loss in the form of ammonia.

Chemical analysis

Analysis of food and faeces samples were done on freeze-dried and ground material. That of urine was done directly, except for energy determination for which freeze-dried material was used. Dry weight, nitrogen and mineral determinations in urine and faeces were done on aliquots of the pooled 5-day collections for each rat. Determination of other components in faeces (fat, starch + maltodextrins, soluble sugars, fibre and energy) were done on aliquots of composite samples containing contributions (dry weight basis) from each rat of the same dietary group proportional to its total amount of faeces excreted. All chemical analyses were done in triplicates.

Water content was determined by drying at 105°C to constant weight. Total soluble sugars were determined by the anthron colorimetric method (Loewus 1952) after extraction in 80% alcohol. The 80% alcohol-insoluble material was further extracted with 40% alcohol for analysis of maltodextrins by the anthron method. Starch content was determined on the resulting residue by the enzymic method of Thivend *et al* (1965). Crude

TABLE 1
Characteristics of yam flours used for formulating rat diets[a]

	D dumetorum			D rotundata		
	Raw	*Boiled*	*Steamed*	*Raw*	*Boiled*	*Steamed*
Ash	39	22	38	30	21	29
Fat	ND	ND	ND	ND	ND	ND
Starch	639	632	554	847	814	651
Maltodextrins	62	109	161	15	59	152
Alcohol-soluble sugars	48	23	30	21	20	29
Digestible carbohydrate[b]	749	764	745	888	894	824
Formic acid fibre	36	43	36	22	19	19
Acid detergent fibre	50	80	70	33	62	79
Crude protein (N × 6·25)	89·3	74·0	83·2	80·7	80·5	81·1
Threonine	4·4	3·5	3·8	3·0	2·9	3·0
Valine	4·7	4·3	4·6	3·6	3·7	3·9
Isoleucine	4·0	3·0	3·8	3·3	3·7	3·5
Leucine	6·9	5·8	6·6	5·5	6·0	5·5
Phenylalanine	3·6	3·5	4·1	4·5	5·0	4·5
Tyrosine	3·9	3·7	4·5	3·0	3·3	3·0
Methionine	2·0	1·7	1·7	1·8	1·8	1·9
Cystine	1·6	1·4	1·3	1·0	1·1	0·9
Lysine	4·9	4·1	4·1	3·8	4·4	3·8
Histidine	2·3	1·8	1·4	1·8	1·8	1·7
Arginine	9·8	6·3	6·1	5·8	6·6	6·4
Tryptophan	ND	ND	ND	ND	ND	ND
Aspartic acid	10·2	8·7	9·5	9·4	9·7	9·9
Glutamic acid	10·7	9·7	13·2	12·1	11·7	11·5
Serine	5·1	4·2	4·3	4·3	4·4	4·4
Proline	2·6	2·6	3·0	2·7	2·6	2·8
Glycine	4·1	3·4	3·8	3·0	3·0	2·9
Alanine	5·4	4·1	4·6	3·7	3·8	3·7
In-vitro starch (%) digestibility[c]						
15 min	4·6	56·2	44·8	3·4	31·8	30·7
3 h	24·1	88·2	94·4	6·5	59·4	68·6
Trypsin inhibitor[d]	1·61	1·31	1·17	1·37	0·64	0·77

[a] Chemical composition in g kg^{-1} DW.

[b] Digestible carbohydrate = starch + maltodextrins + alcohol-soluble sugars.

[c] In-vitro starch digestibility (determined according to Tollier and Guilbot 1971) is expressed as the percentage of starch hydrolysed by pancreatic amylase.

[d] Trypsin inhibitor activity as trypsin units inhibited (TUI) mg^{-1} DW.

fibre content was determined by the formic acid method (Guillemet and Jacquot 1943) and the ADF method (Van Soest 1963). Crude protein was quantified by the Kjeldahl method using a selenium catalyst mixture (Weininger 1936) and 6·25 as a conversion factor for all samples including urine. Amino acids in flours were analysed by ion-exchange chromatography according to the method of Moore and Stein (1963).

Total mineral content in flour, food and faeces was determined by ashing in a furnace at 550°C and individual minerals were determined in the ash solution in 10% HNO_3 as follows: phosphorus by colorimetry using the ammonium phosphate vanadium molybdate method (Stuffins 1967); calcium by flame photometry (Gueguen and Rombauts 1961); magnesium by atomic absorption spectrophotometry; and iron by the ortho-phenanthroline method. Iron in urine was determined by the above method, and calcium, magnesium and phosphorus by colorimetry using Biomerieux Analytical Kits. Trypsin inhibitor activity in the flours was determined according to Kakade *et al* (1974).

The caloric value of food, stool and urine were determined using a Gallenkamp adiabatic bomb calorimeter. Each ground freeze-dried food and stool sample was made into a tablet of about 1 g using a hand press before determination. Determinations on urine samples were carried out as follows: 0·5 g of crystalline cellulose was added to a preweighed glass crucible containing

TABLE 2
Formulation of rat diets

Ingredients (*g kg^{-1} DW*)	*Casein control*	*Protein free*	D dumetorum			D rotundata		
			Raw	*Boiled*	*Steamed*	*Raw*	*Boiled*	*Steamed*
Yam flour	—	—	865	876	872	845	850	842
Wheat starch	750	824	—	—	—	—	—	—
Cellulose	44	44	8	—	8	22	25	26
Casein	99	—	—	—	—	—	—	—
Soyabean oil	50	81	60	45	57	48	50	60
Amino acids[a]								
L-Leucine	—	—	1·91	2·82	2·15	3·27	2·81	3·26
L-Threonine	0·60	—	1·23	0·77	1·68	2·47	1·31	2·43
DL-Threonine	—	—	—	2·37	—	—	2·37	—
L-Valine	—	—	1·41	1·73	1·53	2·46	2·38	2·18
L-Isoleucine	—	—	1·52	2·34	1·68	2·20	1·88	2·03
L-Phenylalanine	—	—	1·15	2·74	0·80	1·00	1·98	1·31
L-Tyrosine	—	—	1·33	—	0·72	1·64	—	1·30
DL-Methionine	1·80	—	1·49	2·70	1·86	1·55	2·86	1·57
L-Cystine	1·13	—	1·35	0·50	1·50	2·00	0·60	2·00
L-Lysine HCl	1·06	—	5·36	6·12	6·14	6·64	5·96	5·65
Histidine HCl	—	—	0·74	1·27	1·69	1·31	1·26	1·42
L-Arginine	1·97	—	—	0·01	0·17	0·62	—	0·14
Tryptophan	—	—	0·98	0·90	0·98	0·99	0·90	1·00
Mineral mix[b]	39·7	39·7	39·7	39·7	39·7	39·7	39·7	39·7
K_2CO_3	5·3	5·3	—	—	—	—	—	—
$MgCO_3$	3·5	3·5	2·0	2·0	2·0	2·3	2·3	2·3
Ammonium iron(III) citrate	0·35	0·35	0·21	0·15	0·22	0·25	0·22	0·19
$ZnSO_4, 7H_2O$	0·07	0·07	0·06	0·03	0·06	0·07	0·04	0·07
$CuSO_4$	0·02	0·02	—	—	—	—	—	—
Vitamin mix[c]	1·73	1·73	1·73	1·73	1·73	1·73	1·73	1·73

[a] Amino acid supplementation of diets was based on the following rat requirements (g kg^{-1} dry weight of diet): threonine, 5·0; valine, 5·5; leucine, 7·9; isoleucine, 5·0; phenylalanine + tyrosine, 9·0; methionine + cystine, 5·9; lysine, 8·5; histidine, 2·6; arginine, 5·5; tryptophane, 1·5.

freeze-dried material from 50 ml of urine; after thorough mixing and recording of the total weight, the whole mixture (less than 1% remained in the crucible) was pressed into a tablet before bomb determination; blank determinations using 0·5 g of crystalline cellulose alone were also made; the caloric value of urine was calculated by subtracting the value for cellulose alone from that for the urine–cellulose mixture.

Nutritional evaluation

The nutritional value of the diets in rats were evaluated using various parameters.

For protein, the following parameters were computed:

- Protein efficiency ratio (PER)

$$\frac{\text{weight gain}}{\text{protein intake}}$$

- Net protein ratio (NPR)

$$\frac{\text{weight gain on diets} + \text{weight loss on protein-free diet}}{\text{protein intake from diets}}$$

- Net protein utilisation (NPU) (%)

$$\frac{N_i - (N_f - N_{ef}) - (N_u - N_{eu})}{N_i} \times 100$$

where N_i is nitrogen intake, N_f faecal nitrogen, N_{ef} endogenous faecal nitrogen (from rats fed the protein-free diet), N_u urine nitrogen and N_{eu} endogenous urine nitrogen.

- Biological value (BV)

$$\frac{N_i - (N_f - N_{ef}) - (N_u - N_{eu})}{N_i - N_f}$$

- True nitrogen digestibility (TND) (%)

$$\frac{N_i - N_f - N_{ef}}{N_i} \times 100$$

TABLE 3
Chemical composition of rat diets (g kg^{-1} DW)

Diet	*Casein control*	*Protein free*	D dumetorum			D rotundata		
			Raw	*Boiled*	*Steamed*	*Raw*	*Boiled*	*Steamed*
Crude protein ($N \times 6{\cdot}25$)	99	1	97	90	96	91	89	94
Crude energy (kcal kg^{-1} DW)	4360	4355	4300	4420	4400	4370	4410	4370
Starch	541	605	583	564	442	646	578	539
Maltodextrins	209	222	72	133	208	38	94	132
Soluble sugars	1	1	43	23	38	22	24	26
Digestible carbohydrate	752	828	698	720	688	706	696	697
Formic acid fibre	63	62	44	60	51	52	72	63
Acid detergent fibre	43	43	48	71	71	49	80	73
Fat	42	67	65	46	65	60	52	58
Ash	47	46	64	54	63	53	50	54
Calcium	9·60	10·0	9·86	10·10	9·54	9·69	9·51	9·67
Phosphorus	6·92	6·0	7·30	6·84	7·06	6·96	6·60	6·75
Magnesium	0·91	1·0	1·33	1·04	1·19	1·04	0·90	1·05
Iron	0·10	0·10	0·09	0·10	0·19	0·11	0·07	0·09
Trypsin inhibitor[a]	0·70	0·69	1·61	0·86	1·17	1·37	0·84	0·77

[a] Trypsin inhibitor activity in trypsin units inhibited (TUI) mg^{-1} DW.

Parameters determined for the other nutrients (fat, digestible carbohydrates, fibre and energy) were:

- Apparent digestibility (AD) (%)

$$\frac{\text{nutrient intake} - \text{faecal nutrient}}{\text{nutrient intake}} \times 100$$

- Apparent coefficient of retention (CR) (%)

$$\frac{\text{nutrient intake} - \text{faecal nutrient} - \text{urine nutrient}}{\text{nutrient intake}} \times 100$$

Data analysis

For food consumption, weight gain, protein and minerals and related parameters, the mean and standard deviation were computed for each dietary rat group from analytical results for each rat of the group. Apparent digestibility of fat, carbohydrate, fibre and energy were calculated from analytical results (triplicates) of composite faeces samples containing contributions (dry weight basis) from each rat of the same dietary group proportional to its total faeces excreted.

TABLE 4
Growth and nitrogen utilisation in rats fed diets based on yams (*D dumetorum* and *D rotundata*)[a]

Diet	*Batch 1*			*Batch 2*				
	Casein control	D dumetorum *boiled*	D rotundata *boiled*	*Casein control*	D dumetorum		D rotundata	
					Raw	*Steamed*	*Raw*	*Steamed*
Food intake (g day^{-1})	20·9a	18·8b	19·3ab	18·1b	16·7b	17·7b	22·6a	16·5b
Weight gain (g day^{-1})	8·1a	6·5b	5·5c	7·0a	4·9bc	6·3ab	4·4c	5·1bc
Apparent food digestibility (%)	91·1a	87·3b	80·0c	91·1a	88·7b	87·9b	42·7d	83·3c
Apparent organic matter digestibility (%)	93·8a	89·1b	81·8c	93·0a	90·4a	89·8a	42·7b	84·8a
Protein efficiency ratio	3·8a	3·9a	3·2b	3·9a	3·0c	3·6ab	2·1d	3·3bc
Net protein ratio	5·0a	5·3b	4·6c	5·3a	4·6c	5·1ab	3·3d	4·9b
True nitrogen digestibility (%)	91·3a	81·3b	70·1c	90·2a	74·6c	80·1b	58·2d	77·8b
Net protein utilisation (%)	79·9a	77·0a	63·3b	77·9a	64·4c	73·9b	47·8d	71·3b
Biological value (%)	87·5b	94·8a	90·3b	86·4b	86·4b	92·2a	81·9c	91·6a

[a] Figures in the same row with different following letters are significantly different at the 5% level. Weight loss, urine and faeces nitrogen data for rats fed the protein-free diet were used for computing the above parameters, as indicated (see nutritional evaluation).

TABLE 5

Apparent digestibility of carbohydrates, fat and energy in rats fed yam-based diets (*D dumetorum* and *D rotundata*) (%)[a]

Diet	*Batch 1*			*Batch 2*				
	Casein control	D dumetorum *boiled*	D rotundata *boiled*	*Casein control*	D dumetorum		D rotundata	
					Raw	*Steamed*	*Raw*	*Steamed*
Starch + maltodextrins	100·0a	97·6a	93·9b	100·0a	99·7a	97·8ab	42·8c	95·2b
Digestible carbohydrate[b]	100·0a	97·1a	91·9b	100·0a	99·6a	97·5a	43·2c	94·0b
Formic acid fibre	38·8b	51·5a	49·3a	39·3a	34·6b	38·5a	27·0c	36·4b
Acid detergent fibre	13·0b	39·0a	41·5a	3·9d	28·1c	42·1a	33·3b	28·3c
Fat	96·7a	89·3b	93·0ab	97·7a	96·5a	95·5ab	96·4a	92·4b
Energy (kcal 100 g^{-1})	92·8a	88·2a	80·8b	92·9a	89·0a	89·1a	59·0c	84·1b

[a] Figures in the same row with different following letters are significantly different at the 5% level.

[b] Digestible carbohydrate = starch + maltodextrins + alcohol soluble sugars.

Paired comparison between groups was done by Student's *t*-test for independent variables, and the significance of *t* values was determined at the 5% level.

RESULTS

Food consumption (total solids) was higher for *Dioscorea rotundata* diets than corresponding *D dumetorum* diets, whatever the type of flour, the most significant difference being observed between diets containing raw yam flour (Table 4).

In contrast, rat growth, apparent food digestibility, apparent organic matter digestibility and all the parameters pertaining to protein utilisation (PER, NPR, TND, NPU and BV) were generally higher for *D dumetorum* than for *D rotundata* diets. The differences between the two yam species were significant for all parameters in comparing diets containing flour from raw or boiled tubers. The differences were not significant between diets containing flours from steamed tubers for all parameters except apparent food digestibility. It is worth noting that there were no significant differences between the casein control diet and diets containing flour from boiled or cooked tubers with regard to most of the above protein utilisation parameters, although the casein diet generally promoted greater protein utilisation. The casein diet was significantly more nutritious than either raw flour diet.

The apparent digestibility of available carbohydrate was higher for *D dumetorum* diets, especially that containing raw flour (Table 5). It should be noted that car-

TABLE 6

Mineral digestibility and retention in rats fed diets based on yams (*D dumetorum* and *D rotundata*)

Diet	*Batch 1*			*Batch 2*				
	Casein control	D dumetorum *boiled*	D rotundata *boiled*	*Casein control*	D dumetorum		D rotundata	
					Raw	*Steamed*	*Raw*	*Steamed*
Apparent digestibility (%)								
Ash	55·2b	56·2a	46·1c	50·8c	63·7a	60·2ab	41·6d	57·8b
Calcium	32·2a	27·3b	26·3b	25·0a	24·0a	22·3a	16·0a	27·0a
Phosphorus	37·8a	39·1a	38·1a	39·0a	39·2a	37·3a	28·3b	39·0a
Magnesium	49·1a	41·8a	45·8a	35·5bc	43·5a	40·5ab	33·2c	45·5a
Iron	—[b]	16·4	—[b]	—[b]	13·7b	50·5a	15·7n	23·7b
Retention coefficient (%)								
Calcium	31·1a	25·7b	24·1b	24·0a	22·3a	21·2a	14·3a	25·0a
Phosphorus	27·1a	27·3a	24·4a	26·3a	24·0a	24·7a	16·5b	23·1a
Magnesium	22·6a	13·2b	17·5b	9·7bc	16·2a	13·0abc	8·0c	14·7ab
Iron	—[b]	15·1	—[b]	—[b]	13·5b	49·8a	14·3b	22·2b

[a] Figures in the same row with different following letters are significantly different at the 5% level.

[b] Iron excreted in faeces is higher than dietary intake.

bohydrate of the raw *D dumetorum* flour is as digestible as that of the instant flours from boiled or steamed tubers. Apparent fibre digestibility was higher for all *D dumetorum* diets when formic acid fibre (mostly lignin) is concerned. But judged by acid detergent fibre (cellulose + lignin) results, *D rotundata* diets had higher fibre digestibility with the exception of that containing steamed flour for which the digestibility was significantly low compared with the corresponding *D dumetorum* diet. Energy digestibility was higher for all *D dumetorum* diets with the most significant difference being observed between the two yam diets containing raw flour. Fat digestibility was practically similar for corresponding diets of the two yams.

Concerning minerals (Table 6), the overall digestibility (ash) was significantly higher for *D dumetorum* diets containing flour from raw or boiled tubers than for similar *D rotundata* diets. Apparent digestibility and coefficient of retention of calcium and phosphorus were slightly higher for *D dumetorum* diets than for *D rotundata* diets. The difference was significant for phosphorus digestibility between diets containing raw flour. In contrast, magnesium digestibility and retention were higher for *D rotundata* than *D dumetorum* for diets containing flour from boiled or steamed tubers and vice versa for those containing flour from raw tubers. The difference was significant between diets containing flours from raw tubers. Iron digestibility and retention values are unreliable as in some cases the amount of this element in faeces turned out to be higher than the dietary intake.

DISCUSSION

It has been known for a long time that raw starch of certain tubers are poorly digestible (Langworthy and Deuel 1922; Booher *et al* 1951) and thought that moisture–heat treatment, even very mild, could render any starch completely digestible (Cummings *et al* 1986). But our results with *D rotundata* show that this is not always the case which is in agreement with those of DeVizia *et al* (1975) who demonstrated that potato starch in biscuits were not entirely digested by children of 1–2 years.

Cooking alone does not guarantee total starch digestibility and metabolism in all cases as these are known to be affected by the source of the starch (Jenkins *et al* 1986). Hence, the assertion by many authors (Jelinek *et al* 1952) that humans digest cereal starches more easily than potato starch. Concerning this study it is worth mentioning that there are strong resemblances between starches of *D dumetorum* and cereals and between those of *D rotundata* and potato, with respect to starch grain structure and sensitivity to α-amylase (Robin 1976; Delpeuch and Favier 1980). These similarities could explain the results obtained.

Differences in the utilisation of proteins between diets of the two yam species can be explained by many factors: protein structure and susceptibility to proteolytic enzymes (Livingstone *et al* 1979), presence of proteinase inhibitors (Whittemore *et al* 1975; Livingstone *et al* 1980) and the nature of the starch present. In fact, different starches can have different effects on the concentration of intestinal enzymes (Buraczewski *et al* 1971), the efficiency of protein digestion by pepsin and trypsin (Lowy *et al* 1959; Tremolières *et al* 1959) and intestinal transit time (Borgida and Laplace 1977). Poorly digestible starch fractions could retain amino acids and impair their absorption and, with prolonged transit time, serve as substrate for bacterial proliferation in the caecum and colon, thus leading to increased faecal nitrogen (El-Harith *et al* 1976; Szylit *et al* 1977; Shetty and Kurpad 1986). Reduced absorption of amino acids, or their use in energy production as observed in rats fed raw Irish potato diets (Fujita *et al* 1982), could explain differences in the biological value of proteins.

In our study, the influence of trypsin inhibitor on protein digestibility is unlikely as its levels in the yam flours were low (Table 1). Although *D rotundata* protein could be less digestible than *D dumetorum* protein and/or more sensitive to moisture-heat treatment capable of causing denaturing and unavailability of certain amino acids, these reasons are not enough to explain the differences in protein digestibility and metabolism observed. Given the composition of the diets studied, the carbohydrate source seems the most likely factor to affect protein utilisation significantly. The differences observed between *D dumetorum* and *D rotundata* diets decrease as the moisture–heat treatment become more severe (from boiling to steaming), but vary according to the digestibility of the yam starches.

In fact, the influence of the nature of dietary carbohydrate on protein digestibility and metabolism has been known for a long time. Yoshida and Morimoto (1955) obtained lower protein digestibility for 10% casein diets containing raw Irish potato starch than those containing maize or sweet potato starch; El-Harith *et al* (1976) showed that the protein efficiency ratio and net protein utilisation of diets containing 16% casein were lower when Irish potato starch was included than when cereal or cassava starch was used. Rao and Rao (1978) observed that the NPU of 10% casein-based diets containing raw Irish potato starch was lower than those containing maize starch, and that cooking only reduced the difference without eliminating it completely.

CONCLUSION

This study shows that whatever their method of preparation, flours from *D dumetorum* promote higher growth rate and have higher nutritional value in the growing rat than corresponding *D rotundata* flours.

Moisture–heat treatment of tubers before processing into flour improved the nutritional value and narrowed the differences observed between corresponding diets of the two yam species, while respecting the above hierarchy especially with regard to protein and carbohydrate utilisation. Although direct statistical comparison between diets containing flours from boiled or steamed tubers cannot be made due to the fact that they were studied in two different assays, it is evident that steaming of tubers resulted in higher digestibility of food, starch and protein and higher net protein utilisation for *D rotundata* diets than boiling. There was no difference between the two treatments with respect to the utilisation of *D dumetorum* flour diets. Both boiling and steaming increased food and starch digestibility for *D rotundata* diets but practically none for *D dumetorum* diets.

The difference in nutritional value between *D dumetorum* and *D rotundata* diets can be explained by differences in the nature and digestibility of starch between the two yam species. Compared to the easily digestible starch of *D dumetorum*, cereal and cassava, poorly digestible starch such as that of *D dumetorum* and Irish potato can impair protein digestibility and amino acid absorption and serve as substrate for bacterial proliferation in the caecum and colon of the rat (due to prolonged intestinal transit time), thus leading to increased faecal nitrogen.

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