African Journal of Food Science Vol. 4(6), pp. 342- 352, June 2010
Available online http://www.academicjournals.org/ajfs
ISSN 1996-0794 ©2010 Academic Journals

Full Length Research paper

Influence of of extrusion variables on some functional properties of extruded millet-soybean for the manufacture of 'fura': A Nigerian traditional food

K. B. Filli[1]*, I. Nkama[2], U. M. Abubakar[2] and V. A. Jideani[3]

[1]Department of Food Science and Technology, Federal University of Technology, Yola, P. M. B. 2076, Yola, Adamawa State, Nigeria.
[2]Department of Food Science and Technology, University of Maiduguri, P. M. B. 1069, Maiduguri, Borno State, Nigeria.
[3]Department of Food Science and Technology, Cape Peninsula University of Technology, Bellville 7535, South Africa.

Accepted 19 April, 2010

'Fura' is a traditional thick dough ball snack produced principally from millet or sorghum which is common in Northern Nigeria. It is consumed with 'nono' (local yoghurt produced from cow milk) or mashed in water before consumption in the form of porridge. The effects of extrusion conditions feed composition (ratio of soybean to millet), percentage moisture wet basis and screw speed (rpm) on the water absorption index (WAI); water solubility index (WSI) and viscosity from millet/soybean flour mixtures were studied using Response surface methodology (RSM) for 'fura' processing. Models were developed and appropriate statistical analysis adopted to test the adequacy of the models. The models showed R^2 = 0.73, 0.76, 0.74 for WAI, WSI and viscosity, respectively, indicating that the model could be used to navigate the design space. Because some of the stationary points were outside the range of the experiment, graphical optimization was adopted to determine the optimum and predicted values. The optimum levels and the corresponding predicted values were obtained. The optimal combination of feed composition (17.7% soybean), feed moisture (27.3% wet basis) and screw speed (161 rpm) resulted in optimal WAI of 4.6 g_{Water} per g_{Sample}. The optimal combination of feed composition (14.77% soybean), feed moisture (15.23%) and screw speed 220 rpm) resulted in optimal WSI of 6.15%. The optimal combinations of feed composition (46.97%), feed moisture (29.34%) and screw speed (174.52rpm) resulted in optimal viscosity of 4.58 Nsm^{-2}.

Key words: Millet, soybean, extrusion, optimization, 'fura', water absorption index, water solubility index, viscosity.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R.Br.) is grown extensively in the dry areas of western and southern India and along the West African sub region including Nigeria, where it is used as food for an estimated 400 million people (Hoseney et al., 1992). More than 80% of the production is used for human consumption, particularly in the semi-arid tropic region of Africa and Asia. 'Fura' is one of the several indigenous food preparations made from pearl millet in West Africa particularly in Nigeria. It is a thick dough ball snack produced principally from millet or sorghum. The mode of preparation varies only slightly among different communities in the region, but the basic ingredient remains the same (that is, millet or sorghum). Depending on the com-munity, it is traditionally consumed with 'nono' (local yog-hurt produced from cow milk) or mashed in water before consumption in the form of porridge. However, the production method lacks process specifications governing functionality, composition, ingredients, additives and shelf life. Processing has remained a home-based or artisanal activity that is carried out with rudimentary equipment and techniques, which is characterized by inconsistent product quality, poor hygiene, very short shelf life and unacceptable standards. 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 h at 35°C (Jideani et al.,

*Corresponding author.E-mail: kbfilli@yahoo.com.

2002); being a single cereal based product it is limiting in the essential amino acid lysine. The inclusion of soybean as a basic ingredient in producing ‘fura’ through extrusion can improve its protein content and functionality. Interest in soybean foods has increased with consumer awareness of its health benefits, especially with soybean related ingredients being utilized as one of the major sources of high-protein fortification (United Soybean Board, 2006; Yeu et al., 2008).

Extrusion cooking has some unique features compared to other heat processes. It is capable of breaking covalent bonds in biopolymers and facilitating reactions otherwise limited by diffusion of reactants and products (Iwe et al., 2001). Extrusion alters the nature of many food constituents, including starches and proteins, by changing their physical, chemical and nutritional properties. 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.

Extrudates are microbiologically safe, can be stored for long periods because of low moisture without need for refrigeration and requires less labour for handling and less packaging materials and storage space (Filli and Nkama, 2007). Extrusion technology could be applied for ‘fura’ processing for the purpose of improving its shelf life and value addition to the product by making it a convenient food item (Nkama and Filli, 2006; Filli and Nkama, 2007).

The water absorption index (WAI) 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). The water solubility index (WSI) describes the rate and extent to which the component of powder material or particles dissolves in water.

It depends mainly on the chemical composition of the powder and its physical state. The WSI often is used as an indicator of degradation of molecular components (Kirby et al., 1988), measures the degree of starch conversion during extrusion which is the amount of soluble polysaccharide released from the starch component after extrusion. Binoy et al. (1996) reported that water solubility index increased with severity of screw configuration. Pelembe et al. (2002) reported increased nitrogen solubility index in extruded sorghum-cowpea porridge. Among functional properties, water holding capacity is important because of the hydro-gen bonds formed between water and polar residues of protein molecules. An increase in shear energy inputs during extrusion can cause deploy-merization and degradation of component. High shear can also cause fragmentation of products from both starch and proteins; the degradation products are small molecules and generally water soluble. Water is absorbed and bound to the starch molecule with resulting change in the starch granule structure (Binoy et al., 1996).

The viscosity of a fluid reflects its resistance to flow and influence acceptability of liquid foods. Viscosity depends on solubility and water holding capacity as well as the structure of components in food. 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 dextrinzation which can result in the reduction of viscosity in gruels and a concomitant increase in caloric and nutrient density (Jansen et al., 1981). In Africa, due to deforestation by utilisation 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 such foods of high nutritional quality and ready to eat products, (Pelembe et al., 2002). Despite incre-ased use of extrusion processing, extrusion is still a complicated process that has yet to be mastered. Small variations in processing contions affect processs variables as well as product quality (Qing-Bo et al., 2005). The objectives of this work was to study the effects of feed composition, feed moisture and screw speed on the water absorption index, water solubility index and viscosity of extruded ‘fura’ from pearl millet and soybean flour mixtures using response surface methodology.

MATERIALS AND METHODS

Flour preparation from millet

Traditional method of flour preparation was used in this study. The process consists of dry cleaning of millet, that is, winnowing using an aspirator. The kernels were thereafter dehulled after mild wetting of the grain using a rice dehuller, India at the Jimeta Main Market, Yola, Nigeria. After dehulling, the grains was washed and then dried in a convection oven at 50°C for 24 h to 14% moisture content. The dried grain was milled using the roller mill equipped with a 150 µm screen.

Flour preparation from soybean

The soybean seeds were steeped in tap water at 28°C for a period of 24 h in a plastic bowl. The kernels were thereafter dehulled using traditional pestle and mortar. The dehulled mass was winnowed using an aspirator. The dehulled soybean kernels were ground in a laboratory disc mill to fine flour. The flour was sieved using a150 µm screen, and the underflow was used for further research work.

Flour preparation from soybean

The soybean seeds were steeped in tap water at 28°C for a period of 24 h in a plastic bowl. The kernels were thereafter dehulled using traditional pestle and mortar. The dehulled mass was winnowed using an aspirator. This was ground in a laboratory disc mill to fine flour. The flour was sieved to pass through a 150 µm screen size.

Spice preparations

Kimba (Negro pepper) and ginger were sorted and cleaned manually before being kept in a convection oven at 60°C for five

Table 1. Independent Variables and Levels used for central composite rotatable design.

Variable	Symbols	Coded variable level				
		-1.68(∝)	-1	0	1	1.68(∝)
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

Table 2. Experimental design extrusion experiment in their coded form and natural units.

Design point	Independent variables in coded form			Experimental variables in their natural units		
	(X_1)	(X_2)	(X_3)	(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

Duplicate tests at all design point except the centre point (0, 0, 0) which was carried out five times. Experiment was carried out in randomized order. (X_1) =feed composition (X_2) = feed moisture and (X_3) = screw speed.

hours. The seeds were then pounded using the traditional pestle and mortar. The mass was ground and sieved using a 150 µm screen size.

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 Zasypkin and Tung-Ching Lee (1998):

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

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

$$W_x = M - C_{SF} - C_{MF}$$

Where C_{SF} or C_{MF} are the masses of either soybean flours (S_F) or 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 and packed in polyethylene bags and kept in the refrigerator overnight to allow moisture equilibration. The samples were however, brought to room temperature before extrusion process.

Experimental design (central composite rotatable designs)

The Response Surface Methodology (RSM) is a widely adopted tool for the quality of optimizations processes (Myers and Montgomery, 1995). The RSM, origially described by Box and Wilson (1951) is effective for responses that affect many factors and their interactions. The central composite rotatable composite design (CCRD), (Box and Hunter, 1957) was adopted to predict responses based on few sets of experimental data in which all factors were varied within a chosen range. A three factors and three level experimental design was adopted for this work (Table 1). The independent variables considerd were feed composition X_1 (%), feed moisture content X_2 (%) and screw speed X_3 (rpm). The independent variables and their variation levels are shown in Table 1. 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 is presented in Table 2.

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. The extruder was fed manually through a screw operated conical hopper at a speed of 30 rpm which ensures the flights of the screw filled and avoiding accumulation of the material in the hopper. This type of feeding provides the close to maximal flow rate for the selected process parameters (constant temperature, constant die and screw geometry but with three variable screw speeds) and three designed feed composition and feed moisture contents. 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 inner barrel is provided with a grooved surface to ensure zero slip at the wall. The barrel is divided into two independent electrically heated zones (that is feed end and central zone) . There is a third zone at the die barrel, electrically heated but not air cooled. The extruder barrel has a 20 mm diameter with lenght to diameter ratio (L:D) of 20:1. The extruder consists of two electrically heated zones. Desired barrel temperature was maintained by a circulating tap water controlled by inbuilt thermostat and a temperature control unit. The feed material was fed into a hopper mounted vertically above the end of the extruder which is equipped with a screw rotated at variable speed. The rotating hopper screw kept feed zone completely filled to achieve a 'choke fed' condition. Experimental samples were collected when steady state was achieved, that is, when the torque variation of plus or minus 0.28 joules (Nm) or about (0.5%) of full scale (Likmani et al.,1991). The extrusion process consisted of 15 individual runs.

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

The WAI and WSI were determined using the method described by Qing-Bo et al. (2005). The ground extrudate was suspended in water at temperature 30℃ for 30 min; it was stirred gently during this period and centrifuged at 3000 × g for 15 min. The supernatant was decanted into an evaporating dish of known weight. The WSI was considered as the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. The WAI was considered as the weight of gel obtained after removal of the supernatant through a strainer (pore size = 500 µm) per unit weight of original dry solids (gH_20/1g sample). Determinations were made in triplicate and the average taken.

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℃. Triplicate determination was carried out and the result averaged.

Statistical analysis

Homogeneous variances or homoscedasticity is a necessary prerequisite for (linear) regression models. Therefore, a reduction in variability within the objective response (dependent variables) was by transforming the data to standardized scores ($z = \frac{x - \bar{x}}{s}$ where x = dependent variable of interest; $\bar{x}$ = mean of dependent variable of interest and s = standard deviation). 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 (*MATLAB* 1984-2000,). To estimate feed composition, feed moisture and screw speed effects each objective response, the standardized scores were fitted to a quadratic polynomial regression model by employing a least square technique (Gacula and Singh, 1984; Wanasundara and Shahidi, 1996). The model proposed for each response of Y was:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \quad (1)$$

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 b_{23} are interaction regression coefficient terms, respectively. Coefficients of determination (R^2) were computed. The adequacy of the models was tested by separating the residual sum of squares into pure error and lack of fit. For each response, response surface plots were produced from the equations, by holding the variable with the least effect on the response equal to a constant value, and changing the other two variables.

RESULTS AND DISCUSSION

Description of model

The model did not show a significant lack of fit (p = 0.0915), with R^2 = 0.73, 0.76, and 0.74 for WAI, WSI and VCSCITY, respectively. The probability of the F value for the model = 0.05 which can explain the reason for variation. Filmore et al. (1976) reported that R^2 value less than 0.8 makes the model unsuitable for any further analysis. However, Yagci and Gogus (2008) reported that with significant probability values (p< 0.001) and non-significant lack of fit, the models could be adequately be used as predictor models, regardless of low coefficient of determinants. If a model has a significant lack of fit, it is not a good indicator of the response and should not be used for prediction (Myers and Montgomery, 2002). We may probably conclude that the proposed models approximates the response surfaces and can be used suitably for prediction at any values of the parameters within experimental range.

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

The effects of treatment variables as linear, quadratic or interaction coefficients are detailed in Table 3. The design point 1 (10% feed composition, 20% feed moisture and 150 rpm screw speed) recorded the maximum WAI value of 5.62 gH_2O/g sample. The lowest value of 4.26 gH_2O/g was however, recorded for design point 10 (36.8% feed composition, 25% feed moisture and 200 rpm screw speed). The model did not show a significant lack of fit (p = 0.0915) with R^2 = 0.73, and the

Table 3. Effect of extrusion variables on WAI, WSI and VISCOSITY of samples.

Coefficient	WAI	WSI	VSCSTY	Experimental runs	WAI		WSI		VCSCITY	
				X_1 X_2 X_3	Obsd.	Prdt.	Obsd.	Prdt.	Obsd.	Prdt.
Linear				(10 : 20 : 150)	5.62	5.73	6.42	6.44	7.44	7.12
b_0	-0.3780	-0.1177	-0.4230	(10 : 30 : 150)	4.77	4.73	5.84	5.84	7.78	8.23
b_1	-0.5860*	-0.3781	-0.7553*	(10 : 20 : 250)	5.47	5.23	6.26	6.34	5.70	5.66
b_2	-0.4960*	-0.5936*	0.3928	(10 : 30 : 250)	5.22	5.43	5.93	6.12	8.34	8.23
b_3	-0.2210	-0.3138	-0.2150	(30 : 20 : 150)	5.34	5.21	6.45	6.34	5.99	6.34
Quadratic				(30 : 30 :150)	4.69	4.76	5.62	5.54	5.33	5.45
b_{11}	-0.0353	-0.2303	0.1738	(30 : 20 : 250)	4.49	4.48	5.74	5.46	4.34	4.23
b_{22}	0.1588	-0.1224	0.2160	(30 : 30 : 250)	4.44	4.42	5.16	5.17	5.98	6.12
b_{33}	0.4306*	0.5253*	0.2301	(3.2: 25 : 200)	5.16	5.18	5.84	6.20	7.80	7.65
				(36.8:25:200)	4.26	4.21	5.21	4.89	4.60	4.45
	0.1096	-0.1269	-0.1984	(20:16.6:200)	5.34	5.65	6.16	6.26	5.52	5.55
	-0.3836	-0.2793	0.0198	(20:33.4:200)	4.58	4.77	5.18	5.43	7.18	7.34
b_{23}	0.3288	0.1269	0.4564	(20 : 25: 116)	5.48	5.48	6.83	6.45	6.85	6.77
R^2	0.7274	0.7592	0.7406	(20 : 25 : 284)	5.14	5.23	6.31	6.12	5.94	6.23
Adjusted R^2	0.4821	0.5425	0.5071	(20 :25: 200)	4.75	4.80	5.84	5.66	5.58	6.34
Lack of fit	NS	NS	*							
Model	*	*	*							
Interaction										
b_{12}										
b_{13}										

[a] $Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$, X_1 = Feed Composition, X_2 = Feed moisture, X_3 = Screw speed[b]*, ** Significant at p < 0.05 and p < 0.01, respectively; NS, not significant.

probability of the F value for the model = 0.05 which can explain the reason for variation. The R^2 value measures the total variation about the mean response as explained by the regression. Since the fitted second-order model provides a good fit, it was used to search for optimum levels of feed composition, feed moisture and screw speed. The effects of treatment variables as linear, quadratic or interaction coefficients are detailed in Table 3. The correlation coefficient of r = 0.85 was significant at ($p \leq 0.05$); therefore, the model could be used to navigate the design space. Hence, the second-order model was judged to be adequate at 0.05%. The effect of extrusion condition on WAI was influenced by linear and quadratic terms significantly ($p < 0.05$) Table 3. The interaction term did not show significant ($p > 0.05$) influence. High water absorption capacity is required to produce 'fura' with acceptable flexibility of consistency. The maximum WSI value of 6.83% was observed for design point 13 (20% feed composition, 25% and 116 rpm screw speed), while the lowest observed value of 5.18% was observed for sample 12 representing 20% feed composition, 33.4% and 200 rpm screw speed (Table 3). The WSI was equally influenced significantly by linear and quadratic terms, ($p < 0.05$), the model did not show a significant lack of fit and recording the coefficient of determinant of R^2 = 0.76 WSI. WSI is often used as an indicator of degradation of molecular components (Yang et al., 2008), which measures the degree of starch conversion during extrusion which is the amount of soluble polysaccharide released from the starch component after extrusion process. WAI has been generally attributed to the dispersion of starch in excess water, and the dispersion is increased by the degree of starch damage due to gelatinization and extrusion–induced fragmentation, that is, molecular weight reduction of amylose and amylopectin molecules (Yagci and Gogus, 2008).

The relationship between depended and independent variables were shown in three dimensional presentation, the response indicated that, increasing feed moisture significantly decreased the WAI of extrudate; increasing the level of soybean flour tends to decrease the WAI Figure 1. This is expected because of oil in soybean which interfered with water uptake. Singh et al. (2007) observed a decrease in WAI with addition of pea grits in extrusion of rice. They explained that a decrease in WAI was due to the dilution of starch in rice pea blends. The WAI 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). Mercier and Feillet (1975) observed that higher amylose results in a higher WAI. Colonna et al. (1989) indicated that WAI decreases with the onset of dextrinization. Pelembe et al. (2002), reported increased WAI as the percentage of cowpea increased in sorghum

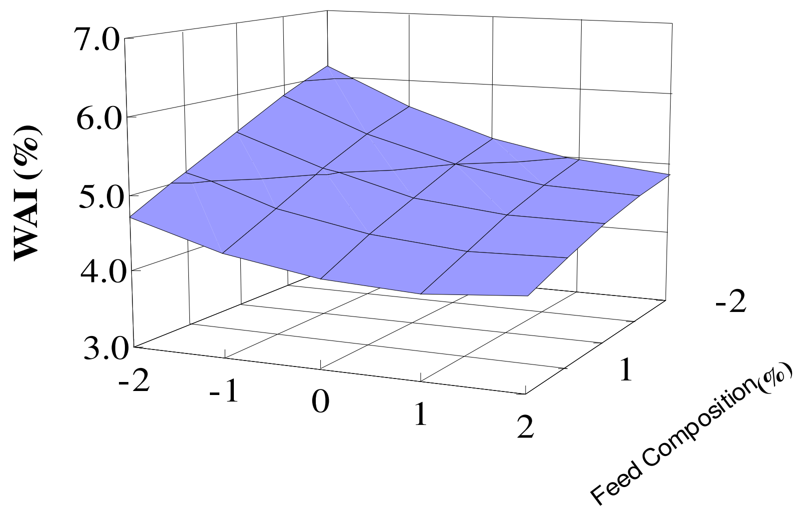

Figure 1. Effect of feed moisture and feed composition on WAI.

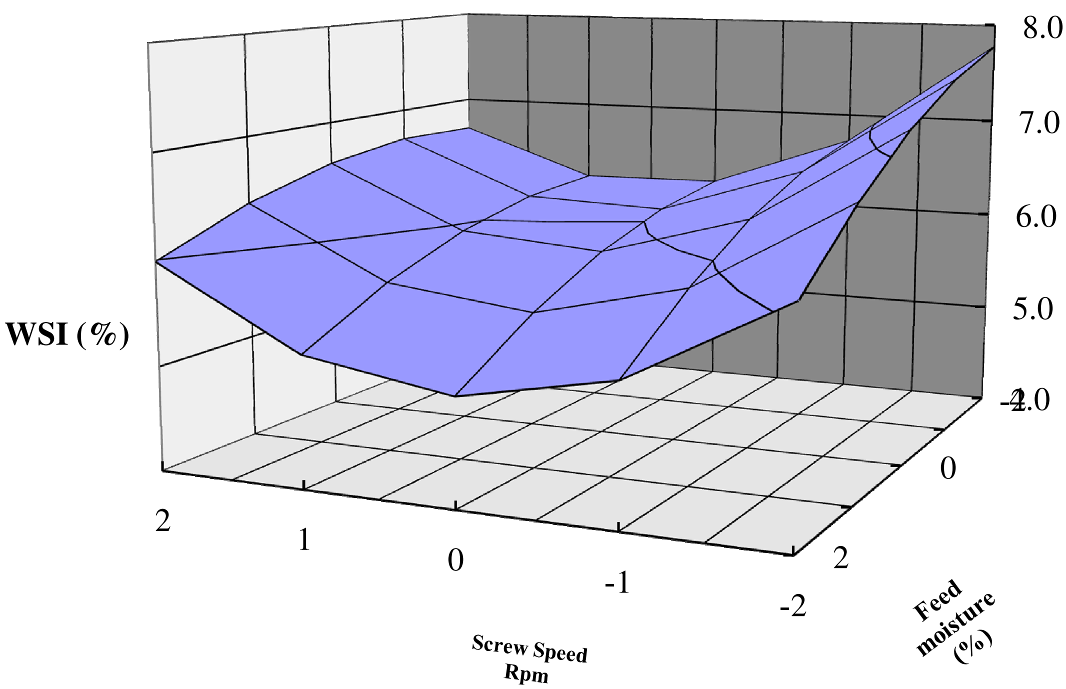

Figure 2. Effect of screw speed and feed moisture on WSI.

extrudates. Cowpea proteins have relatively higher water solubility than sorghum proteins (Chavan and Kadam 1989b). The 3D plot for the WSI indicates that increasing screw speed appears to increase WSI while increasing the feed moisture decreased WSI (Figure 2) significantly. Altan et al. (2008) reported increase in WSI with increase in screw during the extrusion of barley–tomato blends. The increase in WSI with increasing screw speed was consistent with the results reported for corn meal and corn and wheat extrudates (Jin et al., 1995; Mezreb et al., 2003). Mezreb et al. (2003) reported that the increase of screw speed induced a sharp increase of specific mechanical energy, the high mechanical shear degraded the macromolecules, and so the molecular weight of starch granules decreased and hence increased WSI. It could be expected that WSI would decrease since

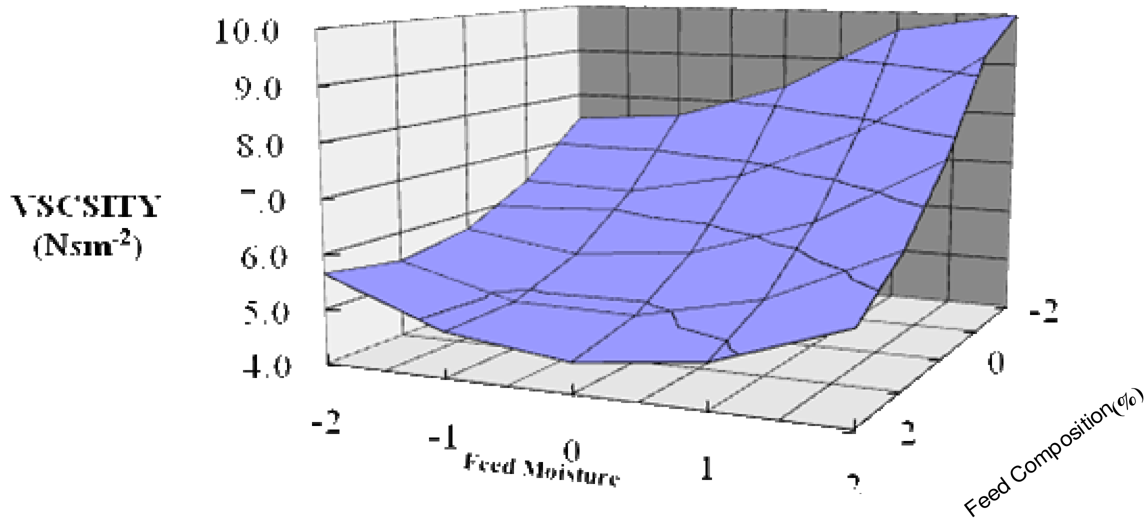

Figure 3. Effect of feed moisture and feed composition on viscosity.

extrudates of high legume content contain more starch aggregates or microgels which will be suspended in water (Gomez and Aguilera, 1983). This suggests that water solubility index (WSI) is not only due to starch contents but also due to water-soluble components, like proteins which are present in soybean. Mercier and Feillet (1975) reported increase in soluble starch with increasing extrusion temperature and decreasing feed moisture. WSI often is used as an indicator of degradation of molecular components (Kirby et al., 1988). 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 Conan, 1971) that proteins are the most reactant components in foods and some of their reactions are essential for functionality. Among functional properties, water holding capacity is important because of the hydrogen bonds formed between water and polar residues of protein molecules.

Viscosity

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. The maximum viscosity value of 8.34 Nsm^{-2} was observed for sample 4 (10% feed composition, 30% feed moisture and 250 screw speed), while the least value of 4.34 Nsm^{-2} was recorded for design point 7 representing 30% feed composition, 20% feed moisture and 250 rpm screw speed Table 3. The viscosity of samples was influenced by linear terms significantly ($p < 0.05$). The coefficient of determinant for the viscosity was $R^2 = 0.74$. Increase in the amount of soybean flour and increase in feed moisture decreased the apparent viscosity of extrudate (Figure 3). In addition to the effect of extrusion, the reduction in viscosity may be attributed to the high level of oil from the soybean flour which consequently decreased the shear effect as a result of lubrication in the metering zone. Increase in moisture on the other hand, will further lubricate the dough leading to less shearing effect. Low moisture in the feed can possibly increase frictional damage, particularly when the residence time is high due to low screw speed. 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). Arambular 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

Table 4. Optimum levels of independent variables for WAI; WSI and VISCOSITY.

Independent variable/Responses	Feed composition (%)	Feed moisture (%)	Screw speed (rpm)	*Predicted value	Nature of stationary point
*WAI g_{Water} per g $_{Sample}$	17.67	27.27	160.8	4.55	Saddle
*WSI (%)	14.77	15.23	219.8	6.15	Saddle
*VISCOSITY(Nsm^{-2})	46.973	29.34	174.52.	4.58	Saddle

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.

This can be attributed to the fact that degradation of the starch occurred during extrusion. It is suggested that starch degradation in the extruded product is a likely significant factor associated low viscosity profiles. The mixtures of raw and extruded starches have potential applications in the industry for functional properties. Arambular et al. *(*1998) reported decreased apparent viscosity of extruded instant corn flour when temperature was increased; though the temperature used in this study was not varied, it was however in the high regime. Likimani et al. (1991) indicated that the degradation of molecular bonding of starch during extrusion influenced the characteristics of the extruded product and was used to characterize the target parameters (solubility and viscosity).

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). Increased screw speed resulted in an increase in input energy which caused stretching and sometimes fracture of protein-protein matrix, thus, making product less viscous when reconstituted, the screw speed from this study influenced viscosity. Linkimani et al. (1991) reported that extrusion induced starch dextrinization which resulted in reduction of viscosity in gruels and a concomitant increase in caloric and nutrient density. Adeyemi and Beckley (1986), reported that a high level of damaged starch would reduce peak viscosity of flour or 'ogi'. Starch dextrinization during extrusion cooking, however, occurred mostly under processing conditions at very high temperature and low moisture (Gomez and Aguilera, 1983) where shear effects were significant. General increase in water absorption of sorghum extrudates was reported by Gomez et al. (1988).

Extrudate photographic responses

The effects of extrusion variables (feed composition, feed moisture and screw speed) can be seen as shown in Plates 1-15. The effect of the independent variables on the expansion ratio of extrudates is evident. The results shown in the photographs describes the changes occurred during extrusion as influenced by the extrusion variables.

Dependent variables and their predictive models

Experimental values were obtained for individual responses Y for the design points. Multiple regression coefficients were obtained by employing a least squares technique to predict quadratic polynomial models for the responses Y. The quadratic regression model for the influenced variables are presented in the equation, where X_1, X_2, and X_3 are the coded values for feed composition, feed moisture and screw speed levels, respectively. The coefficients with one factor represent the effect of the particular factor, while the coefficients with two factors and those with second order terms represent the interaction between the two factors and quadratic effect, respectively. The positive sign in front of the terms indicates synergistic effect, while negative sign indicates antagonistic effect.

$$WAI = -0.3780-0.5860X_1-0.4960X_2-0.2210X_3-0.0353X_1^2 + 0.1588X_2^2+0.4306X_3^2+0.1096X_1X_2-0.3836X_1X_3 + 0.3288X_2X_3$$

$$WSI = -0.1177 - 0.3781X_1 - 0.5936X_2 - 0.3138X_3 - 0.2303X_1^2 - 0.1224X_2^2+0.5253X_3^2-0.1269X_1X_2-0.2793X_1X_3 + 0.1269X_2X_3$$

$$VSCSITY = -0.4230 - 0.7553X_1 + 0.3928X_2 - 0.2150X_3 + 0.1738X_1^2 + 0.2160X_2^2 + 0.2301X_3^2 - 0.1984X_1X_2 + 0.0198X_1X_3 + 0.4564X_2X_3$$

$$EQWS=0.8209+0.5413X_1 - 0.0510X_2 + 0.3823X_3 - 0.0549X_1^2 - 0.4342X_2^2-0.7142X_3^2+0.2001X_1X_2- 0.0150X_1X_3 - 0.0650X_2X_3$$

Optimum conditions

The optimum levels of independent variables and the corresponding predicted values of responses are shown in Table 4. The optimal combination of feed composition (17.7%), feed moisture (27.3%) and screw speed (161

Plate 1 - 15. Shows the physical state of extrudate responses.(1) 10% soybean, 20% feed moisture, 150rpm screw speed; (2) 10% soybean, 30%moisture, 150rpm screw speed; (3) 10% soybean, 20% feed moisture, 250 rpm screw speed; (4) 10% soybean,30% feed moisture, 250rpm screw speed; (5) 30% soybean, 20% feed moisture, 150 rpm screw speed; (6) 30% soybean, 30% feed moisture, 150rpm screw speed; (7)30% soybean, 20% feed moisture, 250 rpm screw speed; (8) 30% soybean, 30% feed moisture, 250 rpm screw speed; (9) 3.2% soybean, 25% feed moisture, 200 rpm screw speed;(10) 36.8% soybean, 25% feed moisture, 200rpm screw speed; (11) 20% soybean, 16.6% feed moisture, 200 rpm screw speed; (12)20% soybean, 33.4%moisture, 200rpm screw speed; (13)20% soybean, 25% feed moisture, 116 rpm screw speed; (14) 20% soybean, 25%, feed moisture, 284 rpm screw speed; (15) 20% soybean, and 25% feed moisture, 200rpm screw speed.

rpm) resulted in optimal WAI of 4.6 g_{Water} per g_{Sample}. All the extrusion variables were located within the range of experimental values of the independent variables; hence, the fitted response equation was adequate for depicting responses near the stationary point. The optimal combination of feed composition (14.77% soybean), feed moisture (15.23%) and screw speed (220 rpm) resulted in optimal WSI of 6.15%. The optimal combination of feed composition (46.97%), feed moisture (29.34%) and low screw speed (174.52) resulted in optimal viscosity of 4.58 Nsm^{-2}.

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, shelf-life of the end product. The (RSM) was effective in explaining the effects of process variables (feed composition, feed moisture and screw speed) during the optimization of water absorption index, water solubility index and the viscosity of 'fura' from millet/soybean flour mixtures by extrusion cooking. Results indicated that the variables were significant on target parameters. The importance of process variables on target parameters could be ranked in the following order: Feed Composition(X_1) > Feed Moisture (X_2) > Screw Speed (X_3). Response variables predicted with model equations under optimum conditions were in general agreement with experimental data. The results from this study could be projected to explore the possibility by interested processors for effective prediction of a known process conditions for the purpose of achieving desired product quality. Extrusion cooking of 'fura' constituted a great improvement on the traditional product that is usually at high moisture content of between 60 - 75% and readily deteriorates on storage at room temperature. Extrudates obtained in this study had moisture content less than 7 g/100g and would not require refigeration for storage.

ACKNOWLEDGEMENT

The funding and support provided by International Foundation for Science (IFS) is gratefully acknowledged and appreciated.

REFERENCES

Adeyemi IA, Beckley O (1986). Effect of period of maize fermentation and souring on Chemical properties and amylograph pasting viscosity of Ogi. J. Cereal Sci., 4: 353.

Altan A, McCarthy KL, Maskan M (2008). Evaluation os snack foods from barley – tomatopomace blends by extrusion processing. J. Food Eng., (84): 231–242.

Arambula VG, Figueroa JDC, Martinez-Bustos F, Ordorica FCA, Gonzalez-Hernandez J (1998). Milling and processing parameters for Corn Tortillas from Extruded instant Dry Masa flour. J. Food Sci., 63 (2): 338-341

Binoy KG, Aaron JO, Gour SC (1996). Reverse screw Element(s) and Feed Composition effects during Twin-Screw Extrusion of ice Flour and Fish Muscle Blends. J. Food Sci., 61(3): 590-595.

Box GEP, Hunter JS (1957). Multifactor experimental design for exploring response surfaces. Annals Math. Stat., 28: 195-242.

Box GEP, Wilson KG (1951). On the experimental attainment of optimum conditions. J. Royal Stat. Soc.,13: 1-45.

Chavan JK, Kadam SS (1989). Nutritional improvement of Cereals fermentation. Crit. Rev. Food Sci. Nutr., 28(5): 349-400.

Colonna P, Tayer J, Mercier C (1989). Extrusion cooking of starch and starchy products. In: Mercier C, Linco P, Harper JM (Eds) Extrusion Cooking. St Paul, MN:American Association of Cereal Chemists. pp. 247-319.

Da S, Akinbala JO, Rooney LW, Miller FR (1982). Evaluation of to quality in sorghum breeding program. *In*: Proceedings of international symposium on Grain quality, Rooney, LW, Murrty DS, Mertins JV(Eds) Pantachem, India. ICRISAT, pp. 11-23.

Davidson VJ, Paton D, Diosady LL, Larocque G (1984). Degradation of wheat Starch in a single-screw extruder: Characteristics of extruded starch polymers. J. Food Sci., 49: 453-458.

Filli KB, Nkama I (2007). Hydration properties of extruded fura from millet and legumes. Br. Food J., 109(1): 68-80.

Filmore EB, Kramer A, Gerald K, (1976). Response surface techniques. In F.E. Filmore A, Kramer K, Gerald (eds.), Systems Analysis for Food Industry AVI, Westport, Connecticut. p. 127.

Gacula (jr) MC, Singh J (1984). *Statistical Methods in Food and Consumer Research,* Academic Press, Inc., New York, pp. 214-272.

Gomez MH, Aguilera, JM (1983). Changes in the starch fraction during extrusion-cooking of corn. J. Food Sci., 48: 378-831.

Gomez MH, RD Waniska LW, Rooney, EW (1988). Extrusion- Cooking of Sorghum Containing Different Amount of Amylose. J. Food Sci., 53(6): 1818-1822.

Gomez MH, Waniska RD, Rooney LW, Lusas E W (1988). Extrusion-Cooking of Sorghum Containing Different Amount of Amylose. J. Food Sci., 53(6): 1818-1822.

Hagenimana A, Xiaolin-Ding, Tao-Fang (2006). Evaluation of rice flour modified by extrusion cooking. J. Cereal Sci., 43(1): 38-46.

Hoseney RC, Faubion JM, Reddy VP (1992). Orgnoleptic implications of milled pearl millet pages 27-32 *in* utilization of sorghum and millets (Gumez MI, House LR, Rooney LW, Dendy DAV. (eds). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Iwe MO, Van Zauilichem DJ, Ngoody PO, Ariahu CC (2001). Residence Time Distribution in a Single- Screw Extruder Processing Soy- Sweet Potato Mixtures. *Lwt*., 34 (7).

Jansen GR, O'Deen L, Tribelhorn RE, Harper JM (1981). The Calorie densities of gruels made from extruded corn-soy blends. Food Nutr. Bull., 3(I): 39

Jideani VA, Nkama I, Agbo EB, Jideani IA (2002). Identification of the hazard and critical control (HACCP) in traditional fura manufacture. Niger. Food J., 19: 42-48.

Jin Z, Hsieh F, Huff HE (1995). Effects of soy fiber, salt, sugar, and screw speed on physical properties and microstructure of corn meal extrudate. J. Cereal Sci. 22: 185-194.

Kirby AR, Ollet AL, Parker R, Smith, AC (1988). An experimental study of screw configuration effects in the twin-screw extrusion-cooking for maize grits. J. Food Eng., 8: 247-272.

Likimani TA, Sofos JN, Maga JA, Harper JM (1991). Extrusion cooking of corn/soy bean mix is presence of thermostable a-amylase. J. Food Sci., (56)1: 99-105.

MATLAB Version 6.0.0.88 Release 12 1984-2000. The Math Works, Inc.

Mercier C, Feillet P (1975). Modification of carbohydrate components by extrusion-cooking of cereal products. Cereal Chem., 52: 283-297.

Mezreb K, Goullieux A, Ralainirina R, Queneudec M (2003). Application of image analysis to measure screw speed influence on physical properties of corn and wheat extrudates. J. Food Eng., 57: 145 -152.

Myers RH, Montgomery DC (2002). Response Surface Methodology: Process and Product Optimization Using Designed Experiment (2nd ed). John Wiley and Sons. Inc.

Myers RH, Montgomery DC (1995). Response Surface Methodology: Process and Product Optimization Using Designed Experiment (2nd ed). John Wiley and Sons. Inc.

Nkama I, Filli KB (2006). Development and Characteristics of Extruded fura from mixtures of pearl millet and grain legumes flours. Int. J. Food properties, 9: 157-165.

Ozcan S, Jackson DS (2005). Functionality behavior of raw and extruded corn starch mixtures. Cereal Chem. 82(2): 223-227.

Pelembe LAM, Erasmus C, Taylor JRN (2002). Development of a Protein – rich Composite Sorghum – Cowpea Instant Porridge by Extrusion Cooking Process. Lebensm – Wiss. U. – Technol., 35: 120-127.

Pomeranz Y (1991). Functional Properties of Food Components, 2nd Edition. Academic Press, Inc., NY.

Qing –Bo D, Ainsworth P, Tuker G, Marson H (2005). The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice – based expanded snacks. *J. Food Eng.* 66: 284-289.

Singh B, Sekhon KS, Singh N (2007). Effects of moisture, temperature and level of pea grits on extrusion behavior and product characteristics of rice. Food Chem., 110: 198-202.

Thomas DJ, Atwell WA (1997). Starches. Eagan Press Handbook Series. Eagan Press, Minnesota, U. S. A.

United Soybean Board, (2006). Consumer attitudes about nutrition; insights into nutrition; health and soyfoods. 13th Annual National Report. Chesterfield, Mo: USB

Wanasundara PK, Shahidi F (1996). Optimization of

hexametaphosphate-assisted extraction of flaxseed protein using response surface methodology. J. Food Sci., 61(3): 604-607.
Wolf WF, Cowan JC (1971). Soybean as a food source. CRC critical Rev. Food Technol., 2(1): 81.
Yagci S, Gogus F (2008). Response Surface Methodology for Evaluation of Physical and Functional Properties of Exruded Snack Foods Developed from Food – by – Products. J. Food Eng., (86) 122–132.
Yang S, Peng J, Lui W, Lin Jenshinn (2008). Effects of adlay species and rice flour ratio on the physicochemical properties and texture characteristic of adlay-based extrudates. J. Food Eng., (84): 489-494.
Yeu K, Lee Y, Lee SY (2008). Consumer Acceptance of an Extruded Soy-Based High-Protein Breakfast Cereal. J. Food Sci., 73(1): S20-S25.
Zasypkin DV, Tung- Ching L (1998). Extrusion of Soybean and Wheat Flour as Affected by Moisture content. J. Food Sci., 63(6): 1058-1061.