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## Characterization of Ready-to-Eat Composite Porridge Flours Made by Soy-Maize-Sorghum-Wheat Extrusion Cooking Process

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**Abstract:** The materials used included sorghum, maize, wheat and soybean and two composite flours were formulated Sorghum-Maize-Soy 1 (SMS1) and Sorghum-Maize-Soy 2 (SMS2). Nutritional and functional characteristics of the two products were determined after High Temperature Short Time (HTST) extrusion; SMS2 had higher content ( $p \leq 0.05$ ) of zinc, magnesium and phosphorus than SMS1. SMS1 and SMS2 had protein content of 23.87 and 17.95% wt (percent weight) respectively with energy value of 1 694.89 and 1 540.88 Kilojoule/100g (KJ/100g) respectively while *In vitro* Protein Digestibility (IVPD) was found at 72.32 and 68.85% wt respectively. Linoleic acid, linolenic acid and all the essential amino acids were found in both extrudates and lysine was well retained during HTST extrusion. In general, changes in proximate composition, minerals and amino acids content during HTST extrusion were significant in both flours while fatty acids content did not change significantly. SMS1 was characterized by a decrease in viscosity on cooling as indicated by setback viscosity value, 12.00 Brabender Unit (BU), a pointer towards low retrogradation property of the flour. SMS1 had the lowest ( $p \leq 0.05$ ) peak viscosity of 15.00 BU but showed the highest ( $p \leq 0.05$ ) paste stability with 2.0 BU of breakdown viscosity. Results showed that SMS1 flour would have better gelation characteristics than SMS2 at similar concentrations with a least gelation concentration of 16.66% (w/v).

**Key words:** Composite flour, ready-to-eat, extrusion, nutritional composition, functional characteristic

### INTRODUCTION

Maternal and child undernutrition remain pervasive and damaging conditions in low income and middle-income countries (Black *et al.*, 2008) although the development of an adequate and accessible food product to a vast majority of the population is one cure for this scourge. Sorghum is a staple food in many African countries and contains reasonable amount of protein, ash, oil and fibre (Drich and Pran, 1987), however, is deficient in essential amino acid content, particularly with respect to lysine. Maize is the world's most widely grown cereal, cultivated across a range of latitudes, altitudes, moisture regimes, slopes and soil types (Smale and Jayne, 2003). In many African and Middle Eastern countries, corn is used for various food preparations. These foods are major sources of calories and nutrients (Akinrele, 1970). Wheat's adaptability to various climates and soils is evident from its wide distribution throughout the world. Wheat is grown to some extent on every continent except Antarctica (Matz, 1991). According to De Ruyter (1974), the use of soy flour in composite flours is emphasized and is quite understandable with regard to the worldwide cultivation of soybean, its protein content and nutritional protein quality. The addition of soy flour to that of sorghum, maize and wheat will overcome their deficiency of some nutritional composite like the essential amino acid lysine.

Peleme *et al.* (2002) reported that, in Africa, due to deforestation by utilization of wood for fuel, there is a great need for pre-cooked foods. High-Temperature, Short-Time (HTST) extrusion cooking could be used to produce sorghum-based foods of high nutritional quality and in a ready-to-eat form. According to Brennan (2006), there are many benefits to using extruders to process food materials. Extrusion systems are able to process highly viscous materials that are difficult or impossible to handle using conventional methods. The ability of extrusion systems to carry out a series of unit operations simultaneously and continuously gives rise to savings in labour costs, floor space costs and energy costs whilst increasing productivity. Besides processing advantages, extrusion cooking also can induce some beneficial nutritional and chemical changes in foods (Camire, 2002). Previous important research work on the extrusion cooking of cereals and legumes has been reported (Ding *et al.*, 2006; Bredie *et al.*, 1998; Iwe *et al.*, 2001; Peleme *et al.*, 2002) but nothing has been reported on HTST extrusion cooking of sorghum-maize-soy-wheat composite flour.

The main objectives of this study were to determine the chemical and functional properties of the developed composite flours and the effect of HTST extrusion on some nutritional characteristics of the flours. In addition, an eventual incorporation of the extrudates in others

foods could be considered according to their functional characteristics.

## MATERIALS AND METHODS

**Material procurement:** Sorghum, soybean, wheat and maize were purchased from Wuxi (Jiangsu province) local markets.

**Sample preparation:** Sorghum, wheat and maize grains were sorted, cleaned, dried in an oven at 40°C for 48 h and finally milled into flour to pass a 1.0 mm screen. Soybean grains were sorted, cleaned, dried in an oven for 12-18 h, roasted at 60°C for 25 min and finally milled into flour to pass a 1.0 mm screen. Two composite flours were formulated; Sorghum-Maize-Soy 1 (SMS1) and Sorghum-Maize-Soy 2 (SMS2). SMS1 was a mixture of 45% of soybean, 25% of maize, 25% of sorghum and 5% of wheat flour and SMS2 was a mixture of 25% of soybean, 35% of maize, 35% of sorghum and 5% of wheat flour.

**Extrusion process:** The blend was extruded using a twin screw co-rotating extruder; model A DS-32-II (Jinan Food Machinery China) with a smooth barrel. The extruder had four heating independent zones and the effective cooking zone temperatures were set at 60, 100, 120 and 150°C, respectively. The Length to Diameter (L/D) ratio for extruder was 20:1. The diameter of the hole in the die was 6 mm with a die length of 27 mm. The ingredients were fed into the extruder in the form of flour (particle size: 1.0 mm), after adjusting the moisture content to 10%. The rotation speed was 120 rpm at an average pressure of 8-11 Pascal (Pa). The extrudates were collected and dried in an air oven at 40°C for 10 min. The product were then cooled and milled into flour to pass 0.4 mm screen. Finally, the flour was stored in polyethylene bags at 4°C for further analysis.

### Determination of the functional properties of the product

**Nutritional composition:** Moisture, fat and ash contents were determined according to the procedures specified by the AOAC (1970). Crude protein (N x 6.25) content was determined by the Kjeldahl nitrogen method of the AOAC (1980). Carbohydrate content was determined by the Alkaline 3, 5-dinitrosalicylic acid (DNS) colorimetric method James, 1995). The calorie values were calculated by the Atwater formula (FAO, 1973) using values of 9, 4 and 3.75 Kilocalories for fat, protein and carbohydrate respectively. The conversion from kilocalorie (Kcal) to Kilojoule (KJ) was done using the formula 1 Kcal = 4.184 KJ.

**Water-binding capacity (WBC):** The water-binding capacity was determined by the modified method of Lin and Humbert (1974). A 2 g (10% wt moisture content) sample was added to 20 ml of distilled water in a test

tube, stirred briefly with magnetic stirrer (78HW-1, China) and allowed to stand for 1 h at room temperature (28°C) before being centrifuged at 2460 rpm (Anke TDL-5, China) for 25 min. Supernatant water was decanted by inverting the tubes over filter paper placed in a volumetric flask. The samples were allowed to drain for about 35 min and the weight of bound water was determined by the difference between initial and final weights of the sample.

**The least gelation concentration (LGC):** The least gelation concentration was determined by the method of Coffmann and Garcia (1977).

**Bulk density (BD):** A 50 g flour (8% wt moisture content) samples was put into a 100 ml measuring cylinder. The cylinder was tapped continuously until a constant volume was obtained. The bulk density was calculated as weight of flour (g) divided by flour volume (cm<sup>3</sup>) (Okaka and Potter, 1979).

**Pasting properties:** The pasting properties were evaluated using a Micro Visco-amilograph (Brabender, Type: 803201, Germany). Flour slurry containing 10% solids (w/v, dry basis) was stirred at 160 rpm and heated from 30-95°C at a rate of 5.0°C/min, held at 95°C for 15 min then cooled at the same rate to 50°C. The following parameters were obtained from plotted graphs: Peak viscosity (the maximum hot paste viscosity), final viscosity (viscosity at the end of the test after cooling at 50°C and holding at this temperature), setback viscosity (final viscosity-holding strength), breakdown viscosity (peak viscosity-holding strength or trough) and beginning of gelatinization.

**Nitrogen solubility index:** Nitrogen solubility of the proteins was determined using the method of American Association of Cereals Chemists (Mirmoghtadaie *et al.*, 2009).

**In vitro protein digestibility (IVPD):** *In vitro* protein digestibility was determined according to the method of Saunders *et al.* (1973).

**Amino acid analysis:** Amino acid analysis was performed using ion exchange chromatography following the release of amino acids from the extrudates. A 60 mg sample was mixed with 8 ml of 6 molL<sup>-1</sup> HCl. The hydrolysis was done under vacuum at 110°C for 24 h. After cooling, the hydrolysate was washed, filtered and dried, also under a vacuum, in a water bath at 60°C. The amino acids in the hydrolysate were separated and quantified by injecting 50 µL of the hydrolysate into a Hitachi (Tokyo, Japan) 835-50 amino acid analyzer equipped with a 2.6 mm x 150 mm ion exchange column coated with resin (Hitachi, Tokyo, Japan) 2619. The column temperature was 53°C.

**Minerals analysis:** Samples for minerals analysis were prepared according to the method of James (1995). Minerals were determined using an atomic absorption spectrophotometer (Varian AAS model 220Z).

**Fatty acids analysis:** Fat was extracted from flour with ether absolute. 0.1 g plant oil and 2 ml of 0.5 M NaOH in methanol solution were added to 20 ml tube. The mixture was incubated at 60°C water bath for 30 min until the oil was solubilized. 2 ml of 25% BF<sub>3</sub> in methanol solution were added to the cooled mixture. Then the mixture was incubated at 60°C water bath for 20 min for esterification. Subsequently, 2 ml hexane was added to the cooled mixture and shaken. The solution was centrifuged and the upper no aqueous layers were placed in a tube and dried with anhydrous Na<sub>2</sub>SO<sub>4</sub>. The solution obtained was used for analysis. Fatty acids were identified and quantified by injecting the prepared sample into GC/MS system (model GC-2010 SHIMADZU).

**Statistical analysis:** Each determination consisted of two separate samples, which were analyzed, in triplicate and the figures were then averaged. Data was assessed by the Analysis of Variance (ANOVA) (Snedecor and Cochran, 1987) and by the Duncan's multiple range test with a probability  $p \leq 0.05$  (Duncan, 1955).

## RESULTS AND DISCUSSION

**Proximate composition:** Proximate composition is shown in Table 1. The moisture content of SMS1 and SMS2 after HTST extrusion was 9.63 and 13.88% wt respectively. This can be attributed to starch gelatinization during extrusion cooking as during the process the intermolecular bonds of starch molecules in the presence of water and heat break down, allowing the hydrogen bonding sites (the hydroxyl hydrogen and oxygen) to engage more water. SMS2 contained more sorghum (35%) and more maize (35%) than SMS1, which contained only 25 and 25% of sorghum and maize respectively. More sorghum and maize refer to more starch in the flour thus more water absorption during starch gelatinization. As expected, the protein content of the extrudates increased proportionally with the amount of soybeans in the formulation. The content was 21.51% wt in SMS1 and 17.11% wt in SMS2 before HTST extrusion. Both extrudates showed a significant ( $p \leq 0.05$ )

decrease in crude protein content after HTST extrusion that was 23.87 and 17.95% wt for SMS1 and SMS2 respectively. Camire (2002) reported that the total protein change was not significant during most extrusion operations. The Codex Alimentarius Commission at its 19<sup>th</sup> session (1991) reported that protein content of supplementary foods for older infants and young children should be in the order of 15 g per 100 g of the food on dry matter basis, we concluded that SMS1 would cover the requirement. SMS1 had a higher ( $p \leq 0.05$ ) calorie value of 1 694.89 Kilojoule/100g compare to 1 540.88 Kilojoule/100g for SMS2 after HTST extrusion.

**Water-binding capacity (WBC):** Water binding capacity measures the amount of water absorbed by starch and can be used as an index of gelatinization (Anderson *et al.*, 1969). It also depends on the availability of hydrophilic groups that bind water molecules and on the gel-forming capacity of macromolecules (Onyeka and Dibia, 2002). The ability to absorb water is particularly important during reconstitution into the blend before consumption. SMS1 and SMS2 had water-binding capacities of 2.27 and 4.10 g/g respectively, as shown in Table 2. Lower absorption capacity is desirable for making thinner gruels. WBC increased as the proportion of maize increased in SMS2, this can be attributed to the higher amylose/amylopectin ratio in maize. Mercier and Feillet (1975) observed that higher amylose ratio results in a higher WBC.

**The least gelation concentration (LGC):** Least Gelation Concentration (LGC), an index of gelling tendency of samples, is very important with respect to porridges (Onyeka and Dibia, 2002). Kinsella (1979) reported that protein gels are composed of three dimensional matrices or networks of interwoven and partially associated polypeptides in which the water is trapped. Gels are characterized by a relatively high viscosity, plasticity and elasticity. The ability of protein to form gel and provide a structural matrix for holding water, flavours, sugars and food ingredients is useful in food applications (cited in Yemisi and Kayode, 2007). Protein gel formation usually requires prior heating of a protein to cause at least partial denaturation or unfolding of the polypeptide chains (Coffman and Garcia, 1977). Elofsson *et al.* (1997) noted that gel formation of proteins is the result of a two-step process involving, first

Table 1: Proximate composition of SMS1 and SMS2 before and after HTST extrusion

| Constituents                     | SMS1x                     | SMS2x                     | SMS1                      | SMS2                      |
|----------------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| Moisture (% wt) <sup>1</sup>     | 8.38±0.14 <sup>d</sup>    | 8.88±0.12 <sup>c</sup>    | 9.63±0.11 <sup>b</sup>    | 13.88±0.12 <sup>a</sup>   |
| Fat (% wt)                       | 14.34±0.0.12 <sup>a</sup> | 10.92±0.15 <sup>c</sup>   | 13.36±0.12 <sup>b</sup>   | 9.23±0.16 <sup>d</sup>    |
| Protein (% wt)                   | 21.51±0.14 <sup>b</sup>   | 17.11±0.12 <sup>d</sup>   | 23.87±0.16 <sup>a</sup>   | 17.95±0.16 <sup>c</sup>   |
| Ash (% wt)                       | 2.60±0.14 <sup>a</sup>    | 2.15±0.15 <sup>b</sup>    | 2.62±0.12 <sup>a</sup>    | 2.02±0.11 <sup>b</sup>    |
| Carbohydrate(%wt)                | 53.17±0.15 <sup>c</sup>   | 60.94±0.12 <sup>a</sup>   | 50.5±0.11 <sup>d</sup>    | 56.91±0.12 <sup>b</sup>   |
| Calorie Value(J/Kg) <sup>2</sup> | 1734.18±0.12 <sup>a</sup> | 1653.68±0.18 <sup>c</sup> | 1694.89±0.12 <sup>b</sup> | 1540.88±0.15 <sup>d</sup> |

<sup>1</sup>Percent weight. <sup>2</sup>Kilojoule per 100 gram. <sup>a,b,c,d</sup>Values with different letters in the same raw are significantly different ( $p \leq 0.05$ ). SMS1x and SMS2x, products before HTST extrusion; SMS1 and SMS2, products after HTST extrusion

Table 2: Functional properties of SMS1 and SMS2 after HTST extrusion

| Property                     | SMS1                    | SMS2                    |
|------------------------------|-------------------------|-------------------------|
| Water binding capacity (g/g) | 2.27±0.21 <sup>b</sup>  | 4.10±0.19 <sup>a</sup>  |
| LGC <sup>1</sup> (% w/v)     | 16.99±0.19 <sup>b</sup> | 22.55±0.17 <sup>a</sup> |
| Bulk density (g/ml)          | 0.69±0.18 <sup>a</sup>  | 0.68±0.19 <sup>a</sup>  |
| IVPD <sup>2</sup> (% wt)     | 72.32±0.29 <sup>a</sup> | 68.85±0.25 <sup>b</sup> |

<sup>1</sup>Least gelation concentration. <sup>2</sup>In Vitro Protein Digestibility.

<sup>a,b</sup>Values with different letters in the same row are significantly different ( $p \leq 0.05$ ). SMS1 and SMS2, products after HTST extrusion

the partial denaturation of individual proteins to allow more access to the reactive side groups within the protein molecules and second the aggregation of these proteins by means of reactive side groups into a continuous three dimensional network structure capable of retaining significant amount of water and also exhibiting some structural rigidity. This phenomenon is of importance in foods since it contributes significantly to the textural and rheological properties of various foods (cited in Yemisi and Kayode, 2007).

LGC was taken as a measure of the gelation capacity and the lower the LGC the better the gelation characteristics of the flour. SMS1 had a lower LGC ( $p \leq 0.05$ ) of 16.99% (w/v) than 22.55% (w/v) of SMS2 at pH 6.3 as shown in Table 2, a consequence of higher protein concentration in SMS1. This demonstrated that SMS1 porridge would have better gelation characteristics than SMS2 at similar concentrations. The least gelation concentration reported for legume flours was 14% for lupin seed proteins (Sathe *et al.*, 1982).

**Bulk density (BD):** Bulk density is a measure of heaviness of flour (Oladele and Aina, 2007). SMS1 had a bulk density of 0.69 g/ml, which was not significantly different of that of SMS2 (0.68 g/ml) as shown in Table 2. Their bulk densities were lower than 0.71 g/ml reported for wheat flour (Akubor and Badifu, 2004) and higher than 0.62 g/ml reported for cowpeas (Okaka and Iseih, 1990). Increase in bulk density is desirable in that it offers greater packaging advantage as greater quantity may be packed within constant volume (Molina *et al.*, 1983). However, low bulk density is desirable in preparation of infant and weaning foods. Stojceska *et al.* (2009) reported that Bulk density is highly correlated to the moisture content of the product during extrusion.

**Pasting properties:** The onset of starch gelatinization in SMS2 was found to occur at temperature 22.1°C lower ( $p \leq 0.05$ ) than SMS1. The presence of more starch in SMS2, may contribute, to some extent to its faster gelatinization and lower gelatinization temperature as SMS2 was composed of 35% of maize and 35 % of sorghum compare to 25% of sorghum and 25% maize for SMS1. SMS1 required a longer time (13.21 min) to reach maximum viscosity; this might be due to the lower rate of absorption and swelling of starch granules, as can be seen in Fig. 1.

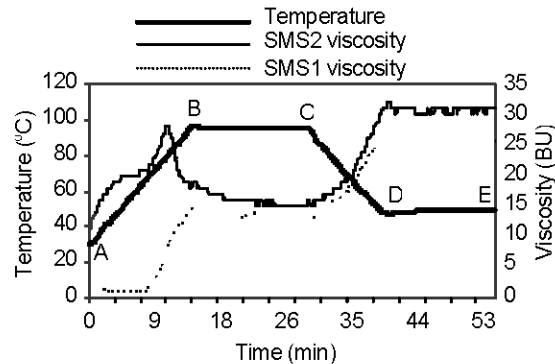


Fig. 1: Amylograph pasting characteristics of SMS1 and SMS2 after HTST extrusion. A-B: Heating period, B-C: Holding period, C-D: Cooling period, D-E: Final holding period

Ragae and El-Sayed (2006) reported that during the holding period of the viscosity test, the material slurries are subjected to high temperature and mechanical shear stress, which further disrupt starch granules in the grains, resulting in amylose leaching out and alignment. This period is commonly associated with a breakdown in viscosity. The ability of starches to withstand heating at high temperature and shear stress is an important factor in many processes. During cooling, re-association between starch molecules, especially amylose, will result in the formation of a gel structure and therefore, viscosity will increase to a final viscosity. This phase is commonly described as the setback region and is related to retrogradation and reordering of starch molecules. The low setback values indicate low rate of starch retrogradation and syneresis. The peak viscosity often correlates with quality of end product and also provides an indication of the viscous load likely to be encountered by a mixing cooker.

As shown in Table 3, the maximum viscosity reached upon starch gelatinization in SMS1 was much lower ( $p \leq 0.05$ ) than that measured on SMS2, their maximum viscosities were respectively 28.0 and 15.0 BU, likely as a consequence of the fat content of the two samples. As fat content increases, the amount of air en-trapped in the structure of the dispersion during mixing increases which causes a decrease in viscosity. SMS1 had the lowest ( $p \leq 0.05$ ) maximum viscosity but it showed the highest ( $p \leq 0.05$ ) paste stability, as indicated by its lowest ( $p \leq 0.05$ ) breakdown viscosity (2.0 BU). This indicates that SMS1 may have good potential as a food ingredient for food exposed to heat treatment at high temperature and mechanical stirring (Ragae and El-Sayed, 2006).

SMS1 was characterized by little decrease in viscosity on cooling as indicated by setback viscosity value, 12.00 BU, a pointer towards low retrogradation property of the flour.

Table 3: Pasting properties of SMS1 and SMS2 after HTST extrusion

| Property                           | SMS1                    | SMS2                    |
|------------------------------------|-------------------------|-------------------------|
| <b>Beginning of gelatinization</b> |                         |                         |
| Time (min) <sup>1</sup>            | 11.05±0.04 <sup>a</sup> | 6.41±0.05 <sup>b</sup>  |
| Viscosity (BU) <sup>2</sup>        | 11.00±0.05 <sup>b</sup> | 21.00±0.06 <sup>a</sup> |
| Temperature (°C) <sup>3</sup>      | 85.00±0.05 <sup>a</sup> | 62.90±0.06 <sup>b</sup> |
| <b>Maximum viscosity</b>           |                         |                         |
| Time (min)                         | 13.21±0.03 <sup>a</sup> | 9.51±0.05 <sup>b</sup>  |
| Viscosity (BU)                     | 15.00±0.05 <sup>b</sup> | 28.00±0.06 <sup>a</sup> |
| Temperature (°C)                   | 96.10±0.04 <sup>a</sup> | 78.70±0.04 <sup>b</sup> |
| <b>Final viscosity</b>             |                         |                         |
| Time (min)                         | 52.31±0.06 <sup>a</sup> | 52.31±0.05 <sup>a</sup> |
| Viscosity (BU)                     | 26.00±0.05 <sup>b</sup> | 31.00±0.04 <sup>a</sup> |
| Temperature (°C)                   | 50.00±0.06 <sup>a</sup> | 50.00±0.06 <sup>a</sup> |
| Breakdown viscosity (BU)           | 2.00±0.05 <sup>b</sup>  | 13.00±0.04 <sup>a</sup> |
| Setback viscosity (BU)             | 12.00±0.06 <sup>b</sup> | 13.00±0.05 <sup>a</sup> |

<sup>1</sup>Minutes. <sup>2</sup>Brabender Unit. <sup>3</sup>Degree Celcius. <sup>a,b</sup>Values with different letters in the same raw are significantly different (p≤0.05).

SMS1 and SMS2, products after HTST extrusion

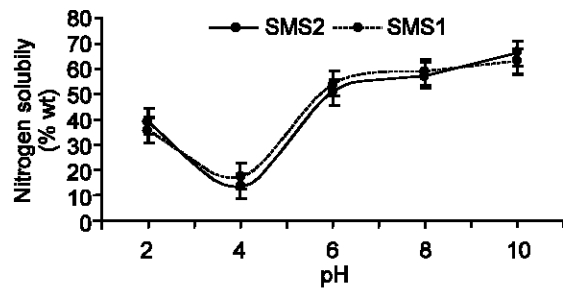


Fig. 2: Nitrogen solubility index of SMS1 and SMS2 after HTST extrusion

**Nitrogen solubility index:** The pH-dependent protein solubility profile for the extrudates is presented in Fig. 2. Both extrudates protein isoelectric point was found between 4.5 and 5.5 and the solubility reduced as the pH increased until it reached the isoelectric point; this was followed by progressive increase in solubility with further increase in pH. Maximum nitrogen solubility was observed at pH 10, 64.52 and 66.02 % wt for SMS1 and SMS2 respectively. Similar observations was reported for winged bean and Chickpea (Sathe *et al.*, 1982) and (Sanchez-Vioque *et al.*, 1999) and coincide with curves reported by Mensa-Wilmot *et al.* (2001).

The characteristics described above can be understood on the basis of the overall ionic charge of the protein with the pH. At low pH values, most of the carboxyl and amino groups from the lateral amino acid chains are protonated in the -COOH and -NH<sub>3</sub><sup>+</sup> forms respectively, and the overall charge of most protein molecules is positive. As the pH increases some of the carboxyl groups are dissociated into -COO<sup>-</sup> and -H<sup>+</sup>, according to their dissociation constants and the positive charges associated with the proteins diminish up to the

isoelectric point, where these are neutralized (Yemisi and Kayode, 2007).

At this point, the protein cannot be hydrated by water molecules, due to the modification of its tertiary and quaternary structures and its solubility reaches a minimum value (Sathe *et al.*, 1982). As the pH increases even more, the amino groups dissociate into -NH<sub>2</sub> and -H<sup>+</sup> and the overall protein charge becomes negative due to the presence of -COO<sup>-</sup> groups and can consequently be hydrated and dissolved in water.

Onyeka and Dibia (2002) noted that during HTST extrusion cooking process, the quaternary structure of proteins opens in the hot moist conditions, to produce a viscous plasticized mass. The proteins are then polymerized, cross-linked and reoriented to form a new fibrous structure. HTST extrusion cooking reduces protein solubility as a function of temperature, probably as a result of thermally induced cross-links among subunits of proteins by heat.

**In vitro protein digestibility (IVPD):** The mean values of the *in vitro* Protein Digestibilities (IVPD) for the extrudates are presented in Table 2. They were 72.32 and 68.85% wt for SMS1 and SMS2 respectively and the presence of more sorghum in SMS2, contributed, to the lower digestibility. Previous works showed that the sorghum has low protein digestibility. Tannin content and high levels of disulphide bonds in sorghum protein are mainly responsible for the reduction in digestibility of sorghum protein. Tannins interact with proteins causing their precipitation. Hamaker *et al.* (1987) attributed this to the formation of disulphide bonds, which results in toughening at the surface and interior of the protein bodies. Camire (2002) reported that extrusion may improve protein digestibility by denaturing proteins, exposing enzyme-accessible sites. Enzymes and enzyme inhibitors generally lose activity due to denaturation. Reductions in protease inhibitors can contribute to better plant protein utilization. 49.25 and 55.85% IVPD were reported for Sudanese and Indian sorghum cultivars respectively (Awadelkareem *et al.*, 2009).

**Amino acid:** The amino acid composition of both SMS1 and SMS2 before and after HTST extrusion is presented in Table 4. Both SMS1 and SMS2 contained all the essential amino acid before and after HTST extrusion. After HTST extrusion, Threonine, Valine, Methionine, Isoleucine, Leucine and tryptophan were higher (p≤0.05) in SMS1 than SMS2. However, Phenylalanine and Lysine presented a highest score (p≤0.05) in SMS2. Lysine content of SMS2 was 7.74 g/100 g; higher than 2.706 g/100 g reported for soybeans and 0.265 g/100 g reported for maize (Matz, 1991).

Table 4: Amino acids content of the SMS1 and SMS2 before and after HTST extrusion

| Amino acid (g/100 g) | SMS1x                  | SMS2x                  | SMS1                   | SMS2                    |
|----------------------|------------------------|------------------------|------------------------|-------------------------|
| Aspartic acid        | 2.27±0.02 <sup>a</sup> | 1.74±0.03 <sup>b</sup> | 2.35±0.04 <sup>a</sup> | 1.72±0.03 <sup>b</sup>  |
| Threonine*           | 8.59±0.03 <sup>b</sup> | 6.77±0.02 <sup>d</sup> | 9.05±0.03 <sup>a</sup> | 6.87±0.03 <sup>c</sup>  |
| Serine               | 1.18±0.04 <sup>c</sup> | 9.41±0.02 <sup>a</sup> | 1.19±0.04 <sup>c</sup> | 9.15±0.01 <sup>b</sup>  |
| Glutamic acid        | 4.41±0.04 <sup>b</sup> | 3.63±0.03 <sup>c</sup> | 4.66±0.01 <sup>a</sup> | 3.63±0.04 <sup>c</sup>  |
| Glycine              | 8.93±0.04 <sup>b</sup> | 6.67±0.07 <sup>c</sup> | 9.27±0.03 <sup>a</sup> | 6.75±0.04 <sup>c</sup>  |
| Alanine              | 1.16±0.03 <sup>a</sup> | 1.03±0.03 <sup>a</sup> | 1.20±0.06 <sup>a</sup> | 1.02±0.02 <sup>a</sup>  |
| Cysteine             | 2.17±0.04 <sup>b</sup> | 1.75±0.02 <sup>c</sup> | 1.18±0.02 <sup>d</sup> | 8.37±0.04 <sup>a</sup>  |
| Valine*              | 8.97±0.06 <sup>b</sup> | 7.27±0.04 <sup>d</sup> | 9.75±0.02 <sup>a</sup> | 7.50±0.01 <sup>c</sup>  |
| Methionine*          | 2.69±0.06 <sup>a</sup> | 2.54±0.04 <sup>b</sup> | 2.33±0.04 <sup>c</sup> | 1.98±0.01 <sup>d</sup>  |
| Isoleucine*          | 7.86±0.04 <sup>b</sup> | 6.20±0.03 <sup>c</sup> | 8.43±0.03 <sup>a</sup> | 6.25±0.06 <sup>c</sup>  |
| Leucine*             | 1.87±0.03 <sup>b</sup> | 1.66±0.04 <sup>c</sup> | 1.99±0.04 <sup>a</sup> | 1.65±0.03 <sup>c</sup>  |
| Tyrosine             | 6.43±0.03 <sup>b</sup> | 5.06±0.03 <sup>d</sup> | 6.95±0.01 <sup>a</sup> | 5.23±0.04 <sup>c</sup>  |
| Phenylalanine*       | 1.04±0.07 <sup>d</sup> | 8.65±0.06 <sup>b</sup> | 1.24±0.03 <sup>c</sup> | 9.56±0.03 <sup>a</sup>  |
| Lysine*              | 1.14±0.04 <sup>b</sup> | 8.30±0.03 <sup>a</sup> | 1.10±0.03 <sup>b</sup> | 7.74±0.06 <sup>ab</sup> |
| Histidine            | 5.52±0.06 <sup>b</sup> | 4.45±0.07 <sup>c</sup> | 6.07±0.03 <sup>a</sup> | 4.59±0.07 <sup>c</sup>  |
| Arginine             | 1.38±0.04 <sup>a</sup> | 1.01±0.05 <sup>b</sup> | 1.48±0.04 <sup>a</sup> | 1.02±0.06 <sup>b</sup>  |
| Tryptophan*          | 1.80±0.02 <sup>b</sup> | 1.51±0.04 <sup>d</sup> | 2.31±0.01 <sup>a</sup> | 1.64±0.04 <sup>c</sup>  |
| Proline              | 1.88±0.03 <sup>a</sup> | 1.25±0.03 <sup>d</sup> | 1.71±0.02 <sup>b</sup> | 1.49±0.03 <sup>c</sup>  |

\*Essential amino acid. <sup>a,b,c,d</sup>Values with different letters in the same row are significantly different ( $p \leq 0.05$ ).  
SMS1x and SMS2x, products before HTST extrusion; SMS1 and SMS2, products after HTST extrusion

Table 5: Minerals content of SMS1 and SMS2 before and after HTST extrusion

| Minerals (ug/g) | SMS1x                     | SMS2x                     | SMS1                     | SMS2                     |
|-----------------|---------------------------|---------------------------|--------------------------|--------------------------|
| Zinc            | 29.47±0.16 <sup>a</sup>   | 27.65±0.17 <sup>b</sup>   | 23.96±0.16 <sup>d</sup>  | 24.18±0.17 <sup>c</sup>  |
| Iron            | 53.03±0.15 <sup>c</sup>   | 47.70±0.18 <sup>d</sup>   | 96.03±0.18 <sup>a</sup>  | 64.43±0.16 <sup>b</sup>  |
| Magnesium       | 84.16±0.18 <sup>a</sup>   | 83.77±0.17 <sup>b</sup>   | 75.56±0.19 <sup>d</sup>  | 81.87±0.15 <sup>c</sup>  |
| Calcium         | 1720.75±0.19 <sup>a</sup> | 1675.50±0.19 <sup>b</sup> | 966.04±0.21 <sup>c</sup> | 890.82±0.18 <sup>d</sup> |
| Phosphorus      | 534.01±0.18 <sup>d</sup>  | 585.11±0.18 <sup>c</sup>  | 602.52±0.18 <sup>b</sup> | 618.41±0.19 <sup>a</sup> |

<sup>a,b,c,d</sup>Values with different letters in the same row are significantly different ( $p \leq 0.05$ ).

SMS1x and SMS2x, products before HTST extrusion; SMS1 and SMS2, products after HTST extrusion

De la Gueriviere *et al.* (1985) reported that excessive Maillard browning during extrusion cooking could result in losses of lysine up to approximately 50% (cited by Camire, 2002). However, changes in Lysine content for both SMS1 and SMS2 was not significant, this coincide with the observations from Konstance *et al.* (1998), Corn-soy blends extruded for reconstitution as porridge or gruel had good lysine retention.

**Minerals:** The Minerals content of both SMS1 and SMS2 before and after HTST extrusion are presented in Table 5. Zinc, iron, magnesium, calcium and phosphorus content have been determined. After HTST extrusion SMS1 showed the highest score ( $p \leq 0.05$ ) in iron (96.03 ug/g) and calcium (966.04 ug/g) content and SMS2 showed the highest score ( $p \leq 0.05$ ) in zinc (24.18 ug/g), magnesium (81.87 ug/g) and phosphorus (618.41 ug/g) content. Minerals content before and after HTST extrusion was significantly different for both SMS1 and SMS2, this did not coincide with what was reported by Camire (2002), mineral content and bioavailability are generally retained well during extrusion. However, Iron and phosphorus content increased significantly in both SMS1 and SMS2 after HTST extrusion. Camire (2002) noted that total iron increased by as much as 38% due to extrusion.

On the other hand, Cisse *et al.* (1998) reported that weaning food blends of pearl millet, cowpea and peanut had greater iron availability and protein digestibility compared to similar foods processed by roasting (cited by Camire, 2002). None of the processed blends provided adequate iron to meet infant needs, however.

**Fatty acids:** Table 6 presents the fatty acid composition of SMS1 and SMS2 before and after HTST extrusion. After HTST extrusion, both extrudates contained 52% wt of linoleic acid and linolenic acid content was 6.54 and 5.94% wt for SMS1 and SMS2 respectively. In general, HTST extrusion did not promote significant changes in fatty acids content in both SMS1 and SMS2. However, myristic acid, which was not present in both SMS1 and SMS2 before HTST extrusion, was found in both extrudate, in the range of 0.05-0.06% wt. Linoleic and linolenic acid average content reported for soybean oil were 50.8 and 6.8% respectively (Erickson, 1995). Unlike other processing methods, extrusion cooking does not promote significant *cis-trans* isomerisation of unsaturated lipids. Maga (1978 reported that corn and soy blends had 1.5% more *trans*-fatty acids after extrusion (cited in Camire, 2002).

Table 6: Fatty acids composition of SMS1 and SMS2 before and after HTST extrusion

| Fatty acids (% wt)       |                         | SMS1x                   | SMS2x                    | SMS1                     | SMS2                   |
|--------------------------|-------------------------|-------------------------|--------------------------|--------------------------|------------------------|
| Capric acid (C10:0)      | -                       | -                       | -                        | -                        | -                      |
| Lauric acid (C12:0)      | -                       | -                       | -                        | -                        | -                      |
| Myristic acid (C14:0)    | -                       | -                       | -                        | 0.06±0.04 <sup>a</sup>   | 0.05±0.04 <sup>a</sup> |
| Palmitic acid (C16:0)    | 11.52±0.04 <sup>b</sup> | 11.71±0.04 <sup>a</sup> | 11.62±0.04 <sup>ab</sup> | 11.61±0.05 <sup>ab</sup> |                        |
| Stearic acid (C18:0)     | 4.00±0.04 <sup>a</sup>  | 3.67±0.05 <sup>b</sup>  | 4.10±0.07 <sup>a</sup>   | 3.79±0.07 <sup>b</sup>   |                        |
| Arachidic acid (C20:0)   | 0.30±0.02 <sup>a</sup>  | 0.32±0.02 <sup>a</sup>  | 0.34±0.07 <sup>a</sup>   | 0.34±0.05 <sup>a</sup>   |                        |
| Behenic acid (C22:0)     | -                       | -                       | -                        | -                        |                        |
| Palmitoleic acid (C16:1) | 0.09±0.02 <sup>a</sup>  | 0.11±0.05 <sup>a</sup>  | 0.10±0.04 <sup>a</sup>   | 0.11±0.07 <sup>a</sup>   |                        |
| Oleic acid (C18:1)       | 23.55±0.04 <sup>d</sup> | 24.61±0.03 <sup>b</sup> | 23.91±0.05 <sup>c</sup>  | 24.79±0.04 <sup>a</sup>  |                        |
| Arachidonic acid (C20:1) | 0.18±0.07 <sup>a</sup>  | 0.17±0.07 <sup>a</sup>  | 0.17±0.07 <sup>a</sup>   | 0.17±0.05 <sup>a</sup>   |                        |
| Linoleic acid (C18:2)    | 53.47±0.05 <sup>a</sup> | 53.22±0.04 <sup>b</sup> | 52.84±0.05 <sup>c</sup>  | 52.85±0.05 <sup>c</sup>  |                        |
| Linolenic acid (C18:3)   | 6.53±0.04 <sup>a</sup>  | 5.87±0.05 <sup>b</sup>  | 6.54±0.04 <sup>a</sup>   | 5.94±0.04 <sup>b</sup>   |                        |

<sup>a,b,c,d</sup>Values with different letters in the same row are significantly different ( $p \leq 0.05$ ).

SMS1x and SMS2x, products before HTST extrusion; SMS1 and SMS2, products after HTST extrusion

**Conclusion:** This study revealed that sorghum, maize, soybean and wheat could be used to produce nutritious and ready-to-eat composite flours. The blends were extruded to provide pre-cooked foods that could be reconstituted at 60°C to a porridge or gruel, eliminating prolonged cooking or degradation of heat labile nutrients. The use of these locally grown cereals and legumes could make a great contribution to food security in sub-Saharan region and other developing countries. However, certain aspects like the digestibility and bio-availability of the macronutrients in these composite flours need further investigation. On the other hand, the composite flours did not meet the recommended micronutrient (minerals) requirements for infants, children and adults therefore, fortification with appropriate micronutrients or micronutrient-dense foodstuffs will be necessary.

Finally, the functional properties such as bulk density, water binding capacity, least gelation concentration and pasting properties analysis helped to consider an eventual incorporation of the extrudates in others foods formulation.

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