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Physical and Functional Properties of Extruded Sorghum-Cowpea Blends: A Response Surface Analysis

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Abstract
Blends of sorghum and cowpea flours (90:10, 80:20 and 70:30 respectively) were extruded at 20%, 22.5% and 25% moisture levels and 120°C, 140°C and 160°C barrel temperatures using a single-screw extruder. Response surface methodology with central composite face-centered (CCF) design was used to model the viscosity, water absorption index (WAI) water solubility index (WSI) sectional expansion index (SEI) and bulk density (BD). Results obtained showed that the viscosity of extrudates varied from 6.90 to 19.58, WAI, 5.10 to 6.69g water/g sample, WSI, 9.50 to 25%, SEI, 2.16 to 4.97 and BD, 0.207 to 0.297 g/cm^{-3}. Feed composition had the most effect on the physical and functional properties of the extrudates followed by extrusion temperature and feed moisture. The coefficients of determination (R^2) varied from 0.71 to 0.97 with a non-significant ($p<0.05$) lack-of-fit for the viscosity, WAI and SEI. Correlation coefficients of the observed and predicted values ranged from 0.60 to 0.95 suggesting the adequacy of the second-order polynomial in predicting these functional and physical properties.
Keywords: Extrudate, Optimization, Viscosity, Water absorption, Expansion.

1. Introduction

Nigeria is the largest producer of sorghum in Africa and third largest the world over (USDA, 2015). Sorghum has however never been industrially developed as a major food for urban areas in Nigeria, except the brewing industry where it is a raw material for malt production and lager beer. There has been the lack of sorghum processed foods such as flour, meal, breads, or other materials for use by working class mothers and bachelors who do not have enough time for making flour from the raw grain.

Gomez *et al.,* (1988) reported on extrusion cooking of three sorghum varieties. According to the workers, decreasing the moisture content during extrusion resulted in increased expansion and decreased density and breaking strength of extrudates. Mercier and Feillet (1975) reported a similar trend for these indices as a function of the extrusion moisture content.

Extrusion processing has become an increasingly popular procedure in the cereal, snack and pet food industries, which utilizes starchy and proteinacious raw materials. The food is at a distinct advantage when working with fabricated foods, since it is possible, within technological limits, to adjust both the composition of starting material and duration of the process to maximize structure and therefore, quality (Stanley, 1986; Fellows, 2000). Extrusion cooking is a High Temperature Short Time (HTST) process (Byrne, *et al*., 2001) which reduces microbial contamination and inactivates enzymes. Extruded products do not require further drying processes. The main purpose of extrusion is to increase variety of foods in the diet by producing a range of products with different shapes, textures, colours, and flavours from basic ingredients (Fellows, 2000).

During extrusion cooking, starch dextrinization (Gomez and Aguilera, 1983 and Gomez and Aguilera, 1984) and amylopectin breakdown due to mechanical shear (Davidson *et al.*, 1984) take place, most especially during low moisture, high shear, single-screw extrusion. Due to pressure build up during fluid flow, high shear stresses are developed, which cause structural transformation in the feed material (Zamre *et al*., 2012). Product quality can also vary considerably depending on the extruder type, screw configuration, feed moisture, barrel temperature, screw speed and feed rate (Fletcher *et al*., 1985).

Many Nigerians do not have access to animal protein. The utilization of extrusion cooking and supplementation of sorghum flour with plant protein such as cowpea flour in the production of a breakfast cereal is likely to increase protein consumption of the consumers.

Cowpea, being richer in lysine than cereal grains, is also valued for its flavor and short cooking time and can be used in a wide variety of ways principally as a nutritious component in human diet. In Nigeria the beans are either eaten as boiled beans or consumed in other forms such as *moin-moin, akara* or *kosai* and *danwake.*

Response surface methodology (RSM) is a collection of statistical techniques for designing experiments, building models, evaluating the effects of the factors and searching for optimal conditions of factors desirable response (Myers, 1976 and Montgomery, 1991). In this work RSM was used to assess the effect of blending of sorghum with cowpea flour, and variation of feed moisture and extrusion temperature on the physical and functional properties of extruded sorghum-cowpea breakfast cereal using response surface methodology.

2. Materials and Methods

2.1 Procurement of raw materials

The red sorghum variety (Chakalari red), was obtained from Maiduguri Monday market. Cowpea (var Kananede) was obtained from the Mubi main market.

2.1.1 Preparation of sorghum flour

About 15 kg of sorghum grains were cleaned using a laboratory aspirator (Vegvari Ferenc Type OB125, Hungary) to remove stalks, chaff, leaves and other foreign matter. They were then washed with treated tap water in plastic basins and sun dried on mats for 2 days (at 38°C and relative humidity of 27.58 %) to 12 % moisture. This was then dehulled using a commercial rice dehuller (Konching 1115, China) and milled using an attrition mill (Imex GX 160, Japan). The flour was sieved to pass mesh number 25 (BS, 1985) before packing in polythene bags for further use.

2.1.2 Preparation of cowpea flour

About 3 kg of cowpea was soaked in water for 10 min to loosen the seed coat. The kernels were then cracked in a mortar with pestle. The seed coat was then washed off in excess water. The beans were oven dried (Model: Chirana HS 201A, Hungary) at 80°C to 12% moisture content and milled into flour (Imex GX 160, Japan) which was sieved to pass mesh number 25 (BS, 1985) before packing in polythene bags for further use (Filli *et al*., 2010).

2.1.3 Blending of sorghum flour with cowpea flour and moisture adjustment

Sorghum flour was blended with cowpea flour in varying proportions (90:10, 80:20, 70:30 respectively). The individual moisture contents of the cowpea and sorghum flours were determined (on dry weight basis) using the hot air oven method (Egan *et al*., 1981) and then the total moisture of the blends adjusted to the desired level according to Zasypkin and Tung-Ching (1998), using the formula below. The blends were mixed and the moisture allowed to equilibrate for one hour before extrusion.

$$C_{cf} = [r_{cf} \times M \times (100-w)] / [100 \times (100-W_{cf})]$$

$$C_{sf} = [r_{sf} \times M \times (100-w)] / [100 \times (100-W_{sf})]$$

$$W_x = M - C_{cf} - C_{sf}$$

Where C_{cf} is the mass of cowpea flour (g); $C_{sf,}$ the mass of sorghum flour (g); $S_{f,}$ and C_f are sorghum flour and cowpea flour respectively; r_{cf} and r_{sf} are the cowpea flour (%) and sorghum flour (%) respectively; M, the total mass of the blend (g); w is the moisture content of final blend (%); W_x is weight of water added (g); $W_{cf,}$ the moisture content of cowpea flour (%); while W_{sf} is the moisture content of sorghum flour (%).

2.2 The extrusion process

Extrusion cooking was done in a single screw extruder (Model: Brabender Duisburg DCE-330), equipped with a variable speed DC drive unit and strain gauge type torque meter. The extruder was fed manually through a screw operated conical hopper. The hopper which is mounted vertically above the end of the extruder is equipped with a screw which was adjusted to 139 rpm. The samples were extruded at a screw speed of 200 rpm, 2.0 mm die diameter, 2 bars pressure and a length/diameter ratio of 20:1. Experimental samples were collected when steady state (constant temperature and torque) was achieved. Variables considered were feed composition, feed moisture content and temperature of extrusion. Extrudates were kept on stainless steel work benches overnight to dry. They were then packaged in polythene bags prior to analysis.

2.3 Determination of physical and functional properties

2.3.1 Determination of viscosity of extrudate paste

The viscosity of extrudates was determined using the Sine-wave Vibro Viscometer (SV series Version 1.12E, A&D Company Limited, Japan) coupled to a desktop computer. Extrudates were first crushed in a mortar with pestle. About 10 g of the ground extrudate was transferred to a beaker and made up to 100 mL with hot water at 60°C to give a 10 % (w/v) concentration (Badau *et al*., 2006). This was mixed and allowed to stand for 10 min. The content was then transferred into a viscometer cup which was then placed and clamped in position on the stage of the viscometer with clips. The plates of the viscometer were then lowered into the cup containing the sample. The viscosity of the samples was read at 40°C.

2.3.2 Water absorption index (WAI) and water solubility index (WSI)

This was determined according to Beuchat (1977). One gram (1g) of sample was mixed with 10 mL distilled water for 30 sec in a centrifuge tube. The samples were then allowed to stand at 25°C for 30 min and centrifuged at 55,000 x g for 30 min. The supernatant was decanted into an aluminium pan of known weight and dried to constant weight at 105°C. The weight of the gel remaining in the centrifuge tube was noted. Results were reported as averages of three determinations.

$$WAI(g/g) = \frac{weight\ gain\ by\ gel}{Dry\ weight\ of\ extrudate}$$

$$WSI(\%) = \frac{weight\ of\ dry\ solids\ in\ supernatant}{Dry\ weight\ of\ extrudates}\ x\ 100$$

2.3.3 Bulk density of extrudates

Bulk density of the extrudates was determined using the method of Qing-Bo *et al*. (2005) as described by the equation below:

$$Bulk\ density = \frac{4a^0}{\pi D^2 L}$$

Where a^o, D, and L are the mass, diameter and length of extrudates, respectively.

2.3.4 Sectional expansion index (SEI)

This was determined according to the procedures of Alvarez Martinez *et al*. (1988). The following equation was used.

$$Sectional\ Expansion\ Index = \left(\frac{De}{D}\right)^2$$

Where D_e is the diameter of extrudate and D is the diameter of the die (mm).

2.3.5 Experimental design

The Central Composite Face-Centered Design (CCFC) used in this work was produced using MINITAB 14 statistical software. Table 1 shows the process variables and their levels used in the design. The experimental matrix used in this study, based on central composite face-centered design, is as shown in Table 2. The experimental space had fourteen star points and six central points, making a total of twenty runs. The data obtained from the study was fitted to the second-order polynomial regression model (Annor *et al*., 2009) of the form:

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}(X_1)^2 + b_{22}(X_2)^2 + b_{33}(X_3)^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + \varepsilon$$

Where X_1, X_2 and X_3 are feed composition (cowpea flour), feed moisture and barrel temperature, respectively; b_o is the regression constant; b_1, b_2 and b_3 are linear regression terms; b_{11}, b_{22} and b_{33} are quadratic regression terms; b_{12}, b_{13} and b_{23} are the cross-product regression terms; ε is the error term.

Table 1: Independent variables and their levels of replication

Parameters	Levels of replication		
	-1	0	+1
Cowpea flour (%), X_1	10	20	30
Feed Moisture (%), X_2	20	22.5	25
Temperature (^{0}C), X_3	120	140	160

Table 2: Central composite face centered (CCFC) design matrix and the independent variables in their coded and actual values.

Runs	X_1	X_2	X_3	Cowpea flour (%)	Feed moisture (%)	Extrusion temp.(°C)
1.	-1	-1	-1	10	20	120
2.	+1	-1	-1	30	20	120
3.	-1	+1	-1	10	25	120
4.	+	+1	-1	30	25	120
5.	-1	-1	+1	10	20	160
6.	+1	-1	+1	30	20	160
7.	-1	+1	+1	10	25	160
8.	+1	+1	+1	30	25	160
9.	-1	0	0	10	22.5	140
10.	+1	0	0	30	22.5	140
11.	0	-1	0	20	20	140
12.	0	+1	0	20	25	140
13.	0	0	-1	20	22.5	120
14.	0	0	+1	20	22.5	160
15.	0	0	0	20	22.5	140
16.	0	0	0	20	22.5	140
17.	0	0	0	20	22.5	140
18.	0	0	0	20	22.5	140
19.	0	0	0	20	22.5	140
20.	0	0	0	20	22.5	140

Key: X_1 = Cowpea flour, X_2 = Feed moisture, X_3 = Extrusion temperature

2.3.6 Statistical analysis

MINITAB version 14 statistical analysis software was used in the statistical analysis of data. Analysis of variance (ANOVA) was used to establish statistical significance of the model. Correlation analysis was used to test the relationship between the predicted and observed values. Numerical optimization and interactive graphs were used to optimize the various input variables and responses.

3. Results and Discussion

3.1 Model description and development

The regression equations for the physical and functional properties of extrudates are presented in Table 3. In the model equations, X_1, X_2 and X_3 which are the independent variables represent feed composition, feed moisture and extrusion temperature respectively. The viscosity, WAI and SEI of the extrudates were not significantly influenced by any of the process variables. The coefficients of determination (R^2) were 0.71, 0.71 and 0.97 respectively with a non-significant lack of fit. For a good fit, the R^2 value of 0.60 was used. Joglekar and May (1987) recommended an R^2 value of 0.80 for a good fit. Malcolmson *et al.* (1993) and Annor *et al.* (2009) however stated that an R^2 of 80% (0.80) appears excessive for preliminary study and therefore recommended that a value of 60% was adequate. The observed and predicted values were also in close agreement (r^2 = 0.85, 0.60 and 0.70 respectively) suggesting a good fit for the models. The fitted model equations are shown below:

$$\text{Viscosity} = 260.103 + 2.2018X_1 - 11.3673X_2 - 1.840X_3 + 0.0207X_1^2 + 0.190X_2^2$$
$$0.0057X_3^2 - 0.0056X_1X_2 - 0.0082X_1X_3 + 0.0149X_2X_3 \quad (R^2 = 0.71).$$

$$\text{WAI} = -24.66 - 0.196X_1 + 2.158X_2 + 0.108X_3 + 0.002X_1^2 - 0.039X_2^2 - 0.0002X_3^2 +$$
$$0.0059X_1X_2 + 0.0001X_1X_3 - 0.0003X_2X_3 \quad (R^2 = 0.71)$$

The WSI was significantly ($p \leq 0.01$) influenced by the interaction effects of feed composition and extrusion temperature. The R^2 value was 0.85 with a significant lack of fit. The r^2 was 0.91 for the observed and predicted values signifying a good fit for the model as presented below:

$$\text{WSI} = 145.482 + 1.535X_1 - 9.728X_2 - 0.538X_3 + 0.012X_1^2 + 0.238X_2^2 +$$
$$0.003X_3^2 + 0.0005X_1X_2 - 0.013X_1X_3 - 0.007X_2X_3 \quad (R^2 = 0.85).$$

$$\text{SEI} = 37.675 - 0.0065X_1 - 1.2782X_2 - 0.292X_3 - 0.0004X_1^2 + 0.0248X_2^2 + 0.001X_3^2 +$$
$$0.0002X_1X_2 - 0.0005X_1X_3 + 0.0016X_2X_3 \ (R^2 = 0.74).$$

The bulk density was significantly ($p \leq 0.01$) influenced by the linear effects of feed composition and extrusion temperature. It was also significantly ($p \leq 0.01$) affected by the quadratic effects of feed composition and extrusion temperature and the interaction effects of feed composition and extrusion temperature and extrusion temperature and feed moisture. The R^2 value was 0.97 with a significant lack of fit ($p<0.05$). The r^2 value was 0.95 suggesting a good fit for the model equation.

$$BD = -0.7500 + 0.1888X_1 + 0.0207X_2 + 0.0151X_3 + 0.0002X_1^2 - 0.0011X_2^2 - 0.0001X_3^2 + 0.0001X_1X_3 + 0.0002X_2X_3 \quad (R^2 = 0.97).$$

Table 3: Regression coefficients for physical and functional properties of sorghum- cowpea extrudates

Coefficients	WAI	WSI	SEI	BD	Viscosity
b_o	-24.660	145.482	37.675	-0.7499	260.103
b_1	-0.1959	1.535	-0.0065	0.1888**	2.2018
b_2	2.1584	-9.728	-1.2782	0.0207	-11.3673
b_3	0.1080	-0.538	-0.2920	0.0151**	-1.8400
Quadratic					
b_{11}	0.0021	0.012	0.0004	0.0002**	0.0207
b_{22}	-0.0391	0.238	0.0248	-0.0011	-0.0487
b_{33}	-0.0002	0.003	0.0010	-0.0001**	-0.0022**
Interaction					
b_{12}	0.0059	0.005	0.0002	-----	0.0101*
b_{13}	0.0001	-0.013**	-0.0005	0.0001**	-0.0008
b_{23}	-0.0003	-0.007	0.0016	0.0002**	-0.0017
R^2	0.7072	0.8499	0.7362	0.9707	0.8612
Adjusted R^2	0.4437	0.7148	0.4987	0.9444	0.7362
Lack of Fit	NS	NS	NS	NS	NS

$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}(X_1)^2 + b_{22}(X_2)^2 + b_{33}(X_3)^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + \varepsilon$; WAI = water absorption index, WSI = water solubility index , SEI = sectional expansion index , BD = bulk density, * Significant at $p \leq 0.05$, and **$p \leq 0.01$ respectively, NS = not significant.

3.2 Viscosity of extrudates

The viscosity of the sorghum-cowpea extrudates varied from 6.90 to 19.58 Nsm^{-2}. The viscosity of the extrudates was negatively affected by increases in the feed moisture and extrusion temperature. Increasing the per cent cowpea in the feed up to 27% caused an increase in the viscosity of samples but progressively decreased thereafter (Figure 1). Feed moisture had the most effect on viscosity of the extrudates followed by extrusion temperature. Arambula *et al.* (1998) observed similar decreases in apparent viscosity of extruded instant corn flour when temperature was increased. Extruded corn starch was reported to produce lower viscosity profiles than raw starch due to starch degradation during extrusion (Ozcan and Jackson, 2005). During extrusion cooking, two important reactions (protein denaturation and starch gelatinization) in dough can affect viscosity (Chakraborty and Banerjee, 2009). Extruded starch can have an improved functionality in food applications, particularly in instantized hot or cold paste applications (Ozcan and Jackson, 2005). Cold paste viscosity was found to be influenced by an interaction between feed moisture and throughput rate. The swell peak area was found to be greater in starch extruded at higher moistures and higher die temperatures (Mason and Hoseney, 1986). Reduction in the viscosity of extrudates increases their nutrient density and energy (Badau *et al.*, 2006 and Filli *et al.*, 2010). This is important because, the consumer eats less of the food to get the desired amounts of nutrients. The optimum value of the viscosity (10 Nsm^{-2}) of the extrudates was located at 16% feed composition, 23.45% feed moisture and extrusion temperature of 148°C.

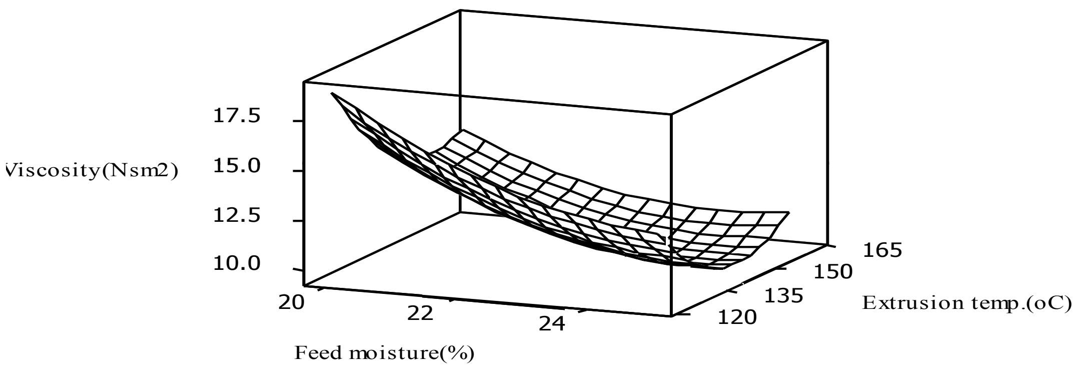

Figure 1(a) Effect of feed moisture and extrusion temperature on viscosity of sorghum-cowpea extrudates.

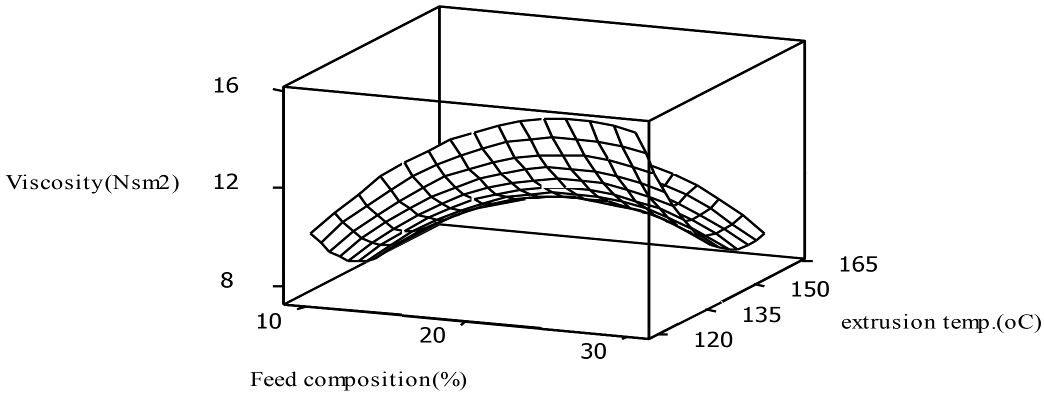

Figure 1(b) Effect of feed composition and extrusion temperature on viscosity of sorghum-cowpea extrudates

3.3 Water absorption index (WAI)

The water absorption index (WAI) of the extrudates varied from 5.10 to 6.69g H_2O/g sample (Table not shown). The effect of feed composition, feed moisture and extrusion temperature on the water absorption index (WAI) for the sorghum-cowpea extrudates are presented in Figure 2. Increasing the feed moisture and extrusion temperature had a positive effect on the water absorption index (WAI). The increase in the WAI due to the increasing amounts of cowpea in sorghum extrudates was earlier reported by Pelembe *et al*. (2002). Filli *et al.* (2007) similarly found that the swell volume and water swelling capacity of extruded fura samples increased with the addition of 20 to 30% cowpea flour. This was explained as the higher amylose/amylopectin ratio of cowpea. Mercier and Feillet (1975) observed that higher amylose ratio results in a higher WAI. From the response surface curves (Figure 2) it could be observed that the WAI tended to decrease at extrusion temperature of 160^{o}C. This may be explained by the decomposition or degradation of starch at temperatures above 140^{o}C (Gujska and Khan, 1990). It is generally agreed that barrel temperature exerts greatest effect on the extrudates by promoting gelatinization (Ding *et al*., 2005). Ozcan and Jackson (2005) on the other hand observed that extrusion cooking increased water absorption and water solubility indices of corn starch. WAI depends on the availability of hydrophilic groups which bind water molecules and the gel-forming capacity of the macromolecules (Narbutaite *et al*., 2008). Bhattacharya *et al.* (1986) found that increase in soybean protein led to increased water holding capacity of extrudates. This was further explained that soy protein concentrate has more hydrophilic sites than does corn gluten meal. Cowpea protein being a legume protein like soybean may have such hydrophilic sites which can contribute to water binding properties of the extrudates. Mercier and Feillet (1975) observed that higher amylose ratio results in a higher WAI. Gujiska and Khan (1990), while assessing extruded pinto and navy beans found that WAI increased with increase in temperature from 110 to 132^{o}C. A further increase in temperature to 150^{o}C resulted in a decrease in WAI for navy beans as degradation of starch began to take place. Water absorption measures the amount of water absorbed by starch and can be used as an index of gelatinization (Anderson *et al*., 1969). The water absorption index is a measure of the volume occupied by the extrudates starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion (Qing-Bo *et al.*, 2005). The WAI is an important attribute in breakfast cereal. The higher the WAI values, the better the product. Feed moisture had the most influence on the WAI followed by feed composition. The optimum WAI of 5.8 g/g water was found at 18.1% cowpea substitution, 24% feed moisture and extrusion temperature of 138^{o}C.

3.4 Water solubility index (WSI)

The water solubility index (WSI) of the extrudates in this work ranged from 9.50 to 25.0% (Table not shown). The WSI of the extrudates increased with the addition of cowpea flour (Figure 3). Cowpea proteins are reported to have relatively higher water solubility than sorghum proteins (Serna-Saldivar and Rooney, 1995 and Chavan *et al*., 1989). Pelembe *et al.* (2002) suggested that WSI is not only due to starch content but other soluble components. Corn starch solubility was reported to increase with decreasing extrusion moisture content from 33 to 15% however, at extrusion moisture below 15%, starch solubility was lower (Jackson *et al*., 1990). The WSI in this study was most influenced by the feed moisture followed by extrusion temperature. The optimum WSI of 14% was located at 20.4% feed composition, 22.45% feed moisture and extrusion temperature of 120^{o}C. Water solubility index is used as an indicator of degradation of molecular components (Narbutaite *et al*., 2008 and Ding *et al*., 2005). It is an indication of degree of gelatinization of starch. It also measures the amount of soluble polysaccharides released from the starch component after extrusion (Ding *et* *al*., 2005). Gelatinized or cooked starch polymers in solution can exist in several physical forms such as, trapped in granule remnants, entangled in gelled masses, as individual molecules, recrystallized (retrograded) polymers, and perhaps as combination of the above forms. Processing conditions influence the distribution of these forms and thus the water solubility of the product (Jackson *et al*., 1990).

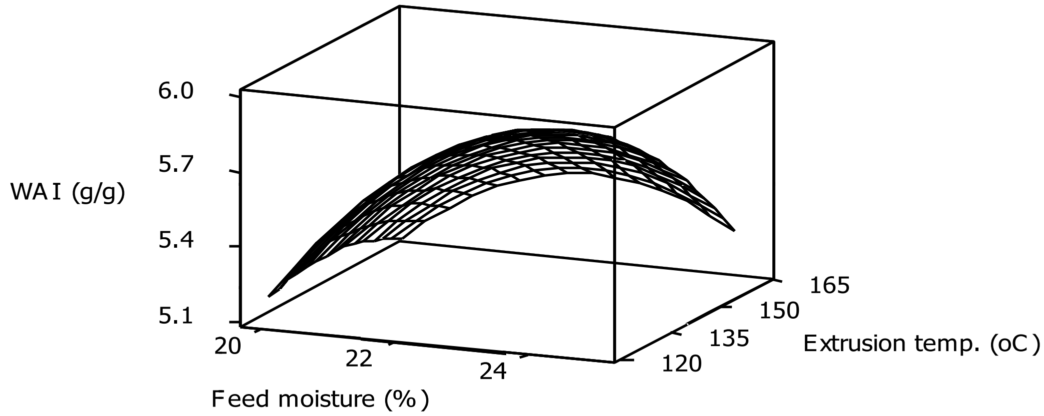

Figure 2: Effect of feed moisture and extrusion temperature on water absorption index of sorghum-cowpea extrudates.

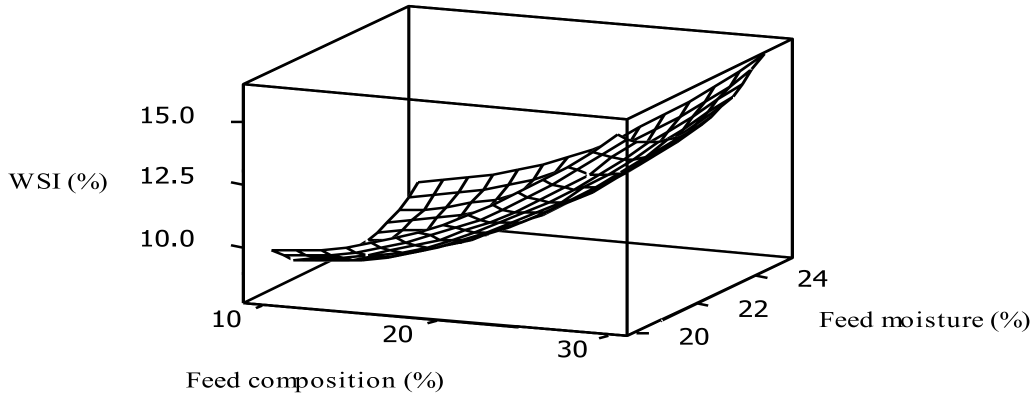

Figure 3: Effect of feed composition and feed moisture on water solubility index of sorghum-cowpea extrudates

3.5 Sectional expansion index (SEI)

Values for the sectional expansion index (SEI) varied from 2.16 to 4.97 (Table not shown). The response surface curves for SEI of sorghum – cowpea extrudates are presented in Figure 4. The SEI generally decreased as the per cent cowpea and feed moisture of samples increased. The combined effect of cowpea supplementation and extrusion temperature also negatively affected the SEI. Pelembe *et al*. (2002) observed similar decreases in expansion ratio of sorghum-cowpea extrudates and attributed it to the amount of cowpea increased in the extrudates. Paton and Splatt (1984) and Filli (2009) reported similar trends. Increasing the protein content of the samples generally caused a decrease in the SEI. Paton and Spratt (1984) showed that increasing protein content in the feed mixture may decrease expansion ratio during extrusion cooking. Chinnaswamy and Hanna, (1988) observed that the expanded volume of cereal flour decreases with increasing amounts of protein and lipids but increases with starch content. Expansion index describes the degree of puffing undergone by the sample as it exits the extruder (Asare *et al*., 2004). According to Baladran-Quintana *et al*. (1998), expansion ratio is an important characteristic of extruded products being developed as a snack and ready-to-eat products by food industries. At higher extrusion temperatures, starch becomes more fully cooked and therefore expands better (Baladran-Quintana *et al*., 1998). Extruded ready-to-eat breakfast cereals are expected to have high SEI which is a desirable attribute for the products. Harper (1981b) explained that the negative effect of increased feed moisture on SEI is a common phenomenon in snack foods, which may be due to the fact that the amount of puffing in a food product depends on the pressure differential between the die and the atmosphere. Foods with higher moisture content tend to be more viscous than those having lower moisture content and therefore the pressure differential is smaller for higher moisture foods leading to a less puffed product. The SEI was most affected by the feed moisture followed by extrusion temperature. The optimum value of 3.6 for the SEI of the extrudates was found at 115 feed composition 25% feed moisture and extrusion temperature of 135ºC.

3.6 Bulk density (BD)

The values for bulk density (BD) of the samples ranged from 0.207 to 0.297g/cm^3 (Table not shown). The BD of the extrudates increased with increase in the cowpea flour of the feed (Figure 5). It was also affected by the feed moisture; the higher the feed moisture, the lower the BD. Bhattacharya *et al*. (1986) explained that increasing product moisture content leads to a less puffed and hence a denser product. The bulk density of the samples increased with increase in both feed moisture and feed composition (Figure 5). The high bulk density of higher per cent cowpea blends may be related to the lower ratio of amylose/amylopectin in sorghum. Amylopectin exerts a positive influence while amylose exerts a negative influence on expansion ratio (Feldberg, 1969). Bulk density is inversely related to expansion ratio. At higher feed moisture levels, the bulk density is also high. This is because, the extrusion cooking is not enough to cause vaporisation of the moisture and hence a denser product is produced (Asare *et al.*, 2004). Bulk density is an indication of porosity of a product which influences package design and could be used in determining the type of packaging material required. It is also important in infant feeding where less bulk density is desirable (Iwe and Onalope, 2001). High values of bulk density are important for some extruded products such as noodles and spaghetti but not in breakfast cereals which require high expansion ratios. The bulk density of the extrudates was most affected by feed composition followed by the extrusion temperature. The optimum value of bulk density (0.24 g/cm^3) of the extrudates was found at 17.5% feed composition, 22% feed moisture and extrusion temperature of 154ºC.

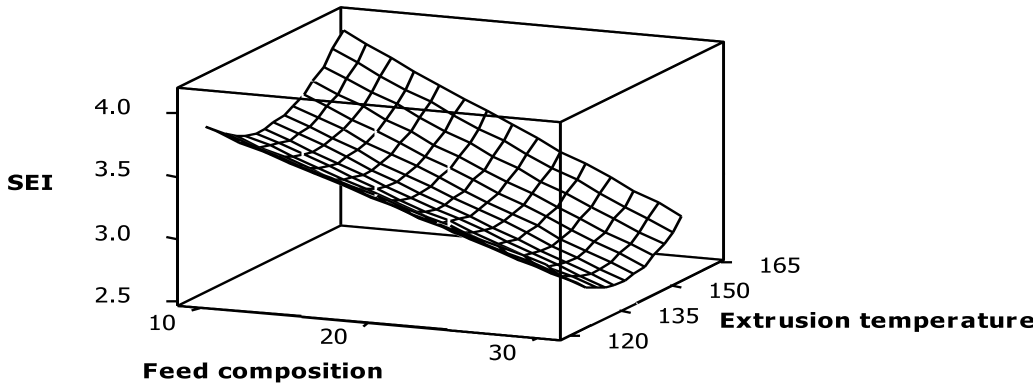

Figure 4: Effect feed composition and extrusion temperature on the sectional expansion index of sorghum-cowpea extrudates

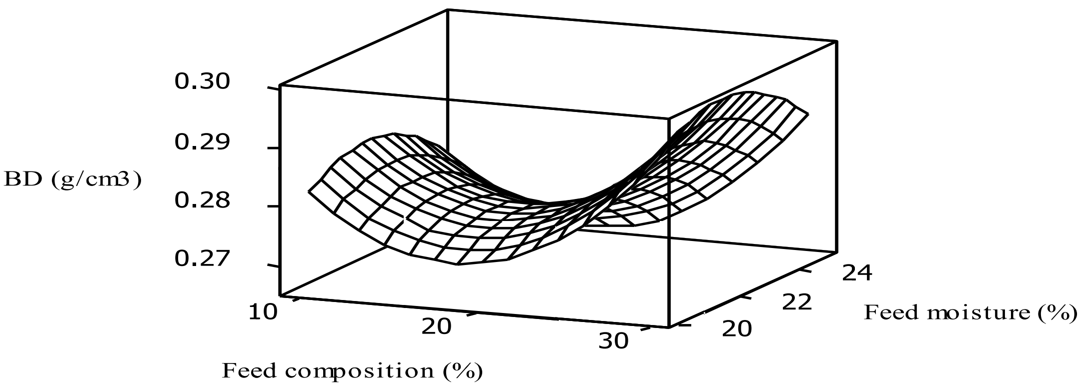

Figure 5: Effect of feed composition and feed moisture on the bulk density of sorghum-cowpea extrudates

3.7 Optimization

Numerical optimization and interactive graphs were used to optimize the various input variables and responses. The factor levels were adjusted from the interactive optimization plots until the highest desirability value possible (maximum is 100%) was obtained for the particular response in question. The value of such a response at this point was considered the optimum. The optimum values for WAI, WSI, SEI, BD and viscosity were 5.8 g/g H_2O, 14%, 3.6, 0.24 g/cm^3, 5 cm^3 and viscosity respectively.

Table 4: Optimization of functional and physical properties of sorghum-cowpea extrudates

Responses	Feed composition (%)	Feed moisture (%)	Extrusion temperature (°C)	Optimum value
WAI	18.1	24.0	138	5.8 g/g H_2O
WSI	20.4	22.45	120	14.0 %
SEI	11.0	25.0	135	3.6
BD	17.5	22.0	154	0.24 g/cm^3
ASV	12.0	21.5	151	5.0 cm^3
Viscosity	16.0	23.45	148	10.0 Nsm^{-2}

Pate 1: Photographic responses of sorghum-cowpea extrudates

The photographs of the various sorghum–cowpea extrudates are presented in plates C1 to C15. Plate C8 (20% cowpea, 22.5% moisture at 140°C) showed the highest expansion followed by plate C11(10% cowpea, 20% moisture at 160°C), C12 (10% cowpea, 25% moisture at 160°C), C4 (30% cowpea, 20% moisture at 120°C) and C15 (30% cowpea, 25% moisture at 160°C) respectively. The lowest expansion can be seen in plate C2 (10% cowpea, 25% moisture at 120°C) followed by plates C10 (30% cowpea, 22.5% moisture at 140°C), C13 (20% cowpea, 22.5% moisture at 160°C), and C14 (30% cowpea, 20% moisture at 160°C) respectively.

4. Conclusion

A well expanded, instantized breakfast cereal with good water absorption properties and low viscosity was produced from sorghum-cowpea blends. Optimum levels were established for WAI, WSI, BD, SEI and viscosity of the sorghum-cowpea extrudates. Feed moisture had the most effect on the functional and physical properties followed by the amount of cowpea flour incorporated in the feed. The experimental results suggest that the application of response surface methodology, with central composite face-centered design, could be a good approach to the development of breakfast cereals from sorghum- cowpea flour blends.

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