3030 J. Agric. Food Chem. 2002, 50, 3030–3036

JOURNAL OF
AGRICULTURAL AND
FOOD CHEMISTRY

Evaluation of the Nutritional Characteristics of a Finger Millet Based Complementary Food

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Finger millet (*Eleusine coracana*), kidney beans (*Phaseolus vulgaris*), peanuts (*Arachis hypogoea*), and mango (*Mangifera indica*) were processed separately and then combined, on the basis of their amino acid scores and energy content, into a complementary food for children of weaning age. The finger millet and kidney beans were processed by germination, autoclaving, and lactic acid fermentation. A mixture containing, on a dry matter basis, 65.2, 19.1, 8.0, and 7.7% of the processed finger millet, kidney beans, peanuts, and mango, respectively, gave a composite protein with an in vitro protein digestibility of 90.2% and an amino acid chemical score of 0.84. This mixture had an energy density of 16.3 $kJ \cdot g^{-1}$ of dry matter and a decreased antinutrient content and showed a measurable improvement in the in vitro extractability for calcium, iron, and zinc. A 33% (w/v) pap made from a mix of the processed ingredients had an energy density of 5.4 $kJ \cdot g^{-1}$ of pap, which is sufficient to meet the energy requirements of well-nourished children of 6−24 months of age at three servings a day and at the FAO average breast-feeding frequency.

KEYWORDS: ***Eleusine coracana*; *Phaseolus vulgaris*; *Arachis hypogoea*; *Mangifera indica*; complementary food; chemical score; energy density; processing**

INTRODUCTION

Most infants are first fed with breast milk, a food supply that provides adequate nutrition and some resistance to disease (*1*). At ∼4−6 months of age, it becomes necessary to introduce other foods into the diet, because human milk alone is insufficient to meet the ever increasing nutrient needs of the infants (*2*). Before this age, the relatively high permeability of the young infants' digestive tract contributes to the risk of penetration by foreign bodies, especially proteins, which can cause hypersensitivity reactions (*3*), and therefore a child should be exclusively breast-fed. Most studies have shown that growth faltering in children coincides with the commencement of the introduction of complementary foods (CFs), mainly due to their nutritional inferiority, improper feeding practices, and increased risk of gastrointestinal infections. Improving the nutritional value of traditional CFs can therefore help to alleviate child malnutrition.

In many countries in Africa CFs are usually made of a cereal flour, which is boiled in water. In the past decades composite flours, usually consisting of a cereal/legume ratio of 70:30, have been introduced in many communities for use as CFs (*4*, *5*). These foods may make only limited nutritional contributions unless they are processed to reduce their bulk density and antinutritional factors. Finger millet is the cereal of choice for the preparation of porridges for children and for the sick and old in India and Africa. It is considered to be more palatable and its mineral composition, especially calcium content, is greater than that of sorghum or maize (*6*). Although the 8−11% total protein content of finger millet is comparable to that of other cereals, it is limiting in lysine but has sulfur-containing amino acids at levels equal to that of milk protein (*7*). Kidney beans are an important source of dietary protein, especially in regions where animal proteins may be unavailable or expensive (*8*). They are easy to prepare and soften easily when boiled in water.

Technologies such as germination, cooking, and lactic acid fermentation are simple and inexpensive and have been practiced for many years by communities in developing countries to process cereals and legumes. Germination is mainly used to lower dietary bulk in cereals because it converts significant amounts of starch, which is principally responsible for viscosity in cereal gruels, to sugars and short-chain oligosaccharides (9). Cooking denatures proteins (*10*) and gelatinizes starch granules,

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10.1021/jf011008a CCC: $22.00

rendering them more digestible. Lactic acid fermentation gives fermented foods a sour taste and lowers the pH of the food, rendering it stable against the growth of Gram-negative bacteria, the main pathogens in foods for children in developing communities (*11*, *12*).

A lot of emphasis has been laid on developing cereal−legume CFs to address mainly protein energy malnutrition. Complementary food formulations should also target vitamin A and micronutrient deficiency, especially Ca, Fe, and Zn, which are deficient in many diets for children (*13*).

This study was undertaken to formulate a complementary food using finger millet, kidney beans, peanuts, and mango based on their amino acid scores and energy value, with minimum antinutritional composition and improved digestibility. The CF was targeted to meet the energy needs of children of 6−24 months of age at consumption levels not exceeding their gastric capacity.

MATERIALS AND METHODS

Processing. Finger millet (*Eleucine coracana* var. *lanet*) was obtained from Kenya (1998 harvest). Kidney beans (*Phaseolus vulgaris* var. Rose Coco), which are widely grown in Kenya, were purchased in Gent, Belgium. Extraneous materials and broken seeds were removed by sorting. The seeds were washed carefully with distilled water and the floats discarded. They were then drained, spread in trays, and left to air-dry overnight (37 °C). Finger millet and kidney beans were processed separately (**Figure 1**). They were soaked, germinated, milled, autoclaved and fermented, as described previously (*7*), and then dried on trays in a room at 37 °C for 24 h.

Peanuts (*Arachis hypogoea*) were purchased in Gent, Belgium. They were dried for 3 h at 37 °C and then dehusked. Any discolored or broken seeds were discarded. The sound seeds were then spread on a tray to not more than two seeds deep, introduced into an air oven at 150 °C, and roasted for 20 min with occasional turning. The roasted seeds were milled with a Braun kitchen blender to a smooth paste (**Figure 1**).

Mangoes (*Mangifera indica*) from South Africa were purchased in Gent, Belgium. They were washed in running tap water, peeled, and destoned to obtain the pulp (edible portion). The pulp was whisked in a kitchen blender to obtain a slurry. This was sieved through a muslin cloth to obtain mango puree (**Figure 1**).

Formulation of the Complementary Food. The energy values of the ingredients were calculated on the basis of 16.7, 16.7, and 37.7 $kJ{\cdot}g^{-1}$ for carbohydrates, proteins, and fat, respectively. The energy value of dietary fiber was taken as 8.4 $kJ{\cdot}g^{-1}$ (*14*). On the basis of the amino acid profiles and scores of the ingredients and their energy content, the Solver function (linear programming) in Excel (Excel 2000 for Windows, Microsoft Corp.) was used to maximize energy in the blend at the greatest possible amino acid chemical score.

The finger millet was restricted to not less than 60% of the blends' dry matter because, with less than this amount, the millet flavor in the resulting pap is masked by the other ingredients. This was important because communities in East Africa, the target population for which the CF was designed, are familiar with and prefer porridges with the typical finger millet flavor.

The mangoes were restricted to <8%, a level at which the mix acquired a fruity flavor. Because mangoes have a particularly well-balanced amino acid profile when compared to other ingredients, an unrestricted mango contribution leads to a predominance of mango, which would give a lower energy density in the mix.

To make the processed CF, germinated, autoclaved, and fermented flours of finger millet and kidney beans together with roasted peanut paste and mango puree were blended in a kitchen mixer. The mix was dried on trays at 37 °C for 24 h. The dried mix was then milled and packed in polyethylene bags (**Figure 1**). An unprocessed CF was made also by mixing raw flours of finger millet and kidney beans together with roasted peanut paste and mango puree, followed by drying and milling as described for the processed CF.

Laboratory Analysis. *Determination of Viscosity.* A porridge was made by reconstituting the unprocessed mix in water at 10% (w/v). The resultant slurry was mixed with a kitchen blender to obtain a smooth texture. It was pasteurized by boiling in a water bath for 25 min (**Figure 1**). This period was chosen to correspond to the average period during which mothers in Kenya boil pap (personal observation). Immediately after pasteurization, the porridge was kept at 30 °C in a water bath and the viscosity determined by a Bohlin CVO rheometer. A plate−plate 40 technique at 0.5 mm gap was used, and the shear rate was set at 209.5 s^{-1}. The rheometer was set to single sweep, with a delay of 10 s and integration at every 10 s for 120 s with the sample being held at isothermal conditions (30 °C). To determine an optimum viscosity for the processed CF, porridges of increasing solid content were made and their viscosities determined as described above.

Chemical Analysis. Porridges were made by reconstituting the CF in water at 10 and 33% (w/v) for the unprocessed and processed mixes, respectively. They were pasteurized as described for viscosity analysis. Before chemical analysis, the processed and unprocessed complementary paps were thinly spread on a tray and dried at 37 °C for 24 h. The resultant flakes were milled in a coffee mill to a fine flour (200 mesh), which was then packed in low-density polyethylene (LDPE) bags and stored at −18 °C until analysis.

The moisture, protein, and lipid contents of the ingredients and final foods were determined by the air oven, Kjeldahl, and Soxhlet methods (AOAC Methods 925.10, 920.87, and 922.06, 1995, respectively) (*15*). Nitrogen to protein conversion factors of 5.83 for peanuts and millet (*6*) and 6.25 for beans and mango were used. The three-enzyme in vitro pH-stat procedure as described in FAO (*16*) was used to analyze the in vitro protein digestibility. In vitro extractability of Ca, Fe, and Zn was evaluated by using pepsin−pancreatin digestion as described by Miller et al. (*17*). The amounts of Fe and Zn were determined by atomic absorption spectrophotometry (AOAC Method 970.12, 1995) (*15*), whereas Ca was determined by flame photometry (AOAC Method 963.13, 1995) (*15*).

The CFs and their ingredients were analyzed for starch by using the glucoamylase method (AOAC Method 979.10, 1995) (*15*) and for reducing and nonreducing sugars by using a titrimetric method (AOAC Method 939.03, 1995) (*15*). CFs were also analyzed for rapidly and slowly digestible and resistant starch according to the method of Englyst et al. (*18*), and for total, soluble, and insoluble dietary fiber by using an enzymatic gravimetric method (AOAC Method 991.43, 1995) (*15*).

Amino acid analysis was carried out on the raw and processed ingredients as described by Mbithi-Mwikya et al. (*7*). The amino acid composition of the CFs was derived from the values of the individual ingredients using linear programming. The essential amino acid scores were calculated by dividing the amino acid contents by the values in the reference protein (*16*). The chemical score of the CFs corresponded to the lowest value of these essential amino acid scores.

Calculations and Statistical Analysis. Unless otherwise stated, all experiments were conducted in triplicate, and the means and standard deviations (SD) are reported. An analysis of variance of the results was done at 95% confidence interval ($\alpha \leq 0.05$) using a paired sample *t* test. This analysis was done using SPSS 9.0 (SPSS Inc., Chicago, IL) for Windows (1998) computer software.

RESULTS AND DISCUSSION

Nutrient Composition of the Raw and Processed Ingredients. In kidney beans and finger millet, starch is the principal nutrient (**Table 1**). During processing, starch content decreased by 22% in finger millet and by 25% in kidney beans. These starch losses can be attributed to hydrolysis of starch into sugars, which increased from 2.2 to 13.4% on dry matter basis in finger millet and from 2.2 to 11.2% on dry matter basis in kidney beans. Also, the loss can be attributed to the use of carbohydrates by respiring microorganisms during processing. Starch content in mangoes and peanuts was low, averaging 2.0 and 5.5% on dry matter basis, respectively, when compared with other ingredients (**Table 1**). Mangoes predominantly contained sugar, ∼78.5% of their dry matter. Acharya and Shah (*19*) obtained

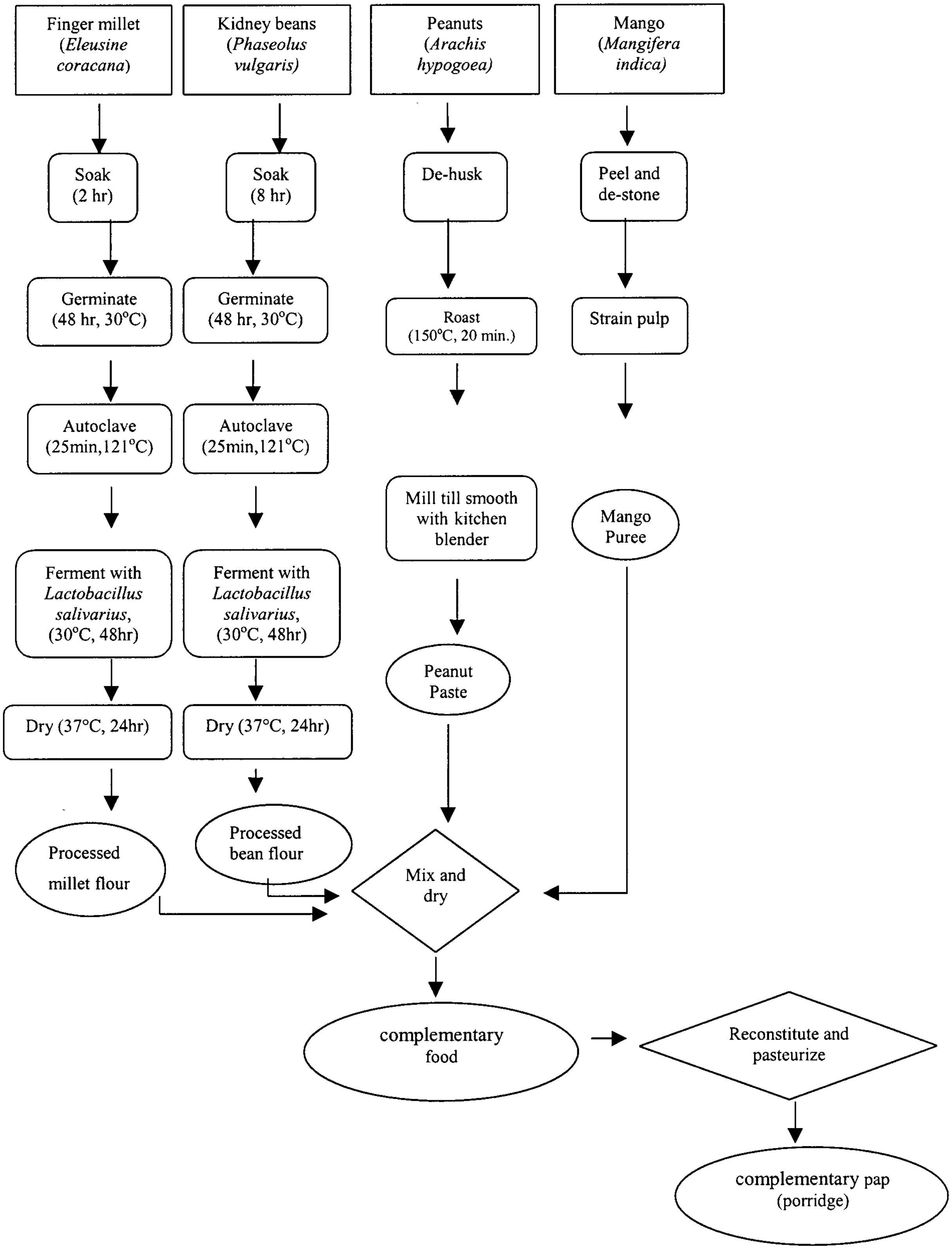

Figure 1. Flow diagram of the production process for the complementary food.

18.9% carbohydrates in mango pulp of 20.4% solids, which is greater than our results. Sugar content in peanuts was 2.6 and 2.7% in the raw and roasted samples, respectively.

There were no significant changes ($\alpha \leq 0.05$) in protein content during processing of either peanuts, kidney beans, or finger millet (**Table 1**). Sopade and Obekpa (*20*) obtained 24.3% proteins in peanuts, a value less than the 31.5% obtained here.

The fat content increased significantly ($\alpha \leq 0.05$) during processing in kidney beans and finger millet (**Table 1**). Usha Antony et al. (*12*) found a decrease in fat content during fermentation of finger millet using endogenous grain microflora. Differences obtained may be related to our extra use of a germination step, as well as to differences in microbial strains active during fermentation.

Table 1. Nutrient Composition of Ingredients Used in the Formulation of the Complementary Food^a

			peanuts^b				finger millet^b				kidney beans^b			
	mango puree		raw		roasted		raw		processed		raw		processed	
constituent	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
starch	2.0	0.3	5.5^a	0.7	5.7^a	0.9	72.5^a	0.8	56.5^b	0.6	46.9^a	1.2	35.2^b	0.7
reducing sugars	21.1	1.0	1.2^a	0.3	1.1^a	0.2	0.3^a	0.2	9.2^b	1.2	0.4^a	0.1	8.5^b	1.6
nonreducing sugars	57.4	0.5	1.4^a	0.2	1.6^a	0.3	1.9^a	0.1	4.2^b	0.4	1.8^a	0.2	2.7^a	0.9
protein	3.2	0.5	31.5^a	0.7	31.2^a	0.4	6.5^a	0.8	7.7^a	0.8	23.3^a	0.3	25.4^a	0.9
fat	1.3	0.4	51.6^a	1.2	52.0^a	0.9	1.6^a	0.2	2.7^b	0.2	2.0^a	0.3	3.5^b	0.2

[a] All values given as grams per 100 g of dry weight. [b] All values with different superscripts between raw and processed samples are significantly different at the 95% level ($\alpha \leq 0.05$).

Table 2. Essential Amino Acid Scores^a of the Ingredients Used in the Complementary Food

	chemical scores							
	peanuts		mango	finger millet		kidney beans		
amino acid	raw	processed^b	raw	raw	processed^b	raw	processed^b	FAO^c (1991)
threonine	0.77	0.82	1.26	1.22	1.19	1.39	1.35	3.4
valine	1.09	1.16	1.07	1.77	1.75	1.44	1.45	3.5
methionine + cysteine	1.02	0.94	0.92	1.50	1.34	0.75	0.74	2.5
isoleucine	1.19	1.26	1.00	1.49	1.49	1.55	1.56	2.8
leucine	1.02	1.03	0.97	1.55	1.54	1.28	1.30	6.6
phenylalanine + tyrosine	1.51	1.50	1.15	1.53	1.52	1.49	1.52	6.3
histidine	1.21	1.23	1.11	1.30	1.26	1.55	1.54	1.9
lysine	0.60	0.54	1.09	0.44	0.47	1.24	1.20	5.8
tryptophan	1.15	1.10	1.05	1.32	1.51	0.96	0.94	1.1

[a] Essential amino acid scores were calculated by dividing the amino acid amounts (grams per 100 g of protein) by the values in the last column (*16*). [b] Either roasting (peanuts) or germination, autoclaving, and fermentation (kidney beans and finger millet). [c] FAO–WHO reference essential amino acid profile for children 2–5 years of age in grams of amino acid per 100 g of protein (*16*).

Table 3. Ratios of Ingredients Used in Preparation of the Complementary Foods (in Grams of Dry Matter per 100 g of Dry Matter in the Mix)

complementary food	finger millet	kidney beans	peanuts	mango
raw ingredients	65	22	8	5
processed ingredients	65.2	19.1	8	7.7

Table 4. Composition of Complementary Food with Raw and Processed Ingredients^a

	complementary food	
	with raw ingredients	with processed ingredients
Components (Grams per 100 g of DM)		
starch	56.7^a ± 2.3	43.7^b ± 1.5
reducing sugars	2.1^a ± 0.3	11.4^b ± 0.1
non reducing sugars	6.0^a ± 0.8	8.1^b ± 0.3
total dietary fiber	16.2^a ± 1.7	14.5^a ± 1.1
insoluble dietary fiber	10.7^a ± 2.2	7.3^a ± 1.6
soluble dietary fiber	5.6^a ± 1.4	8.6^b ± 0.5
fat	5.6^a ± 0.3	6.8^b ± 0.5
protein	11.6^a ± 0.9	11.8^a ± 0.7
Minerals (Milligrams per 100 g of DM)		
calcium	174.8^a ± 1.7	202.5^b ± 1.9
iron	5.83^a ± 0.25	5.58^a ± 0.10
zinc	2.23^a ± 0.12	2.12^a ± 0.18
Antinutrients		
tannins (% DM)	0.27^a ± 0.01	nd^b ^{b}
phytates (% DM)	1.15^a ± 0.03	0.22^b ± 0.02
trypsin inhibitor substances (units/g of DM)	0.59^a ± 0.11	nd^b ^{b}

[a] Values in the same row with different superscripts are significantly different at the 95% level ($\alpha \leq 0.05$). [b] nd, not detectable.

Amino Acid Profiles. Mangoes had the most balanced amino acid profile of the samples analyzed, with amino acid scores >0.9 for all essential amino acids (**Table 2**). Its chemical score was 0.92, with methionine + cysteine as the limiting amino acids. Roasted peanuts were deficient in lysine, threonine, and methionine + cysteine, which were 54, 82, and 94% of the value recommended for the preschool child (*16*), respectively. Changes in amino acid profiles during processing of kidney beans and finger millet are discussed elsewhere (*7*). The chemical scores in the processed state were 0.74 for kidney beans and 0.47 for finger millet, with methionine + cysteine and lysine as the limiting amino acids, respectively.

Nutrient and Antinutrient Composition of the Complementary Food. The optimized ratios of ingredients used in the preparation of both the raw and processed CFs are given in **Table 3**.

Carbohydrate Content. The total starch content of the weaning food decreased by 23% after processing (**Table 4**). This can be attributed to conversion of starch to sugars, especially during germination of finger millet (*9*) and kidney beans (*21*). Sugar content increased by 140% in the processed CF. In addition to the decrease in viscosity accompanying degradation of the starch, the increase in sugar content improves the flavor of the complementary pap.

The decrease in total starch content was accompanied by a change in starch digestibility. The rapidly digestible starch (RDS) and slowly digestible starch (SDS) fractions increased by 83.5 and 26.7%, respectively. This was accompanied by a 49.9% decrease in the resistant starch (RS) fraction (**Table 5**). The overall net effect was therefore an improvement in starch digestibility. Given that starch forms the vast bulk of calories consumed by children in developing countries, improvement

Table 5. Some Nutritional Properties of the Complementary Foods[a]

	complementary food	
nutritional property	raw ingredients	processed ingredients
chemical score (amino acids)	0.78	0.84
in vitro protein digestibility (% protein)	$69.5^a \pm 1.9$	$90.2^b \pm 2.4$
net protein utilization	53.5	74.0
rapidly digestible starch (% starch)	$10.3^a \pm 1.4$	$18.9^b \pm 1.1$
slowly digestible starch (% starch)	$47.2^a \pm 1.8$	$59.8^b \pm 1.5$
resistant starch (% starch)	$42.5^a \pm 2.3$	$21.3^b \pm 2.7$
calcium extractability (%)	$55.9^a \pm 0.5$	$91.7^b \pm 0.5$
iron extractability (%)	$5.1^a \pm 0.2$	$52.1^b \pm 0.5$
zinc extractability (%)	$40.9^a \pm 1.2$	$83.4^b \pm 0.4$
energy (kJ$\cdot$g^{-1} DM)	16.3	16.3
percentage of energy from fat	13.0	15.7
percentage of energy from protein	11.9	12.1
acidity (% DM, assayed as lactic acid)	$0.5^a \pm 0.1$	$2.0^b \pm 0.2$

	complementary pap	
nutritional property	raw ingredients	processed ingredients
viscosity (10% w/v) (Pa$\cdot$s)	$1.041^a \pm 0.009$	$0.011^b \pm 0.004$
% (w/v) in pap of optimum viscosity	10	33
energy density (kJ/g of porridge)	1.6	5.4
pH	$5.2^a \pm 0.3$	$3.5^b \pm 0.5$

[a] Values in the same row with different superscripts are significantly different at the 95% level ($\alpha \leq 0.05$).

Table 6. Essential Amino Acid Scores[a] and Amino Acid Content of Protein in the Complementary Foods with Raw and Processed Ingredients

	complementary food				
	raw ingredients		processed ingredients		
amino acid	score	g/100 g of protein	score	g/100 g of protein	FAO (1991) (g/100 g of protein)
threonine	1.21	4.11	1.20	4.08	3.4
valine	1.52	5.31	1.50	5.24	3.5
methionine + cysteine	1.13	2.83	1.00	2.49	2.5
isoleucine	1.45	4.06	1.47	4.12	2.8
leucine	1.35	8.90	1.33	8.78	6.6
phenylalanine + tyrosine	1.51	9.49	1.51	9.48	6.3
histidine	1.37	2.61	1.37	2.61	1.9
lysine	0.78	4.51	0.84	4.87	5.8
tryptophan	1.15	1.26	1.16	1.28	1.1

[a] Essential amino acid scores were calculated by dividing the amino acid amounts by the values in the reference protein (*16*).

of its digestibility greatly enhances their nutritional status. The soluble fiber fraction increased significantly ($\alpha \leq 0.05$) from 5.6 to 8.6% after processing (**Table 4**).

Fat Composition. Fat content increased slightly with processing from 5.6 to 6.8% (**Table 4**). This fat content supplied 15.8% of the total energy in the processed CF (**Table 5**). Several authors have recommended that fat should supply 30−45% of the energy intake for children less than 2 years of age (*22*). There is little evidence to support the necessity of this level of fat intake, so long as the needs for essential fatty acids are met and the energy density of the diets exceed minimal criteria (*23*). FAO/WHO (*24*) have recommended that linoleic acid provide at least 3% of the total energy in the diet. The linoleic acid contents in peanuts and millet, the principal providers of fat to the CF, are about 14.7 and 2.0% on a dry matter basis, respectively (*6*). Linoleic acid therefore provides almost 6% of the energy of the CF.

Fat, because it is more energy dense than carbohydrates and does not contribute to an increased viscosity in porridges, augments the energy value of the CF. The extra addition of 1 teaspoon (~4 g) of oil to 100 g of unprocessed CF increases its energy density from 1.6 to 3.0 kJ$\cdot$g^{-1}. For the processed CF, the energy density increases from 5.4 to 6.6 kJ$\cdot$g^{-1}. The possibility of having higher fat contents in a CF must be balanced between their possible increase in the palatability of the diet (*25*), on the one hand, and the shortening of the shelf life of the product due to increased oxidative rancidity (*26*), on the other hand.

Protein and Antinutrient Contents. The protein content was unaffected by processing ($\alpha < 0.05$). In the processed CF, it is 11.8% of the dry matter (**Table 4**) or 12.1% of the energy (**Table 5**). In vitro protein digestibility increased by 30% in the processed CF, relative to the raw CF (**Table 5**), which may be attributed to the decrease in the level of antinutrients (*27*, *28*). Tannins and trypsin inhibitor substances decreased to undetectable levels, whereas phytates decreased by 81% (**Table 4**) with processing.

About 240 mL containing 33% (w/v) of the processed CF is required to cover the estimated protein needs from CFs (9.1 g$\cdot$day^{-1}) for a 12−24-month-old child of low breast milk intake. In this research, the essential amino acid profile proposed by the FAO (*16*) was used as a basis for calculating amino acid scores. Considerable debate exists about amino acid requirements (*29*), and estimates vary by a factor of 2 or 3 for some amino acids on the basis of the method used to estimate requirements (*30*). From the FAO (*16*) requirements, the limiting amino acid in our formulation was lysine, with scores of 0.78 and 0.84 in the raw and processed CF, respectively (**Table 6**).

Energy Content. The raw and processed CFs had an energy content of 16.3 kJ$\cdot$g^{-1} DM (**Table 5**). Energy values should be viewed in light of their density in the ready-to-eat form of a CF. The viscosity of a >10% (w/v) slurry of the raw CF was considered to be too thick for a 6−12-month-old infant to swallow. A viscosity of 1.04 Pa$\cdot$s (**Table 5**) was considered to be the upper limit in a pap for children. A 10% solids content (w/v) was therefore considered for preparing a pap from the unprocessed formula. The energy density of this pap was 1.6 kJ$\cdot$g^{-1}.

It may be unrealistic to expect a child to consume a CF more than three times a day, while still breast-fed and tasting some of the adult diets. We assumed a feeding frequency for the CF of no more than three meals a day. Assuming that the median weights of a well-nourished child are 8.3 kg at 7 months, 9.5 kg at 10 months, and 11.5 kg at 18 months, the amounts that could be consumed at a single meal (gastric capacities) are 249, 285, and 345 g for the respective ages (*23*). The recommended minimum energy densities of CFs for feeding twice a day for well-nourished children of low to average breast-feeding rate are then 5.4 and 3.7, 6.5 and 4.9, and 7.7 and 6.2 kJ$\cdot$g^{-1} for children of the 6−8, 9−11, and 12−24 month age groups, respectively (*23*, *31*). Because the energy density of the raw CF is less than half of the requirements for a child 6−8 months of age and of average breast-feeding frequency, the unprocessed formulation was considered to be inadequate for complementing the diet of a child of weaning age.

The processed CF could be solubilized up to 33% (w/v) before a viscosity equivalent to that of a 10% (w/v) solution of the unprocessed formula was obtained (**Figure 2**). The pap at this level was fluid, with flow characteristics visually slightly thinner than those of melted honey. It was considered optimum

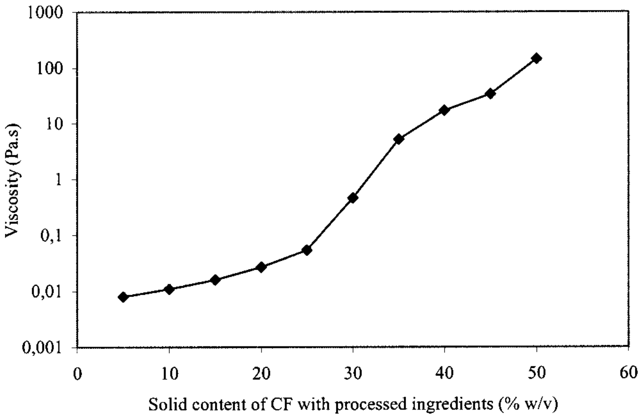

Figure 2. Changes in viscosity (Pa·s) of the complementary food made from processed ingredients as a function of solid content (% w/v).

for feeding an infant of 6–8 months of age. Its energy density was 5.4 kJ·g^{-1}. This is more than that recommended for children of 6–12 months of age who are breast-fed at average rate and given two or three servings a day (*23*). This food could also meet the energy requirements of children of 12–24 months at a feeding frequency of three times a day.

Ca, Fe, Zn, and Vitamin A Contents. Except for iron in children <12 months, and assuming a low bioavailability, the Ca, Fe, and Zn contents of the CF met the estimated needs of infants and children younger than 24 months of age if given three feedings a day (**Table 4**). Even though it is important to have large amounts of these inorganic elements in foods, it is also important to have them in a form in which they are easily digestible and available to the body. Extractability of minerals and trace elements under simulated gastrointestinal conditions is an indicator of bioavailability in foods (*32*). In vitro Ca, Fe, and Zn extractability increased by 64, 922, and 104%, respectively, after processing (**Table 5**). These increases are mainly attributed to a decrease in phytic acid, which was also observed during our research (**Table 4**). Sandberg et al. (*33*) indicate that phytates can be one of the factors in foods responsible for the inhibition of iron, zinc, and calcium absorption and that mineral availability can mainly be increased after degradation of inositol hexa- and pentaphosphates.

The CF was not analyzed for provitamin A content. Mangoes were added at a 7.7% level (dry matter) in the processed CF (**Table 3**). Assuming that mangoes (~82% moisture content) contain on average 201 μg and kidney beans (~10.3% moisture content) on average 67 μg of retinol equivalents (RE) per 100 g of edible portion (*6*), mango would supply 86 μg of RE and kidney beans 14 μg of RE to 100 g of dry CF. The estimated daily needs of vitamin A for children at 6–8 months of age are taken as 350 μg RE (*34*). CF should supply 13 μg of RE per day at an average breast-milk intake (*31*). Therefore, 100 mL of the 33% (w/v) complementary pap supplies more than the daily needs for vitamin A from CF for children at 6–8 months of age and at average breast-milk intake.

Conclusion. To evaluate the suitability of locally available raw materials and processing techniques in the preparation of CFs for infants, we carried out a validation study that focused on a complete range of nutritional characteristics, including energy density, viscosity, micronutrient extractability, and protein quality. A 10% (w/v) pap made from a composite mix of roasted peanuts and mango puree with unprocessed finger millet and kidney beans was too high in antinutrients and too low in energy density to be used as a CF for children. However, a 33% (w/v) CF made with the processed ingredients had a similar viscosity but an energy density sufficient to meet the recommendations for children of 6–24 months of age, at three servings per day. This food had a low content of antinutrients and a high nutrient digestibility. The pH of the complementary food was 3.5, which inhibits the growth of Gram-negative bacteria, the principal pathogens in food for children in developing countries.

On the basis of a comprehensive chemical analysis, this study has demonstrated that germination and lactic acid fermentation can be useful technologies in the processing of CFs. When properly optimized and used in rural communities, these technologies can help to reduce the risk of energy and micronutrient deficiencies in children of weaning age.

LITERATURE CITED

(1) Rowland, M. G.; Rowland, S. G.; Cole, T. J. Impact of infection on the growth of children from 0 to 2 years in an urban West African community. *Am. J. Clin. Nutr.* **1988**, *47*, 134–138.

(2) Lutter, C. K.; Mora, J. O.; Habicht, J. P.; Rasmussen, K. M.; Robson, D. S.; Herrera, M. G. Age specific responsiveness of weight and length to nutritional supplementation. *Am. J. Clin. Nutr.* **1990**, *51*, 359–364.

(3) Hendricks, K. M.; Badruddin, S. H. Weaning recommendations: the scientific basis. *Nutr. Rev.* **1992**, *50*, 125–133.

(4) Malleshi, N. G.; Desichakar, H. S. R. Nutritive value of malted millet flours. *Plant Foods Hum. Nutr.* **1983**, *36*, 191–196.

(5) King, R. D.; Puwastien, P. Effects of Germination on the Proximate Composition and Nutritional Quality of Winged Bean (*Psophocarpus tetragonolobus*) Seeds. *J. Food Sci.* **1987**, *52*, 106–108.

(6) Souci, S. W.; Fachmann, K.; Kraut, H. *Food Composition and Nutrition Tables*, 6th ed.; Medpharm GmbH Scientific Publishers: Stuttgart, Germany, 2000; pp 547–548, 811–812, 986–987, 1014–1015.

(7) Mbithi-Mwikya, S.; Ooghe, W.; Van Camp, J.; Ngundi, D.; Huyghebaert, A. Amino Acid Profiles after Germination and Lactic Acid Fermentation of Finger Millet (*Eleusine coracan*) and Kidney Beans (*Phaseolus vulgaris* L.). *J. Agric. Food Chem.* **2000**, *48*, 3081–3085.

(8) Sánchez-Mata, M. C.; Peñuela-Teruel, M. J.; Cámara-Hurtado, M.; Díez-Marqués, C.; Torija-Isasa, M. E. Determination of Mono-, Di-, and Oligosaccharides in Legumes by High-Performance Liquid Chromatography Using an Amino-Bonded Silica Column. *J. Agric. Food Chem.* **1998**, *46*, 3648–3652.

(9) Mbithi-Mwikya, S.; Van Camp, J.; Yiru, Y.; Huyghebaert, A. Nutrient and antinutrient changes in finger millet (*Eleusine corocan*) during germination. *Food Sci. Technol.* **2000**, *33*, 9–14.

(10) Dhurandhar, N. V.; Chang, K. C. Effect of cooking on firmness, trypsin inhibitors, lectins and cystine/cysteine content of Navy and Red Kidney beans (*Phaseolus vulgaris*). *J. Food Sci.* **1990**, *55*, 470–474.

(11) Mensah, P.; Tomkins, A. M.; Drasar, B. S.; Harrison, T. J. Fermentation of cereals for reduction of bacterial contamination of weaning food in Ghana. *Lancet* **1990**, *336*, 140–143.

(12) Usha Antony; Sripriya, G; Chandra, T. S. Effect of Fermentation on the Primary Nutrients in Finger Millet (*Eleusine coracana*). *J. Agric. Food Chem.* **1996**, *44*, 2616–2618.

(13) Walter, T. Impact of iron deficiency on cognition in infancy and childhood. Review. *Eur. J. Clin. Nutr.* **1993**, *47*, 307–316.

(14) Livesey, G.; Buss, D.; Coussement, P.; Edwards, D. G.; Howlett, J.; Jonas, D. A.; Kleiner, J. E.; Muller, D.; Sentco, A. Suitability of traditional energy values for novel foods and food ingredients. *Food Control* **2000**, *11*, 249–289.

(15) AOAC. *Official Methods of Analysis*, 16th ed.; AOAC International: Arlington, VA, 1995; Methods 920.87, 922.06, 925.10, 939.03, 963.13, 970.12, 979.10, 991.43.

(16) Food and Agricultural Organization of The United Nations (FAO). Amino acid scoring pattern. In *Protein Quality Evaluation*; FAO/WHO Food and Nutrition Paper; Rome, Italy, 1991; Vol. 51, pp 21−25.

(17) Miller, D. D.; Schricker, B. R.; Rasmussen, R. R.; Van Campen, D. An *in vitro* method for estimation of iron availability from meals. *Am. J. Clin. Nutr.* **1981**, *34*, 2248−2256.

(18) Englyst, H. N.; Kingman, S. M.; Cummings, J. H. Classification and measurement of nutritionally important starch fractions. *Eur. J. Clin. Nutr.* **1992**, *46*, 33−50.

(19) Acharya, M. R.; Shah, R. K. Some microbiological and chemical properties of mango pulp samples. *J. Food Sci. Technol. −India* **1999**, *36*, 339−341.

(20) Sopade, P. A.; Obekpa, J. A. Modeling water absorption in soybean, cowpea and peanuts at three temperatures using Peleg's equation. *J. Food Sci*. **1990**, 1084−1087.

(21) Mbithi-Mwikya, S.; Van Camp, J.; Rodriguez, R.; Huyghebaert, A. Effects of Sprouting on Nutrient and Antinutrient Composition of Kidney Beans (*Phaseolus vulgaris* var. Rose Coco). *Eur. Food Res. Technol.* **2000**, *212* (2), 188−191.

(22) Michaelsen, K. F.; Jorgensen, M. H. Dietary fat content and energy density during infancy and childhood: the effect on energy intake and growth. *Eur. J. Clin. Nutr.* **1995**, *49*, 467−483.

(23) WHO. *Complementary Feeding of Young Children in Developing Countries: a Review of Current Scientific Knowledge*; Geneva, Switzerland, 1998; 228 pp.

(24) Food and Agricultural Organization (FAO), World Health Organization (WHO). *Fats and Oils in Human Nutrition*; Report of a joint expert consultation; Rome, Italy, 1994.

(25) Sanchez-Grinan, M. I.; Peerson, J. M.; Brown, K. H. Effect of dietary energy density on total ad-libitum energy consumption by recovering malnourished children. *Eur. J. Clin. Nutr*. **1995**, *46*, 197−204.

(26) Mate, J. I.; Frankel, E. N.; Krochta, J. M. Whey Protein Isolate Edible Coatings: Effect on the Rancidity Process of Dry Toasted Peanuts. *J. Agric. Food Chem.* **1996**, *44*, 1736−1740.

(27) Kataria, A.; Chauhan, B. M.; Punia, D. Antinutrients and protein digestibility (in vitro) of mungbean as affected by domestic processing and cooking. *Food Chem*. **1989**, *52*, 9−17.

(28) Singh, U.; Kherdekhar, M. S.; Jambunathan, R. Studies on desi and kabuli 9. Chickpea (*Cicer arietinum* L.) cultivars, the levels of amylase inhibitors, levels of oligosaccharides and *in vitro* starch digestibility. *J. Food Sci*. **1982**, *47*, 510−512.

(29) Dewey, K. G.; Beaton, G.; Fjeld, C.; Lonnerdal, B.; Reeds, P. Protein requirements of infants and children. *Eur. J. Clin. Nutr.* **1996**, *65*, 1403−1409.

(30) Young, V. R.; Borgonha, S. Nitrogen and Amino Acid Requirements: The Massachusetts Institute of Technology Amino Acid Requirement Pattern. *J. Nutr.* **2000**, *130*, 1841S−1849S.

(31) Benbouzid, D.; de Benoist, B. Complementary feeding of young children in developing countries: a review of current scientific knowledge. In *Complementary Feeding of Young Children in Africa and the Middle East*; Dop, M. C., Benbouzid, D., Trèche, S., de Benoist, B., Verster, A., Delpeuch, F., Eds.; World Health Organization: Geneva, Switzerland, 1999; pp 15−25.

(32) Usha Antony; Chandra, T. S. Antinutrient reduction and enhancement in protein, starch, and mineral availability in fermented flour of finger millet (*Eleusine corocan*). *J. Agric. Food Chem*. **1998**, *46*, 2578−2582.

(33) Sandberg, A. S.; Carlsson, N. G.; Svanberg, U. Effects of Inositol Tri-, Tetra-, Penta-, and Hexaphosphates on *In Vitro* Estimation of Iron Availability. *J. Food Sci.* **1989**, *54*, 159−161, 186.

(34) Olson, J. A. Vitamin A. In *Present Knowledge in Nutrition*; Ziegler, E. E., Filer, L. J. Eds.; Ilsi Press: Washington, DC, 1996; pp 109−119.

Received for review August 1, 2001. Revised manuscript received January 29, 2002. Accepted January 29, 2002. We gratefully acknowledge the Belgium Agency for Development Cooperation, the Flemish Inter-University Council (V.L.I.R.), and Nutrition Tiers Monde for providing grants to carry out this research.

JF011008A