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Effect of process variables on the hydration properties and acceptability of extruded millet-soybean blends for fura manufacture

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Abstract

Purpose – Fura is a traditional thick dough ball snack produced principally from millet or sorghum which is common in Nigeria. It is consumed with nono (local fermented milk) or mashed in water before consumption in the form of porridge. The purpose of this paper is to study the optimization of feed composition, feed moisture and screw speed on acceptability and hydration properties of fura extrudates from pearl millet and soybean flour mixtures.

Design/methodology/approach – The effects of extrusion conditions feed composition (ratio of soybean to millet), percentage moisture wet basis and screw speed (rpm) on the hydration properties and the acceptability of fura from millet-soybean flour mixtures were studied using a single screw extruder. Response surface methodology (RSM) was adopted to evaluate the hydration properties responses of fura extrudates.

Findings – The models showed $R^2 = 0.863$, 0.825, 0.898 and 0.741 for hydration power (HP), effect of quantity of water on swell volume (EQWSV), wettability (WTBLTY) and viscosity respectively indicating that the model was a good fit and could be used to navigate the design space. The result indicates that increasing the level of soybean flour resulted in decreased HP of fura extrudates. The overall acceptability sensory scores show that the fura extrudate design point 11 representing 20 percent soybean, 16.6 percent feed moisture and 200rpm recorded the highest acceptability (7.25) with significant differences from the other extrudates in terms of colour, flavor, texture and overall acceptability.

Originality/value – The extrusion cooking data from this study could help predict the expected performance in investigations of potential use of millet and soybean to explore the possibility of industrial projection.

Keywords Food crops, Food testing, Extrusion, Fura, Millet, Soybean, Hydration properties, Acceptability

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1. Introduction

Fura, a traditional thick dough ball snack produced principally from pearl millet or sorghum is a common food in Nigeria. Jideani *et al.* (2001) described its preparation from moist millet flour, blended with spice, compressed into balls and boiled for 30 minutes. While still hot, the cooked dough is worked in the mortar with pestle (with the addition of hot water) until smooth, slightly elastic, cohesive lump (fura) is formed. The fura dough is rolled into about 25-30 g balls by hand and dusted with millet flour. The mode of preparations may vary slightly among different communities, but the basic ingredient remains the same (i.e. millet or sorghum). Depending on the community it is consumed by crumbling the fura balls into fermented whole milk *kindrimo* or skim milk *nono* or mashed in water before consumption in the form of porridge. In Nigeria the Fulani cattle herdsmen consume fura on their daily journey in search of fresh green grass for their animals. In addition the product is usually consumed as a meal in the morning, afternoon or evening. Despite its popularity fura consumption and acceptance has some draw back because its preparation is carried out using rudimentary equipment and techniques, which is characterized by inconsistent product quality, process specifications governing composition, ingredients, additives, poor hygiene, short shelf life, and unacceptable standard. Fura has a limited storage life with a range of 3-4 days at refrigeration storage (5°C), 1-2 days at room temperature (25°C) and 18 hours at 35°C (Jideani *et al.*, 2002). Usually, a day after production, fura shows visible mold growth on the surface, the short shelf-life has always been a major deterrent to large scale production (Jideani *et al.*, 2001); and being a single cereal based product is limiting in the essential amino acid lysine.

High temperature short time (HTST) extrusion cooking technology has limitless applications in processing of cereal based products. Extrusion cooking is a popular means of preparing snacks and ready to eat foods. It is a versatile and efficient method of converting raw materials into finished food products. Its advantages include energy efficient, lack of process effluents and versatility with respect to ingredient selection, and the shapes and textures of products that can be produced. Extrusion processing is used for processing of starch as well as proteinaceous material. Therefore, extrusion cooking of pearl millet and inclusion of soybean as a basic ingredient in producing fura is of great interest, because it can be used to improve shelf life, nutritional status and physical state of the product. Development of recipes containing soybean is being promoted as a nutritional supplement (USAID, 1996; Iwe *et al.*, 2001; Obatolu, 2002). Addition of soybean protein to extruded corn products have been studied for making products with improved nutritional value. For fura to be a market oriented product, its functionality, nutritional status and shelf life has to be ensured and standardized.

There is a trend in the food industry to develop convenience products, such as puffed snack foods and breakfast cereals, of high nutritional value (Yang *et al.*, 2008). Extrusion of snack foods demands close control of many variables such as feed moisture, feed composition, feed particle size, feed rate, barrel temperature, screw speed, screw configuration, and die geometry (Meng *et al.*, 2010). They further reported that, these material and process variables determine the extent of macromolecular transformation during extrusion, which in turn influence the rheological properties of the food melt in the extruder and consequently, the product characteristics of extrudates. Physical characteristics such as expansion, density and hardness are important parameters to evaluate the consumer acceptability of the final product (Pantil *et al.*, 2007). The suitability of extruded foods for a particular application depends on their functional properties like water absorption, water solubility, oil absorption indexes, expansion ratio index, bulk density and viscosity of the dough (Ali *et al.*, 1996; Lazou and Krokida, 2010). Only a few studies have been reported on extrusion cooking of pearl millet alone or in combination with legumes, most attention have been on wheat, rice, maize and barley. Jideani *et al.* (2001) reported that improving the processing, packaging and storage life of fura are of interest before food manufacturers can think of large scale production. Nkama and Filli (2006) and Filli and Nkama (2007) reported that extruded fura from pearl millet-legume blends provided consumers with a fast, easy way to prepare nutritious fura which is similar to the traditional fura. Extrusion enhanced the water uptake of the product, with reduction in viscosity which is an indication of concomitant increase in nutrient density, but the process method was not optimized. The objective of this work was to study the optimization of feed composition, feed moisture and screw speed on acceptability and hydration properties of fura extrudates from pearl millet and soybean flour mixtures.

2. Materials and methods

2.1 Flour preparation from pearl millet

Pearl millet grain was winnowed using an aspirator Vegvari Ferenc (OB125, Hungary). This was followed by dehulling after mild wetting of the grain using a rice dehuller (Indian make). The grains were washed and then dried in a Chirana convection oven model (HS 201A, Czech Republic) at 50°C for 24 hours to 14 percent moisture content. The dried grain was milled using a Brabender roller mill (OHG DUISBURG model 279002, Germany) equipped with a 150 μm screen.

2.2 Flour preparation from soybean

Soybean seeds were steeped in tap water at 28°C for a period of 24 hours in a plastic bowl. The seeds were dehulled using wooden pestle and mortar. The grains were washed and the hulls removed. The grains were thereafter dried in a Chirana convection oven model (HS 201A, Czech Republic) at 50°C for 24 hours to 14 percent moisture content and the mass was winnowed to remove the remaining lighter materials using an aspirator Vegvari Ferenc (OB125, Hungary). The dehulled soybean kernels were ground in a laboratory disc mill (Nigeria) to fine flour. The flour was sieved using a 150 μm screen, and the underflow was used for further research work.

2.3 Spice preparations

Kimba (Negro pepper) and ginger were sorted and cleaned manually before drying in a Chirana convection oven model (HS 201A, Czech Republic) at 60°C for five hours. This was followed by pounding using the wooden pestle and mortar. The mass was ground and sieved using a 150 μm screen size.

2.4 Blend preparations and moisture adjustment

Millet flour (M_F) and soybean flour (S_F) were mixed at various weight ratios, and the total moisture contents of the blends adjusted to the desired values with a mixer as described by Zasypkin and Tung- Ching (1998). Weights of the components to be mixed were calculated using the following formula:

$$C_{SF} = \frac{[r_{SF} \times M \times (100 - w)]}{[100 \times (100 - w_{SF})]} \tag{1}$$

$$C_{MF} = \frac{[r_{MF} \times M \times (100 - w)]}{[100 \times (100 - w_{MF})]} \quad (2)$$

$$W_X = M - C_{SF} - C_{MF} \quad (3)$$

C_{SF} and C_{MF} are the masses of soybean flours (S_F) and millet flour (M_F), respectively, r_{SF} or r_{MF} are respective percentages of either soybean flours (S_F) or millet flour (M_F) in the blend, d.b.; ($r_{SF} + r_{MF} = 100\%$); M is the total mass of the blend; w, the moisture content of the final blend, percentage wet weight basis (w.w.b.); W_X is the weight of water added; and w_{SF} and w_{MF} are the moisture contents of S_F and M_F, respectively. The blends were mixed in a plastic bowl with the addition of the spices (Kimba and Ginger) at 1 percent level based on traditional formula; and the whole packed in polyethylene bags which was kept in the refrigerator at 8°C overnight to allow moisture equilibration. The samples were however brought to room temperature before extrusion process.

2.5 Experimental design and data analysis

A three-factor central composite rotatable composite design [CCRD] (Box and Hunter, 1957) was adopted to study the effect of feed composition (X_1), feed moisture content (X_2) and screw speed (X_3) on hydration power (HP), effect of quantity of water on the swell volume (EQWSV), wettabilty (WBLTY), viscosity (VSCTY) and sensory evaluation during extrusion of pearl millet and soybean flour mixtures on fura extrudates. The independent variables and their variation levels are shown in Table I. The levels of each variables were established according to literature information and preliminary trials. The outline of the experimental layout with the coded and natural values are presented in Table II. For each standardized scores, analysis of variance (ANOVA) was conducted to determine significant differences among the treatment combinations. Also, data were analyzed using multiple regression procedures (SPSS, 1998). A quadratic polynomial regression model was assumed for predicting individual responses (Gacula and Singh, 1984; Wanasundara and Shahidi, 1996). The model proposed for each response of Y was:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \quad (4)$$

where Y = the response X_1 = Feed Composition, X_2 = Feed Moisture, X_3 = Screw Speed, b_0 = intercepts, b_1, b_2, b_3 are linear, b_{11}, b_{22}, b_{33} are quadratic and b_{12}, b_{13} and

Variable	Symbols	Coded variable level $-1.68(\propto)$	-1	0	1	$1.68(\propto)$
Feed composition (%)	X_1	3.2	10	20	30	36.8
Feed moisture (%)	X_2	16.6	20	25	30	33.4
Screw speed (Rpm)	X_3	116	150	200	250	284

Notes: Transformation of coded variable (x_i) levels to uncoded variables (X_i) levels could be obtained from the following equation: $X_1 = 10x_1 + 20$; $X_2 = 5x_2 + 25$; $X_3 = 50x_3$

Table I. Independent variables and levels used for central composite rotatable design

Table II. Experimental design extrusion experiment in their coded form and natural units

Design point	Independent variables in coded form (X_1)	(X_2)	(X_3)	Experimental variables in their natural units (X_1)	(X_2)	(X_3)
1	−1	−1	−1	10	20	150
2	−1	+1	−1	10	30	150
3	−1	-1	+1	10	20	250
4	−1	+1	+1	10	30	250
5	+1	−1	−1	30	20	150
6	+1	+1	−1	30	30	150
7	+1	−1	+1	30	20	250
8	+1	+1	+1	30	30	250
9	−1.68	0	0	3.2	25	200
10	+1.68	0	0	36.8	25	200
11	0	−1.68	0	20	16.6	200
12	0	+1.68	0	20	33.4	200
13	0	0	−1.68	20	25	116
14	0	0	+1.68	20	25	284
15	0	0	0	20	25	200

Notes: Duplicate tests at all design point except the center point (0, 0, 0) which was carried out five times and the result averaged; experiment was carried out in randomized order; (X_1) = feed composition (%), (X_2) = feed moisture (%) and (X_3) = Screw speed (rpm)

b_{23} are interaction regression coefficient terms. Coefficients of determination (R^2) were computed.

2.6 Extrusion exercise

Extrusion cooking was performed in a single screw extruder, model (Brabender Duisburg DCE-330, Germany) equipped with a variable speed D-C drive unit, and strain gauge type torque meter. The screw has a linearly tapered rod and 20 equidistantly positioned flights. A round channel die with separate infolding heater was used. The die used was a cone shaped channel with 45 degrees entrance angle, a 3 mm diameter opening and 90 mm length. The screw was a 3:1 compression ratio. The extruder barrel has a 20 mm diameter with length to diameter ratio (L:D) of 20:1. The extrusion process consisted of 15 individual runs and conducted randomly.

2.7 Hydration power (HP) % water absorbed

Eighty (80 ml) of distilled water at 30°C were added to 10 g pulverized extrudates then allowed to stand for one hour in a 150 ml beaker. The hydrated extrudates was collected by inverting the beaker over a 150μm screen for 60 sec (Bhattacharya *et al.*, 1986). The percentage hydration was defined as:

$$\%\,Hydration\,power = \frac{Weight\ of\ sample\ -\ Initial\ dry\ weight}{Initial\ dry\ weight} \times 100 \qquad (5)$$

2.8 Wettability (WTBLTY)

Wettability of products was determined according to Onuma and Bello (1988) procedures. One gram of each sample was placed in a 25 ml graduated cylinder with a diameter of 1 cm. A finger was placed over the open end and the cylinder was inverted and clamped at a height of 10 cm from the surface of a 600 ml beaker containing 500 ml distilled water. The finger was removed to allow the test material to be dumped, and the time required for the sample to become completely wet was recorded. Triplicate measurements were made and the average result taken.

2.9 Effect of quantity of water on the swell volume of samples (EQWSV)
This was determined according to the method described by Mensah and Sefa-Dedeh (1991). Two gram samples were weighed and placed into graduated 50 ml measuring cylinders. Different amounts of distilled water (5, 7, 9, 11, and 13 ml) were added to each cylinder and left for 30 minutes. Triplicate determinations were made and the average result taken.

2.10 Viscosity
Viscosity was determined with the aid of rotational viscometer model (Rheotest 2 type) made in Hungary, equipped with concentric cylinders. The system has provision for tempering vessel, that is, connecting a liquid circulation thermostat to the correct temperature was ensured. Viscosity measurement was carried out at 30°C. Triplicate determination was carried out and the result averaged.

2.11 Sensory evaluation
One hundred gram of pulverized fura was added to 500 ml of *nono* (fermented skim milk) in a 1000 ml beaker each for all the 15 extruded fura samples, this preparation is based on traditional formulation called *fura da* nono. 100 g sugar was added to each of the preparation and these samples were used for sensory evaluation test. Twenty semi-trained member judges (28-45 year old males and females) were employed. The prepared samples were placed on tables inside a plastic bowl provided with individual booths. The panelists were to taste and swallow each of the gruel (*fura da* nono*)* and rinse their mouth with tap water between samples. The panelists were familiar with *fura* da *nono* and were asked to indicate their opinion on four sensory attributes, namely the colour, flavour, texture(gritness) and the overall acceptability using Hedonic scale rating of 9 = liked extremely to 1 = disliked extremely as described by Ihekoronye and Ngoddy (1985). Acceptability scores using the mean of the observations were recorded and analyzed.

3.0 Results and discussions

3.1 Hydration power (HP)
The ability of food to absorb and retain water plays a major role in the texture performance of foods. Water absorption without food components dissolution results in swelling (expansion) and will impart such characteristics as body, viscosity and adhesion. Other functional property like gelation also contributes to desirable properties of foods. The mean value of hydration power (HP) of fura samples is presented in Table III. From the results it shows that maximum value of hydration power (347.33 percent) was observed for design point 1 representing (10 percent soybean level, 20 percent feed moisture and 150 rpm screw speed), while the lowest value (257.10 percent) was observed for design point 10 representing (36.8 percent soybean flour, 25 percent feed moisture and 200 rpm screw speed). The regression coefficients for the second order polynomial equations showing the linear, quadratic and interactions effects is presented in Table IV. Analysis of variance (table not shown) shows that all

Independent variables			Dependent variables[a]			
X_1	X_2	X_3	HP	EQWSV	WBLTY	VCSCTY
10	20	150	347.33 ± 0.23	15.74 ± 0.23	1.61 ± 0.23	7.44 ± 0.34
10	30	150	268.84 ± 0.68	15.56 ± 0.56	1.62 ± 0.12	7.78 ± 0.36
10	20	250	342.43 ± 0.98	16.20 ± 0.34	1.63 ± 0.23	5.70 ± 0.46
10	30	250	335.93 ± 0.65	15.89 ± 0.46	1.61 ± 0.26	8.34 ± 0.58
30	20	150	336.82 ± 0.75	16.10 ± 0.49	1.75 ± 0.21	5.99 ± 0.28
30	30	150	266.33 ± 0.87	16.31 ± 0.55	1.74 ± 0.18	5.33 ± 0.52
30	20	250	264.92 ± 0.54	16.53 ± 0.33	1.76 ± 0.22	4.34 ± 0.76
30	30	250	266.42 ± 0.85	16.61 ± 0.52	1.77 ± 0.17	5.98 ± 0.63
3.2	25	200	324.32 ± 0.57	16.19 ± 0.35	1.51 ± 0.24	7.80 ± 0.43
36.8	25	200	257.10 ± 0.68	17.10 ± 0.87	1.85 ± 0.16	4.60 ± 0.41
20	16.6	200	324.04 ± 0.47	16.15 ± 0.45	1.68 ± 0.34	5.52 ± 0.74
20	33.4	200	259.37 ± 0.96	16.06 ± 0.44	1.65 ± 0.23	7.18 ± 0.29
20	25	116	326.23 ± 0.72	15.39 ± 0.31	1.66 ± 0.46	6.85 ± 0.55
20	25	284	322.19 ± 0.73	16.03 ± 0.39	1.64 ± 0.25	5.94 ± 0.36
20	25	200	279.62 ± 0.71	16.72 ± 0.67	1.67 ± 0.26	5.58 ± 0.27

Notes: X_1 = Feed composition (%); X_2 = Feed moisture (%) and X_3 = Screw speed (rpm); [a]HP = Hydration power; EQWSV = Effect of quantity of water on swell volume; WBLTY = Wettability; VCSCTY = Viscosity; values are replicate averages of three determinations with standard deviation values shown

Table III.
Experimental design and hydration properties of the extruded pearl millet-soybean fura

	Responses[a]			
Coefficient	HP	EQWSV	WBLTY	VSCSTY
Linear				
b_0	−0.4790*	0.8209*	−0.2476	−0.4230
b_1	−0.5850*	0.5413*	0.4362*	−0.7553*
b_2	−0.5629*	−0.0510	−0.3904	0.3928
b_3	−0.0351	0.3823*	−0.0664	−0.2150
Quadratic				
b_{11}	0.1149	−0.0549	−0.0542	0.1738
b_{22}	0.1252	−0.4342*	0.0891	0.2160
b_{33}	0.4620*	−0.7142*	0.3279	0.2301
Interaction				
b_{12}	0.0585	0.2001	0.1348	−0.1984
b_{13}	−0.4898*	−0.0150	−0.2022	0.0198
b_{23}	0.5264*	−0.0650	0.4718	0.4564
R^2	0.863	0.825	0.8980	0.7406
Adjusted R^2	0.739	0.667	0.6297	0.5071
Lack of fit	*	NS	*	*
Model	*	*	NS	*

Notes: $Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$; X_1 = Feed Composition, X_2 = Feed Moisture, X_3 = Screw Speed; *significant at $p < 0.05$; NS, not significant; [a]HP =Hydration power; EQWSV = Effect of quantity of water on swell volume; WBLTY = Wettability; WAI = Water absorption index; VSCSTY = Viscosity

Table IV.
Regression equation coefficients for objective responses

the three variables linear, quadratic and interaction effects influenced the HP of fura extrudates significantly ($p < 0.05$). Feed composition (level of soybean), feed moisture and screw speed showed negative linear coefficient effect an indication of reduction in HP when process variables were increased. The quadratic effect however showed positive by extrusion variables indicating increase in HP as process variables were increased quadratically. The interaction effect of both feed composition and screw speed indicated negative effect on the HP of extrudates and was significant ($p < 0.05$). The coefficient of determinant shows a good correlation ($R^2 = 0.863$) with actual observations Table IV. From the result of this study it shows that increase in the percentage of soybean and feed moisture appears to influence the HP negatively. The negative correlation between increase in percentage soybean flour and HP of fura may be attributed to the high oil content contributed by soybean because whole soybean flour was used in this study. The increased percentages of oil in the feed possibly reduced starch gelatinization to full scale thereby affecting the HP of extrudates. The water absorption index measures the amount of water absorbed by starch and can be used as an index of gelatinization, since native starch does not absorb water at room temperature (Anderson *et al.*, 1970; Collona *et al.*, 1989; Ding *et al.*, 2006; Lazou and Krokida, 2010). Hydration depends on availability of hydrophilic groups which bind water molecules and on the gel forming capacity of macromolecules (Gomez and Aguilera, 1983). Although legume proteins have hydrophilic groups, the protein denaturation during extrusion cooking leads to loss of hydration capacity of proteins. The lower hydration capacity is favored by the formation of inter- and intra-molecular protein bonds with amylose and amylopectin (Fernandez-Gutierrez *et al.*, 2004). Thus, the addition of proteins in extrudates can decrease starch molecular degradation (Matthey and Hanna, 1997). Filli and Nkama (2007) reported that increase in the level of groundnut had negative effects on the hydration power of extruded fura products. Singh *et al.* (2007) reported decrease in water absorption of rice-pea grits blends with increase in the percentage of pea grits, they attributed it to the dilution of the starch in rice by the addition of the pea grits. Kuakpetoon and Wang (2007) reported that lipid restricted the swelling power of starch granules. Jones *et al.* (2000) had earlier reported reduction in water absorption with decrease in starch content. The possible explanation for decreased HP with increased feed moisture may be attributed to decreased expansion of fura samples with increase in feed moisture (result not shown) which decreases water uptake as a result of fewer capillary units formed within the fura extrudates.

Considering the elastic properties of the amylopectin network as being responsible for diametral expansion is helpful in explaining such role of moisture. This is a commonly observed phenomenon in many extruded foods, which can be attributed to the fact that the amount of expansion in a food material depends on pressure differential between the die and the atmosphere. Food with lower moisture content tend to be more viscous than those having higher moisture content and therefore the pressure differential is smaller for higher moisture foods leading to a less expanded product and fewer capillary units which consequently results in decreased HP. Increased water content in the melt would soften the amylopectin molecular structure and reduce its elastic characteristics to decrease diametral expansion (Alvarez-Martinez *et al.*, 1988). The water absorption measures the volume occupied by the extrudate starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion (Qing-Bo *et al.*, 2005). Maximum water absorption values were previously reported by Williams *et al.* (1977), and Gomez and Aguilera (1984), who suggested that maximum gelatinization during cooking of corn grits and corn starch, occurred at (27-29 percent) feed moisture content. Likimani *et al.* (1991), reported that water absorption index of starch paste could be used as indices of extent of starch hydrolysis under different extrusion conditions. El-Dash *et al.* (1984) further reported that gelatinized starch readily absorb water to form paste that had higher final viscosity at room temperature than native starch. Gelatinization, the conversion of raw starch to a cooked and digestible material by the application of water and heat, is one of the important effects that extrusion cooking has on the starch component of foods, (Qing-Bo *et al.*, 2005). Water is absorbed and bound to the starch molecule with resulting change in the starch granule structure. It has been established (Pomeranz, 1991; Wolf and Cowan, 1971) that proteins are the most reactant components in foods and some of their reactions are essential for functionality. Singh *et al.* (2007) reported that the general increase in water absorption by extrudates could be attributed to protein denaturation, starch gelatinization and swelling of crude fiber, which occurred during extrusion cooking, could all be responsible for the increased water absorption. An increase of water absorption is generally advantageous since this parameter determines the suitability of extruded products for use in situations that involve water bonding (Aguilera *et al.*, 1980).

3.2 Effect of quantity of water on the swell volume of samples (EQWSV)

The mean experimental data as influenced by the extrusion variables (feed composition, feed moisture and screw speed) on the response of the effect of quantity of water on the swell volume (EQWSV) of fura extrudates is presented in Table III. The effect of quantity of water added on the swelling capacities of products gives an indication of quantity of water required for full swelling (Filli and Nkama, 2007). The experimental mean value shows that the EQWSV ranged from 15.39-17.10 cm^3. The regression coefficients for the second order polynomial equations are presented in Table IV. Analysis of variance (table not shown) shows that among the variables, total linear effect ($p < 0.05$) dominates over the total interaction effect ($p < 0.05$) and the total quadratic significant ($p < 0.05$) effect. Among the individual variables, feed composition recorded maximum positive significant ($p < 0.05$) effect on the EQWSV of fura extrudates. This suggests that increasing the level of soybean resulted in increased EQWSV. This was followed by the screw speed indicating positive significant ($p < 0.05$) linear effect. The individual variable feed moisture indicated negative significant ($p < 0.05$) effect, suggesting increase in feed moisture resulted in decrease in EQWSV. A high correlation coefficient of determinant $R^2 = 0.825$, $p < 0.05$ indicates the suitability of the model as a predictor of responses. Filli and Nkama (2007) reported that, there were no significant differences in the wettabilities of extruded fura samples ($p < 0.05$) with the exception of fura extrudates from millet-groundnut blends that indicated significant differences ($p < 0.05$) in wettabilities as a result of increase in the amount of groundnut. The physically entrapped water in foods does not flow from tissue of foods even when they are cut or minced. Such water behaves almost like pure water. Nearly all of the water in tissues and gels can be categorized as physically entrapped capability (water holding capacity) of foods which has a profound effect on food quality and acceptance.

3.3 Wettability (WTBLTY)

Results of the experimental mean values of wettability of fura extrudates is presented in Table III. The mean wettability values ranged from 1.51-1.85 minutes. The regression coefficient for the model of fura wettability is presented in Table IV. Analysis of variance (table not shown) indicates that the linear effects of the independent variables significantly ($p < 0.05$) affected the WTBLTY of fura extrudates. The regression coefficient of the linear term was significant ($p < 0.05$) for the wettability with feed composition showing positive effect suggesting that linear increase in the independent variable feed composition (percentage soybean) indicated increase in the wettability of fura extrudate Table IV. Both feed moisture and the screw speed indicated negative linear effect which means increasing the levels of feed moisture and screw speed resulted in reduced wetting periods for fura extrudates. From the results it shows that as the level of soybean was increased the wetting period increased as expected. It can therefore be inferred that because of the increased fat content as level of soybean increased in the fura sample, it resulted in increased wetting time which may be attributed to the surface of the particle being coated with fat which eventually resulted in longer time before wetting. Filli and Nkama (2007) reported that the term wettability describes the ability of the powder particle to absorb water on its surface, thus initiating reconstitution. This property largely depends on particle size and existing porosity. The nature of the surface of the particles can also affect wettability; for example the presence of free fat can hinder wettability. The coefficient of determinant R^2 indicated that 89.80 percent of the wettability was attributed to the independent variables (feed composition, feed moisture and screw speed), and only about 10 percent of the total variation of the wettability could not be explained by the model. This indicated that the accuracy and general ability of the polynomial model was good, and the analysis of the response trends using the model was considered to be reasonable in explaining the wettability of fura samples.

3.4 Viscosity

Results of the experimental mean values of viscosity of fura extrudates is presented in Table III. The maximum viscosity value of 8.34Nsm^{-2} was observed for design point 4 (10 percent feed composition, 30 percent feed moisture and 250 screw speed), while the least value of 4.34 Nsm^{-2} was recorded for design point 7 representing 30 percent feed composition, 20 percent feed moisture and 250 rpm screw speed Table III. The viscosity of samples was influenced by the feed composition linear effect terms significantly ($p < 0.05$) and showed a negative effect. This suggests that increase in the level of soybean resulted in decreased viscosity. The linear effects of feed moisture indicated positive influence on the viscosity of fura extrudates. The coefficient of determinant for the viscosity was $R^2 = 0.74$. Increase in the amount of soybean flour resulted in decreased apparent viscosity of extrudate while increase in feed moisture resulted in increased viscosity of fura extrudates. In addition to the effect of extrusion, the reduction in viscosity as the level of soybean was increased may be attributed to the high level of oil from the soybean flour as increase in oil content of formulations generally decreases their viscosities. The possible explanation for the effect of moisture is low moisture in the feed can possibly increase frictional damage, particularly when the residence time is high due to low screw speed consequently will lead to lower viscosity of extrudates. The viscosity of a paste depends on to a large extent on the degree of gelatinization of the starch granules and the rate of molecular breakdown. Viscosity generally depends on solubility and water holding capacity as well as the structure of components in a food system.

Viscosity profile can be thought of as a reflection of the granular changes in the starch granule that occur during gelatinization, (Thomas and Atwell, 1997). Extrusion can induce starch dextrinization resulting in reduction of viscosity in gruels and a concomitant increase in caloric and nutrient density (Jansen *et al.*, 1981). Arambula *et al.* (1998) reported decreased apparent viscosity of extruded instant corn flour when temperature was increased. Davidson *et al.* (1984) reported that viscosity over a heating and cooling cycle have been used to characterize the changes in extruded products in numerous studies. This characteristic is affected by both physical modifications of the granule structure as well as changes to the structures of the starch polymers. They further reported that, the characteristics of the paste viscosity curves were significantly altered by extrusion processing with extrudates showing low values. Pelembe *et al.* (2002) reported that, reduced viscosity of protein-rich sorghum – cowpea extrudate could be very beneficial for infant feeding. The high bulk (low nutrient density) of cereal weaning porridges is a major cause of infant malnutrition in Africa, since it limits nutrient intake (Da *et al.*, 1982).

Hagenimana *et al.* (2006), reported that viscosity values of extruded rice flours were far less than those of their corresponding unprocessed rice flour dispersed in the Micro Visco Amylo Graph (MVAG), indicating that their starches have been partially pregelitinized by extrusion process. They reported that peak viscosity indicated a high positive correlation with hot paste viscosity and cold paste viscosity with $r > 0.70$ ($p < 0.01$). Ozcan and Jackson (2005) reported that during extrusion cooking of corn starches, extruded starch had higher water absorption and water solubility indices, and they had lower rapid viscoamylograph viscosity profiles when compared with raw starch. The high bulk (low nutrient density) of cereal weaning porridges is a major cause of infant malnutrition in Africa, since it limits nutrient intake (Da *et al.*, 1982).

Run	Independent variables* X_1	X_2	X_3	Hedonic ratings CLOR[1]	FLVR[2]	TXTRE[3]	O/ACCA[4]
1	10	20	150	6.45^{b}	6.87^{b}	6.67^{b}	6.50^{b}
2	10	30	150	6.40^{b}	6.70^{b}	6.43^{b}	5.64^{c}
3	10	20	250	6.54^{b}	6.88^{b}	6.78^{b}	6.66^{b}
4	10	30	250	6.30^{b}	6.34^{bc}	6.38^{b}	6.45^{b}
5	30	20	150	6.41^{b}	6.87^{b}	6.56^{b}	6.55^{b}
6	30	30	150	5.80^{bc}	6.12^{b}	6.34^{b}	5.89^{c}
7	30	20	250	5.40^{c}	6.34^{b}	6.11^{bc}	5.65^{c}
8	30	30	250	5.80^{bc}	5.55^{c}	5.65^{c}	5.78^{c}
9	3.2	25	200	6.35^{b}	6.78^{b}	6.57^{b}	6.44^{b}
10	36.8	25	200	5.56^{c}	5.56^{c}	5.55^{c}	5.54^{c}
11	20	16.6	200	7.30^{a}	7.56^{a}	7.54^{a}	7.25^{a}
12	20	33.4	200	5.80^{bc}	5.76^{c}	5.69^{c}	5.78^{c}
13	20	25	116	6.72^{b}	6.76^{b}	6.66^{b}	6.75^{b}
14	20	25	284	5.53^{c}	5.55^{c}	6.54^{b}	5.55^{c}
15	20	25	200	5.40^{c}	5.65^{c}	6.23^{b}	5.64^{c}

Notes: 1 = Color; 2 = Flavor; 3 = Texture; 4 = Overall acceptability; *Experimental runs indicating the levels of the variables; sample means with entire different subscript letters in each attribute column are significantly different at ($p < 0.05$)

Table V.
Descriptive sensory evaluation of fura extrudates

3.4 Sensory evaluation

Sensory property is defined as the acceptance of the sensory attributes of a product by consumers who are the regular users of the product category (Galvez and Resurrection, 1992). The result of sensory evaluation for fura extrudates is presented in Table V. The results show that all products appear to be acceptable on the average by panelist. The color scores showed that there was a narrow difference in acceptability among fura extrudates with low scores from runs 7, 10, 14, and 15 showing significant differences ($p < 0.05$) from the other extrudates. For the flavor acceptability runs 8, 10, 12, 14, and 15 indicted significance differences ($p < 0.05$) from the other runs with lower scores. The sensory scores for the texture showed that runs 8, 10 and 12 indicated significance differences ($p < 0.05$) from the other extrudates recording low scores. The design point 10 of fura extrudate made representing (36.8 percent soybean, 25 percent feed moisture and 200 rpm) recorded the lowest acceptability. Obatolu (2002) reported that level of fortification of millet with soybean should not exceed 30 percent for good acceptability. The overall acceptability sensory scores shows that the fura extrudate design point 11 representing (20 percent soybean, 16.6 percent feed moisture and 200rpm) recorded the highest acceptability (7.25) with significant differences from the other extrudates in terms of color, flavor, texture and overall acceptability Table V. The acceptability of the extruded fura from blends of millet-soybean in this study with improved protein content (result not shown) has justified the basis of advocating cereal-legume complementation as a method of improving the protein content of cereal-based traditional foods like fura.

4. Conclusion

Extruded fura was produced from pearl millet and soybean blends using a single screw extruder through designed experiments using RSM. The decision to include soybean flour and to adopt extrusion cooking was motivated by the need to improve its protein content and quality, physical state, functionality, safety and shelf-life of the end product. The results obtained from this study revealed that increase in the level of soybean and feed moisture resulted in decreased hydration power of fura samples. The study provided information on minimum amount of water required to achieving full swell volume during preparation before consumption. Extrudates showed the potential of absorbing water as much as at least four (4) times their weight which is an indication of improved functionality of the product. The protein content and quality (result not shown) was improved. The importance of influence of process variables on extrudates hydration responses could be ranked in the following order: Feed Composition(X_1) $>$ Feed Moisture (X_2) $>$ Screw Speed (X_3). The sensory evaluation shows that fura samples were acceptable by panelists that are used to the product. However, the sample with the highest amount of soybean (36.8 percent) suffered by recording the lowest overall acceptability. Extrusion cooking of fura constituted a great improvement on the traditional product that is usually at high moisture content of between 60-75 percent and readily deteriorates on storage at room temperature. Extruded fura obtained in this study had moisture content less than 7 g/100 g (result not shown) and would not require refigeration for storage. The extrusion cooking data from this study could help predict the expected performance in investigations of potential use of millet and soybean to explore the possibility of industrial projection.

References

Aguilera, J.M., Rossi, F., Hiche, E. and Chichester, C.O. (1980), "Development and evaluation of an extrusion-texturized peanut protein", *Journal of Food Science*, Vol. 45 No. 2, pp. 246-250, 254.

Ali, Y., Hanna, M.A. and Chinaswamy, R. (1996), "Expansion characteristics of extruded corn grits", *LWT – Food Science and Technology*, Vol. 29 No. 8, pp. 702-707.

Alvarez-Martinez, L., Kondury, K.P. and Harper, J.M. (1988), "A general model for expansion of extruded products", *Journal of Food Science*, Vol. 53 No. 2, pp. 609-615.

Anderson, R.A., Conway, H.F. and Peplinski, A.J. (1970), "Gelatinization of corn grits by roll cooking, extrusion cooking and steaming", *Starch – Starke*, Vol. 22 No. 4, pp. 130-135.

Arambula, V.G., Figueroa, J.D.C., Martinez-Bustos, F., Ordorica, F.C.A. and Gonzalez-Hernandez, J. (1998), "Milling and processing parameters for corn tortillas from extruded instant dry masa flour", *Journal of Food Science*, Vol. 63 No. 2, pp. 338-341.

Bhattacharya, M., Hanna, M.A. and Kaufmann, R.E. (1986), "Textural properties of extruded plant protein blends", *Journal of Food Science*, Vol. 51 No. 4, pp. 988-993.

Box, G.E.P. and Hunter, J.S. (1957), "Multifactor experimental design for exploring response surfaces", *Annals Math. Stat.*, Vol. 28 No. 1, pp. 195-242.

Collona, P., Tayeb, J. and Mercier, C. (1989), "Extrusion cooking of starch and starchy products", in Mercier, C., Linko, P. and Harper, J.M. (Eds), *Extrusion Cooking*, American Association of Cereal Chemists, St Paul, MN, pp. 247-320.

Da, S., Akinbala, J.O., Rooney, L.W. and Miller, F.R. (1982), "Evaluation of to quality in sorghum breeding program", in Rooney, L.W., Murrty, D.S. and Mertins, J.V. (Eds), *Proceedings of International Symposium on Grain Quality*, ICRISAT, Pantachem, pp. 11-23.

Davidson, V.J., Paton, D., Diosady, L.L. and Larocque, G. (1984), "Degradation of wheat Starch in a single-screw extruder: characteristics of extruded starch polymers", *Journal of Food Science*, Vol. 49 No. 2, pp. 453-458.

Ding, Q.B., Ainsworth, P., Plunkett, A., Tucker, G. and Marson, H. (2006), "The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks", *Journal of Food Engineering*, Vol. 73 No. 2, pp. 142-148.

El-Dash, A.A., Gonzalas, R. and Ciol, M. (1984), "Response surface methodology in the control of thermoplastic extrusion of starch", in Jowitt, R. (Ed.), *Extrusion Cooking Technology*, Elsevier Applied Science Publishers, London, p. 51.

Fernandez-Gutierrez, J.A., Martin-Marthinez, E.S., Martinez-Bustos, F. and Cruz-Orea, A. (2004), "Physicochemical properties of casein-starch interaction obtained by extrusion process", *Starch – Starke*, Vol. 56 No. 5, pp. 190-198.

Filli, K.B. and Nkama, I. (2007), "Hydration properties of extruded fura from millet and legumes", *British Food Journal*, Vol. 109 No. 1, pp. 68-80.

Gacula, M.C. Jr and Singh, J. (1984), *Statistical Methods in Food and Consumer Research*, Academic Press, New York, NY, pp. 214-272.

Galvez, F.C.F. and Resurrection, A.V.A. (1992), "Reliability of the focus group technique in determining the quantity characteristics of mung bean [*Vigna radiata* (L) *Wilczae*] noodles", *Journal of Sensory Studies*, Vol. 7, pp. 315-326.

Gomez, M.H. and Aguilera, J.M. (1983), "Changes in the starch fraction during extrusion – cooking of corn", *Journal of Food Science*, Vol. 48, pp. 378-381.

Gomez, M.H. and Aguilera, J.M. (1984), "A physico-chemical model for extrusion of corn starch", *Journal of Food Science*, Vol. 49, pp. 40-44.

Hagenimana, A., Ding, X. and Fang, T. (2006), "Evaluation of rice flour modified by extrusion cooking", *Journal of Cereal Science*, Vol. 43 No. 1, pp. 38-46.

Ihekoronye, L.J. and Ngoddy, P.O. (1985), *Integrated Food Science and Technology for the Tropics*, Edu. Macmillan Publishers, London.

Iwe, M.O., Van Zauilichem, D.J., Ngoody, P.O. and Ariahu, C.C. (2001), "Residence time distribution in a single- screw extruder processing soy-sweet potato mixtures", *LWT – Food Science and Technology*, Vol. 34 No. 7, pp. 478-483.

Jansen, G.R., O'Deen, L., Tribelhorn, R.E. and Harper, J.M. (1981), "The calorie densities of gruels made from extruded corn-soy blends", *Food Nutr. Bull.*, Vol. 3 No. 1, p. 39.

Jideani, V.A., Nkama, I., Agbo, E.B. and Jideani, I.A. (2001), "Survey of Fura production in some northern states of Nigeria", *Plant Foods for Human Nutrition*, Vol. 56 No. 1, pp. 23-36.

Jideani, V.A., Nkama, I., Agbo, E.B. and Jideani, I.A. (2002), "Identification of the hazard and critical control (HACCP) in traditional fura manufacture", *Nigerian Food Journal*, Vol. 19, pp. 42-48.

Jones, D., Chinnaswamy, R., Tan, Y. and Hanna, M. (2000), "Physicochemical properties of ready-to-eat breakfast cereals", *Cereal Food World*, Vol. 45, pp. 164-168.

Kuakpetoon, D. and Wang, Y. (2007), "Internal structure and physicochemical properties of corn starches as revealed by chemical surface gelatinization", *Carbohydrate Research*, Vol. 342, pp. 2253-2263.

Lazou, A. and Krokida, M. (2010), "Functional properties of corn and corn-lentil extrudates", *Food Research International*, Vol. 43 No. 2, pp. 609-616.

Likimani, T.A., Sofos, J.N., Maga, J.A. and Harper, J.M. (1991), "Extrusion cooking of corn/soy bean mix is presence of thermostable a-amylase", *Journal of Food Science*, Vol. 56 No. 1, pp. 99-105.

Matthey, F.P. and Hanna, M.A. (1997), "Physical and functional properties of twin-screw extruded whey protein concentrate-corn starch blends", *LWT – Food Science and Technology*, Vol. 30 No. 4, pp. 359-366.

Meng, X., Threinen, D., Hansen, M. and Driedger, D. (2010), "Effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack", *Food Research International*, Vol. 43 No. 2, pp. 650-658.

Mensah, E.O. and Sefa-Dedeh, S. (1991), "Traditional food-processing technology and high protein food production", *Food Nutr. Bull.*, Vol. 13 No. 1, pp. 43-49.

Nkama, I. and Filli, K.B. (2006), "Development and characteristics of extruded fura from mixtures of pearl millet and grain legumes flours", *International Journal of Food Properties*, Vol. 9 No. 2, pp. 157-165.

Obatolu, V.A. (2002), "Nutrient and sensory qualities of extruded malted or unmalted millet/soybean mixture", *Food chemistry*, Vol. 76 No. 2, pp. 129-133.

Onuma, B.D. and Bello, A.B. (1988), "Physicochemical and functional properties of winged bean flour and isolate compared with soy isolate", *Journal of Food Science*, Vol. 53 No. 2, pp. 450-454.

Ozcan, S. and Jackson, D.S. (2005), "Functionality behavior of raw and extruded corn starch mixtures", *Cereal Chemistry*, Vol. 82 No. 2, pp. 223-227.

Pantil, R.T., Berrios, J.D., Tang, J. and Swanson, B.G. (2007), "Evaluation of methods for expansion properties of legumes extrudates", *Applied Engineering in Agriculture*, Vol. 23 No. 6, pp. 777-783.

Pelembe, L.A.M., Erasmus, C. and Taylor, J.R.N. (2002), "Development of a protein-rich composite sorghum-cowpea instant porridge by extrusion cooking process", *LWT – Food Science and Technology*, Vol. 35 No. 2, pp. 120-127.

Pomeranz, Y. (1991), *Functional Properties of Food Components*, 2nd ed., Academic Press, New York, NY.

Singh, S., Gamlath, S. and Wakeling, L. (2007), "Nutritional aspects of food extrusion: a review", *International Journal of Food Science and Technology*, Vol. 42 No. 8, pp. 916-929.

SPSS (1998), *SPSS Release 11, Standard Version*, SPSS Inc, Chicago, IL.

Thomas, D.J. and Atwell, W.A. (1997), *Starches. Eagan Press Handbook Series*, Eagan Press, St Paul, MN.

Qing-Bo, D., Ainsworth, P., Tuker, G. and Marson, H. (2005), "The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks", *Journal of Food Engineering*, Vol. 66 No. 3, pp. 284-289.

USAID (1996), *Annual Food Assistance Report*, United States Agency for International Development, Washington, DC.

Wanasundara, P.K.J.P.D. and Shahidi, F. (1996), "Optimization of hexametaphosphate-assisted extraction of flaxseed protein using response surface methodology", *Journal of Food Science*, Vol. 61 No. 3, pp. 604-607.

Williams, M.A., Horn, R.E. and Rugul, R.P. (1977), "Extrusion – an in depth look at a versatile process", *Journal of Food Engineering*, Vol. 49 No. 9, pp. 99-103.

Wolf, W.F. and Cowan, J.C. (1971), "Soybean as a food source", *CRC Critical Review in Food Technology*, Vol. 2 No. 1, pp. 81-158.

Yang, S., Peng, J., Lui, W. and Lin, J. (2008), "Effects of adlay species and rice flour ration on the physicochemical properties and texture characteristic of adlay – based extrudates", *Journal of Food Engineering*, Vol. 84 No. 3, pp. 489-494.

Zasypkin, D. and Tung- Ching, L. (1998), "Extrusion of soybean and wheat flour as affected by moisture content", *Journal of Food Science*, Vol. 63 No. 6, pp. 1058-1061.

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