

Effects of Blend and Processing Method on the Nutritional Quality of Weaning Foods Made from Select Cereals and Legumes

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ABSTRACT

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Weaning blends, formulated in a 60% cereal to 40% legume combination using teff, pearl millet, cowpea, and peanut, were evaluated for changes in nutritional quality due to the effects of blend and processing method. Four blends were prepared by each of four traditional processing methods: control (unprocessed), roasting, germination, and natural fermentation. The main effect of blend formulation proved to be the stronger determinant of nutrient density, while processing method produced the strongest effect on weaning food viscosity. Germinated blends yielded viscosity measurements significantly below those resulting from

other processing methods. Germination of ingredients increased nutrient density and in vitro protein digestibility, while roasting and fermentation produced little change from the control product. Complementation of cereal flours with peanut yielded weaning foods with a significantly ($P < 0.01$) higher nutrient density, increased in vitro protein digestibility and lower viscosity when compared to cowpea-based blends. The use of 20% whole grain teff in weaning blends increased protein content but did not significantly increase nonstarch polysaccharide content as compared to weaning blends without teff.

An estimated 190 million children under the age of five years are reported to be chronically malnourished (Grant 1994). Within tropical developing countries, the mortality rate for infants below one year of age is estimated to be 10–20 times greater than in industrialized nations of the world (Nout 1993). The 1990 United Nations Summit on Children mandated global goals for increasing the survival, protection, and development of children worldwide, with a primary emphasis on the reduction of malnutrition in children less than five years of age. Since a combination of nutritionally inferior diets and improper feeding practices are major contributing factors to the development of childhood malnutrition (Huffman and Martin 1994), one proposed approach was to improve the nutritional value of traditional weaning foods (Grant 1994). The advantages and disadvantages of traditional preparation methods compared to commercial production remain a timely debate (Harper and Jansen 1985, Nout 1993). Traditional methods employ roasting, germination, and fermentation of grains. These technologies are often used separately or in combination during infant weaning food preparation. The nutritional profiles of a variety of weaning blends prepared by traditional technologies were examined (Ahmed et al 1981, Mosha and Svanberg 1983, Okeiyi and Futrell 1983, Marero et al 1988, Pedersen et al 1989, Ashturkar et al 1992, Gahlawat and Sehgal 1992b, Dahiya and Kapoor 1993), but these studies failed to adequately compare the contribution of individual processing methods to changes in nutritional quality.

Weaning foods supplement an infant's milk intake and provide a transition to the modified adult diet (Walker 1990). Food quantity is not always the issue, but food quality contributes to continued prevalence of malnutrition (McGuire 1991). The energy density must be sufficient to permit adequate caloric intake and meet energy needs of the growing infant. Researchers (Desikachar 1980, Brandtzaeg et al 1981, Walker and Pavitt 1989) identified food viscosity as the critical issue and frequently the limiting factor prohibiting adequate nutritional intake. Mosha and Svanberg (1983) suggested a semiliquid consistency with a measured viscosity of 1,000–3,000 cps as the most suitable for infant feeding.

Weaning foods are traditionally composed of staple cereals and legumes prepared either individually or as composite gruels (Aguilera and Lusas 1981, Walker 1990, Alameida-Dominguez et al 1993, Huffman and Martin 1994). Peanut (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* L.), and pearl millet (*Pennisetum glaucum* L.) are major agricultural products grown in many developing nations. Teff (*Eragrostis tef*), a lesser known cereal, is indigenous to Africa and is currently being grown in some areas of the United States. This cereal is considered high in nutritional quality, but limited information is available about its usefulness in weaning blends (Cheverton and Chapman 1989).

The objectives of this study were: 1) to evaluate the effect of traditional processing methods (roasting, germination, and natural fermentation) on the nutritional quality of a weaning blend in terms of nutrient density and viscosity; 2) to compare the nutritional significance of peanut versus cowpea when used as a legume complement; 3) to test the value of teff as a cereal complement; and 4) to determine the traditional processing method with the best potential for improving the nutritional quality of the weaning food.

MATERIALS AND METHODS

Materials

Ingredients for the composite blends were acquired from the following sources: 1) peanut (*Arachis hypogaea* L., cv. Spanish) from Birdsong Peanut Co. (Gorman, TX); 2) brown teff (*Eragrostis tef*) from Arrowhead Mills (Hereford, TX), 1994 crop year; 3) pearl millet (*Pennisetum glaucum*, cv. HMG 100) from Coastal Plains Experiment Station (Tifton, GA), 1993 crop year; and 4) cowpea (*Vigna unguiculata* L., cv. California Blackeye No. 5) from Pennington Seed Company (Cullman, AL). All seeds were stored at 4°C.

Seed Cleaning, Decortication, and Milling

Pearl millet, teff, cowpea, and peanut were manually cleaned of debris. Split and discolored seeds were discarded. Millet seeds were mechanically decorticated to an 80% pearling index using a barley pearler (Seedburo, Chicago, IL). Pearling index was calculated by the difference in weight as percentage of original weight. Cowpea seed coats were manually removed after soaking in deionized water for 10 min. After seed coat removal, soaked cowpeas were oven-dried in a forced-air oven (Fisher Econotemp Lab Oven model 15F) at 40°C for 12 hr to return to <10% moisture content. Peanut testa were manually removed for all treatments. Due to the extremely small seed size and the inability to decorticate, teff was used as a whole seed flour.

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Teff, millet, and cowpea seeds were milled to flour using a stone mill (Lee household flour mill, model S-600, EM Lee Engineering, Milwaukee, WI). Peanut kernels were ground to paste using a Straub grinding mill, model 4E (Straub Co., Philadelphia, PA). Peanut pastes and milled flours were stored at 4°C in plastic bags until gruel preparation and analysis.

Weaning Blend Formulation

Weaning blends were formulated in 60% cereal to 40% legume ratios, which yielded the highest projected amino acid scores based on infant lysine requirements (FAO/WHO/UNU 1985). Amino acid scores were calculated using reported amino acid data for teff (Macrae et al 1993), pearl millet (Macrae et al 1993), cowpea (USDA 1986), and peanut (USDA 1986). Ingredients were weighed and blends formulated in proportions as follows: PMP (60% pearl millet + 40% peanut), PMC (60% pearl millet + 40% cowpea), TPMC (20% teff + 40% pearl millet + 40% cowpea), and TPMP (20% teff + 40% pearl millet + 40% peanut).

Study Experimental Design

Samples were divided into four weaning blends and four processing treatments. A 4 × 4 factorial design giving 16 treatments with two replicates and two samples was used for statistical analysis. Analysis of variance (ANOVA) was used to statistically test for significant variations between blends and processing methods. Tukey's honestly significant difference (HSD) test was used to identify significant differences among mean main effects for blend and processing method (Pedersen 1985).

Processing Methods

Roasting. For greater temperature control, all seeds were roasted in a forced-air oven (Fisher Econotemp Lab Oven model 15F) at 160°C. Ingredients were roasted on a Pyrex glass tray until a malted aroma and flavor developed, then cooled under a room fan. Final selected seed weights and roasting times were: 150 g of teff (30 min), 150 g of pearl millet (30 min), 200 g of cowpea (25 min), and 325 g of peanut (40 min).

Germination. Before soaking, all seeds were pretreated for 5 min with 200 ppm of bleach containing 5.25% sodium hypochlorite, mixed in deionized water to control microbial growth (Hsu et al 1980, Nattress et al 1987). Seeds were rinsed, then soaked in deionized water (1:3, w/v) for 9 hr at ambient temperature (23–25°C). Seeds were drained and placed on perforated aluminum pans lined with filter paper, then placed in a dark, temperature-controlled cabinet at 30°C for germination. Teff and pearl millet were germinated for 48 hr (John and Gopaldas 1988), while peanut (Gopaldas et al 1982) and cowpea (Nnanna and Phillips 1988, 1990) were germinated for 24 hr. Germinating seeds were rinsed twice daily with deionized water to reduce microbial growth and to maintain adequate hydration. Sprouted seeds were dried in a forced-air oven at 50°C for 12–20 hr to a moisture content <10% (wb). Cowpea seed coats and peanut testa were separated from seeds and sprouts using a room fan. Dried sprouts were stored at 4°C until grinding to flour.

Natural fermentation. Fermentation was performed using the microorganisms naturally present on the grain surface. Slurries of the four composite blends (1:4, w/v) were made from control (unprocessed) ingredients by mixing 200 g of flour with 800 mL of sterile, deionized water in a sterile beaker. Sorbic acid as potassium sorbate (0.1%, w/w) was added as a mold inhibitor. A blank fermentation was conducted using 0.1% sorbic acid mixed with 800 mL of sterile, deionized water. Slurries were fermented in a temperature-controlled incubator (Fisher Isotemp, model 115 D, Fisher Scientific) at 30°C for 72 hr to reach a pH of 3.6–4.1 (Chavan and Kadam 1989a). Duplicate aliquots of fermentation liquid were taken each day to measure pH (Accumet, model 50) and titratable acidity by AOAC method 950.07 (AOAC 1990). Results were reported as percent lactic acid (1 mL of 0.1N NaOH =

0.0090 g of lactic acid). After a 72-hr fermentation period, the slurries were transferred into aluminum pans, then oven-dried at 55°C (Fisher Econotemp Lab Oven model 15F) for 48 hr. Fermented dried blends were further milled to a fine flour using a Rival home coffee grinder (Rival Co., St. Louis, MO).

Gruel Preparation

Cooked blends (gruels) were prepared in a 15% (w/v) concentration (135 g of flour mixed with 900 mL of deionized water). An initial flour paste was made mixing 135 g of flour and 200 mL of deionized water. To the paste, 700 mL of boiling deionized water was added and mixed well. Flour-water slurries were cooked in a boiling waterbath until the temperature reached 95°C. Cooking was continued an additional 15 min with stirring every 5 min. Gruel temperature was recorded at 5-min intervals to ensure standardized cooking procedures. Cooked gruels were transferred to aluminum pans, sealed in plastic bags and frozen at –4°C until freeze-dried for further analysis.

Viscosity

Sample gruels were prepared in a 15% (w/v) concentration based on a 20-mL volume. A paste was made by mixing 3 g of flour with 5 mL of deionized water. To the paste, 15 mL of boiling deionized water was added and mixed well. The paste was heated in a boiling waterbath, cooked at 95°C for 10 min, and stirred every 5 min during cooking. Using a graduated syringe, 8 mL of the gruel was dispensed into a small sample adapter (Brookfield Engineering Laboratories, Inc.) for viscosity determination. Viscosity was measured using a Brookfield HBTD (DVII+) viscometer and SC4-21 spindle at 50 rpm and 40°C. The temperature of the small sample chamber was maintained using a waterbath controller (Lauda Co., model 123, Germany).

Sample Preparation and Proximate Analysis

Cooked blends were lyophilized (Virtis Consol 24 freeze drier, Gardner, New York), sealed in plastic bags, then stored at –4°C until analysis. Proximate analyses of initial ingredients and lyophilized gruels were conducted using standard methods. Moisture content of ingredients was determined as follows: grains, flours, and gruels by AOAC air-oven method 925.10 (AOAC 1990), peanut paste by Approved Method 44-19 (AACC 1995), and sprouts by drying to constant weight at 105°C for 5 hr (Chen et al 1975). Protein was determined by micro-Kjeldahl using the Tecator Digestion System and Kjeltac Auto 1030 Analyzer (Tecator AB, Sweden). Fat was determined by ether extraction using the Soxtec System HT method (Tecator Soxtec System HT 1043 Extraction Unit, Tecator AB, Sweden). Ash was determined by AOAC method 923.03 (AOAC 1990) and carbohydrate was calculated as the percentage difference (Livesey 1995).

Energy Value

The energy value of the gruels was calculated using values of 4 kcal/g of protein, 4 kcal/g of carbohydrate, and 9 kcal/g of fat (Livesey 1995).

Dietary Fiber as Nonstarch Polysaccharides

A colorimetric method reported by Englyst and Hudson (1987) was used for the determination of dietary fiber as nonstarch polysaccharides (NSP). The enzyme reagents used in the procedure were pullulanase (Promozyme 200L, EC 3.2.1.41) obtained from Novo Nordisk Bioindustrials, Inc. (Danbury, CT) and α -amylase (EC 3.2.1.1) in the form of pancreatin (Sigma P1750, hog pancreas 4X USP).

In Vitro Protein Digestibility

Protein digestibility was determined by a modification of the in vitro method described by Gauthier et al (1982). A 4-hr digestion period was used based on data obtained by Osilaja (1986) and

Chung et al (1979), indicating that this time period should be adequate to simulate digestion in an infant or small child.

A sample containing 600 mg of protein (6.25 × N) was mixed in 100 mL of 0.1N HCl in an Erlenmeyer flask and incubated for 30 min at 37°C in a waterbath. The pH was adjusted to 1.9 using 1N NaOH. A 20-mL aliquot of pepsin solution (5 mg/mL) (Sigma P-7000; activity 120 units/mg of protein) prepared in 0.1N HCl was added to the sample. The digestion mixture was incubated at 37°C in a waterbath for 30 min. The pepsin digestion was stopped by adjusting to pH 8 using 1N NaOH. A 20-mL portion of pancreatin solution (5 mg/mL prepared in deionized water, Sigma P1750, porcine pancrease 4 × USP) was added to the digestion mixture.

The mixture was introduced into a dialysis bag (Spectra/Por7; 45 mm × 27 cm, molecular weight cutoff 1,000; Spectrum Medical Industries, Inc., Los Angeles, CA), sealed, and placed inside a glass cylinder (30 cm × 5.2 cm, i.d.) containing 300 mL of sodium phosphate buffer (0.1M, pH 8) at 37°C. The glass cylinder was suspended in a 37°C circulating waterbath maintained by a heating circulator (Fisher Scientific Co., model 73). At 15-min intervals, the dialysis bag was manually inverted and the dialysate solution mixed. The sodium phosphate dialysate, (0.1M, pH 8) was changed every hour over a 4-hr period, at which time the digestion mixture was recovered. A 15-g aliquot of the digestion mixture was analyzed for nitrogen content (Tecator Digestion System and Kjeltec Auto 1030 Analyzer; Tecator AB, Sweden). Residual nitrogen content was taken as a measure of the degree of digestion.

RESULTS AND DISCUSSION

Weaning Food Viscosity

Blend formulation, processing method and their interactive effects yielded significantly different ($P < 0.01$) viscosity levels (Table I) as measured at 50 rpm and 40°C using the Brookfield HBDT (DVII+) viscometer. Peanut-based blends (PMP and TPMP) were consistently lower in viscosity than cowpea-based blends (PMC and TPMC). The higher fat content of peanut-based blends (Table II) showed a significant negative correlation ($r = -0.673$, $P < 0.01$) to viscosity. This correlation suggests a higher viscosity can be expected from blends with a lower fat content. Hellström et al (1981) showed a similar correlation in weaning gruels made from wheat and fieldpea flour. A larger percentage of fat decreases the carbohydrate content, reducing the amount of starch available for gelatinization. Jacobs et al (1995) related viscosity to the extent of starch granule swelling. While Dearden et al (1981) described changes in cereal gruel consistency with the addition of fat, Szczodrak and Pomeranz (1992) found lipids reduced swelling of starch granules. Amylose, the starch component primarily responsible for gelatinization, formed insoluble complexes with lipids which reduced starch swelling capabilities upon heating.

Processing method showed the most obvious influence on viscosity. Germination produced a liquid product with a viscosity <50 cps. Viscosity measurements at this low level were below the

suggested semiliquid consistency (1,000–3,000 cps) advocated for a cereal-based gruel used in infant feeding. The low viscosity allows flexibility for manipulating the product consistency by increasing the solids concentration. This also provides a simple, inexpensive means for increasing the product's nutrient density. The significant ($P < 0.01$) decrease in viscosity observed from germinated flours was attributed to the increase in amylase activity within the seed (Parvathy and Sadasivam 1982). Similar results were reported in germinated flours from millet (Brandtzaeg et al 1981), sorghum (Mosha and Svanberg 1983), and barley (Hansen et al 1989).

Roasting produced a pasty product with an increased viscosity over other processing methods. Increases in viscosity were attributed to the differences in percent moisture content of the component flours (Table III). The reduced flour moisture allowed a higher percentage dry matter content within the gruels. Fermentation failed to significantly change viscosity, although viscosities for some fermented blends appear lower than most control blends. During fermentation, the weaning blend pH decreased (Fig. 1) and titratable acidity increased (Fig. 2) with time. Reductions in pH to 3.8–4.0 decreased paste viscosity in other cereal gruels (Hellström et al 1981, Lorri and Svanberg 1993b).

Nutrient Composition of Weaning Foods

The nutritional composition of each weaning blend made by four processing methods is summarized in Table II. Protein content varied significantly ($P < 0.01$) among blends and processing methods. Blend formulation was the stronger main effect accounting for the greatest amount of variation in protein content ($r^2 = 0.723$). Mean separation using Tukey's HSD showed protein content to be significantly different among all blends. Peanut-based blends (PMP and TPMP) were significantly higher in protein than cowpea-based blends (PMC and TPMC) for all processing methods. The initial difference in protein content between decorticated peanut and decorticated cowpea seeds (Table III) contributed to the variations observed. Blends containing teff (TPMC and TPMP) were higher in protein than blends without teff (PMP and PMC). The higher protein content of teff compared to the decorticated pearl millet (Table III) allowed for increased protein content of the total food product. Roasting did not significantly alter protein content but germination and fermentation produced significantly ($P < 0.05$) higher protein yields. Chavan and Kadam (1989a,b) attributed the small increases in protein observed with cereal germination and natural fermentation to the loss of dry matter. Reductions in dry matter result from the metabolism of carbohydrates, changing the nutrient distribution within the seed.

Fat content (Table II) among weaning blends varied primarily due to blend formulation ($r^2 = 0.981$). Peanut-based blends (PMP and TPMP) were significantly ($P < 0.01$) higher in fat than cowpea-based blends (PMC and TPMC). As an oilseed, decorticated peanut contained 51% (db) fat (Table III) compared to the 1.3% (db) found in decorticated cowpea. Its use in weaning blend formulations not only increased protein but the increased fat pro-

TABLE I
Effects of Blend and Processing Method on Viscosity^a (cps) of Cooked Weaning Blends

Blend ^b	Control	Roasting	Germination	Fermentation	Blend Mean ^{c,d}
PMP	1,515 ± 343	1,333 ± 112	20 ± 0	1,128 ± 296	999b
PMC	2,717 ± 239	5,056 ± 41	29 ± 0	4,497 ± 784	3,075a
TPMC	4,037 ± 437	4,496 ± 60	31 ± 0	3,427 ± 106	2,998a
TPMP	1,143 ± 140	1,185 ± 170	28 ± 0	733 ± 47	772b
Process mean ^{c,e}	2,353y	3,018x	27z	2,446y	...

^a Viscosity measured at 15% (w/v) with Brookfield HBDT (DVII+) viscometer at 50 rpm, 40°C. Mean values of two replicates ± one standard deviation.

^b PMP = 60% pearl millet + 40% peanut; PMC = 60% pearl millet + 40% cowpea; TPMC = 20% teff + 40% pearl millet + 40% cowpea; TPMP = 20% teff + 40% pearl millet + 40% peanut.

^c Blend × process interaction significant ($P < 0.01$). Mean separation using Tukey's honestly significant difference ($P < 0.01$).

^d Mean values for each blend followed by the same letter in the same column are not significantly different.

^e Mean values for each processing method followed by the same letter in the same row are not significantly different.

vided a more concentrated caloric source rich in the essential fatty acid, linoleic acid (C18:2 ω 6) (Hudson 1987, Salunkhe et al 1992). Additional fat can easily be added to the cowpea-based formulations, but extra preparation steps increase the work load of the caregiver. In reality, desirable and more expensive commodities such as oils are often consumed by household members other than the targeted child (Huffman and Martin 1994).

The effects of processing method on fat content were less obvious. Germination significantly ($P < 0.01$) increased fat over other processing methods. Germinated blends presented a mean fat content of 12.8% compared to 9.9% for control blends. The apparent increase observed with germination was from the decrease in carbohydrate fractions resulting in a redistribution of nutrient percentages (Lorenz 1980).

TABLE II
Nutrient Content^a and In Vitro Protein Digestibility (IVPD) of Weaning Blends

Nutrient (% , db)	Blend ^b	Control	Roasting	Germination	Fermentation	Blend Mean ^{c,d}
Protein (N \times 6.25) ^e	PMP	21.3 \pm 0.0	21.1 \pm 0.5	23.5 \pm 0.2	21.8 \pm 0.1	21.9b
	PMC	17.1 \pm 0.1	17.1 \pm 0.0	20.0 \pm 0.1	17.5 \pm 0.0	17.9d
	TPMC	17.8 \pm 0.1	17.7 \pm 0.1	21.3 \pm 0.0	17.9 \pm 0.0	18.7c
	TPMP	21.8 \pm 0.1	21.6 \pm 0.2	24.6 \pm 0.0	22.3 \pm 0.1	22.6a
	Process mean ^{c,f}	19.5r	19.4r	22.4p	19.9q	
Fat ^e	PMP	18.9 \pm 0.8	19.4 \pm 0.1	23.5 \pm 0.3	20.1 \pm 0.2	20.5e
	PMC	0.8 \pm 0.0	0.8 \pm 0.0	2.4 \pm 0.0	0.6 \pm 0.1	1.2f
	TPMC	1.0 \pm 0.0	1.0 \pm 0.1	2.5 \pm 0.1	0.7 \pm 0.0	1.3f
	TPMP	19.0 \pm 0.4	19.9 \pm 0.3	23.0 \pm 0.9	19.1 \pm 0.7	20.2e
	Process mean ^{c,f}	9.9t	10.3t	12.8s	10.1t	
Nonstarch polysaccharides ^e	PMP	1.7 \pm 0.2	1.6 \pm 0.1	4.5 \pm 0.0	1.6 \pm 0.1	2.3h
	PMC	3.4 \pm 0.8	3.4 \pm 0.9	7.9 \pm 0.2	2.6 \pm 0.5	4.3g
	TPMC	4.1 \pm 0.7	3.9 \pm 0.3	9.7 \pm 1.3	3.3 \pm 0.8	5.3g
	TPMP	2.1 \pm 0.5	1.9 \pm 0.1	4.9 \pm 0.4	1.9 \pm 0.1	2.7h
	Process mean ^{c,f}	2.8v	2.7v	6.7u	2.3v	
Ash ^g	PMP	1.7 \pm 0.0	1.7 \pm 0.0	2.1 \pm 0.0	1.7 \pm 0.0	1.8l
	PMC	2.0 \pm 0.0	2.0 \pm 0.0	2.4 \pm 0.0	1.9 \pm 0.0	2.1j
	TPMC	2.3 \pm 0.0	2.2 \pm 0.0	2.7 \pm 0.0	2.2 \pm 0.0	2.3i
	TPMP	1.9 \pm 0.0	1.9 \pm 0.0	2.4 \pm 0.0	1.9 \pm 0.0	2.0k
	Process mean ^{c,f}	2.0x	2.0x	2.4w	1.9x	
IVPD ^g	PMP	51.2 \pm 0.3	53.6 \pm 0.8	55.8 \pm 2.1	56.1 \pm 0.8	54.2m
	PMC	43.9 \pm 2.5	43.3 \pm 1.8	50.5 \pm 0.2	50.0 \pm 0.2	46.9n
	TPMC	43.9 \pm 1.9	44.1 \pm 2.1	53.6 \pm 1.1	52.0 \pm 0.8	48.4n
	TPMP	52.0 \pm 1.3	50.4 \pm 1.4	58.4 \pm 1.1	56.8 \pm 0.6	54.4m
	Process mean ^{c,f}	47.8z	47.9z	54.6y	53.7y	

^a Mean values of two replicates \pm one standard deviation.

^b PMP = 60% pearl millet + 40% peanut; PMC = 60% pearl millet + 40% cowpea; TPMC = 20% teff + 40% pearl millet + 40% cowpea; TPMP = 20% teff + 40% pearl millet + 40% peanut.

^c Mean separation using Tukey's honestly significant difference ($P < 0.01$) except protein (process) and ash ($P < 0.05$).

^d Mean values for each blend followed by the same letter in the same column are not significantly different.

^e Blend \times process interaction significant ($P < 0.01$).

^f Mean values for each processing method followed by the same letter in the same row are not significantly different.

^g Blend \times process interaction not significant ($P < 0.05$).

TABLE III
Composition of Weaning Food Ingredients^a

Ingredients	Moisture	Protein (N \times 6.25)	Fat	Carbohydrate	Ash	Nonstarch Polysaccharides
Pearl millet						
Whole	12.2	12.5	3.8	82.0	1.8	6.0
Decorticated	10.6	11.6	2.9	84.4	1.2	7.9
Roasted	3.9	...	...	...	...	...
Germinated	9.0	14.8	...	...	...	...
Teff						
Whole	8.9	14.6	2.9	80.1	2.4	6.2
Roasted	3.2	...	...	...	...	...
Germinated	10.5	21.2	...	...	...	...
Cowpea						
Whole	11.9	23.0	0.9	72.9	3.2	12.9
Decorticated	8.9	25.2	1.3	70.4	3.1	9.5
Roasted	4.3	...	...	...	...	...
Germinated	8.6	26.0	...	...	...	...
Peanut						
Whole	6.1	34.0	44.8	18.7	2.4	4.3
Decorticated	6.0	34.9	51.0	11.6	2.5	3.3
Roasted	1.9	...	...	...	...	...
Germinated	5.5	33.6	...	...	...	...

^a All values are means of two observations (% dry basis), except for moisture (% , wet basis).

Nonstarch polysaccharides (NSP) are a measure of dietary fiber. Blend formulation and processing method significantly ($P < 0.01$) contributed to NSP content (Table II). Peanut-based blends (PMP and TPMP) were significantly lower in NSP than were cowpea-based blends (PMC and TPMC). A comparison of teff formulations (TPMC and TPMP) to nonteff formulations (PMP and PMC) showed no significant difference ($P < 0.01$) in NSP content. The inclusion of whole grain teff at the 20% level did not contribute to the differences observed in NSP content. Germination significantly ($P < 0.01$) increased NSP content of weaning blends while roasting and fermentation yielded no significant changes. Because of the potential for reducing available energy and bioavailability of other nutrients, Williams (1995) suggested weaning foods provide <5 g/day of dietary fiber. The NSP content for the germinated peanut-based blends fell slightly below this upper limit, while cowpea-based blends exceeded the limit. The use of whole grain teff and millet along with the inclusion of sprouts produced an increased NSP content in germinated blends.

Ash content represents the total mineral content in foods. All blends varied significantly ($P < 0.05$) in percent ash (Table II) resulting from differences among individual ingredients (Table III). Germination significantly ($P < 0.05$) increased percent ash over other processing methods. Neither roasting nor fermentation produced significant changes in percent ash of the individual blends. Lorenz (1980) reported increases observed during germination to be apparent rather than true increases and result from the losses of dry matter. A greater importance must be placed on germination's ability to increase mineral availability through destruction of phytate (Bartnik and Szafranska 1987, Chavan and Kadam 1989b, Larsson and Sandberg 1992, Gahlawat and Sehgal 1992a).

Based on the Gauthier method (1982), mean *in vitro* protein digestibilities (IVPD) ranged from 46.9–54.4% for blend effects (Table II) and 47.8–54.6% for processing method effects (Table II). Because a 4-hr digestion and dialysis period was used, those values appear lower but comparable to others obtained from longer digestion times. Osilaja (1986) showed 42–45% digestibility with a 5-hr digestion period of similar cowpea products (beancake and moin-moin). Protein digestibility varied significantly ($P < 0.01$) among weaning blends due to both blend and processing method. The peanut-based formulations (PMP and TPMP) were 13.8% higher in protein digestibility than the cowpea-based blends (PMC and TPMC). Germination and fermentation improved IVPD 12–14% over control blends, while roasting produced no significant change. A reduction in phytic acid may have contributed to the improved digestibility observed in germinated

and fermented blends. Khetarpaul and Chauhan (1990) reported improved IVPD with 24-hr germination of pearl millet, while Kumar and Chauhan (1993) reported maximum reduction of phytic acid due to increased phytase enzyme activity in pearl millet within 48 hr of germination. Lorri and Svanberg (1993a) found increased IVPD in lactic fermentation of high tannin cereals. Improvements in IVPD with fermentation were associated with proteolytic enzyme production by microorganisms (Khetarpaul and Chauhan 1990).

Energy Density and Nutrient Distribution

Walker (1990) suggested an energy density of 370 kcal/100 g (db) as the minimum desirable level for infant weaning foods. The calculated energy densities obtained for the experimental blends ranged from 395 to 509 kcal/100 g (Table IV) and were comparable to those reported by other researchers (Pedersen et al 1989, Almeida-Dominguez et al 1993). At 15% (w/v) concentration, the energy density of the cooked product adjusts to 59–76 kcal/100 mL. Energy density was significantly different ($P < 0.01$) due to blend formulation and the blend effects produced the greatest variation ($r^2 = 0.985$) in the final caloric value of the product. Separation of means due to the blend effects shows no difference in energy density among peanut-based blends (PMP and TPMP) or among cowpea-based blends (PMC and TPMC). The peanut-based blends provided $\approx 20\%$ more kcal than cowpea-based blends due to the higher percent fat. Table V shows the mean caloric distribution of macronutrients of the weaning blends. Fat provided an average of 37% of the total kcal for peanut-based blends compared to 2.8% for cowpea-based blends. The Committee on Nutrition for the American Academy of Pediatrics suggests that for adequate growth and development, an infant's diet should provide 30–50% of total dietary calories from fat and 3% of the total calories from the essential fatty acids, linoleic (C18:2 ω 6) and linolenic acid (C18:3 ω 3) (Udall and Kilbourne 1988). In comparison, fat provides 40–60% of the total dietary calories in human milk (American Academy of Pediatrics 1993, Udall and Kilbourne 1988). The lower fat content of the cowpea formulations could place a growing infant at risk for essential fatty acid deficiency (Walker and Hendricks 1985). Cowpea-based blends were higher in NSP or dietary fiber (Table II). Increased NSP can result in an over estimation of available energy. The caloric value of fiber remains controversial and was estimated at 2 kcal/g instead of 4 kcal/g for other saccharides (Goranzon and Forsum 1986). The high energy density and low

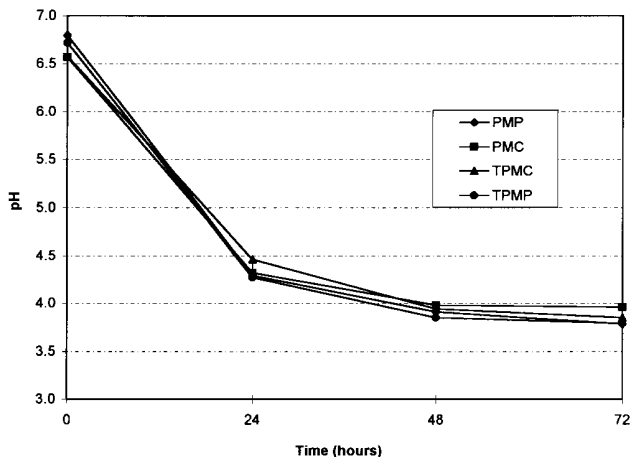


Fig. 1. Changes in weaning food pH with time during natural fermentation at 30°C. PMP = 60% pearl millet + 40% peanut; PMC = 60% pearl millet + 40% cowpea; TPMC = 20% teff + 40% pearl millet + 40% cowpea; TPMP = 20% teff + 40% pearl millet + 40% peanut.

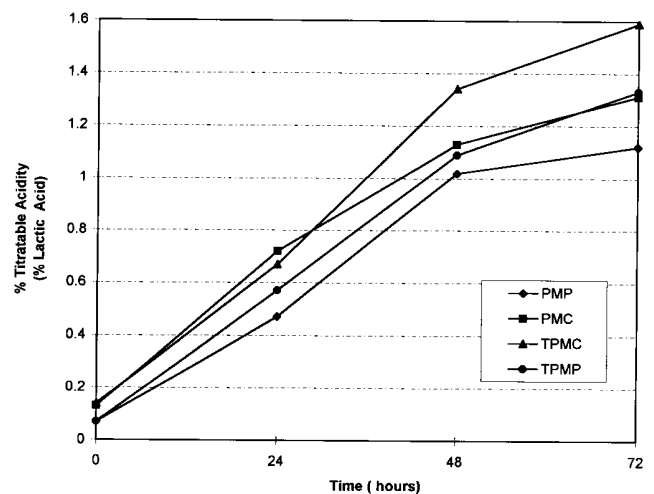


Fig. 2. Changes in titratable acidity of weaning foods with time during natural fermentation at 30°C. PMP = 60% pearl millet + 40% peanut; PMC = 60% pearl millet + 40% cowpea; TPMC = 20% teff + 40% pearl millet + 40% cowpea; TPMP = 20% teff + 40% pearl millet + 40% peanut.

TABLE IV
Effects of Blend and Processing Method on Energy Density (kcal/100 g, db) of Cooked Weaning Blends^a

Blend ^b	Control	Roasting	Germination	Fermentation	Blend Mean ^{c,d}
PMP	488 ± 4	490 ± 0	509 ± 2	494 ± 1	495.3a
PMC	396 ± 0	396 ± 0	403 ± 0	395 ± 1	397.5b
TPMC	396 ± 0	396 ± 0	401 ± 1	395 ± 0	397.0b
TPMP	487 ± 2	492 ± 2	505 ± 4	488 ± 4	493.0a
Process mean ^{c,e}	441.7y	443.5y	454.5x	443y	

^a Mean values of two replicates ± one standard deviation at 15% (w/v) concentration.

^b PMP = 60% pearl millet + 40% peanut; PMC = 60% pearl millet + 40% cowpea; TPMC = 20% teff + 40% pearl millet + 40% cowpea; TPMP = 20% teff + 40% pearl millet + 40% peanut.

^c Blend × process interaction significant ($P < 0.01$). Mean separation using Tukey's honestly significant difference ($P < 0.01$).

^d Mean values for each blend followed by the same letter in the same column are not significantly different.

^e Mean values for each processing method followed by the same letter in the same row are not significantly different.

TABLE V
Comparison of Mean Caloric Distribution of Macronutrients Between Peanut-Based and Cowpea-Based Weaning Blends Prepared by Traditional Processing Methods

Macronutrient Distribution	Control	Roasting	Germination	Fermentation	Process Mean ^a
Peanut-based blends ^b					
kcal/100 g, dry basis	488.0	491.0	507.0	491.0	494.0
% Protein kcal ^c	17.7	17.4	19.0	18.0	18.0
% Fat kcal	35.0	36.0	41.0	35.9	37.0
% Carbohydrate kcal	47.4	46.6	40.0	46.1	45.0
Cowpea-based blends ^d					
kcal/100 g, dry basis	396.0	396.0	402.0	395.0	397.3
% Protein kcal ^c	17.7	17.6	20.6	18.0	18.5
% Fat kcal	2.0	2.1	5.5	1.5	2.8
% Carbohydrate kcal	80.4	80.4	74.0	80.6	78.9

^a Overall mean values for all processing methods.

^b Overall mean values for all peanut -based blends (PMP [60% pearl millet + 40% peanut] and TPMP [20% teff + 40% pearl millet + 40% peanut]).

^c Protein-to-energy ratios.

^d Overall mean values for all cowpea -based blends (PMC [60% pearl millet + 40% cowpea] and TPMC [20% teff + 40% pearl millet + 40% cowpea]).

NSP content of peanut illustrates one advantage of using this oilseed in infant weaning formulations.

Energy density in relation to viscosity is termed dietary bulk. While there was a significant ($P < 0.01$) difference in energy density between peanut-based and cowpea-based blends (Table IV), there was a wider range in viscosity (Table I). Germination significantly ($P < 0.01$) increased energy density. The higher caloric value of germinated blends relates to the apparent increase in protein and fat components of those blends. Cooked products prepared from germinated blends produced a liquid product with a higher caloric value. The lower viscosity allows flexibility for increasing the solids concentration which increases the product's energy density. Brandtzaeg et al (1981) increased the solids concentration (w/v) of germinated finger millet and green gram 300% while maintaining the same viscosity. This becomes an important issue when examining the volume of food required to meet a growing infant's energy needs.

Protein-to-energy ratios (P-E ratios) (Table V) provide an indication of the protein sufficiency in the diet and illustrate an appropriate balance of protein to energy. This ratio represents the energy contribution of protein in relation to the total caloric value of the food product (% protein kcal) (Pellet 1990). Walker (1990) reported the P-E ratio for human milk to be 7 and desirable ratios for cereal based weaning foods to be 10–13. Both peanut and cowpea blends exceeded recommended P-E ratios. Reducing the legume component to 30% may be more suitable. Early formulations from the Food for Peace Program provided P-E ratios of 20–25 (Senti 1969). While ratios at this range may not be detrimental to the infant, it does represent protein intake beyond the infant's needs.

Selection Criteria for Determining Optimal Weaning Food

A ranking system using eight nutritional criteria was devised (Table VI) to determine the optimal blend combination. Based on

the relative importance and interrelationship of those criteria, ranking was reported on an equal weight basis. The weighting of those criteria as to relative importance produced identical conclusive results. The four blends within each processing group were ranked from 1 to 4 (best to worst) to objectively determine the choice weaning blend. The blend yielding the lowest score was considered to possess the most suitable nutritional characteristics. Peanut-based blends PMP and TPMP yielded the lowest total ranking scores within each processing method. These blends were concluded to possess the most desirable nutritional profiles among the blends studied. Germination proved advantageous over other processing methods. Germination decreased viscosity, increased energy density, increased protein digestibility and showed apparent increases in protein, fat, and ash.

The nutritional goal of a weaning food is to supplement the child's intake and not to provide total support during the transition from a milk-based diet to a modified adult diet. Based on the caloric needs of a 1-year-old child, germinated blends PMP and TPMP at 15% (w/v) concentration can provide >60% of the calories in 1,000 mL of cooked gruel. This volume requires feeding the child three to four meals per day. In some developing countries, children are often fed less frequently. Because viscosity is below target, the solids concentration can easily be increased to 20–30% (w/v) reducing the number of meals required to meet estimated needs. In addition, other food items or flavoring agents may be easily added without a significant effect on viscosity.

CONCLUSIONS

An infant weaning food of high nutrient density can be formulated and prepared from a combination of teff, pearl millet, cowpea, and peanut. Blend formulation shows the strongest impact on nutritional qualities and should receive priority over processing method in the design and development of an infant weaning food.

TABLE VI
Ranking^a of Weaning Blends for Determining Optimal Nutritional Profile

Blend ^b	Amino Acid Score ^c	kcal/100 g (dry basis)	Fat	Ash	NSP ^d	Protein-to-Energy Ratio	IVPD ^e	Viscosity ^f	Total Score
Control									
PMP	4	1	2	4	1	2	2	0	16
PMC	2	3	4	2	3	1	3	0	18
TPMC	1	3	3	1	4	4	3	1	20
TPMP	3	2	1	3	2	3	1	0	15
Roasting									
PMP	4	2	2	4	1	1	1	0	15
PMC	2	3	4	2	3	2	4	1	21
TPMC	1	3	3	1	4	4	3	1	20
TPMP	3	1	1	3	2	3	2	0	15
Germination									
PMP	4	1	1	3	1	1	2	0	13
PMC	2	3	4	2	3	3	4	0	21
TPMC	1	4	3	1	4	4	3	0	20
TPMP	3	2	2	2	2	2	1	0	14
Fermentation									
PMP	4	1	1	4	1	1	2	0	14
PMC	2	3	4	2	3	1	4	1	20
TPMC	1	3	3	1	4	2	3	1	18
TPMP	3	2	2	3	2	3	1	0	16

^a Most desirable (1) to least desirable (4).

^b PMP = 60% pearl millet + 40% peanut; PMC = 60% pearl millet + 40% cowpea; TPMC = 20% teff + 40% pearl millet + 40% cowpea; TPMP = 20% teff + 40% pearl millet + 40% peanut.

^c Amino acid score = lysine (mg/g of protein)/66 mg/g of protein (infant requirement). Calculated scores: 48 (PMP), 67 (PMC), 69 (TPMC), 50 (TPMP).

^d Nonstarch polysaccharides.

^e In vitro protein digestibility.

^f Viscosity score (0 = <3,000 cps, 1 = >3,000 cps).

Differences in nutritional quality due to the blend effects accounted for the largest percentage of variance in percent protein, percent fat, and energy density. The complementation of teff and pearl millet flours with peanut decreased viscosity, increased energy density, and improved in vitro protein digestibility over blends using cowpea as the legume complement. Based on the ranking data, peanut-based blends exhibited a more suitable nutritional profile than cowpea-based blends. The formulation of weaning blends with 20% whole grain teff did not significantly increase NSP or affect the nutrient distribution. The use of whole grain teff at higher levels would require further study. Processing method showed a greater effect on viscosity than on nutritional quality. While the physical and metabolic changes induced by germination yielded improvements in nutrient density and consistency, roasting and fermentation showed only slight variations from the control products.

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