NUTRIENT AND ANTINUTRIENT COMPOSITION OF EXTRUDED ACHA/SOYBEAN BLENDS

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ABSTRACT

The nutrient and antinutrient composition of raw and extruded blends of acha and soybean was evaluated. Acha and soybean grains were cleaned and milled into flour separately and sieved to pass 0.75–1.00 mm mesh. The moisture content of the flours was determined. Soybean flour was added to acha flour at 25% levels of substitution. The moisture content of the blends was adjusted to 25% levels. The blend was extruded using a Brabender laboratory single-screw extruder (Duisburg DCE-330 model, Duisburg, Germany). Amino acid profile, proximate composition, minerals and some water-soluble vitamins of raw and extrudate samples were determined. The oxalate, saponin, tannin, and phenol, content of raw and extrudate samples were also quantified. The results showed that the amino acids of the raw blend were higher (14.00–50.38%) than either of the sole flours. Extrusion cooking resulted in the depletion of some amino acids between 2.96 and 40%, with methionine and phenylalanine recording the highest and least losses. As expected, fat content of the blend increased from 2.8 to 8.33% alongside the protein (7.05–14.28%).

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*Extrusion cooking did not have significant (*P *≤ 0.05) effect on these parameters. The results for mineral content showed that extrudate zinc, magnesium and chromium content decreased but not significantly (*P *≥ 0.05), while iron, nickel, selenium and sodium increased significantly (*P *≤ 0.05). Blending acha and soybean raised the water-soluble vitamins content of the feed when compared with the levels of the vitamins in raw acha flour. Extrusion cooking significantly (*P *≤ 0.05) decreased these minerals. Blending acha flour and soybean flour at 25% level of soybean flour substitution resulted in dilution of all the antinutrients evaluated. Extrusion cooking further lowered these nutrients with saponin being totally eliminated.*

PRACTICAL APPLICATIONS

Quantifying the nutrient and antinutrient composition of extrudates of acha and soybean encourages the adoption and utilization of the extruded products from acha and soybean. By establishing the levels of these nutrients, the safety and nutrient densities of the resultant products are also highlighted.

INTRODUCTION

"Acha" (*Digitaria exilis* Skippis Staph.) is also known as "Fonio," "fundi" or hungry rice in different savannah zones of West Africa. The protein content of acha is unique in that it has greater methionine content than other cereal proteins. It is also high in digestible energy but low in oils and minerals (Victor and James 1991).

Soybeans (*Glycine max* [L.] Merrill), a versatile pulse, constitutes the staple food in parts of the globe. It is the richest, cheapest and best source of vegetable protein available to mankind. With high protein, high polyunsaturated fat content and absence of cholesterol and lactose, soybean is an excellent source of the essential amino acids vital for body growth, maintenance and reproduction. It is also a good source of minerals and vitamins (Iwe 2003).

Blending of acha and soybean would provide a wide range of both high calorie and protein food if properly processed. Proper processing would constitute in the application of simple rugged, low-cost processing systems that have been adopted in some least developing countries (LDCs). The use of low-cost food extruders fits into this definition. The ability of extrusion cooking to process various plant materials either alone or in blends into foods of high nutritional quality has meant a great deal to food fortification, particularly in the LDCs where diet is mostly derived from cereals or roots. The extrusion process is versatile, and efficient, and is used for converting raw ingredients to intermediate and finished foods. It adds a great value and variety to products and is expected to enhance the production, processing, storage and commercialization of acha/soybean products for a wide range of uses (Akinyele 1987).

An anonymous source (Anon 2003) reported that the World Health Organization (WHO) called protein energy malnutrition (PEM) the silent emergency. According to this report, PEM is an accomplice in at least half of 10.4 million child deaths each year. The WHO (2001) reported that malnutrition cast long shadows, affecting close to 800 million people with 20% of all such people in the LDCs. Reports of these wide-growing nutritional problems have been documented in Nigeria (Smith and Oluwoye 1988). Those mostly affected are children, lactating mothers, pregnant women and the elderly. Majority of these people are found in the rural areas and urban slums where common heritage of poverty, ignorance, poor sanitation and other conditions contribute to the problems of malnutrition, interfere with its solution and thus perpetuate a vicious cycle.

The blending of acha (high in methionine content and deficient in other essential amino acids) and soybean (deficient in methionine content and rich in other essential amino acids) would provide reasonable levels of complementarity. The retention of these essential nutrients would be enhanced through the application of a flash processing system as extrusion cooking. Furthermore, extrusion cooking principles have been widely applied for the retention of nutrients, and adequate heat treatment against antinutritional factors, etc.

The precooking of cereal/legume mixes has been advocated. Iwe (2003) explained that precooking would be important in developing countries where quick cooking saves scarce fuel and simplifies preparation. It was further explained that partial cooking can serve to destroy enzyme action such as lipases and lipoxygenases, which if active could cause off-flavor development. Again, a precooked product that requires minimal further cooking before serving has the advantage that water and other added ingredients are pasteurized in the process. To achieve such aims of precooking targeting enzyme denaturation, antinutrient inhibition, microbial inactivation, general product acceptability, etc., extrusion cooking presents the best option.

There is currently scanty information on the general application of extrusion technology in solving nutritional problems in Nigeria, while there is a dearth of information on specific application of extrusion technology in acha/soybean blend formulation and extrusion processing. This present work was therefore undertaken to evaluate the nutrient and antinutrient composition of extruded mixtures of acha and soybean.

MATERIALS AND METHODS

The materials used in this study were soybean (*G. max* [L.] Merrill) TGX 1448-2E and acha (*D. exilis*). Soybean was obtained from the seed store of the National Cereals Research Institute Bida, Niger State, Nigeria. Acha was purchased from Vom Local Market in Plateau State, Nigeria.

Soybean was cleaned to remove immature grains and other foreign materials. The sorted grains were washed in clean tap water. The washed grains were sun dried for 3–4 h at 34–40C, cracked in a commercial attrition mill and winnowed manually to remove hulls. The grits were further milled in an attrition mill into flour. Acha was also sorted and winnowed manually. Cleaned grains were milled using the attrition mill. The flours (soybean and acha) were sieved to pass a laboratory sieve mesh of 0.75–1 mm. The moisture content of the flours was determined and adjusted to 25% according to Wilmot (1998).

Extrusion was carried out using a Branbender Laboratory single-screw extruder (DCE-330 Model, Duisburg, Germany). It was powered by a decoder drive (Type 832, 500) and driven by a 5.94-kW motor. The grooved band had a length/diameter ratio of 20:1. The extruder had variable screws and heaters with a fixed die diameter of 2 mm and length of 40 mm. A feed hopper mounted vertically above the end of the extruder and equipped with a screw that rotated at a constant speed of 80 rpm on a vertical axis takes feed into the extruder. The wet flour was allowed to equilibrate for 2–3 h before extrusion. The extruder run was stabilized using acha flour. After steady state conditions were attained, emerging extrudates were collected and air dried at ambient temperature (24–27C) for about 12 h, then packed in cellophane packs and stored in the refrigerator at 4 ± 3C for further analysis.

The proximate composition, mineral contents and antinutritional composition of raw and extrudate samples were determined according to AOAC (1984). Amino acid profile was determined in raw and extruded samples according to Spackman *et al.* (1958). Vitamins were evaluated in raw and extruded samples according to the methods described by the British Pharmacopoeia (1988).

RESULTS AND DISCUSSION

The proximate composition of raw and extruded samples is presented in Table 1. The results showed that blending acha and soybean resulted in increase in fat and protein contents of the blend relative to the raw acha flour. Fat content increased from 2.83 to 8.33%, while protein increased from 7.05 to 14.28% with concomitant reduction in carbohydrate (70.44–53.88%). Extrusion cooking at 25% soybean addition, 25% moisture content, 150 rpm

TABLE 1.
PROXIMATE COMPOSITION OF RAW FLOURS AND EXTRUDED SAMPLES

Nutrient	Raw flour samples			Extruded samples
	Acha	Soybean	Acha/soybean	Acha/soybean
Fat (%)	2.83 ± 0.57[a]	20.87 ± 1.8[b]	8.33 ± 1.3[c]	5.13 ± 1.1[d]
Protein (%) Nx 6.25	7.05 ± 0.07[a]	33.57 ± 0.50[b]	14.28 ± 0.72[c]	12.62 ± 0.45[c]
Moisture (%)	11.50 ± 0.58[a]	11.17 ± 1.04[a]	10.62 ± 2.08[b]	8.25 ± 0.17[c]
Ash (%)	3.27 ± 0.20[a]	3.07 ± 0.12[a]	3.13 ± 0.64[a]	3.53 ± 0.12[a]
Carbohydrate (%)	75.35 ± 0.20[a]	14.99 ± 10.96[b]	53.88 ± 0.00[c]	55.59 ± 0.00[c]
Energy (KJ)	14.35 ± 2.83[a]	17.66 ± 0.00[a]	12.59 ± 0.00[a]	30.47 ± 0.00[b]

Values are means and standard deviations of three determinations. Means with the same letter along rows are not significantly different at 5% probability level.

screw speed (SS) and 150C barrel temperature led to decreases in the fat content (from 8.33 to 5.13%) and protein from 14.28 to 12.62%. These decreases were not significant ($P \geq 0.05$), however, the extrudates' fat and protein contents were still higher than sole acha fat and protein contents. The extrudates' fat and protein contents were still higher than sole acha fat and protein contents. The values obtained in this study for raw acha and raw soybean flours (Table 1) were close to values reported in literature (Salunkhe *et al.* 1992; Iwe and Ngoddy 1998; Okoh 1998) and the differences in value might be due to environmental and genetic variations of cultivars used. Acha and soybean blends had higher values of fat, and protein, which indicated that blending improved the proximate composition of the extrudate product. The results of this study confirmed earlier report (Elegbede 1998) that fortification of cereals with 25% soybean gave products of balanced nutrient composition. In addition, Iwe *et al.* (2003) reported that blending soybean and sweet potato flour resulted in increased nutritional status of the blends. The decreases in moisture, carbohydrate, ash and energy, although expected, might be due to dilution effect. These decreases made the blends less bulky, viscous and higher in solid matter content (Obatolu 2002). The results also showed that the blends recorded above 6% fat, thus meeting the requirement for complementary formulations (Obatolu 2002).

Extrusion cooking of acha and soybean flour showed that fat composition reduced in acha/soybean flour extrudates. This was expected and confirmed earlier reports (Guzman *et al.* 1992; Bhatnagar and Hanna 1994a; Rampersad *et al.* 2003). Explanations of this phenomenon had been hinged on the complexes formed by amylose and fatty acids, which resulted in decrease in the ratio of the length of maximum absorbance (Bhatnagar and Hanna 1994b).

Protein content of extrudates decreased but the decrease was not significant ($P \geq 0.05$). Reduction in protein content led to concomitant increase in

TABLE 2.
AMINO ACID PROFILE OF RAW AND EXTRUDED SAMPLES (g/100 g PROTEIN)

Amino acids	Raw samples			Extruded sample	% "aa" loss/gain in extruded sample	
	Acha	Soybean	Acha/soybean	Acha/soybean	Acha/soybean	
					Loss	Gain
Lysine	2.35	6.50	3.51	2.96	15.67	–
Histidine	2.20	2.80	2.55	2.4	5.88	–
Arginine	3.80	2.29	4.25	3.62	14.80	–
Aspartame	3.60	9.53	5.27	4.88	7.40	–
Threonine	3.95	3.92	3.41	3.06	10.26	–
Serine	3.50	4.07	3.51	4.11	–	17.09
Glutamine	4.00	15.16	9.61	11.00	–	16.55
Proline	3.30	5.39	1.02	3.85		4.23–
Glycine	3.40	6.45	4.16	4.66	–	12.02
Alanine	3.00	3.66	3.71	1.81	4.85–	
Cysteine	2.90	1.5	1.71	1.81	–	5.85
Valine	5.75	5.08	5.31	4.21	20.72	–
Methionine	4.80	1.49	2.20	1.32	40	–
Isoleucine	4.00	4.83	4.41	3.35	24.04	–
Leucine	9.90	7.98	8.01	8.32	–	3.87
Tryptophan	3.50	3.18	3.19	3.04	4.79	–
Phenyalanine	5.00	4.66	4.72	4.58	2.96	–

extrudate carbohydrate. However, Wilmot and Nelson (1998), Iwe *et al.* (2003), Obatolu (2002) and Osho and Adenekan (1995) had indicated marginal increases in protein content of extrudates. This decrease might be due to the gelatinization effect of the extrusion processing (Rampersad *et al.* 2003) resulting in increase in the starch content of the extruded products.

The caloric value of extrudates increased. This was expected and was in conformity with reported (Osho and Adenekan 1995; Iwe *et al.* 2001) trends.

Extrusion cooking resulted in reductions in some amino acids such as lysine, histidine, arginine, aspartame, theronine, methionine, etc., while increments were noticed in serine, cysteine, etc. (Table 2). Values obtained from this work were higher than values reported for potato/soybean blends (80:20) by Iwe *et al.* (2001), malted sorghum/soybean (70:30) by Osho and Adenekan (1995) and closer to the values reported by Obatolu (2002).

Maillard reactions, which were inevitable due to the presence of lysine and reducing sugars offered by both the acha starch melt and soybean flour, resulted in reductions not only of lysine but in over 50% of amino acids evaluated (Table 2).

The cysteine content of the raw blend of acha/soybean represented a 19.89% decrease in sole acha cysteine composition and a 5.85% decrease in

TABLE 3.
MINERAL COMPOSITION (mg/100 g) OF RAW AND EXTRUDED SAMPLES, DRY WEIGHT BASIS

Mineral	Raw flour samples			Extruded sample	Increase/decrease in mineral content in extruded samples (%)	
	Acha	Soybean	Acha/soybean	Extruded samples	Increase	Decrease
Zn	1.67[a]	3.60[a]	1.40[a]	0.09[d]		93.57
Ca	36.50[a]	29.45[a]	47.83[a]	34.30[a]		28.29
Fe	3.50[a]	1.00[a]	1.10[a]	3.60[a]	69.44	
Ni	11.00[a]	1.10[a]	1.50[a]	2.10[a]	28.57	
Mg	71.00[a]	131.10[a]	109.13[a]	81.40[a]		34.57
Se	1.50[a]	1.80[a]	1.50[a]	1.60[a]	6.25	
Cr	1.07[a]	9.10[a]	1.80[c]	0.53[d]		70.56
Na	21.30[a]	14.70[a]	22.00[a]	36.00[d]	38.89	
K	293.30[a]	286.70[b]	360.00[c]	176.00[d]		51.11

Reported values are means of three determinations. Means with the same letter along rows are not significantly different at 5% probability level.

the cysteine content of acha/soybean extrudate. For methionine, the decrease was 12.89% of the value of the raw soybean flour while it represented 66.67% decrease in the methionine value of the raw acha/soybean flour blend. These losses were higher than reported values (Bjork and Asp 1983; Asp and Bjorck 1989; Iwe *et al.* 2001). This might be due to the use of full-fat soybean without initial preheat treatment to inactivate lipoxygenase enzymes and other antinutritional enzymes whose activities might have been triggered off by the addition of water before extrusion, thus leading to higher destruction of amino acids. It could also be a consequence of dilution effect due to excess extrudate moisture.

The results for the mineral content (Table 3) were in agreement with the values reported by Irving and Jideani (1997), Del valle *et al.* (1981) and Obatolu (2002) for similar cereals/soybean blends. It, however, differed from the values reported by Victor and James (1991) and Nnam (2000). These differences could be due to acha cultivar and analytical methods employed. Extrusion cooking of the acha/soybean blends resulted in decreases in some of the minerals. However, the extrudates were still higher in mineral composition than the raw acha flour, except in its calcium content. The results agreed with the report (Artz *et al.* 1992) that increases in extrusion temperature resulted in increased amount of trace elements in extrudates. The results of this present study showed that there were significant ($P \leq 0.05$) increases in Na, Fe and Ni and significant ($P \leq 0.05$) decreases were observed in K, Ca and Mg.

TABLE 4.
SOME WATER SOLUBLE VITAMINS OF RAW AND EXTRUDED SAMPLES

Vitamin (mg/100 g)	Raw samples			Extruded samples
	Acha	Soybean	Acha/soybean	Acha/soybean
B_2	0.03 ± 0.00^a	0.90 ± 0.00^b	$0.70 \pm 0.00c$	0.01 ± 0.00^a
B_6	2.70 ± 0.21^a	5.50 ± 0.07^b	4.10 ± 0.14^c	2.20 ± 0.07^d
Vitamin C	0.01 ± 0.01^a	0.03 ± 0.01^a	0.01 ± 0.00^a	0.01 ± 0.01^a

Values are means and standard deviations of three determinations. Means with the same letter along rows are not significantly different at 5% probability level.

Increases in such transition elements have been attributed to screw wear in the extruder (Artz *et al.* 1992).

Comparing the extrudate values to the recommended nutrient composition of fortified complementary foods, per daily ration, it was observed that the extruded blends were only deficient in zinc and selenium.

The results of water-soluble vitamins of raw samples (Table 4) showed that while the values for B_6 approximated the value (2.3 mg/100 g) reported by Salunkhe *et al.* (1992) and Iwe (2003), the values of ascorbic acid and B_2 were below the values 35 mg/100 g ascorbic acid, 0.7 mg/100 g B_2 and 2 mg/100 g B_6 reported by Del valle *et al.* (1981). When compared with the values (0.34 mg/100 g B_2, 15.9 mg/100 g ascorbic acid) reported for raw maize (Ayatse *et al.* 1983), the results showed that raw maize had higher values of B_2, and ascorbic acid. The differences depended on the location and situation of soils where the grains were obtained, their cultivars and application of local processing techniques Okoh (1998).

Extrusion cooking did not have significant adverse effects on the vitamins studied (Table 4).

Riboflavin (B_2) was retained in the extrudate with 6% decrease. Harper (1988) reported the decrease in B_2 with increase in feed moisture content (FMC) and at high SS. However, the decreases were not significant ($P \geq 0.05$). The relative stability of riboflavin (B_2) to extrusion conditions had also been reported (Lorenz *et al.* 1980). However, the results obtained in respect for B_6 showed that decrease in the extrudate was high (86.36%). These results were at variance with some (Lorenz *et al.* 1980) report. Although the reason for the instability of B_6 is not fully understood, it might, however, be due to the high SS resulting in increased shearing in the extruder barrel.

Ascorbic acid values recorded in this study (Table 4) showed no significant ($P \geq 0.05$) reduction. Harper (1981) reported the loss of ascorbic acid at extrusion temperatures of 160C. Loss of ascorbic acid had been attributed to

TABLE 5.
ANTINUTRITIONAL COMPOSITION OF RAW AND EXTRUDED SAMPLES

Samples	Oxalate (%)	Phenol (mmol/L)	Phytate (mg/mL)	Tannin (mg/mL)	Saponin (mg/mL)
R/acha	Trace	6.10^{a}	5.00^{b}	3.00^{a}	Trace
R/soybean	2.13^{a}	2.10^{b}	8.70^{a}	2.12^{b}	2.25^{a}
R/acha/soybean	1.66^{a}	0.95^{c}	5.98^{b}	2.32^{b}	1.58^{b}
E/acha/soybean	1.07^{b}	1.30^{c}	3.60^{c}	Trace	Trace

Values are means and standard deviations of two determinations. Means with the same letter along columns are not significantly different at 5% probability level.
R, raw; E, extruded.

oxidation (Harper 1988). However, extrudates of blends of acha/soybean flours showed that ascorbic acid was protected. The reason for this protection may be due to the reduced residence time (17–23 s) at 150 rpm, 150 SS 25% FMC and 25% soybean flour.

The results of the antinutritional components of raw and extruded sample are shown in Table 5.

The phytate composition ranged between 1 and 3 mg/mL in the raw samples (acha and soybean flours). Blending acha and soybean flours produced a blend with intermediate value probably due to dilution effect. Extrusion cooking further reduced the level of phytate in the extrudates. The values obtained in this study were comparable to 1–3% phytic acid reported for soybean and soybean meals (Salunkhe *et al.* 1992; Iwe 2003). It would be expected that lowering of this compound should enhance the content of such minerals as zinc and iron in the extrudates as phytic acid has been implicated in making these minerals unavailable.

The levels of tannin ranged from 2.00 to 3.00 mg/mL in raw acha and soybean flours, respectively. Blending had no significant ($P \geq 0.05$) influence in the tannin content of the blend. Extrusion of blend of acha/soybean flours resulted in significant ($P \leq 0.05$) reduction in the values of tannin. The values recorded in this study were below the 4.5% reported earlier for soybean (Iwe 2003) and the 1.1–2.5% reported for extruded sorghum/soybean flours. Although the report of Osho and Adenekan (1995) indicated that presently there are no permissible levels of tannin in food, the results from this study, however, were low such that a high margin of safety could be assumed.

Results obtained from this study indicated that saponins were not present in raw acha flour. Saponins (0.6%) had been reported in defatted soybean meal (Iwe 2003). Extrusion cooking completely reduced the saponin to trace levels in the extrudates. In that report (Iwe 2003), the presence of antinutritional properties was attributed to saponins, yet soybean saponins have been shown to be harmless (Osho and Adenekan 1995).

The results of this study showed that, like saponins, there was only a trace amount of oxalate in acha flour. Values obtained for raw soybean were in agreement with earlier reports (Iwe 2003). Blending acha and soybean flours favored reductions in oxalate. This was probably due to dilution effects.

CONCLUSION

The results from this work showed that blended acha and soybean flours contained macro- and micronutrients in amounts that met recommended levels. Extrusion did not deleteriously affect these nutrients. However, extrusion cooking depleted most of the antinutrients evaluated. It is concluded that extrusion of blends of acha and soybean would produce ready-to-eat meals adequate in macro- and micronutrients and safe in its composition of antinutrients.

REFERENCES

AKINYELE, I.O. 1987. Combinations of cereals, legumes and meat products in extrusion products. In *Cereals and Legumes in the Food Supply* (D. Jacqueline and M.O. Elizabeth, eds.) pp. 219–235, Iowa State University Press America, Iowa.

ANONYMOUS. 2003. *Malnutrition: The Silent Emergency*, pp. 3–11, Watch Tower Bible Society, New York, NY.

AOAC. 1984. *Official Methods of Analysis*, 14th Ed., The Association of Official Analytical Chemists, Washington, DC.

ARTZ, E.W., RAO, S.K. and ROBERT, M.S. 1992. Lipid oxidation in extruded products as affected by extrusion temperature and selected antioxidants. In *Food Extrusion Science and Technology* (J.L. Kokini, C.T. Ho and M.V. Karwe, eds.) pp. 449–460, Marcel Dekker, New York, NY.

ASP, N.G. and BJORCK, I. 1989. Nutritional properties of extruded foods. In *Extrusion Cooking* (C. Mercier, P. Linko and J.M. Harper, eds.) pp. 399–433, American Association of Cereal Chemists, Inc., St. Paul, MN.

AYATSE, J.O., EKA, O.U. and IFON, E.T. 1983. Chemical evaluation of the effect of roasting on the nutritive value of maize (*Zea mays* linn). Food Chem. *12*, 135–147.

BHATNAGAR, S. and HANNA, M.A. 1994a. Amylose–lipid complex formation during single-screw extrusion of various corn starches. Cereal Chem. *71*, 582–587.

BHATNAGAR, S. and HANNA, M.A. 1994b. Extrusion processing conditions for amylose–lipid complexing. Cereal Chem. *71*(6), 587–593.

BJORK, I. and ASP, N.G. 1983. The effects of extrusion cooking on nutritional value – a literature review. J. Food Eng. *2*, 281–308.

BRITISH PHARMACOPOEIA. 1988. British Pharmaceutical Council, 1998. 2v British Medicines Commission. Department of Health, UK.

DEL VALLE, F.R., VILLANUEVA, H., REYES-GOVEA, J., ESCOBEDO, M., BOURGES, H., PONCE, J. and MONOZ, M.J. 1981. Development, evaluation and industrial production of a powdered soy oats infant formula using a low cost extruder. J. Food Sci. *46*, 192–197.

ELEGBEDE, J.A. 1998. Legumes. In *Nutritional Quality of Plant Foods* (A.U. Osagie and U.O. Eka, eds.) pp. 53–83, University of Benin, Benin City, Nigeria.

GUZMAN, B.L., LEE, T.C. and CHICHESTER, C.O. 1992. Lipid binding during extrusion cooking. In *Extrusion Science and Technology* (J.L. Kokini, C.T. Ho and M.V. Karwe, eds.) pp. 427–436, Marcel Dekker, New York, NY.

HARPER, J.M. 1981. *Extrusion of Foods*, Vol. I and II, pp. 1–3, 77–78, CRC Press, Boca Raton, FL.

HARPER, J.M. 1988. Effects of extrusion processing on nutrients. In *Nutritional Evaluation of Food Processing*, 3rd Ed. (E. Karmas and R.S. Harris, eds.) pp. 365–360, Van Nostrand Reinhold Company, New York, NY.

IRVING, D.W. and JIDEANI, I.A. 1997. Microstructure and composition of *Digitaria exilis* Stapf (acha): A potential crop. Cereal Chem. *74*, 224–228.

IWE, M.O. 2003. *The Science and Technology of Soybeans. Chemistry Nutrition Processing and Utilization*, 1st Ed., Rojoint Communication Services Ltd., Uwani, Enugu, Nigeria.

IWE, M.O. and NGODDY, P.O. 1998. Proximate composition and some functional properties of extrusion cooked soybean and sweet potato blends. Plant Foods Hum. Nutr. *53*, 121–132.

IWE, M.O., VAN ZUILICHEM, D.J., NGODDY, P.O. and LAMMER, W. 2001. Amino acid and protein dispersibility index of blends of extruded soy and sweet potato flours. Lebensm.-Wiss. Technol. *34*, 71–75.

IWE, M.O., VAN ZUILICHEM, D.J., STOLP, W. and NGODDY, P.O. 2003. Effect of extrusion cooking of soy-sweet potato blends on available lysine content and browning index of extrudates. J. Food Eng. 1–5.

LORENZ, K., JANSEN, G.R. and HARPER, J.M. 1980. Nutrient stability of full-fat soy flour and corn-soy blends produced by low-cost extrusion. Cereal Foods World *25*, 161–162, 171–172.

NNAM, N.M. 2000. Evaluation of the effect of sprouting on the viscosity, proximate composition and mineral content of hungry rice, acha (*Digitaria exilis*) flours. Nig. Food J. *18*, 57–62.

OBATOLU, V.A. 2002. Nutrient and sensory qualities of extruded malted or unmalted millet/soybean mixture. Food Chem. *76*, 129–133.

OKOH, P.N. 1998. Cereal grains. In *Nutritional Quality of Plant Foods* (A.U. Osagie and U.O. Eka, eds.) pp. 32–52, Post harvest Unit Biochem, University of Benin, Benin City, Nigeria.

OSHO, S.M. and ADENEKAN, I.G. 1995. Production and nutritional evaluation of soybean fortified malted sorghum meal extrudate. In *Processing and Industrial Utilization of Sorghum and Related Cereals in Africa* (J.M. Menyinga, I. Bezuznch, C.C. Nwasike, P.M. Sedojo and A. Tenkouano, eds.) pp. 109–118, OAU/STRC–SAFGRAD Publication, Ouagadougou, Burkina Faso.

RAMPERSAD, R., BADRIE, N. and COMMISSION, G.E. 2003. Physicochemical and sensory characteristics of flavoured snacks from extruded cassava/pigeon pea flour. J. Food Sci. *68*, 363–367.

SALUNKHE, D.K., CHAVAN, J.K., ADSULE, R.N. and KADAM, S.S. 1992. *World Oilseeds: Chemistry, Technology and Utilization*, pp. 9–50, AVI Book Van Noastrand Reinhold, New York, NY.

SMITH, I.F. and OLUWOYE, O.R. 1988. Energy, protein and selected intakes of low, middle and high income Nigerians. Nutrition *8*, 249–254.

SPACKMAN, D.H., STEIN, E.H. and MOORE, S. 1958. Automatic recording apparatus for use in chromatography of amino acids. Anal. Chem. *30*, 1185–1190.

VICTOR, J.T. and JAMES, D.B. 1991. Proximate chemical composition of acha (*Digitaria exilis*) grain. J. Sci. Food Agric. *56*, 561–563.

WILMOT, B. 1998. Extrusion and oil expelling. In *Soybean Processing for Food Uses. A Training Manual* (W.W. Sheldon, ed.) pp. 149–157, International Soybean Programme (INTSOY), Department of Food Science and Human Nutrition, University of Illinois, Urbana, IL.

WILMOT, B.W. and NELSON, A.I. 1998. Extrusion of oilseeds. In *Soybean Processing for Food Uses. A Training Manual* (W.W. Sheldon, ed.) pp. 144–148, International Soybean Programme (INTSOY), Department of Food Science and Human Nutrition, University of Illinois, Urbana, IL.

WORLD HEALTH ORGANIZATION (WHO). 2001. *The State of the World's Children*, UNICEF, New York, NY.