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Nutritional Quality and Storage Stability of Extruded Weaning Foods Based on Peanut, Maize and Soybean

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Abstract. Samples of extruded high protein weaning foods were produced using blends of peanuts, maize and soybean to achieve the desired level of protein. The extruded products, based on a raw and a preroasteds mix of ingredients, were developed and characterized in terms of the hot paste viscosity characteristics, chemical and nutritional quality, amino acid composition, and storage stability. A comparative evaluation of the extruded products was undertaken in relation to two similar existing products: the traditional roasted maize flour weaning food, and the commercial version. In general, the extruded products were found to have better nutritional quality as indicated by the high protein content of 16.5–18.7% and quality, and excellent rat growth response. For both types of extruded weaning foods developed, between sixty- and one hundred-fold increases in mean weight gain of test rats were recorded over those eating the traditional sample. Correspondingly, the PER values which were between 2.3 and 2.5, were almost thrice the values obtained for the existing products. Significantly higher feed efficiency ratios were also obtained for the extruded products. Hematological data of test animals showed normal values for white blood cell (WBC) count, red blood cell (RBC) count, hemoglobin (Hb) levels and packed cell volume (PCV) for all the weaning foods studied, except the existing traditional roasted maize flour. In terms of storage stability of the extruded products, predicted shelf life periods of 7.8–10.4 months were obtained for the extruded raw blend, and 5.6–7.1 months for the extruded preroasted blend when stored at the average ambient temperature of about 30 °C in Ghana. In general, the preroasting treatment was found to reduce the quality characteristics of the extruded product.

Key words: Extruded weaning food, Nutritional quality, Storage stability, Maize, Peanut, Soybean

Introduction

Traditional weaning foods in Ghana and many other developing countries are based on cereals (mainly, maize, millet and sorghum) without adequate supplementation with high quality protein sources. Cereals are not only low in protein content but also deficient in certain essential amino acids. Over dependence on such poor protein sources is the main cause for the widespread protein-energy malnutrition problems in these areas. The realization of the nutritional inadequacy of the Ghanaian traditional weaning foods in supporting proper growth and development has given rise to extensive research and development efforts aimed at providing relatively inexpensive local substitutes for children and babies. The improvement of protein quality in weaning foods in Ghana has been geared toward the incorporation or supplementation of cereal-based weaning foods with grain legumes and oilseeds. The main focus is on peanuts, cowpeas and soybeans.

The Peanut Collaborative Research Program (CRSP) was established to address the constraints of peanut utilization in semi arid tropical (SAT) Africa. The potential dietary role of peanuts in SAT African countries has been determined and the need for research identified to: increase utilization of peanuts into refined/processed forms; prevent or minimize aflatoxin contamination; improve packaging to increase shelf-life of peanut products; utilize peanut flour to increase value of cereal and legume-based foods; and improve methods of storage and handling of peanuts and peanut products. The current Peanut CRSP project between Alabama A&M University and the Food Research Institute of Ghana has been formulated to address research needs based on the utilization of peanuts to increase the value of cereal and legume-based foods. The development of high protein weaning foods by extrusion cooking is the focus of the project. In an earlier study, standard extrusion parameters were established for extrusion cooking of blends of peanuts, maize and soybeans to achieve products with the desired physical and sensory characteristics as well as ease of extrusion [1].

The purpose of the present study was to establish, in relation to existing products, the nutritional quality and storage stability of extruded weaning foods based on peanuts, maize and soybeans. The effects of preroasting before extrusion on the quality characteristics was also determined.

Materials and Methods

Materials

Maize, peanuts and soybeans used for blend formulations and extrusion in the studies were obtained from local suppliers in Accra. The local Ghanaian normal dent white variety of maize (*Zea mays*), the reddish brown local 'Kpedevi' variety of peanuts, and the 'Salintuya' variety of soybeans were used throughout the study.

Blend Formulation and Preparation

The blend formula of 75% maize, 10% peanuts and 15% soybeans was based on previous work that established this ratio as the best to achieve the desired protein content of the product to contribute effectively to efforts at combating Protein-Energy Malnutrition using locally available raw materials, while promoting increased peanut production and utilization in the country [1–4]. This ratio of ingredients was used to produce two sets of high protein weaning foods by extrusion cooking. The first product was obtained by extruding the raw grains without any heat pretreament while the second product was prepared from preroasted grains before extrusion. Figure 1 information shows the flow diagram for the preparation of the samples for extrusion. The grains were first cleaned separately by removing extraneous materials such as chaff and stones, after which the bad grains were removed by sorting. The soybeans were dehulled by breaking in a disc attrition mill and winnowing. The grains were then weighed, mixed in an Apex Y-cone blender (Apex Construction Ltd. Soho Square, London, W1 UK) and

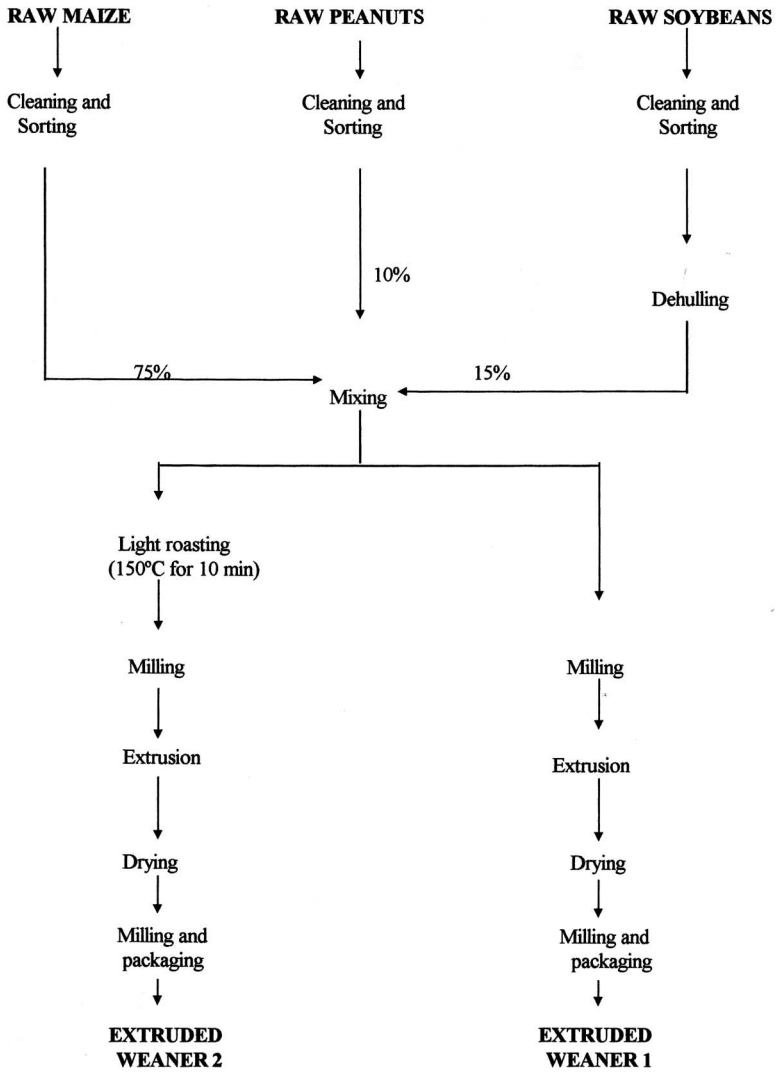

Figure 1. Flow diagram for the preparation of extruded weaning foods from blends of pre-roasted and un-roasted maize, peanut and soybean.

milled to a particle size of about 300–400 μm. Where preroasting was desired, the grains were first roasted separately in a gas heated pan roaster equipped with a mechanical stirrer (FATECO, Ghana Ltd.) maintained at 150 °C.

Extrusion Cooking of Blends

Extrusion cooking of the flour blend formulations was carried out in the Insta-Pro extruder (Model JR 500, Insta-Pro International, Des Moines, IA 50322, USA)

using the method described by Plahar et al. [1]. The screw speed was maintained at 500 rpm, with a feed rate of 4.6 kg/min, water flow rate of 20 litres/hour, and extrusion temperature of 100 °C–105 °C. Feed particle size was 300–400 μm with feed moisture content of 16–18%. The products were extruded through a single die of diameter 8.0 cm and cut with 1,500 rpm rotating blades into about 1.0 cm thick pellets. The pellets were dried for 3 h at 65 °C in a hot air cabinet dryer (R. Royce Industrial Ovens, Romsey, Hants, England).

Milling, Packaging and Storage

The resulting dried extrudates were milled in a disc attrition mill to a mean particle size of 300 μm, packaged in 500 g lots in polyethylene bags and sealed using the Impulse Heat Sealer (Model CD-300, Dea Lun Co. Ltd., Taiwan). The samples were kept in frozen storage at −20 °C until ready for analysis and consumer acceptability tests.

Chemical Quality Evaluation of Extruded Weaning Foods

Samples of extruded weaning foods developed and similar existing products were analyzed for moisture, protein and ash following standard methods [5]. Fat and free fatoy acids (FFA) contents of the samples were determined using the chloroform/methanol extraction technique described by Bligh and Dyer [6].

Determination of Trypsin Inhibitor Activity

Trypsin inhibitor activity was determined by the method of Hamerstrand et al. [7]. One-gram portions of the samples were extracted by soaking overnight at 4 °C in 50 mL 0.01 NaOH (pH was adjusted to 8.4–10.0). The suspensions were diluted so that 2 mL of the sample extract inhibited 40–60% of standard trypsin used in the analysis. For the analysis on inhibition of trypsin, synthetic benzoyl DL arginine-p-nitro anilide (BAPNA) was used as substrate. Residual enzyme activities were determined in systems containing 2 mL aliquots of the sample extracts by measuring the absorbance at 410 nm. Trypsin inhibitor activity (TIA) in terms of milligrams pure trypsin per gram sample was calculated as: TIA = $[(2.632 \times D \times A_1)/S]$ mg pure trypsin inhibited/g sample, where A_1 = change in absorbance due to trypsin inhibition/mL diluted sample extract, D = dilution factor and S = weight of sample (g).

Color

Color of the extrudates was measured using the Minolta Chroma Meter CR-310. This is to provide an objective assessment of the color of the products for comparison.

Amylograph Pasting Viscosity Measurements

The pasting properties of the extruded products as well as samples of traditional and commercial weaning foods were determined with a Brabender VISCO/amylo/GRAPH (Model VA-VE, C. W. Brabender Instruments, Inc., South Hackensack, NJ) equipped with a 700 cm-g sensitivity cartridge. A 10% slurry of the flour sample was prepared with distilled water and the shrry was heated uniformly (1.5 °C per min) from 25 °C to 95 °C, held at 95 °C for 15 min, and cooled at the same rate to 50 °C [8]. In the case of the extruded product, a 20% slurry had to be used to achieve any meaningful increases in viscosity. The resulting amylograms provided pasting temperatures, peak viscosities, viscosity at 95 °C, stability, cooking times and set-back viscosities.

Nutritional and Biochemical Studies

Animal studies were used to evaluate the products in terms of the nutritional, biochemical, hematological and histopathological quality. Four-week old weaning albino rats (*Rattus norvegicus*) obtained from the Department of Biological Sciences Animal House, University of Science and Technology, Kumasi, Ghana, were divided into groups of six and acclimatized after which they were put on the test diet. The basic composition of the diet was as follows: vegetable oil (8%), vitamin premix (1%), mineral premix (1%), cellulose (1%), test diet or casein (10%), sugar (7%) and corn starch added to make up to 100%. Food and water were given *ad libitum*; the weights of the animals were recorded daily for a period of four weeks. The feed intake was recorded and the Protein Efficiency Ratio (PER), Feed Efficiency Ratio (FER) (weight gained per gram feed intake) and mean weight gain calculated. The physical appearance of the animals was recorded. The rats were then sacrificed and blood for hematological analyses was quickly drawn by jugular incision and put in ethylenediamine-tetraacetate (EDTA) solution. Blood for serum protein and enzyme determination was drawn into tubes and centrifuged for 30 min. The serum obtained was stored in a refrigerator for subsequent analysis. Organ body weight ratios were determined for heart, lungs, kidney, spleen and liver.

Aspartate Transaminase was measured by the method of Reitman-Frankel [9]. AST substrate (0.5 ml) was warmed at 37 °C for 5 min and incubated with 0.1 ml serum for exactly 60 min. One ml dinitrophenyl hydrazine (DNPH) was added and allowed to react for 20 min. The mixture was then reacted with 5 ml 0.4 M N_aOH, allowed to stand for 10 min and absorbance read at 520 nm against a blank. For serum albumin, the Bromocresol green (BCG) method of Bartholomew and Delaney [10] was used. Samples of blood serum (0.02 ml) were mixed thoroughly with 4 ml buffered indicator (BCG) and read at 600 nm against a blank of 0.02 ml distilled water with buffered indicator.

The hemoglobin (Hb) content was measured by the method of Cartwright [11] while the packed cell volume (PCV) was determined by the microhematocrit

method described by Hercberg et al. [12]. For the estimation of red blood cells (RBC), 0.02 mL blood samples were mixed with anticoagulant (sequesterine) and diluted in 4 mL formol citrate solution. The diluted blood was placed in a counting chamber and the red cells counted under a dry objective lens. Similarly, white blood cell (WBC) counts were obtained by diluting the blood and sequesterine mixture in 0.38 mL diluting fluid made up of 1.5% glacial acetic acid, 0.5% malachite green and 98% water. The diluted blood was mounted in a counting chamber and white blood cells counted.

Amino Acid Analysis

Amino acid composition of samples was determined in triplicate following digestion under vacuum with 6N HCl in sealed ampoules at 110 °C for 22h. The hydrolysates were derivatized and analyzed for amino acids on a Waters HPLC system controlled by Millenium 2010 software (Waters Div., Millipore corp., Milford, MA., USA). Cystine was determined as cysteic acid using performic acid oxidation [13]. The colorimetric technique of Opienska-Blauth et al. [14] was used for the determination of tryptophan.

Storage Stability Tests

Accelerated storage stability tests were used to estimate the shelf-life of the products developed. Fifty gram lots of samples of the extruded weaning foods developed were sealed in polyethylene bags using the Impulse Heat Sealer (Model CD-300, Dea Lun Co. Ltd., Taiwan). The sealed samples were stored in each of three incubators maintained at 30, 45 and 55 °C. Samples were removed at different time intervals and analyzed for loss of quality based on specific components lost or developed. The different rates of deterioration occurring in the sealed samples at the different temperatures was used in calculating the shelf-life of the products according to the method of Labuza [15]. Non-enzymatic browning and free fatty acids content were used as the index for deterioration and shelf-life estimation. In the use of non-enzymatic browning (a zero order reaction) as an index of storage stability in the accelerated storage tests, the browning pigments (melanoidin pigments) were extracted in 50% ethanol, and the concentration determined at an absorbance of 420 nm.

Statistical Analysis

The data were analyzed using SPSS/PC+ Version 3.0 statistical software. Statistical parameters were estimated using analysis of variance. Differences between means were evaluated by the least significant difference test and significance was accepted at $p \leq 0.05$.

Table 1. Chemical composition and color of existing and extruded weaning foods[a]

Component	Existing weaning foods		Extruded weaning foods	
	Tradiational Tom brown[a]	Commercial Tom brown[b]	Raw blend[c]	Preroasted blend[c]
Moisture (%)	5.2 ± 1.0	6.6 ± 1.2	8.6 ± 0.7	7.2 ± 0.8
Protein (%)	9.2 ± 0.6	12.2 ± 0.9	16.5 ± 1.2	18.7 ± 0.6
Fat (%)	4.1 ± 0.3	8.3 ± 1.0	9.6 ± 1.0	10.4 ± 0.7
Ash (%)	1.2 ± 0.4	1.4 ± 0.3	2.7 ± 0.3	2.0 ± 0.3
Carbohydrates (%)	80.3 ± 0.7	71.5 ± 1.3	62.5 ± 2.5	61.7 ± 0.7
Energy (kcals)	377.6 ± 5.3	392.0 ± 6.3	376.1 ± 3.7	389.9 ± 2.6
Iron (mg/100 g)	4.1 ± 0.5	4.6 ± 0.7	5.1 ± 0.6	5.7 ± 0.8
Phosphorus (mg/100 g)	278.0 ± 3.8	350.8 ± 4.7	382.6 ± 2.4	394.6 ± 3.1
Calcium (mg/100 g)	31.8 ± 1.3	105.4 ± 3.0	240.3 ± 1.8	251.3 ± 2.1
FFA (% as oleic)	11.9 ± 2.5	9.7 ± 1.6	6.8 ± 0.4	7.1 ± 0.6
TIA (mg/g sample)	—	—	0.38 ± 0.08	0.19 ± 0.03
Color				
L	92.72 ± 0.21	96.81 ± 0.12	97.45 ± 0.08	90.41 ± 0.26
a	0.37 ± 0.08	0.32 ± 0.04	0.24 ± 0.02	0.31 ± 0.05
b	2.08 ± 0.41	1.84 ± 0.11	1.53 ± 0.02	2.43 ± 0.23

[a]Values are means ± standard deviations of measurements from three extrudates.
[b]Roasted maize flour.
[c]Flour prepared from a blend of roasted maize and peanut.

Results and Discussion

Chemical Characteristics and Color of Extruded Weaning Foods

The proximate composition, selected mineral contents, trypsin inhibitor activity and free fatty acid contents of existing traditional and extruded weaning foods are given in Table 1. Protein, fat and ash contents of both extruded products were over twice the content of the existing traditional sample. Iron, calcium and phosphorus were also in greater concentrations in the extruded products. This is the direct result of the fortification of the extruded products with soybeans and peanuts which have higher concentrations of these nutrients. The commercial Tom Brown product has peanuts as one of the ingredients, hence the higher content of protein over the traditional counterpart. The extrusion process adequately reduced the trypsin inhibitor contents of the products to very low levels, with the preroasting causing further decreases in the activity of this antinutritional factor which was contributed to the blend by the addition of raw soybeans. Plahar and Annan [16], in earlier studies, observed a reduction in trypsin inhibitor activity from 25 to 0.3 mg/g sample after boiling soaked soybeans for 20 min. The value of 0.3 mg/g sample was considered safe for maximum nutritional benefits [17].

Generally, the FFA levels in the extruded products were quite low compared to the existing products. A better storage stability of the extruded products is therefore expected.

With regards to color of samples, lightness factors are expressed in terms of 'L' values which indicate lightness or darkness on a scale of 100 to 0. The chromatibreak city coordinates, which represent hue and chroma, are expressed by 'a' and 'b,' respectively. In general, the weaning food sample extruded from the raw blends showed higher scores for lightness than the preroasted samples (Table 1). The positive values of 'a' and 'b' for both samples indicate the dominance of red and yellow coloration in the samples, with the products from the preroasted blends being significantly more red and yellow than the raw blend samples. The preroasting treatment resulted in browning reactions that gave rise to the greater discoloration. Extrusion cooking of raw blends, using the stated parameters resulted in lighter products with less red and yellow color.

Amylograph Pasting Characteristics of Weaning Foods

The amylograms of existing and extruded weaning foods were replotted on rectangular coordinates and superimposed for comparison (Fig. 2). Individual values for pasting temperature, pasting time, peak viscosity, viscosity at 95 °C, 15 min height, paste stability, viscosity at 50 °C, set back viscosity and cooking time are also shown in Table 2. The extruded preroasted weaning food showed a gelatinization

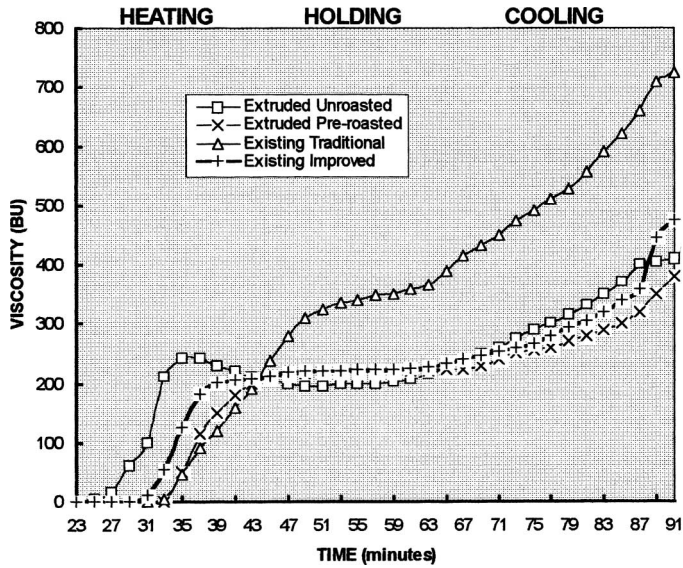

Figure 2. Amylograph pasting characteristics of existing and extruded weaning foods.

Table 2. Pasting viscosities of existing and extruded weaning food samples[a]

	Existing weaning foods		Extruded weaning foods	
	Traditional Tom Brown	Commercial Tom Brown	Raw blend	Preroasted blend
Pasting temp. (°C)	75.0 ± 1.2	70.0 ± 0.8	62.6 ± 0.7	77.5 ± 1.0
Pasting time (min)	33.3 ± 0.4	30.0 ± 0.5	25.0 ± 0.8	35.0 ± 0.6
Peak visc. (BU)	310 ± 12.0	220 ± 8.0	243 ± 7.0	218 ± 10.0
Viscosity @ 95 °C (BU)	280 ± 15.0	218 ± 10.0	198 ± 12.0	215 ± 9.0
15-minute height at 95 °C (BU)	360 ± 8.0	246 ± 10.0	210 ± 11.0	220 ± 10.0
Paste stability (BU)[b]	−50 ± 12.0	−26 ± 4.0	33 ± 9.0	−2 ± 1.0
Visc. @ 50 °C (BU)	725 ± 14.0	475 ± 7.0	405 ± 12.0	350 ± 8.0
Set-back value (BU)	415 ± 11.0	255 ± 9.0	162 ± 8.0	132 ± 6.0
Ease of Cooking (min)[c]	15.7 ± 1.2	19.0 ± 2.8	10.0 ± 1.4	16.0 ± 2.2

[a]Values are means ± standard deviation of triplicate determinations.
[b]Paste stability = difference between the peak viscosity and that obtained at the end of holding period. BU = Brabender Unit.
[c]Ease of cooking = difference between time to reach gelatinization temperature and time to obtain maximum viscosity during heating.

temperature similar to the existing traditional and commercial samples, while a significantly faster gelatinization was achieved with the extruded unroasted samples. This is an indication of the hardening effect of the roasting treatment on the samples and the consequent slow solubility of the starch granules. In general, all the weaning food samples produced amylograms with viscosities that were typical of products that had received some degree of heat treatment during preparation. Such products are characterized by relatively low pasting viscosities with no clear-cut peaks. In the present study, only the extruded raw blend samples showed peaks similar to what is normally observed with traditional products like fermented maize meal, the preparation of which involves no heat treatment [18]. This is an indication of the relatively low heat treatment to which the extruded raw blend had been subjected. The traditional existing product typically produced only a semblance of a peak at 310 BU and continued to increase in viscosity on further heating. The lower pasting viscosities observed in the extruded and existing commercial samples are the result of fortification with low starch materials such as peanut and other legume ingredients which diluted the starch concentration in the blend.

Prolonged cooking at 95 °C for 15 min resulted in reduced viscosity for only the extruded unroasted blend. Both the existing commercial sample and the extruded preroasted blend showed some resistance of the starch granules to prolonged heating, while the traditional sample continued to increase in viscosity. Negative values for paste stability were obtained for the existing weaning foods because of the continued increase in viscosity during holding. Cooking times ranged between 10.0 and 19.0 min with the minimum time for ease of cooking recorded for the extruded raw blend.

Hot paste viscosity characteristics of a weaning food, as determined from such amylograms, give an indication of the starch behavior and the rheological characteristics of the cooked product. Viscosity plays a very important role in the acceptability of the product. An acceptable weaning food is supposed to develop into a paste-like porridge when cooked, and become moderately viscous. A watery non-viscous slurry is not acceptable traditionally. In weaning food formulations therefore, it is quite important to ensure that an acceptable degree of viscosity is attained in the cooked product. In the present study, although the starch strength of the traditional extruded weaning foods was slightly reduced by the incorporation of the high protein base fortifying materials, the hot paste viscosities obtained were similar to those of the existing commercial samples and within acceptable limits. Moreover, it is an advantage in terms of increased nutrient density to increase the concentration of the product in a slurry to be cooked in order to achieve the desired viscosity.

Nutritional Quality of Weaning Foods

The physical appearance of rats used in the animal studies showed ideal growth and development with the extruded weaning foods. Rats fed the existing traditional weaning food had spiky fur and rough tails, whereas those on the extruded products had neat fur and fine tails, similar to those fed the casein control diet (Table 3). In earlier studies, Annan and Plahar [19] observed similar improvement in rat growth response when traditional weaning foods were supplemented with local legumes.

The results of the present study also showed that rats fed extruded weaning foods had much higher mean weight gains and Protein Efficiency Ratios (PER) than rats fed existing traditional weaning foods (Table 3). For both types of extruded weaning foods developed, between sixty- and one hundred-fold increases in mean weight gain were recorded over those fed the traditional sample. Correspondingly, the PER values were over 316% and 280% higher for the extruded raw blend and the extruded preroasted blend fed rats, respectively. The values obtained for the extruded products were comparable to those of the casein control diets. Significantly higher feed efficiency ratios (FER) were also obtained for the extruded products. PER values were 2.54 and 2.32 for the extruded raw and preroasted blends, respectively.

Based on earlier studies, PER values of not less than 2.1 and preferably 2.3 for weaning foods have been recommended [20,21]. Thus, the existing weaning foods (both traditional and commercial versions) would not meet the required standards for PER. The extruded weaning foods adequately satisfied the recommended nutritional quality. The slight differences in the nutritive values of the preroasted and the raw blends may be attributed to loss of available lysine in the former due to over processing (i.e. preroasting before extrusion).

The organ to body weight ratios of the test animals showed no organ enlargement that could be due to adverse pathological effect of the diets. The values, especially in the case of the liver, were similar for the extruded products and the casein control (Table 3).

Table 3. Nutritional and histopathological characteristics of test animals fed diets of existing and extruded weaning foods

Characteristic	Casein control diet	Existing weaning foods		Extruded weaning foods	
		Traditional Tom Brown	Commercial Tom Brown	Raw blend	Preroasted blend
Physical appearance of test animals	Smooth fur and smooth tail	Rough tail and spiky fur	Semi-smooth fur and tail	Fat with smooth fur and smooth tail	Smooth fur and smooth tail
Average weight (g)	108.5 ± 2.4	45.0 ± 3.2	60.6 ± 1.5	143.1 ± 1.8	98.4 ± 2.0
Mean weight gain (g)	70.4 ± 3.1	0.8 ± 0.2	15.3 ± 1.3	98.8 ± 2.4	54.1 ± 1.8
Protein efficiency ratio (PER)	2.58 ± 0.33	0.61 ± 0.12	1.43 ± 0.31	2.54 ± 0.48	2.32 ± 0.34
Feed efficiency ratio (FER)	0.41 ± 0.11	0.10 ± 0.02	0.30 ± 0.05	0.40 ± 0.08	0.38 ± 0.06
Organ: body weight ratio					
Lungs ($\times 10^{-3}$)	8.91 ± 0.60	8.70 ± 0.44	5.50 ± 0.15	7.50 ± 1.00	6.58 ± 0.87
Heart ($\times 10^{-3}$)	4.90 ± 0.48	6.00 ± 0.63	5.12 ± 0.52	4.80 ± 0.61	4.12 ± 0.64
Spleen ($\times 10^{-3}$)	8.92 ± 0.51	5.60 ± 0.41	5.49 ± 0.48	8.05 ± 0.52	7.49 ± 0.84
Kidney ($\times 10^{-3}$)	9.82 ± 0.62	12.20 ± 0.82	10.50 ± 0.82	8.68 ± 0.61	7.91 ± 0.77
Liver ($\times 10^{-3}$)	43.16 ± 0.90	56.18 ± 0.66	51.08 ± 0.75	43.41 ± 0.74	45.41 ± 0.81

Table 4. Amino acids composition (g/16 g N) of existing traditional weaning foods and extruded products[a]

Amino acid	Existing weaning foods		Extruded weaning foods	
	Traditional Tom Brown	Commercial Tom Brown	Raw blend	Preroasted blend
Aspartic acid	6.01 ± 0.46c	6.81 ± 0.32b	10.71 ± 0.41a	10.83 ± 0.28a
Threonine	3.54 ± 0.23b	3.61 ± 0.31b	4.92 ± 0.27a	4.69 ± 0.36a
Serine	4.79 ± 0.18b	4.92 ± 0.22b	5.40 ± 0.28a	5.50 ± 0.31a
Glutamic	18.53 ± 0.26c	19.05 ± 0.25b	22.85 ± 0.18a	23.02 ± 0.23a
Proline	8.85 ± 0.20a	9.10 ± 0.29a	8.09 ± 0.31b	8.00 ± 0.33b
Glycine	3.36 ± 0.19b	3.64 ± 0.15b	4.06 ± 0.16a	4.12 ± 0.22a
Alanine	7.26 ± 0.18b	7.73 ± 0.11a	6.51 ± 0.20c	6.38 ± 0.28c
Met. + Cyst.	4.17 ± 0.11a	3.98 ± 0.31a	3.65 ± 0.21b	3.49 ± 0.34b
Valine	4.72 ± 0.20b	4.88 ± 0.21b	5.49 ± 0.30a	5.62 ± 0.32a
Isoleucine	3.51 ± 0.25b	3.92 ± 0.31b	4.68 ± 0.29a	4.31 ± 0.26a
Leucine	12.71 ± 0.46a	12.42 ± 0.51a	10.30 ± 0.55b	10.28 ± 0.60b
Tyr. + Phen.	8.04 ± 0.18c	8.75 ± 0.21b	9.24 ± 0.32a	9.37 ± 0.37a
Lysine	2.73 ± 0.23b	2.85 ± 0.18b	5.20 ± 0.21a	5.81 ± 0.27a
Histidine	2.76 ± 0.16a	2.96 ± 0.11a	2.56 ± 0.09a	2.61 ± 0.12a
Arginine	4.37 ± 0.23c	5.01 ± 0.21b	6.68 ± 0.19a	7.04 ± 0.20a
Tryptophan	0.71 ± 0.05c	0.82 ± 0.03b	0.93 ± 0.06a	0.97 ± 0.05a

[a]Values are means of three replicates ± standard deviation. Means within a row not followed by the same superscript are significantly different ($p \leq 0.05$).

Amino Acid Composition

The amino acids compositions of the existing traditional weaning foods and the extruded products are given in Table 4. In general, the extruded weaning foods developed had greater concentrations of essential amino acids than any of the existing traditional counterparts. This is by virtue of the fortification of the extruded products with high quality protein sources, peanuts and soybeans, that facilitated mutual complementation of the limiting essential amino acids in the blend components (lysine and tryptophan in maize and the sulfur amino acids in the legumes). The most significant effect of the fortification was the improvements in the lysine and tryptophan contents of the extruded products. Products based on extrusion cooking of fortified blends had as much as a 100% increase in lysine and about a 30% increase in tryptophan content over the existing traditional products. Low protein scores in traditional maize-based weaning foods are due to the low lysine and tryptophan contents as the limiting amino acids. Thus, the protein quality was greatly enhanced and the protein score more than doubled in the extruded sample based products.

For most of the amino acids determined, there were no significant ($p > 0.05$) differences between the composition of the two extruded products. This is expected, as the blend composition was essentially the same for the two samples. Any significant effect due to the preparation treatment should be expected in the

Table 5. Development of browning pigments (A_{420} values) in extruded weaning foods during accelerated storage tests at different temperatures

	Absorbance values at 420 nm					
	Extruded raw blend			Extruded preroasted blend		
Storage period (Days)	30 °C	45 °C	55 °C	30 °C	45 °C	55 °C
0	0.35	0.35	0.35	0.58	0.58	0.58
10	0.37	0.53	1.05	0.61	0.90	2.08
20	0.41	0.70	1.75	0.65	1.22	3.58
30	0.42	0.91	2.45	0.70	1.54	nd
40	0.45	1.07	3.00	0.72	1.86	nd
50	0.46	1.30	nd	0.75	2.18	nd
60	0.49	1.55	nd	0.79	2.50	nd
70	0.52	1.60	nd	0.83	2.82	nd
80	0.54	1.70	nd	0.86	3.24	nd
90	0.57	1.82	nd	0.89	3.36	nd
Rate/day	0.0024	0.0180	0.0700	0.0035	0.0320	0.1500
End-point value	0.75	0.75	0.75	0.75	0.75	0.75
Shelf-life (days)	312.5	41.7	10.7	214.3	23.4	5.0
$E_{a.}$ (cals/mole)		26,797			29,872	
Q_{10} value		3.64			4.24	

bioavailability of these amino acids, especially lysine which may be involved in browning reactions.

Storage Stability of Extruded Weaning Foods

In the accelerated storage tests, non-enzymatic browning and free fatty acids development, were used as indices of storage stability of the two extruded weaning foods developed. For the non-enzymatic browning, the browning pigments (melanoidin pigments) were extracted in 50% ethanol, and the concentration determined from the absorbance at 420 nm. Changes in pigment concentration in the two weaning foods during storage at different temperatures are shown in Table 5. Browning rates were found to follow zero order kinetics at all three temperatures used in the study, for the two products. A faster rate of deterioration, in terms of browning, was observed in the extruded preroasted blend than the extruded raw blend product. This is perhaps due to the fact that the preroasting had already initiated the browning reaction in the product before the extrusion cooking process. Differences in initial glucose to lysine molar ratio were reported to be responsible for differences in the rate of browning in intermediate moisture model systems [22]. Since the two products were supposed to contain similar reactant molar ratios, the only factor that could account for the greater concentration of melanoidins in the preroased blend is the early initiation of browning due to the roasting.

For the extruded raw blend, the daily rate of browning was 0.0024 A_{420} at 30 °C, 0.0180 A_{420} at 45 °C, and 0.0700 A_{420} at 55 °C. The extruded preroasted blend had daily rates of pigment development of 0.0035, 0.0320 and 0.1500 A_{420} at

Table 6. Development of free fatty acids (FFA) in extruded weaning foods during accelerated storage tests at different temperatures

	Free Fatty Acids content (% as oleic)					
	Extruded raw blend			Extruded preroasted blend		
Storage period (Days)	30 °C	45 °C	55 °C	30 °C	45 °C	55 °C
0	6.80	6.80	6.80	7.10	7.10	7.10
10	7.51	11.50	26.20	8.00	10.30	41.10
20	8.14	16.90	46.20	8.82	21.90	75.10
30	8.51	20.20	65.90	9.68	29.30	nd
40	9.60	25.63	nd	10.54	36.85	nd
50	10.15	30.00	nd	11.40	44.10	nd
60	10.42	35.00	nd	12.26	51.50	nd
70	11.90	39.40	nd	13.12	58.95	nd
80	12.16	44.00	nd	14.00	66.34	nd
90	12.83	49.50	nd	14.84	73.70	nd
Rate/day	0.067	0.470	1.970	0.086	0.740	3.400
End-point value	15.60	15.60	15.60	14.40	14.40	14.40
Shelf-life (days)	232.8	33.2	7.9	167.4	19.5	4.2
E_a (cals/mole)		26,449			28,866	
Q_{10} value		3.59		4.03		

30, 45 and 55 °C, respectively. Based on sensory attributes and tolerable level of loss of available lysine determined in preliminary studies, the end-point values for unacceptability were fixed at 0.75 A_{420} for both products. The end-point data were transformed into shelf-life plots on a semi-log scale from which the shelf-life of the weaning food products at different temperatures could be obtained.

Results of the rate of lipid oxidation, as estimated by the free fatty acids (FFA) content of the samples during accelerated storage, are given in Table 6. The preroasted blend again showed a faster rate of deterioration than the raw blend. Rates of production of FFA were found to be faster by 28% at 30 °C, 57% at 45 °C and 72% at 55 °C.

Because of the obvious sensitivity of the two reactions (browning and FFA development) to temperature change, and the fact that these reactions also followed zero order kinetics, the Arrhenius plots (log k vs 1/T) were used to obtain the activation energies, Ea, from which the Q_{10} values were calculated and used to predict the shelf-life at lower temperatures [23]. Based on the browning reactions, the calculated Q_{10} values were 3.64 and 4.24 for the raw and preroasted blends, respectively, while the FFA values also gave Q_{10} values of 3.59 and 4.03. The predicted shelf-life of the products at the different temperatures, based on the calculated Q_{10} values, are given in Table 7 for both lipid oxidation and browning reactions. In general, longer product shelf-life may be assumed if browning is used as the quality index than if quality is based on lipid oxidation. Also, the extruded preroasted weaning food samples were found to have significantly shorter shelf-life than the extruded raw blend samples. At normal refrigeration temperatures, the extruded products can be kept for at least three years. However, at the average

Table 7. Predicted shelf-life of extruded weaning foods at given temperatures based on the Q_{10}

	Predicted Shelf-life (months)			
	Extruded raw blend		Extruded preroasted blend	
Temperature (°C)	Based on FFA ($Q_{10} = 3.59$)	Based on A_{420} ($Q_{10} = 3.64$)	Based on FFA ($Q_{10} = 4.03$)	Based on A_{420} ($Q_{10} = 4.24$)
55	0.26	0.36	0.14	0.17
45	0.95	1.30	0.56	0.71
35	3.39	4.73	2.27	3.00
25	12.18	17.20	9.16	12.70
15	43.74	62.61	36.93	53.87
5	157.03	227.91	148.82	228.39

ambient temperature of about 30 °C in Ghana, the estimated shelf-life of 7.8–10.4 months is expected for the extruded raw blend, and 5.6–7.1 months for the extruded preroasted blend.

Conclusion

The weaning food developed by extrusion cooking of blends of maize, peanuts and soybeans is highly nutritious and can adequately replace the existing low quality traditional counterparts to help enhance the nutritional status of the vulnerable groups in West Africa. The extruded products have excellent rat growth response with predicted shelf life periods of 7.8–10.4 months when stored at the average ambient temperature of about 30 °C. The inclusion of peanuts in the formulation will contribute significantly to increased production and utilization of the crop for enhanced food and nutrition security in the sub-region. In general, the preroasting treatment was found to reduce the quality characteristics of the extruded product.

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