Effect of some extrusion variables on fermented maize-soybean blend

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Abstract The effects of feed moisture, sugar and temperature on extrusion of fermented maize-soybean blend was investigated. Fermentation caused a reduction in sectional expansion index from 1.342 to 1.244, bulk density from 0.5005 to 0.5002 g/cm³ and water absorption index (WAI) from 5.9 to 5.2 but increased specific volume from 7.13 to 7.15 cm³/g and water solubility index (WSI) from 1.2 to 1.7. Increase in feed moisture (20–35 %) reduced sectional expansion index, specific volume, bulk density and water solubility index but increased the water absorption index. An increase in concentration of the sugar reduced extrudate sectional expansion index, specific volume and water absorption index but increased bulk density and water solubility index. Increasing the barrel temperature exhibited a predominant effect on the bulk density of the extruded products. Proximate composition of the samples revealed that the extrudate was high in protein content (between 19.2 and 23.0 %), low in fat and ash contents.

Keywords Maize · Soybean · Fermentation · Temperature · Sugar · Extrusion

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Introduction

Submerged culture and solid state fermentations of cereal and root crops are important food processing technologies for millions of people in sub-Saharan Africa. *Ogi* is a popular fermented food produced by grinding cereals such as maize, sorghum or millet, sieving it wet and then allowing the starch to sediment and ferment in a liquid menstrum (Muller 1970). In Nigeria and some other parts of the world, *Ogi* is used as weaning food for infants, breakfast food for adults and application in traditional medicine (Antai and Nzeribe 1992). It has been reported that in developing countries such as Nigeria protein malnutrition persists as a principal health problem among children below the age of five (UNICEF 2010). Therefore, the need to find inexpensive sources of protein food of good quality cannot be over emphasized. The protein calorie sources of vegetable origin have been proposed as a solution to this problem (Abioye et al. 2011). Soybean (*Glycine max*) is a legume which forms important component of the diets in many developing countries (Aron 2002). Legumes are usually rich in proteins, essential amino acids and minerals, and are used to supplement other foods (Etonihu et al. 2009). Extrusion has gained attention and emphasis in the food industry since it is an important technique which, besides increasing the variety of processed food, presents more advantages when compared with other traditional systems of food processing (Guy 2001; Harper 1981). Today's health conscious consumers have shown a preference towards value added products, and in general, more nutritious food items (Brady 2007). The opportunity to supplement common sour corn starch with a legume like soybean of higher nutritional value is inherently beneficial to public interests. In general, extrusion of starchy foods results in gelatinization of starch, denaturation of protein, and formation of complexes between starch and lipids and between proteins and lipids (Guy 2001). The complexes between starches and lipids are due to the ability of the

amylose fraction of starches to bind lipids such as fatty acids. The decrease in expansion and the increase in bulk density of starch can also be compared to the swelling of native starch upon gelatinization (Bhatnagar and Hana 1994; De pilli 2011). During extrusion, due to the effect of high temperature and mechanical forces, proteins lose their globular structure. There occurs cleavage of bonds responsible for the 2nd and 3rd order structure of proteins, due to which polypeptide chains become straightened and extended and unfolded protein structures subjected to the effect of mechanical forces form layered structures (Camire et al. 1990). Proteins can form non-covalent disulphide bonds, block polar groups, form complexes with oxidized lipids, and create complexes of maillard reaction products. On the other hand, the most important transformations in starch material caused by extrusion and dependent on the water content, are gelatinization, dextrinisation, and melting. Transformations have an enormous effect on the physical properties of the end-product (Pérez-Navarrete 2008; Włodarczyk-Stasiak and Jamroz 2008). Acidification of the feed material causes depolymerisation of starch which in turn affects reconstitutability, viscosity, expansion behavior and strength of the extruded product (Sriburi and Hill 2000). The type and concentration of sugar influences expansion and shrinkage properties and promotes maillard reactions thereby influencing product qualities such as reconstitution, bulk density, texture and colour. For the production of nutritious acceptable food, rates of starch fortification seem to vary according to the nature of each material (Berrios 2004). Desirable properties in the extrudates are obtained by finding the appropriate processing condition as well as the proper composition of the raw material. Therefore, the aim of this study was to investigate the effect of extrusion variables (temperature and moisture content) and the amount of sugar on the proximate composition and functional properties of fermented maize–soybean blend.

Materials and methods

Raw materials

Maize and Soybean flours used during this study were of good grade and were obtained from the Food and Technology Laboratory of the Institute of Agro-Food Science and Technology, Beijing, China.

Fermentation

The flours were composited in 70:30 ratio and made into 100 g/200 ml slurry using distilled water then inoculated with 10 ml/100 ml of previously fermented maize–soybean slurry (backslop culture containing mixed colonies) and were

allowed to ferment at room temperature (25 ± 2 °C) for a period of 72 h. The fermented material was spread thinly on an aluminum tray and dried in a Memmert Cabinet at 45 °C up to 10 % moisture content. It was then milled using a pilot scale Retsch Grindomix GM 100 (F. Kurt Retsch GmbH, Germany) and sifted through a 600 µm sieve.

Extrusion process

The fermented dried flour was divided into four batches and moisture contents adjusted to 20, 25, 30, and 35 % by injecting an appropriate amount of 20 °C distilled water to the blends by varying the water injection rate of the pump via an inlet port. Extrusion was carried out in a Brabender 20 DN single-screw laboratory extruder (Brabender OHG Duisburg, Germany) having a uniformly tapered screw with a nominal compression ratio of 2:1, diameter 19 mm and length to diameter ratio of 20:1. The die diameter was 4 mm and screw speed at feed in let was kept constant at 40 rpm. The effect of temperature was determined by varying the barrel temperature in the third zone of the extruder (150, 160, 170 and 180 °C). Control samples of unfermented maize–soybean blend were also extruded.

Effect of sugar

Sucrose was purchased from a local store in Beijing, China and had particle sizes of 100 µm. Moisture content of the fermented and unfermented maize–soybean blend were adjusted to 20 % by pipetting an appropriate amount of 20 °C distilled water to the blend. The material was then divided into 500 g units and portions were premixed with the sugar at 0, 5, 10, 15 and 20 g/100 g. Extrusion was carried out in a Brabender 20 DN single-screw laboratory extruder at a screw speed of 160 rpm.

Sectional expansion index

The extrudates were collected in plastic bags, allowed to cool for 2 h then stored in air-tight plastic containers at 25 °C for 24 h to allow for drying and moisture equilibration before measurement of extrudate diameter using a vernier calliper. Sectional expansion index was calculated as $(De/Dd)^2$; where De and Dd were diameter of the cooled extrudate and diameter of the die, respectively.

Specific volume

The extrudates were cut into pieces of approximately 1 cm length. About 10 g of the product was weighed and put into a food can (A 212). Sesame seeds were used to fill the remaining space in the container, with six light shakings of the container to pack down the seeds. Excess seeds were carefully

scraped off the top of the can before weighing. The weight of the can filled with sesame seed was also determined. Water at 20 °C was used to determine the volume of the can. Specific volume (cm³/g) was calculated as

$$\text{Specific volume of extrudate} = \text{VE} / \text{W};$$

Where

W is the weight of extrudate

VE volume of extrudate = S [W1 – (W2 – W)]

Where

W1 is the weight of seed + can

W2 the weight of seed + can + extrudate

S the specific volume of seed = V/W1 – W3

V the volume of can

W3 the weight of can

Bulk density

The extrudates were milled using a pilot scale Retsch Grindomix GM 100 and sieved through a 600 µm sieve. A 50 ml graduated measuring cylinder was tarred and gently filled with 50 g flour. The bottom of the cylinder was repeatedly tapped gently on a laboratory bench until there was no further reduction of sample volume. Bulk density was calculated as weight of the sample/volume (kg/m³).

Water absorption and solubility indices

Samples were sieved through a 500 µm sieve. A 2.0 g ± 0.005 g sample was placed in a tarred centrifuge tube and 20 ml distilled water added. After standing for 15 min (with intermittent shaking every 5 min), the sample was centrifuged at 4000 rpm for 15 min. The supernatant was decanted into a tarred aluminum pan and weight gain in the gel was noted. Water absorption index (WAI) was calculated as [(weight gain of the gel) / (dry weight)]. The supernatant was evaporated to dryness at 105 °C until constant weight. Water solubility index (WSI) was determined as [(weight of dried supernatant) / (weight of dry sample) 100].

Proximate analysis

Moisture content was determined by direct oven drying method; the loss in weight after oven-drying was expressed as % moisture content (AOAC 2006). Crude protein was estimated from the total nitrogen (TN) determined by the micro-Kjeldahl method by multiplying the TN by a factor of 6.25. Crude fat was determined by using the soxhlet extraction method using

petroleum ether as the solvent (AOAC 2006). Ash was measured gravimetrically after ashing at 550 °C to constant weight.

Statistical analysis

Data obtained were subjected to analysis of variance using the Statistical Package for the Social Sciences (SPSS) 17.0 (IBM SPSS Inc., Chicago, IL) and mean separation was carried out with Duncan's new multiple range test to determine significant differences at 5 % probability.

Results and discussion

The sectional expansion index of both the fermented and unfermented corn-soy extrudates ranged from 1.40 to 1.24 and 1.46 to 1.34. Data analysis showed effect of moisture on the sectional expansion index of the products. According to the result higher expansion index are obtained under conditions of lower moisture. The reduction of SEI on fermentation (Fig. 1a) was attributed to acids produced during fermentation which damaged the starch polymers of the melted dough and reduced their capability to form an elastic matrix upon passing through the die. Extrudates expand during high temperature short time extrusion because the dough moisture cannot escape due to high pressures but instead flashes off as steam at the die exit. This leads to increased moisture content of the melt and causes the amylopectin molecular structure to soften and its elastic characteristics to reduce leading to a decrease in SEI (Alvarez-Martinez et al. 1988). An increase in feed moisture also causes a reduction in barrel temperature thereby creating a lower vapour pressure in the melt and resulting in less flashing of moisture and a reduced SEI (Badrie and Mellows 1991). The trapped steam instead condenses in the extrudate on cooling and is responsible for the higher extrudate moisture content. Extrudates with higher moisture contents were compacter and harder after cooling than those with lower moisture contents. This textural difference is because the partially expanded structure of the extrudate processed at high moisture content collapses and solidifies more rapidly during cooling and drying and forms a hard gritty texture. Specific volume is a major performance index for extrusion puffed food. It is a measure of volumetric expansion, which is the sum of radial and axial expansions. The specific volume of extruded products ranged from 7.20 to 7.15 cm³/g and 7.16 to 7.13 cm³/g for the fermented and unfermented samples.

The result showed that under conditions of low moisture, temperature at 170 °C, and 160 rpm of screw speed, the largest specific volumes are observed (Fig. 1b). Extrusion of the fermented flours caused an increase in specific volume. The

Fig. 1 The effect of moisture on (a) SEI (b) specific volume (c) bulk density (d) WAI (e) WSI of fermented and unfermented extruded corn-soybean blends. — UFE Unfermented extruded — FE Fermented extruded

bulk density of extruded products ranged from 0.5009 to 0.5002 g/cm³ and 0.5014 to 0.5005 g/cm³ for the fermented and unfermented samples. Extrusion of the fermented flours caused a decrease in the bulk density (Fig. 1c). Increasing feed moisture resulted in decrease in bulk density ($P \leq 0.05$). The reduction in bulk density of the fermented blend means that a higher flour concentration would be required to make a thin porridge and therefore energy density of the product would increase. Bulk density and SEI are inversely related and they help to explain the phenomenon of expansion as the extrudate exits the die. A high bulk density is associated with a low SEI (Fan et al. 1996a; Carvalho and Mitchell 2000) because a more compact material is obtained after milling a less

expanded product. The milled flour occupies less space and therefore more material is required to fill a unit volume than that obtained by milling a less compact extrudate.

The water absorption index (WAI) measures the volume occupied by the starch after swelling in excess water and indicates the integrity of starch in aqueous dispersion while water solubility index (WSI), often used as an indicator of degradation of molecular components. The water absorption index of extrudates ranged from 3.3 to 5.2 and 4.9 to 5.9 while the water solubility index ranged from 3.8 to 1.7 and 2.3 to 1.2 for both the fermented and unfermented samples. The reduction in WAI and increase in WSI on fermentation (Fig. 1d and e) is an indication that acidic compounds of fermentation may

have accelerated degradation of starch granules and release of water soluble compounds during extrusion. These changes are of nutritional importance because the insoluble native starch is more readily hydrated and solubilised after extrusion and are therefore more susceptible to enzymatic digestion. However, increasing moisture content had insignificant effects on WAI and WSI ($P \geq 0.05$). This is in contrast to the study by Njoki and Faller (2001) who reported that WAI and WSI decrease with decreasing moisture content; whereas Badrie and Mellowes (1991) observed an increase in WAI and decrease in WSI with increasing moisture content. The differences observed here could be attributed to the nature of the raw materials and the extrusion conditions.

Effect of sugar on extrusion

An increase in concentration of the sugar lowered extrudate SEI (Fig. 2a) but increased bulk density (Fig. 2c). Increasing sugar levels compete with starch granules for the limited water available in the system for starch conversion and therefore lower the water activity. This results in less steam being available to feed expanding cells during the expansion process and a decreased rate of starch conversion and therefore reduced elasticity of the melt. Consequently, the extrudates have lower moisture contents, expand less and collapse more readily after leaving the die and so have higher bulk densities. Bulk density is nutritionally important because it determines

Fig. 2 Shows the effect of sugar on (a) SEI (b) specific volume (c) bulk density (d) WAI (e) WSI of fermented and unfermented extruded corn-soybean blends. ■ UFE Unfermented extruded ■ FE Fermented extruded

the energy density of food. Extruded flour with a high bulk density is undesirable since only a small quantity of flour would be required to prepare food. This would have negative implications for child nutrition because of the corresponding decrease in energy density.

The decrease in specific volume (Fig. 2b) with increasing sugar concentration is a further indication of increased susceptibility of the extrudates to collapse and loss of expansion. The collapse phenomenon occurs due to shrinkages resulting from lower melt viscosities and a weak colloidal-like bubble wall caused by reductions in starch concentration and fewer entanglements between starch polysaccharides (Fan et al. 1996a, b; Mitchell and Areas 1992; Sopade and Le Grys 1991). This is in agreement with the findings of Jin et al. (1994) who have also reported that bulk density and specific volume are negatively correlated. WAI declined from 4.4 to 3.2 and 6.0 to 5.3 in the fermented and unfermented samples ($P \leq 0.05$) (Fig. 2d). WAI shows a maximum level at a certain amount of starch conversion (Guha et al. 1998) and therefore a decrease in WAI means that increasing concentration of sugar, increased starch disruption and hence reduced the volume occupied by the granule or starch polymer after swelling in excess water. Replacement of starch with sucrose has been reported to accelerate loss of starch granule structure and crystallinity and results in lower melt viscosity and lower

specific power consumption (Sopade and Le Grys 1991). Water solubility index is related to the amount of low molecular weight products of starch degradation which are easily soluble because of reduced entanglement. Thus, an increase in WSI with increasing sugar concentration was a sign of increased solubilisation of starch (Fig. 2e). This is nutritionally advantageous because depolymerised starch is more susceptible to enzymatic digestion and can be rapidly absorbed in vivo. The fermented extruded blend with sugar added were dark brown in colour than the unfermented extruded blend. This means that reducing sugars formed as a result of mechanical shear of starch reacted with amino acids to form Maillard products. The fermentation acids also may have contributed to browning probably by accelerating oxidative decomposition of the organic material and pigment degradation.

Effect of temperature on extrusion

The results in (Fig. 3a) indicated that variation in the barrel temperature exhibited a predominant effect on the bulk density of the extruded products with a decrease in both samples with increase in the extrusion temperature. Increased gelatinization increases the volume of extruded product consequently bulk density decreases as observed in this work. At high temperature the vapour pressure of the free moisture is also

Fig. 3 Shows the effect of temperature on (a) bulk density (b) WAI (c) WSI of fermented and unfermented extruded corn-soybean blends. — UFE Unfermented extruded — FE Fermented extruded

greater which would cause an increased rate of moisture flashing and puffing up on exit from the die (Harris et al. 1988). The WAI and WSI of extrudates were affected by barrel temperature (Fig. 3b and c). As the barrel temperature increased in the range of 150–160 °C WAI in both samples increased but between the range of 160–180 °C, WAI of the fermented extruded sample decreased from 3.8 to 3.0 while that of the unfermented extruded sample increased. Initial increase and subsequent decrease in WAI were also reported for maize grits (Ollet et al. 1990). The initial increase in WAI was attributed to higher proportion of gelatinized starch granules and maximum WAI indicated complete gelatinization and the subsequent decrease is due to further macromolecular degradation, which increases the solubility of starch. WSI increased from 5.0 to 5.6 and 6.6 to 8.0 for the unfermented and fermented sample extrudates, respectively as barrel temperature increased from 150 to 180 °C. The increase in WSI therefore shows macromolecular degradation with the intensity of extrusion condition. Large amount of soluble materials are released at high extrusion temperature, high screw speed and low feed moisture content.

Proximate composition of extrudates

The proximate composition (%) of the fermented and unfermented extrudates is shown in Tables 1 and 2. There was increase in the protein content of all the fermented extruded samples and over the raw sample while there was a decrease in the unfermented samples extruded at different temperature. The increase in protein content was highest (23.3 %) in the

Table 1 Proximate composition of fermented and unfermented corn-soy samples extruded at different moisture content (mean±SD)

	Protein	Moisture	Ash	Fat
Samples fermented and extruded with different moisture				
FE20	23.3±0.28	9.8±0.28	3.9±0.00	4.9±0.14
FE25	23.0±0.56	10.8±0.28	3.8±0.00	4.8±0.07
FE30	22.2±0.21	11.8±0.28	3.7±0.00	6.2±0.60
FE35	22.0±0.35	11.9±0.49	3.6±0.00	4.4±0.28
Samples unfermented and extruded with different moisture content				
UFE20	22.4±0.14	11.4±0.21	ND	6.8±0.70
UFE25	22.3±0.42	12.8±0.28	3.8±0.00	5.8±0.42
UFE30	20.7±0.21	12.6±0.00	3.6±0.00	6.4±0.56
UFE35	19.2±0.28	14.3±0.00	3.2±0.00	4.4±0.28
RAW	20.9±0.00	10.4±0.21	4.1±0.07	9.8±0.00

Values represent means of triplicate determinations

FE20 Fermented extruded at 20 % moisture, FE25 Fermented extruded at 25 % moisture, FE30 Fermented extruded at 30 % moisture, FE35 Fermented extruded at 35 % moisture, UFE20 Unfermented extruded at 20 % moisture, UFE25 Unfermented extruded at 25 % moisture, UFE30 Unfermented extruded at 30 % moisture, UFE35 Unfermented extruded at 35 % moisture

Table 2 Proximate composition of fermented and unfermented corn-soy samples extruded at different temperature °C (mean±SD)

	Protein	Moisture	Ash	Fat
Samples fermented and extruded at different temperature				
FE150	22.3±0.70	11.2±0.15	3.6±0.00	4.9±0.13
FE160	22.2±0.14	11.3±0.05	3.3±0.00	5.0±0.42
FE170	22.5±0.70	10.0±0.32	3.6±0.00	5.8±0.56
FE180	22.4±0.14	9.3±0.11	3.7±0.00	5.9±0.28
Samples unfermented and extruded at different temperature				
UFE150	19.6±0.70	13.0±0.10	3.3±0.00	5.7±0.42
UFE160	20.1±0.21	11.9±0.25	3.3±0.00	6.5±0.14
UFE170	19.9±0.00	11.1±0.10	3.3±0.00	7.0±0.42
UFE180	19.2±0.14	12.6±0.41	3.2±0.00	6.5±0.91
RAW	20.9±0.00	10.4±0.21	4.1±0.07	9.8±0.00

Values represent means of triplicate determinations

FE150 Fermented extruded at 150 °C, FE160 Fermented extruded at 160 °C, FE170 Fermented extruded at 170 °C, FE180 fermented extruded at 180 °C, UFE150 Unfermented extruded at 150 °C, UFE160 Unfermented extruded at 160 °C, UFE170 Unfermented extruded at 170 °C, UFE180 Unfermented extruded at 180 °C

sample fermented and extruded with 20 % moisture content. The increase in protein content in the fermented extruded samples may be due to a decrease of carbon ratio in the total mass, resulting in redistribution of nutrient percentages. Microorganisms utilize carbohydrates as an energy source and produce carbon dioxide as a by-product. This causes the nitrogen in the fermented samples to be concentrated and thus the proportion of protein in the total mass increases. The decrease in the protein content in the samples extruded at different temperature could be as a result of denaturation of the protein due to high thermal energy in which the feed was subjected to during extrusion cooking. The thermo-mechanical action during extrusion brings about gelatinization of starch, denaturation of protein and inactivation of enzymes, microbes and anti-nutritional factors (Bhattacharya and Prakash 1994). As the amount of heat treatment during extrusion increases, more protein in the extrudates are denatured resulting in decrease in both the Protein dispersibility index (PDI) and Nitrogen solubility index (NSI) (Stanley 1989).

Fat provides lubrication effect in the compressed polymer mix as well as modifies the eating quality of extrudates (Guy and Home 1994). The fat content of the fermented and unfermented extruded samples ranges between 4.4 to 6.2 and 4.9 to 5.9 for samples fermented and extruded at different moisture and temperature and 4.4 to 6.8 and 5.7 to 6.51 for samples unfermented and extruded at different moisture and temperature. There was a decrease in fat of all the samples (Tables 1 and 2). The decrease in the fermented samples could be as a result of microbial hydrolysis mainly due to the activity of lipase enzyme. Fat content declined after extrusion or cooking due to the formation of starch–lipid complexes that are

resistant to lipid extraction techniques (Camire 2001). Bjork and Asp (1983) stated that high temperature (>200 °C) and screw speed (>300 rpm) during extrusion can cause lipids gradation. Also fatty acids in the material can form complexes with amylose making it more difficult to extract crude fat for quantification.

Moisture content of samples is presumed as one of the most important determination of shelf stability. Values between 9.3 and 14.3 % were observed for the extruded meat analogue samples. This is within a range that could prevent microbial activity that enhances spoilage and also ensure shelf stability of the extrudates. High moisture products usually have shorter shelf life stability compared to lower moisture products (Ashworth and Draper 1992). From Tables 1 and 2, the extrudates moisture content decreases as barrel temperature increases but increases as feed moisture increases. Extrusion cooking aided by high temperature and screw speed induces structural changes in food proteins in the form of shrinkage that causes a pressure driven flow of water out of the extrudates which resulted in a reduction in water holding capacity. This is similar to the findings of (Asare et al. 2010).

Ash gives an indication of inorganic elements that are present in a food as minerals. The original ash content of the flour was 4.1 % but after extrusion cooking, it decreased to between 3.2 and 3.9 %. The decrease in ash content of the fermented extrudates compared to the unfermented sample might be due to lactic acid accumulation with concomitant increase in acidity and a decrease of dry matter yields. The decrease in ash content may be due to the fact that some biological macromolecules were released into the solution from such structures during extrusion (Yagoub and Abdalla 2007).

Conclusion

In this study, fermented maize-soybean blend was used to produce extruded meat analogue at constant screw speed, different moisture content and barrel temperature. Fermentation caused a reduction in bulk density and water absorption index (WAI) but increased specific volume and water solubility index (WSI) of the samples which are of nutritional importance. The proximate and functional properties of the products were affected by temperature and moisture level. We have shown that a self-preserving low moisture fermented corn- soy blend that can readily reconstitutes in warm water can be obtained by extrusion processing. Challenges still remain in scaling up these results, determining the influence of other process variables and improvements in the nutrient quality.

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References

- Abioye VF, Ade-Omowaye BIO, Babarinde GO, Adesigbin MK (2011) Chemical, physico chemical and sensory properties of soy plantain flour. *Afri J Food Sci* 5(4):176–180
- Alvarez-Martinez L, Kondury KP, Harper JM (1988) A general model for expansion of extruded products. *J Food Sci* 53(2):609–615
- Antai SP, Nzeribe E (1992) Suitability of using sieved and unsieved maize mash for production of *Ogi*-a fermented cereal food. *Plant Foods for Hum Nutri* 42:25–30
- AOAC (2006) Official methods of analysis, 18th edn. Association of Official Analytical Chemists, Washington DC
- Aron I (2002) Crop production in dry region. Vol. II. Leonard Hill, London, pp 255–257
- Asare EK, Sefa- Dedeh S, Afoakwa EO, Sakyi-Dawson E, Budu AS (2010) Modeling the effects of feed moisture and ingredient variations on the physical properties and functional characteristics of extruded sorghum-groundnut-cowpea blends using response surface methodology. *Inter J Food Engr* 6(4):1–17
- Ashworth A, Draper A (1992) The potential of traditional technologies for increasing the energy density of weaning foods: a critical review of existing knowledge with particular reference to malting and fermentation. Centre for Human Nutrition, London, pp 1–50
- Badrie N, Mellows WA (1991) Effect of extrusion variables on cassava extrudates. *J Food Sci* 56:1334–1337
- Berrios JJ (2004) Sodium bicarbonate and the microstructure, expansion and color of extruded black beans. *J Food Process Preserv* 28(5): 321–335
- Bhatnagar S, Hana MA (1994) Amylose-lipid complex formation during single-screw extrusion of various corn starches. *Cereal Chem* 71(6): 582–587
- Bhattacharya S, Prakash M (1994) Extrusion of blends of rice and chick pea flours; A response surface analysis. *J Food Eng vol* 21(3):315–330
- Bjork I, Asp NG (1983) The effect of extrusion cooking on nutritional value—a literature review. *J Food Eng* 2:281–308
- Brady K (2007) Effects of processing on the nutraceutical profile of quinoa. *Food Chem* 100(3):1209–1216
- Camire ME (2001) In: Guy R (ed) Extrusion cooking: technologies and applications. Wood head Publishing Co, Cambridge, pp 109–129
- Camire ME, Camire A, Krumhar K (1990) Chemical and nutritional changes in foods during extrusion. *CRC Crit Rev Food Sci Nutr* 29(1):35–57
- Carvalho CWP, Mitchell JR (2000) Effect of sugar on the extrusion of maize grits and wheat flour. *Inter J Food Sci Tech* 35(6):569–576
- De Pilli T (2011) Study of starch-lipid complexes in model system and real food produced using extruding-cooking technology. *Innovative Food Sci and Emerg Tech* 12(4):610–616
- Etonihu AC, Ayodele JT, Ibrahim M (2009) Proximate and amino acid composition of wheat species of *Pigeon pea* grown in Kogi State, Nigeria. *Nig J Biochem Mole Biol* 24(2):32–36
- Fan J, Mitchell JR, Blanshard JMV (1996a) The effect of sugars on the extrusion of maize grits: I. The role of the glass transition in determining product density and shape. *Inter J Food Sci Technol* 31:55–65
- Fan J, Mitchell JR, Blanchard JMV (1996b) The effect of sugars on the extrusion of maize grits: II. Starch conversion. *Inter J Food Sci Technol* 31:67–76

- Guha M, Ali SZ, Bhattacharya S (1998) Effect of barrel temperature and screw speed on rapid visco analyzer pasting behaviour of rice extrudate. *Inter J Food Sci Technol* 33:259–266
- Guy R (2001) Extrusion cooking: technologies and applications. Wood head publishing, Cambridge, p 288
- Guy RCE, Home AW (1994) Extrusion and co-extrusion of cereals, in Ref. 15: p 331–349
- Harper JM (1981) Extrusion of foods. CRC Press, Boca Raton, Florida, Vol. I p 212
- Harris PL, Cuppet SL, Lee KW (1988) A scanning electron microscope study of maize gluten meal and soy extrudate. *Cereal Chem* 65(2): 228–232
- Jin Z, Hsieh F, Huff HE (1994) Extrusion cooking of corn meal with soy fiber, salt and sugar. *Cereal Chem* 71(3):227–234
- Mitchell JR, Areas JAG (1992) In: Kokini JL, Ho C, Karwe MV (eds) Food extrusion science and technology. Marcel Dekker Inc, New York, pp 345–360
- Muller HG (1970) Traditional cereal processing in Nigeria and Ghana. *Ghana J Agric Sci* 3:187–191
- Njoki P, Faller JF (2001) Development of an extruded plantain/corn/soy weaning food. *Inter J Food Sci Technol* 36:415–423
- Ollet AL, Parker R, Smith AC, Miles MJ, Morires VM (1990) Macro structural changes during the twins crew extrusion cooking of maize grits. *Carbohydr Poly* 13:69–84
- Pérez-Navarrete C (2008) Effect of extrusion on nutritional quality of maize and lima bean flour blends. *J Sci Food Agric* 86(14):2477–2484
- Sopade PA, Le Grys GA (1991) Effect of added sucrose on extrusion cooking of maize starch. *Food Control* April, pp 103–109
- Sriburi P, Hill SE (2000) Extrusion of cassava starch with either variation in ascorbic acid concentration or pH. *Inter J Food Sci Technol* 35: 141–154
- Stanley DW (1989) In: Mercier C, Linko P, Harper JM (eds) Extrusion cooking. American Association of Cereal Chem, St. Paul, pp 321–341
- United Nations Children Emergency Fund (2010) Child nutrition, New York, USA. Published for UNICEF by Oxford Universities Press, pp 56
- Włodarczyk-Stasiak M, Jamroz J (2008) Analysis of sorption properties of starch-protein extrudates with the use of water vapour. *J Food Eng* 85(4):580–589
- Yagoub AA, Abdalla AA (2007) Effect of domestic processing methods on chemical, invitro digestibility of protein and starch and functional properties of bambara groundnut (*Voandzeia subterranean*) seed. *Research J Agric and Biol Sci* 3:24–34