Application of response surface methodology for the evaluation of proximate composition and functionality of millet-soybean fura extrudates

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Fura is a traditional thick dough ball snack produced principally from millet or sorghum which is common in Northern Nigeria. It is consumed with nongo (traditional yoghurt produced from cow milk) or mashed in water before consumption in the form of porridge. A three-factors of three level central composite rotatable design CCRD was adopted to study the effect of feed composition ($X_1$), feed moisture content ($X_2$) and screw speed ($X_3$) on proximate compositin and amino acid during extrusion of pearl millet and soybean flour mixtures for the purpose of fura production. Extruded fura was produced from pearl millet and soybean, blends using a single screw extruder. Regression models were developed to predict the variables. The result of proximate composition shows that protein, carbohydrates, fat, ash and moisture were significantly influenced by the linear, quadratic and interaction terms of independent variables ($p<0.05$), with $R^2 = 0.96, 0.96, 0.94, 0.79$ and $0.80$, respectively. The coefficients showed good fit for the model. Regression models for data were significant ($P<0.05$) with satisfactory coefficients of $R^2$ for lysine, leucine, isoleucine, valine, threonine and tryptophan which were 0.92, 0.95, 0.79, 0.88, 0.83 and 0.71; the coefficients shows good fit. The effect of extrusion conditions on water absorption index (WAI) was influenced by liner and quadratic terms significantly ($p<0.05$). The water solubility index (WSI) was equally influenced significantly by linear and quadratic terms, ($p<0.05$). Extrusion conditions affected the expansion ratio (ER) by the linear term and bulk density (BD) by both linear and quadratic terms significantly ($p<0.05$). The models showed good fit with $R^2 = 0.92$ and 0.96 for ER and BD respectively. The CCRD was effective in optimizing the process condition for fura as influenced by feed composition, feed moisture and screw speed. The importance of process variables on system parameters and physical properties could be ranked in the following order: Feed Composition ($X_1$) > Feed Moisture ($X_2$) > Screw Speed ($X_3$). The protein quantity and quality of fura increased interms of amino acid profile which justified the reason for fortification of millet with soybean for fura production. 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.

Key words: Millet; Soybean, extrusion, fura, protein, amino acid, functionality.

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 where it is used as food for an estimated 400 million people (Hoseney et al., 1992). Pearl millet (Pennisetum glaucum) is a cereal used as a food grain, with an estimated 64 million acres of pearl millet being grown in Africa and India. It is known to have a higher protein content and better amino acid balance than sorghum (Dendy, 1995). It is grown mostly in regions of low rainfall and is capable of withstanding adverse agro climatic conditions. Several food preparations are made from pearl millet in Africa and India (Vogel and Graham, 1979; Subramanian and Jambunathan, 1980a). Although carbohydrates are their main contribution, they also provide proteins and other nutrients like fats, fiber, vitamins and minerals. It is
generally known that the major drawbacks of cereals is their low protein content and the limited biological quality of their proteins which is highly deficient in lysine (Waliszewski et al., 2000; Martinez – Flores et al., 2005; Nkama and Fili, 2006) when compared with proteins of animal sources.

Legumes on the other hand are cheaper sources of proteins when compared to animal proteins in developing countries (Singh and Jambunathan, 1991). One way of evaluating the nutritional quality of a protein is by its chemical score, obtained by comparing its essential amino acid composition to that of a standard reference protein (e.g. whole egg protein). The limiting amino acids in legumes are the ones containing sulphur (methionine and cystine). Their percentage in soybean protein however is about 70% of that of whole egg protein. On the other hand, for a plant protein, soybean protein is exceptionally rich in lysine and can serve as a valuable supplement to cereal foods where lysine is a limiting factor.

Grain legumes are traditionally consumed as human foods, along with cereals in various forms. Grain legume proteins are rich sources of lysine, but are usually deficient in sulphur containing amino acids, methionine, and cystine. It is well known that addition of legumes to cereals increases both content and quality of protein mix (Obatolu, 2002; Plahar et al., 2003). Wu et al. (2010) reported the inclusion of flaxseed to maize improved the protein content and quality. Health and nutrition is the most demanding and challenging field in this present era and would continue to be in the future as well. Maintaining and increasing the nutritional quality of food during food processing is always a potentially important area of research, especially in the developing countries.

Fura is one of the indigenous foods prepared from cereals in West Africa sub region. It is a traditional thick dough ball snack produced principally from pearl millet or sorghum. The mode of preparation varies only slightly among different communities, but the basic ingredient remains the same (i.e. millet or sorghum). Depending on the community, it is consumed with nono (local yoghurt produced from cow milk) or mashed in water before consumption in the form of porridge. Acceptability of fura has suffered some drawback, because it's processing method which has remained a home-based or artisanal activity that is carried out with rudimentary equipment and techniques, characterized by inconsistent product quality, poor hygiene, very short shelf life and unacceptable standards.

Furthermore the product lacks process specifications governing composition and ingredients. Fura has a limited storage life with a range of 3 - 4 days at refrigeration storage (5°C), 1 to 2 days at room temperature (25°C) and 18 hours at 35°C (Jideani et al., 2002); being a single cereal based product it is limiting in the essential amino acid, lysine. Among all amino acids, lysine is the most limiting essential amino acid in cereal-based products, which are the majority of extruded products (Sin et al., 2006). As a means of resolving issues related to malnutrition associated with the consumption of cereal based foods like fura, due to their low protein content, fortification of millet with soybean can go a long way in improving the protein quantity and quality of fura which is traditionally made solely from pearl millet.

Extrusion cooking may be defined as the process by which moistened, starchy, and /or proteinaceous materials are plasticized and cooked in a tube by a combination of pressure, heat, and mechanical shear. The resulting high temperatures within the tube promote gelatinization of starch components, denaturation of proteins and stretching and restructuring of tractile components. This is followed by exothermic expansion of the product that is shaped by the openings in the die. These formed ropes are subsequently cut into shaped segments of the length desired (Smith and Ben-Gera, 1980).

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.

Despite increased use of extrusion processing, extrusion is still a complicated multiple -input - multiple output process that has yet to be mastered. Small variations in processing conditions can affect process variables as well as product quality depending on the extruder type, screw configuration, feed moisture, and temperature profile in the barrel session, screw speed, die configuration and feed rate (Qing – Bo Ding et al., 2005; Neelam et al., 2006). Deterioration of nutritional quality, owing to high temperature, lack of process control etc is a challenging problem in most traditional cooking methods (Singh et al., 2007).

The extrusion process denatures undesirable enzymes, inactivates some antinutritional factors (trypsin inhibitors, haemagglutinins, tannins and phytates); sterilizes the finished product; and retains natural colours and flavours of foods (Fellows, 2000; Bhandari et al., 2001; Guy, 2001). Feeds which have ingredients such as soybean meal and cereal grains can be made more digestible, and the nutrients are therefore made more available. The process has found numerous applications, including increasing numbers of ready-to-eat cereals products (Harper, 1989; Eastman et al., 2001; Singh et al., 2007).

The inclusion of soybean as a basic ingredient in producing fura through extrusion can improve its physical state 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). Nkama and Filli (2006) and Filli and Nkama (2007) reported that extruded fura from cereal 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 a reduction in viscosity which is an indication of concomitant increase in nutrient density, but the process method was not optimized.

High temperature, short-time (HTST) extrusion cooking could be used to produce such foods of high nutritional quality and ready to eat products (Conway and Anderson, 1973; Akinyele, 1987; Obatolu, 2002; Obatolu and Cole, 2000; Pelembé et al., 2002). Modeling of extrusion processing involves consideration of process parameters, system parameters, and product properties. Though mathematical modeling of food extrusion process has benefited from available information on plastic extrusion, modeling of quality changes during food extrusion is a difficult task. Response surface method (RSM) is a statistical – mathematical tool which uses quantitative data in an experimental design to determine, and simultaneously solve multivariate equations, to optimize processes (Sefa – Dedeh et al., 2003); it has been successfully used for developing, improving and optimizing processes (Wang et al., 2007). Functional properties of food products play an important role in consumer acceptance.

Appearance, size, shape, texture, consistency, viscosity and mouthfeel are some of the important physical characteristics in various food products. The same attribute considered desirable in one food may be undesirable in another. For an example, high viscosity is desirable in a soup but not in a beverage. The processor selects his ingredients and process in order to obtain the desirable properties to food systems is called functionality. Foods are complex systems consisting of various components such as proteins, fats, carbohydrates and mineral salts which have influence on functional properties. Therefore, the overall functionality of one ingredient cannot be considered independent of the others. Rather, the observed functional effects are the result of interaction between the ingredients.

This has made the study of functionality a difficult exercise. Although considerable information exists on the subject, it is not well defined and organized. The lack of universally accepted techniques for determination of functional properties, and standardized terminology in description, has further complicated the matter. Nevertheless, studies on functionality of individual food ingredients in simple systems are useful to predict, control and eventually impart desirable characteristics to real food systems. The term functionality as applied to food ingredients is defined as any property, aside from nutritional attributes, that influences an ingredient’s usefulness in food. Most functional properties affect the sensory characteristics of food (especially their textural attributes) but also can play a major role in the physical behavior of foods or food ingredients during their preparation, processing storage (Fenema, 1985).

The objectives of this work was to study the effects of process variables feed composition (ratio of soybean to millet), feed moisture content and screw speed on the physico-chemical properties and determine the optimum condition of extrudates from pearl millet and soybean flour mixtures using response surface methodology.

MATERIALS AND METHODS

Flour preparation from millet

The process of flour preparation consists of dry cleaning of millet i.e. winnowing using an aspirator, Vegvari Ferenc (OB125, Hungary). 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 were washed and then dried in a Chirana convection oven model (HS 201A, Czech Republic) at 50°C for 24 hours to 14% moisture content. The dried grain was milled using a Brabender roller mill (OHG DUIISBURG model 279002, Germany) 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 hours in a plastic bowl. The kernels were thereafter dehulled using traditional pestle and mortar. After dehulling, 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% 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 150μm screen, and the underflow was used for further research work.

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. The seeds were then milled 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 (Mi) and soybean flour (Si) 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 Lee, (1998). Weights of the components to be mixed were calculated using the following formula:

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

(1)

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

(2)

\[ W_X = M - C_{SF} - C_{MF} \]  

(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 & Ginger) at 1% level based on traditional formulation; and the whole packed in polyethylene bags which were kept in the refrigerator overnight to allow moisture equilibration. The samples were however brought to room temperature before extrusion process.

**Experimental design and data analysis**

A three-factor three levels 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 the proximate composition and amino acid profile during extrusion of pearl millet and soybean flour mixtures for fura production. 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 are presented in Table 2. Homogeneous variances or homoscedasticity is a necessary pre-requisite 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 (SPSS, 2008). 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:

\[ Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_1^2 + b_5 X_2^2 + b_6 X_3^2 + b_7 X_1 X_2 + b_8 X_1 X_3 + b_9 X_2 X_3 \]  

(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 \( b_{23} \) are interaction regression coefficient terms.

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 fitted quadratic equations, by holding the variable with the least effect on the response equal to a constant value, and changing the other two variables.

**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 ensured 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 length to diameter ratio (L/D) of 20:1. 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 ±0.28 joules (Nm) or about 0.5% of full scale (Likmani et al., 1991). The extrusion process consisted of 15 individual runs and was conducted randomly.

**Moisture analysis**

Moisture contents of raw and extrudate samples were determined as described by AOAC (1984). Triplicate determinations were carried out and the result averaged.

**Crude fat determination**

Crude fat of samples was determined using soxhlet fat extraction system as described by AOAC (1984).

**Crude protein determination**

Protein content was determined by Kjeldahl Method as described by AOAC (1984). Triplicate determinations were carried out and the result averaged.

**Ash determination**

Ash was determined as described by method of AOAC (1984). Triplicate determinations were carried out and the result averaged.

**Determination of carbohydrates**

The percentage carbohydrate was determined by difference as described by Egan et al. (1981).
Amino acid analysis

The method of Sotelo et al. (1994) was used in determining the amino acid content of the extrudates. One gram of sample was dissolved in 20 ml of 6N HCl. This was then poured into a hydrolysis tube with screw cap and hydrolyzed for 22 hour under a nitrogen atmosphere. The acid was evaporated using a rotary evaporator and residue washed three times with distilled water. The extracted sample was dissolved in 1ml acetate buffer of pH 3.1. After dilution to a known volume, the hydrolysate was transferred into a Beckman system (model 6300) high performance amino acid analyzer. Amino acid scores were calculated as gram per 100 gram protein (g/100g protein). Triplicate determinations were carried out and the result averaged.

Expansion ratio (puff ratio)

Expansion ratio can be of two indices, diametral and longitudinal as described by Sopade and Le Grys (1991). Diametral expansion is defined as the diameter of the extrudate whilst longitudinal expansion is defined as the length per unit dry weight. The diameter was determined after cooling of the extrudate, 10 samples were assessed for each extrudate and for each sample; diameters at three different positions were taken using vernier calipers and the result averaged. Expansion ratio expressed as the diameter of the extrudate to the diameter of the die.

Bulk density

The bulk density of extrudates was calculated using the methods described by Qing-Bo et al. (2005) as follows:

\[
\text{Density} = \frac{4 \times m}{\pi \times D^2 \times L}
\]

Where \( p \) is the bulk density of extrudate (Kgm\(^{-3}\)), \( m \) is the mass of extrudate with diameter \( D \) and \( L \) is the extrudate length per kilogram (m/Kg). The samples were randomly selected and replicated 10 times and the average value taken.

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 30ºC for 30 minutes; it was stirred gently during this period and centrifuged at 3000 x g for 15 minutes. 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 = 500µm) per unit weight of original dry solids (gH\(_2\)O/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, i.e. connecting a liquid circulation thermostat to the correct temperature was ensured. Viscosity measurement was carried out at 30ºC. Triplicate determination was carried out and the result averaged.

RESULTS AND DISCUSSIONS

Model description

Table 3 shows the coefficients of the variables in the models and their corresponding coefficients of determinant (R\(^2\)). The model did not show a significant lack of fit (P = 0.0915), with R\(^2\) = 0.79, 0.79 and 0.71 for the ash, isoleucine and tryptophan respectively. The probability of the F value for the model equals to 0.05, which can explain the reason for variation. 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 value of the parameters within experimental range. The responses modeled as linear, quadratic and interactions of three independent variables were tested for adequacy and model fitness using ANOVA. The selections of adequate models were determined using model analysis, lack of fit test and high R\(^2\) analysis. The lack of fit test compared the residual error to the pure error from replicated design points. The
model with no significant lack of fit and high $R^2$ was selected, (Table 3).

**Proximate Composition**

Regression coefficients for objective responses for extruded fura proximate composition are presented in Table 3. Analysis of variance (Table not shown) indicates that the linear, quadratic and interaction terms effects of the independent variables significantly ($P < 0.05$) affected the proximate composition. From the result it shows that CHON (protein), CHO (carbohydrate), FAT (fat), ASH (ash) and HOH (moisture content) were significantly influenced by the linear, quadratic and interaction terms ($P<0.05$), with $R^2$ = 0.96, 0.96, 0.94, 0.80 and 0.80, respectively. The coefficients showed good fit for the model. The positive significant linear coefficients of feed composition $X_i$ (level of soybean) indicated that the effects on CHON and FAT were an increase i.e. increase in the level of soybean resulted in increased CHON and FAT contents.

The negative effect of both linear and quadratic coefficients of feed composition ($X_i$) on the CHO suggests that both linear and quadratic effects decreased the CHO contents of fura extrudates. The regression analyses results (Table 3) show clearly that the feed composition (level of soybean) had positive linear effect ($P<0.05$) on the protein, fat and ash contents of fura extrudates. Similar observation is shown for the quadratic effect indicating positive correlation for the protein, fat and ash content of extrudates. The most important variable which influenced the protein content was the feed composition (level of soybean) which was expected, because soybean is used for supplementation with cereals.

The mean experimental value of proximate composition of extruded fura samples is presented in Table 4. From the result it shows that the mean values of crude protein content ranged from 14.13 – 23.35%. In the case of fat content, the mean value ranged from 5.04 – 9.68% (Table 4). Obatolu (2002) similarly reported an increase in protein and fat content during extrusion of millet and soybean blends. This increase is a desirable effect for complimentary formulations. Eleven formulations, out of the 15 design points in this study have met up the minimum fat requirement of 6% for complimentary formulations (Mitzer et al., 1984).

The predicted value plotted from the regression equation (not shown) indicated that the plot for proximate composition of protein (CHON) content increased as the level of soybean flour was increased, while screw speed seems not to show any significant effect on the CHON content. There was a tremendous increase in FAT content as the level soybean was increased. Increase in feed moisture appears not to have shown any significant influence on the FAT content. Inclusion of soybean flour appears to have influenced the compositions; protein and fat content significantly as soybean flour was increased in the blend. The 3D plot (not shown) indicated that increase in the level of soybean flour resulted in decreased carbohydrate (CHO) content. The influence of feed moisture and feed composition on the ash (ASH) content showed that there was marginal increase and remained almost constant (3D plot not shown).

From the view point of protein content, which is the basis for advocating cereal – based complementation as a method of improving the protein content of cereal – based traditional foods, it can be said to be justified by the results of this study. Several workers have also reported marked improvements in the protein content of cereals when fortified with legumes (Akpapanam and Sefa – Dedeh, 1995; Sefa – Dedeh et al., 2003; Nkama and Filli, 2006; Sumathi et al., 2007; Curic et al., 2007; Kasprzak and Rzedzicki, 2008). Furthermore, soybean is often used to improve the protein quality of cereal blends, due to its high levels of protein (40%) and fat (20%); in addition it is particularly high in lysine (Harper, 1980; Hagenimana et al., 2007).

**Amino acid profile**

The regression coefficients for the model of millet – soybean based extruded fura amino acid profile are presented in Table 3. The regression models for the data were significant ($P<0.05$) with satisfactory recorded coefficients of $R^2$ for lysine, leucine, isoleucine (I/leucine), valine, threonine and tryptophan were 0.92, 0.95, 0.79, 0.88, 0.83 and 0.71; the coefficients showed good fit for the model. Analysis of variance (Table not shown) indicates that the linear effects of the independent variables significantly ($P < 0.05$) affected the lysine, isoleucine, leucine, valine, threonine and tryptophan. Examination of the regression analysis shows that the feed composition $X_i$ (level of soybean) indicated positive linear effect ($P<0.05$) for lysine, isoleucine, leucine, valine, threonine and tryptophan. Both linear and interaction terms showed no significant ($P>0.05$) effect on the I/leucine content. The positive significant linear coefficients of the independent variable (feed composition) on lysine, I/leucine, leucine, valine, threonine and tryptophan; were based on increases in their levels as soybean flour was added in the
The mean experimental values of amino acid profile for fura extrudates are presented in Table 5. The lysine content of extrudate tremendously increased as expected as a result of inclusion of soybean flour. From the results, the mean lysine content ranged from 5.45 to 6.82 g/100 protein. The design points of mixtures with lower levels of soybean resulted in higher methionine content. This effect may be attributed to the fact that cereals like pearl millet are rich in methionine. Related observations have been made by other authors for blends of cereals and legumes (Isaac and Johnson, 1975; Obatolu, 1998; Obatolu, 2002). The 3D surface plots (not shown) for amino acids indicated that, increasing the level of soybean flour resulted in increased values for lysine, threonine, valine and tryptophan of fura extrudates. The mean experimental data of the amino acids profile from this study revealed that, the amino acid values were present in adequate amount if compared with the recommended values of FAO/WHO (1973).

Addition of soybean protein to extruded corn products have been practiced to improve its nutritional value (Neumann et al., 1984; Harris et al., 1988; Obatolu, 2002). Obatolu (2002) reported that, mixtures of malted millet and soybean significantly improved protein quantity and quality in terms of amino acid profile. Soybean-corn blends are widely used in the Food for Peace Programme and large amounts of corn/soy blend have been supplied as emergency relief and developmental aid to poor countries around the world (USAID, 1996). Nkama and Malleshi (1998) reported that, lysine increased by 75% as a result of supplementation of millet with cowpea at 83:17 ratio. They also reported similar increase in the amount of other essential amino acids as a result of supplementation.

Legumes, usually provide a larger protein intake and amino acid balance when consumed with cereals, which can significantly improve the protein quantity and quality (Bressanani, 1975). Pelembe et al. (2002) reported that protein content of extrudates increased proportionally with the amount of cowpea flour in sorghum, during extrusion of sorghum – cowpea mixtures. Soybean protein provides nutritional benefits other than protein fortification as indicated in several investigations (Faller et al., 1999).

Anderson et al. (1995) presented a meta-analysis of more than 30 studies in which soybean protein was substituted for animal protein and found a positive hypocholesterolemic effect when substantial quantities of soy protein were added to the diet. The nutritional value of protein is dependent on the quantity, digestibility and availability of its essential amino acids. Digestibility is considered as the most determinant of protein quality in adults, according to FAO/WHO/UNU (1985). Although digestibility test was not conducted in this study, Singh et al. (2007) reported that, protein digestibility value of extrudates is higher than non-extruded products. The possible cause might be denaturation of proteins and inactivation of antinutritional factors that impair digestion (Singh et al., 2007). The nutritional value of vegetable protein is usually enhanced by mild extrusion cooking conditions, owing to increase in digestibility (Srihara & Alexander, 1984; Hakansson et al., 1987; Colonna et al., 1989; Areas 1992; Singh et al., 2007).

**Expansion ratio (ER)**

Multiple linear regression analysis of the experimental data yielded second order polynomial model for expansion ratio (Table 3). The mean values of expansion ratios (ER) of the extruded fura samples are shown in Table 4. Analysis of variance (table not shown) indicates that only the linear effects of the independent variables significantly (P<0.05) affected the expansion ratio. The response equation coefficient for ER is presented in Table 3. The models showed good fit with R² =0.92 for ER. This suggests a very good fit to the experimental data and the model could be used to describe the process.

The negative significant (P < 0.05) linear coefficients of feed composition (X₁) and feed moisture (X₂) indicated that their effects on ER were a decrease. Moisture plays a key role in the mechanism responsible for expansion. Considering the elastic properties of the amylopectin network in food materials as being responsible for diametral expansion and 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.

The fact that a long slit die was used probably facilitated bubble growth in the longitudinal direction. Harmann and Harper (1973) postulated two factors in governing expansion: (a) dough viscosity, and (b) elastic force (die swell in the extrudate). The elastic forces will be dominant at low moisture and temperature. The bubble growth, which is driven by the pressure difference between the interior of the growing bubble and atmospheric pressure resisted primarily by the viscosity of the bubble wall, dominate the expansion at high moisture content high temperature (Panmananbhan & Bhattacharyya, 1989).

A viscoelastic melt in a food extruder expands due to flashing of moisture at the die exit. The expansion process can be described as nucleation in the die, extrudate swelling immediately beyond the die, followed by bubble growth and collapse (Kokini et al., 1991). Increased water content in the melt would soften the
Table 3. Regression equation coefficients for objective responses  Proximate Composition and Amino acid profile1, 2

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>CHON</th>
<th>CHO</th>
<th>FAT</th>
<th>ASH</th>
<th>HOH</th>
<th>LYSNE</th>
<th>I/LECNE</th>
<th>LEUCNE</th>
<th>VALINE</th>
<th>MET-CYT</th>
<th>THRNE</th>
<th>TRYTPN</th>
<th>ER</th>
<th>BD</th>
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<tbody>
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<td>Linear</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>B_0</td>
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<td>-0.1301</td>
<td>-0.1241</td>
<td>0.7169*</td>
<td>0.4529</td>
<td>-0.0346</td>
<td>-0.0893</td>
<td>0.6954</td>
<td>-0.7468</td>
<td>0.4150</td>
<td>0.4952</td>
<td>-0.2424</td>
<td>0.2005</td>
</tr>
<tr>
<td>B_1</td>
<td>1.1227*</td>
<td>-1.1181*</td>
<td>1.1084*</td>
<td>0.8182*</td>
<td>0.2241</td>
<td>0.9550*</td>
<td>0.9270*</td>
<td>1.0336*</td>
<td>0.8716*</td>
<td>-0.5338</td>
<td>0.9218*</td>
<td>0.8549*</td>
<td>-0.2890*</td>
<td>0.2558*</td>
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<tr>
<td>B_2</td>
<td>0.0006</td>
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<td>0.0973</td>
<td>0.0461</td>
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<td>-0.0028</td>
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<td>-0.1174</td>
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<td>1.0557*</td>
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<tr>
<td>B_3</td>
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<td>0.0319</td>
<td>0.0010</td>
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<td>-0.0005</td>
<td>0.0756</td>
<td>0.0251</td>
<td>0.0154</td>
<td>0.0722</td>
<td>-0.2084*</td>
</tr>
<tr>
<td>Quadratic</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>B_{11}</td>
<td>0.2179*</td>
<td>-0.1804*</td>
<td>0.2531*</td>
<td>0.5412*</td>
<td>-0.3008</td>
<td>-0.0031</td>
<td>0.1601</td>
<td>-0.0857</td>
<td>-0.5632*</td>
<td>0.5675</td>
<td>-0.2369</td>
<td>-0.2869</td>
<td>0.2251</td>
<td>-0.2652*</td>
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<tr>
<td>B_{22}</td>
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<td>-0.3008*</td>
<td>-0.1631</td>
<td>0.0508</td>
<td>0.1275</td>
<td>-0.1538</td>
<td>0.1672</td>
<td>-0.0755</td>
<td>-0.1556</td>
<td>0.0845</td>
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<td>B_{33}</td>
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<td>0.1102</td>
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<td>-0.4491</td>
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<td>-0.1678</td>
<td>0.0695</td>
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<td>-0.1744</td>
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<td>-0.1139</td>
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<tr>
<td>Interaction</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>B_{12}</td>
<td>-0.0202</td>
<td>0.0164</td>
<td>0.0311</td>
<td>-0.0560</td>
<td>0.0035</td>
<td>0.0635</td>
<td>-0.0193</td>
<td>-0.0133</td>
<td>0.0633</td>
<td>0.0252</td>
<td>0.2506</td>
<td>-0.0331</td>
<td>0.0308</td>
<td>0.0095</td>
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<tr>
<td>B_{13}</td>
<td>0.0159</td>
<td>0.0126</td>
<td>0.0044</td>
<td>-0.0187</td>
<td>-0.1012</td>
<td>0.0353</td>
<td>-0.0138</td>
<td>0.0111</td>
<td>0.0448</td>
<td>0.0151</td>
<td>0.1291</td>
<td>-0.0728</td>
<td>-0.0993</td>
<td>0.1068</td>
</tr>
<tr>
<td>B_{23}</td>
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<td>-0.0706</td>
<td>0.0151</td>
<td>-0.0560</td>
<td>0.5617*</td>
<td>0.0776</td>
<td>-0.0193</td>
<td>-0.0819</td>
<td>0.0541</td>
<td>-0.1463</td>
<td>0.0684</td>
<td>0.0463</td>
<td>-0.0034</td>
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</tr>
<tr>
<td>R^2</td>
<td>0.9567</td>
<td>0.9592</td>
<td>0.9367</td>
<td>0.7904</td>
<td>0.7980</td>
<td>0.9180</td>
<td>0.7910</td>
<td>0.9480</td>
<td>0.8750</td>
<td>0.4860</td>
<td>0.8330</td>
<td>0.7070</td>
<td>0.9150</td>
<td>0.9639</td>
</tr>
</tbody>
</table>

Adjusted R^2

| Lack of fit | NS | * | * | NS | NS | * | * | * | NS | NS | NS | NS | * | * |

*Model*

1 Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1^2 + b_5X_2^2 + b_6X_1X_2 + b_7X_1X_3 + b_8X_2X_3

X_i = Feed Composition, X_5 = Feed Moisture, X_6 = Screw Speed  2Significant at P < 0.05; NS, not significant 3CHON = Protein; FAT = Fat; CHO = Carbohydrate; ASH = Ash; HOH = Water; ER = Expansion ratio; BD = Bulk density.

amyllopectin molecular structure and reduce its elastic characteristics to decrease diametral expansion (Avarrez-Martinez et al., 1988). In addition increased level of soybean (X_5) flour marginally decreased expansion ratio which is expected because of the high fat in the soybean flour. Feed moisture has been identified as the main factor affecting extrudate expansion and density (Faubion & Hosney, 1982; Harper and Tribelhorn, 1992; Gujral et al., 2001). Extrudates can expand in both the cross-sectional (diametrical) direction and the longitudinal direction (Launary and Lisch, 1983). A porous, expanded, sponge-like structure is formed inside extrudates as a result of many tiny steam bubbles created by the rapid release of pressure after exiting the die (Conway, 1971). Increased feed moisture during extrusion would provoke change in the amyllopectin molecular structure of the material reducing the melt elasticity thus decreasing the expansion and increasing the density of extrudate (Qing-Bo et al., 2005). A puffer extrudate was reported by decreasing the lipid content in the feed mix (Bhattacharya and Hanna, 1988). Singh et al. (2007) reported decrease in ER with increase in feed moisture of rice – pea grits extrudates. Extruded snacks possess the typical texture of puffed, light and crispy. Some physical properties of extruded snack were reported including bulk density of 48-64 g/L, 50-160 g/L (Moore, 1994) and 59 10g/L (Boonyasirikool et al., 1996) and expansion ratio of 3.06 - 3.83 (Mohamed, 1990) and 4.03 (Boonyasirikool et al., 1996). From the regression equation it shows that increasing screw speed appears to increase the expansion ratio.
Modified starch/soybean protein isolate mixtures had expansion of extrudate containing soybean protein. Seker, (2005) reported that increasing screw speed had higher sectional starch. He further reported that mixtures of soybean protein isolate/modified starch had higher sectional starch. 

Filli and Nkama, (2007) reported that pearl millet: groundnut (70:30) fura had the while the pearl millet: groundnut (70:30) fura had the

Table 4. Experimental design and proximate composition of the extrudates

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Dependent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>CHON</td>
</tr>
<tr>
<td>10</td>
<td>14.68±0.23</td>
</tr>
<tr>
<td>10</td>
<td>14.25±0.12</td>
</tr>
<tr>
<td>10</td>
<td>14.13±0.34</td>
</tr>
<tr>
<td>10</td>
<td>14.76±0.22</td>
</tr>
<tr>
<td>30</td>
<td>20.20±0.13</td>
</tr>
<tr>
<td>30</td>
<td>20.36±0.67</td>
</tr>
<tr>
<td>36.8</td>
<td>20.24±0.44</td>
</tr>
<tr>
<td>36.8</td>
<td>15.65±0.56</td>
</tr>
<tr>
<td>2.2</td>
<td>23.35±0.41</td>
</tr>
<tr>
<td>20</td>
<td>16.6</td>
</tr>
<tr>
<td>20</td>
<td>33.4</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>

*X1 = Feed composition (%); X2 = Feed moisture (%) and X3 = Screw speed (rpm). CHON = Protein; FAT = Fat; CHO = Carbohydrate; ASH = Ash; HOH = Water; ER = Expansion ratio; BD = Bulk density. Values are replicate averages of observed data which was used for RSM analysis.

Table 5. Design points and amino acid profile of the extrudates

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Dependent variables</th>
</tr>
</thead>
<tbody>
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<td>5.58</td>
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<tr>
<td>10</td>
<td>6.29</td>
</tr>
<tr>
<td>10</td>
<td>6.15</td>
</tr>
<tr>
<td>10</td>
<td>6.34</td>
</tr>
<tr>
<td>3.2</td>
<td>5.75</td>
</tr>
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<td>36.8</td>
<td>6.82</td>
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<td>20</td>
<td>6.11</td>
</tr>
<tr>
<td>20</td>
<td>6.14</td>
</tr>
<tr>
<td>20</td>
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</tr>
<tr>
<td>20</td>
<td>5.93</td>
</tr>
<tr>
<td>20</td>
<td>6.14</td>
</tr>
</tbody>
</table>

*X1 = Feed composition (%); X2 = Feed moisture (%) and X3 = Screw speed (rpm). Values are replicate averages. Standard deviation is not shown but replicate values were used for RSM analysis.

Seker, (2005) reported that increasing screw speed improved sectional expansion and reduced bulk density of extrudate during extrusion of soybean protein and corn starch. He further reported that mixtures of soybean protein isolate/modified starch had higher sectional expansion indices than those of native starch/soybean protein isolate, indicating that feed materials (in addition to phase transition) may contribute to the reduced expansion of extrudate containing soybean protein. Modified starch/soybean protein isolate mixtures had lower bulk densities than native starch/soybean protein isolate mixtures and it is suggested that bulk densities of extrudate containing high levels of soybean protein can be reduced by inclusion of cross linked starch in the extrusion mix. Chaiyakul et al. (2009) reported that expansion was greatest for low protein, low moisture and high temperatures during the extrusion of high protein glutinous rice based snack. These relationships have been reported elsewhere for corn and wheat based snacks (Bhattacharya and Hanna, 1987; Chinnaswamy and Hanna, 1990; Faubion and Hosney, 1982; Ilo et al., 1999). Filli and Nkama, (2007) reported that pearl millet: cowpea fura (80:20) had the highest puff ratio of 4.71 while the pearl millet: groundnut (70:30) fura had the...
least puff ratio, 2.90.

**Bulk density (BD)**

The mean values of bulk densities (BD) of the extruded products are shown in Table 4. Bulk density measures the total volume of the extrudates, indicating the extent of expansion which can influence extrudate functional properties. The experimental mean value of BD varied from 0.12 to 0.45 g cm\(^{-3}\). Analysis of variance (table not shown) indicates that the linear and quadratic effects of the independent variables significantly (P < 0.05) affected the bulk density. The response equation coefficient for BD is presented in Table 3. The models showed good fit with R\(^2\) = 0.96 for BD. This suggests a very good fit to the experimental data and the model could be used to describe the process. The positive significant (P < 0.05) linear coefficients of both feed composition (X\(_1\)) and feed moisture (X\(_2\)) indicated that their effect on BD was an increase as their levels increased. However, the negative significant (P < 0.05) coefficients linear effect of screw speed (X\(_3\)) and quadratic effect of feed composition resulted in a decrease in BD. Hagenimana et al. (2006) reported that the BD increased with increase in moisture content during the extrusion of rice flour. Traditionally, extrudate expansion has been expressed in terms of radial enlargement and decrease in density which have been correlated with changes in melt moisture and temperature. Bulk density is a measure of how much expansion has occurred as a result of extrusion. The heat developed during extrusion can increase the temperature of the moisture above the boiling point so that when the extrudate exits from the die, a part of the moisture would quickly flash-off as steam and result in an expanded structure with large alveoli and low bulk density.

On the other hand, if not enough heat is generated to flash-off enough of the moisture (either through low process temperature or high feed moisture), less expansion occurs resulting in a high bulk density product with collapsed cells which usually disintegrates on cooling. High bulk density product is an indication of more uniform and continuous protein matrix and therefore, the extrudate is dense with parallel layers, no air pockets and is not spongy upon hydration (Taranto et al., 1978). Qing – Bo et al. (2005); Meng et al. (2010) reported extrudate density to be most depended on feed moisture, increased feed moisture lead to sharp increase of extrudate density. Screw speed was observed to have slight impact on the density of extrudate.

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

The effects of treatment variables as linear, quadratic or interaction coefficients and observed experimental values for water absorption index (WAI) and water solubility index (WSI) are detailed in Table 6. The experimental design point 1 recorded the maximum WAI value of 5.62 g H\(_2\)O/g sample. The lowest value of 4.26 g H\(_2\)O/g was however recorded for design point 10. The model did not show a significant lack of fit (p = 0.0915) with R\(^2\) = 0.73, and the 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 6. The correlation coefficient of r = 0.85 was significant at (p < 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 while the lowest observed value of 5.18 % was observed for design point 12 representing (Table 6). 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, which is, molecular weight reduction of amylase 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. 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 amylase results in a higher WAI. Colonna et al. (1989) indicated that WAI
decreases with the onset of dextrinization. Pelembre et al. (2002), reported increased WAI as the percentage of cowpea increased in sorghum extrudates. Cowpea proteins have relatively higher water solubility than sorghum proteins (Chavan et al., 1989b).

Altan et al. (2008) reported increase in WSI with increase in screw speed 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 sheared 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 extrudates of high legume content contain more starch aggregates or microgels which will be suspended in water (Gomez and Aquilera, 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 component 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 result of observed values for viscosity of samples and regression coefficients is presented in Table 6. The maximum viscosity value of 8.34Nsm⁻² was observed for experimental run 4, while the least value of 4.34 Nsm⁻² was recorded for design point 7 (Table 6). The viscosity of samples was influenced by linear terms significantly (p<0.05). The coefficient of determinant for the viscosity was R² =0.74. Increase in the amount of soybean flour and increase in feed moisture decreased the apparent viscosity of extrudate 3D not shown. 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

### Table 6. Regression equation coefficients for objective responses WAI, WSI and VISCOSITY of samples.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>WAI</th>
<th>WSI</th>
<th>VISCOSITY</th>
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<td></td>
</tr>
<tr>
<td>b₀</td>
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<td>-0.1177</td>
<td>-0.4230</td>
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<td>b₁</td>
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</tr>
<tr>
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<td>b₃</td>
<td>-0.2210</td>
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</tr>
<tr>
<td>b₁₁</td>
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</tr>
<tr>
<td>b₃₃</td>
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<td>0.5253*</td>
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<td>Interaction</td>
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</tr>
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<td>b₁₂</td>
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<td>-0.1984</td>
</tr>
<tr>
<td>b₁₃</td>
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<tr>
<td>b₂₃</td>
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<td>0.4564</td>
</tr>
<tr>
<td>R²</td>
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<td>0.7592</td>
<td>0.7406</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.4821</td>
<td>0.5425</td>
<td>0.5071</td>
</tr>
</tbody>
</table>

- Obsd. = Observed
- Prdt. = Predicted

*Y = b₀ + b₁X₁ + b₂X₂ + b₃X₃ + b₁₁X₁X₂ + b₂₂X₁X₂ + b₃₃X₂X₃ + b₁₂X₁X₃ + b₁₃X₁X₃ + b₂₃X₂X₃ X₃ = Feed Composition, X₅ = Feed Moisture, X₆ = Screw Speed*

* ** Significant at P < 0.05 and P < 0.01, respectively; NS, not significant.
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 deextrinization 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. Plembe 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 Visc Amylo Graph (MVAG), indicating that their starches have been partially pregelatinized 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 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.

Likimani et al. (1991) reported that extrusion induced starch deextrinization 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 deextrinization 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).

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 of the amino acids. The quadratic regression model for the influenced variables are presented below where X1, X2, and X3 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.

**LYSINE** = 0.4529 + 0.9550X1 + 0.0973X2 + 0.0319X3 – 0.0031X1X2 – 0.1631X2X3 – 0.3980X3X4 + 0.0635X1X2 + 0.0353X1X3 + 0.0776X2X3

**I/LEUCINE** = -0.0346 + 0.9270X1 + 0.0461X2 + 0.0010X3 + 0.1601X1X2 + 0.0508X2X3 – 0.1678X3X4 - 0.0193X3 - 0.0138X4 + 0.193X1X3 - 0.0199X2X3

**LEUCINE** = -0.0893 + 1.0336X1 - 0.916X2 + 0.0929X3 – 0.0857X1X2 + 0.1275X2X3 + 0.0695X3X4 - 0.0133X3X2 + 0.0111X1X3 - 0.0819X2X3

**VALINE** = 0.6954 + 0.8716X1 - 0.0028X2 + 0.0005X3 - 0.5632X1X2 - 0.1538X2X3 - 0.1494X3X4 + 0.0633X1X2 + 0.0448X1X3 - 0.0541X2X3

**MET-CYST** = -0.7468 – 0.5338X1 - 0.0011X2 - 0.0756X3 + 0.5675X1X2 + 0.1672X2X3 + 0.1958X3X4 + 0.0258X1X2 + 0.0151X1X3 - 0.1463X2X3
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 describe the changes that occurred during extrusion as influenced by the extrusion variables.

Extrude 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 describe the changes that occurred during extrusion as influenced by the extrusion variables.

Conclusion

Millet – soybean based fura extrudates were produced using a single screw extruder through designed experiments using response surface methodology (RSM). Extrusion resulted in dehydrated, precooked product (result of moisture content not shown) that would require only reconstitution in either cold or warm water before consumption. Extrudates showed the potential of absorbing water as much as at least 4 (times) their weight which is an indication of improved functionality of the product. Extrusion cooking of fura constituted a great improvement on the traditional product that is at high moisture content of between 60 -75% and readily deteriorates on storage. Extrudates obtained in this study had moisture content less than 7g/100g and would not require refigeration for storage. The RSM was effective in studying the effects of process variables (feed composition, feed moisture and screw speed) for fura processing by extrusion cooking.

Results showed that the variable (X1) level of soybean was more relevant on the chemical composition rather than physical properties. The results revealed that the variables were significant on proximate composition and amino acid profile. Fortification of pearl millet with soybean yielded extrudates with higher protein and lysine contents, a limiting amino acid in cereals. Attempts to improve the nutritional properties of cereal based foods have been reported (Akapunam and Sefa – Dedeh, 1995; Sefa – Dedeh et al., 2003; Nkama and Filli, 2006; Sumathi et al., 2007; Curic et al., 2007; Kasprzak and Rzedzicki, 2008). There was a negative significant (P < 0.05) linear coefficient of feed composition (Xfat) and feed moisture (X2) indicated that their effects on ER were a decrease. For the bulk density there was a positive significant (P < 0.05) linear coefficients of both feed composition (X1) and feed moisture (X2) indicated that their effect on BD were an increase as their levels increased.

The importance of process variables on target parameters could be ranked in the following order: Feed Composition (X1) > Feed Moisture (X2) > Screw Speed (X3). The data observed from the study revealed that the essential amino acids were present in adequate amount if compared with the recommended values of FAO/WHO (1973). Taking into account the nutritional and economical aspects of soybean in fortifying pearl millet for fura extrudate production appears to be promising. The results of this study can be carried out in industrial scale production of fura for the purpose of ensuring food security, wealth creation for sustainable economic development.

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