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# The Effect of Extrusion Conditions on the Physical and Functional Properties of Millet – Bambara Groundnut Based Fura

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**Abstract** Studies were conducted on the Extrusion of fura from pearl millet and Bambara groundnut applying the Response Surface Methodology (RSM) consisting of 15 design points, using a single screw laboratory Brabendar extruder. The effects of three extrusion variables (feed composition – percentage Bambara groundnut to pearl millet, feed moisture content and screw speed) on some physical properties (bulk density, 'BD' expansion ratio, 'ER', mass flow rate, 'MFR', average residence time, 'ART' and specific mechanical energy, 'SME') and some functional properties (water absorption index, 'WAI', water solubility index, 'WSI' and viscosity); of fura extrudates were evaluated using response surface method (RSM). Models were developed and appropriate statistical analysis adopted to test the adequacy of the models. Linear, quadratic and interaction regression and coefficient terms and coefficients of determinants were computed to test the adequacy of the models and response surface plots were also produced from the equation and model. The linear, quadratic and interaction terms were significant ($p<0.05$) for ART and SME, however for MFR interaction term was not significant ($p>0.05$), however the linear and quadratic terms were significant ($p<0.05$). The error analysis showed that lack of fit was not significant ($p<0.05$) for ART. The regression models for data were significant ($p<0.05$) with satisfactory coefficients $R^2$ of 0.87, 0.87 and 0.92 for ART, MFR and SME respectively indicating a good fit. The coefficients of variation (CV) were less than <10%. Extrusion conditions affected the ER significantly ($p<0.05$) by linear and interaction terms. The BD was influenced by only the linear term ($p<0.05$). The $R^2$ were 0.82 and 0.84 for ER and BD respectively, suggesting good fit. Linear, quadratic and interaction terms affected WAI. However only linear and quadratic terms indicated influence on the WSI. The $R^2$ were 0.93 and 0.84 for WAI and WSI respectively. The samples shows that, linear, quadratic and interaction terms influenced viscosity significantly ($p<0.05$) with the linear term showing more effect and the $R^2$ was 0.88 for viscosity, The lysine content (result not shown) of extrudates tremendously increased as expected as a result of inclusion of Bambara groundnut. The essential amino acids (result not shown) were present in adequate levels if compared with the recommended values of FAO/WHO (1973).

***Keywords:*** *extrusion, fura, pearl millet, bambara groundnut, physical and functional properties*

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## 1. Introduction

Pearl millet [*Pennisetum glaucum* (L) Leake] is an important cereal, contributing to the calorie and protein requirements of people in the semi-arid tropics (SAT) [1]. This crop is grown mostly in regions of low rainfall and is capable of withstanding adverse agro climatic conditions. More than 80% of the production is used for human consumption, particularly in the SAT region of Africa and Asia. There are several food preparations made from pearl millet in Africa and India [2]. Sorghum and millets are the most droughts – tolerant cereal grain crops and require little input management during growth, but as with other crops they yield better with good husbandry [3]. With increasing world population and decreasing water supplies, these crops represent important crops for future human use. While millets are vital food crops for millions of people in parts of Africa and Asia, they are an underutilised resource in most developed countries, with sorghum being used primarily as animal feed [4]. Many countries in the developing world have become heavily dependent on imported foods and the conditions for their local production are poor or non-existent making the demand for traditional based products not attractive [5]. In Nigeria pearl millet has remained a staple food for the poor especially in the northern part of the country.

Bambara groundnut (*Vigna subterranea*) is an underutilised African legume cultivated throughout sub-Saharan Africa. It is mainly produced as a subsistence crop, usually by the poor women farmers on soils that are too poor to support the growth of other crops. In much of Africa, Bambara groundnut is the third most important legume after groundnut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*). Bambara groundnut has several production advantages in that it can yield on soils of low fertility and with little rainfall as the pearl millet; however, it is nutritionally superior to other legumes and is the preferred food crop of many local people. Despite its importance as a source of livelihood food source, this crop has received little research attention and the majority of the information and knowledge is held by the producers themselves or in unpublished material. International interest in Bambara groundnut is just beginning to grow as researchers have started to understand the role and importance of this crop in livelihood food security. It is evident that there is keen research interest in the crop, mainly because of its popularity with local farmers and consumers. However, most of the researches is carried out in isolated laboratories and field stations with little co-ordination or structure. The seed stores very well and is not prone to attack by pests or disease. However, the dried seed becomes very hard to cook, requiring large amounts of time, effort and fuel to cook. This limitation is believed to be the main constraints to its increased utilisation. From the point of view of utilization, cooking quality of Bambara groundnut is very important. It may be expected that Bambara groundnut will be utilized more extensively if suitable fast processing technology like extrusion is adopted on a commercial basis which can make its products more acceptable, nutritious and digestible.

The global lifestyle, which is characterized by limited free time and increased working hours, have turned consumers to the consumption of ready-to-eat products. In addition, children worldwide, are attracted to several snack products which are particularly tasty and easy to be consumed. Therefore, food industries have increased the production of ready-to-eat products using several processes. Among these processes is extrusion, which is a high temperature-short time process. It is a well-established industrial technology, which is characterized by, continuous cooking, mixing and forming processing and produces direct expanded materials, with high quality [7]. Extrusion cooking is a flexible and continuous process by which food biopolymers and ingredients are mixed, plasticized, cooked and formed by combination of moisture, temperature, pressure, and mechanical shear. Extrusion cooking of cereals is a very important process in the food and feed industry, since it regards a wide range of products, as snack-foods, baby-foods, cereals for breakfast and pasta etc [8]. Extruders usually minimize the operating costs and rationalize the productive process, combining energetic efficiency and versatility. Nevertheless, the rheological properties and the fluid-dynamic behaviour of food compounds make extrusion cooking a very complex process. Screw configuration, mixing paddles, external barrel and final die are typical components of a twin-screw extruder. Screws and mixing paddles play the most important role in the extrusion process, since they transport, mix, cut and stretch the ingredients inside the extruder.

Fura is an example of the indigenous foods prepared from millet in Nigeria. It is a traditional thick dough ball snack produced principally from millet or sorghum which is very common in Nigeria, [9]. The mode of preparation varies only slightly among different communities in the region, 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, [8]. But nowadays where scarcity of milk is pronounced and common in Nigeria, fura is consumed mostly without the *nono* for the simple reason that *nono* is hard to come by; furthermore the consumption and the acceptability of fura has suffered some drawback, because the method of processing has remained a home-based or artisanal activity that is carried out with rudimentary equipment and techniques. This result in product that is characterized by inconsistent product quality, poor hygiene, very short shelf life and unacceptable standards. In addition 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 - 2 days at room temperature (25°C) and 18 hours at 35°C [10]. Fura, being a single cereal based product 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 [11]. As a means of resolving issues related with this limitation, due to their low protein content, fortification of millet with Bambara groundnut can go a long way in improving the protein quantity and quality of fura which is usually made from cereal solely. According to Gujska et al. [12], extrusion cooking has good potential for making desirable forms of beans economically available in developing countries. Non-traditional methods of processing legumes such as thermal extrusion are needed for expanded utilization of dry edible beans. It is well known fact that addition of legumes to cereals increases both content and quality of protein mix [13]. Wu et al. [14] reported the inclusion of flaxseed to maize to improve the protein content and quality. Limited efforts have been made by the scientific community to diversify the food uses of pearl millet and Bambara groundnut by the application of modern technology to upgrade the traditional methods of contemporary food processing technology for the utilization of these materials.

Modelling of extrusion processing involves consideration of process parameters, system parameters, and product properties. Thus, extrusion cooking modelling is a multiple input and multiple output process. Though mathematical modelling of food extrusion process has benefited from available information on plastic extrusion, modelling 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 or products [15]; it has been successfully used for developing, improving and optimizing processes [16].

The objective of this work was to study the effect of moisture content, feed composition (level of Bambara groundnut) and screw speed on the physical and functional properties of Millet – Bambara groundnut based fura extrudates using response surface methodology to model the process parameters.

## 2. Materials and Methods

### 2.1. Flour Preparation from Pearl Millet

The process of flour preparation involved dry cleaning of millet followed by winnowing using Vegvari Ferenc aspirator OB125, made in Hungary. The kernels were dehulled after mild wetting of the grain with a rice dehuller made in India at the Jimeta Main Market Yola, Nigeria. The dehulled grains were washed with water and then dried in a Chirana convection oven model (HS 201A, Czech Republic) at 50°C for 24h to 14% moisture content. The dried dehulled mass was milled with a Brabender roller mill (OHG DUISBURG model 279002, Germany) which was equipped with a 150µm screen and the underflow used for further research work.

### 2.2. Flour Preparation from Bambara Groundnut

Bambara groundnut seeds were steeped in tap water at 28°C for a period of 30 minutes to loosen the seed coat in a plastic bowl. This was followed by decortications using the traditional pestle and mortar made of wood. The kernels which were in mixture with the hulls were thereafter dried at 50°C to approximately14% moisture content in a Chirana convection oven model (HS 201A, Czech Republic) for 24 hours. The dried grain mass was winnowed to remove the hulls and other remaining lighter materials were removed with a Vegvari Ferenc aspirator OB125, Hungary. The winnowed Bambara groundnut kernels were ground in a laboratory disc mill (made in Nigeria) to fine flour. The flour obtained was sieved using a 150µm screen size Brabender (OHG Duisburg type, Germany) and the underflow was used for further research work.

### 2.3. Spice Preparations

Kimba (Negro pepper) and ginger were sorted and dry cleaned manually before drying in a Chirana convection oven model (HS 201A, Czech Republic) at 60°C for five hrs. The seeds were then pounded using the traditional pestle and mortar made of wood. The mass was ground and sieved using a 150µm screen size and the underflow was used for further research work.

### 2.4. Mix Preparation and Moisture Adjustment

Millet flour ($M_F$) and Bambara groundnut flour ($B_F$) 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 Lee, [17]. Weights of the components to be mixed were calculated using the following equations:

$$B_F = \frac{\left[r_{BF} \times M \times (100 - w)\right]}{\left[100 \times (100 - w_{BF})\right]} \quad (1)$$

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

$$W_X = M - B_F - M_F \quad (3)$$

$B_F$ and $M_F$ are the masses of Bambara groundnut flours ($B_F$) and millet flour ($M_F$), respectively, $r_{BF}$ or $r_{MF}$ are respective percentages of either Bambara groundnut flours ($B_F$) or millet flour ($M_F$) in the blend, d.b.; ($r_{BF}$ + $r_{MF}$ = 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 $w_{BF}$ and $w_{MF}$ are the moisture contents of $B_F$ 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 was kept in the refrigerator overnight to allow moisture equilibration. The samples were however brought to room temperature before extrusion process.

**Table 1. Independent Variables and Levels used for Central Composite Rotatable Design**

| | | Coded variable level | | | | |
|---|---|---|---|---|---|---|
| Variable | Symbols | -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**

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

## 2.5. Experimental Design Central Composite Rotatable Design (CCRD)

The Response Surface Methodology (RSM) is a widely adopted tool for the quality of optimizations processes [18]. The RSM, originally described by Box and Wilson, [19] is effective for responses that affect many factors and their interactions. The central composite rotatable composite design (CCRD), [20] 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 (level Bambara groundnut flours) $X_1$ (%); 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.

## 2.6. Theory

To estimate the effect of feed composition, feed moisture content and screw speed on each objective response, the standardized scores were fitted to a quadratic polynomial regression model by employing a least square technique [21,22]. The model proposed for each response of Y was:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3 \quad (4)$$

Where Y = the responses $X_1$ = Feed Composition, $X_2$ = Feed Moisture, $X_3$ = Screw Speed, $b_0$ = intercepts, $b_1$, $b_2$, $b_3$ represents the linear terms, $b_{11}$, $b_{22}$, $b_{33}$, = represents the quadratic terms 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.

## 2.7. Extrusion Exercise

Extrusion cooking was performed in a single screw extruder model (Brabender Duisburg DCE-330), Germany which was 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 30rpm 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 barrel temperatures were 150°C, 170°C and 150°C for the three heating zones respectively and 150°C of die temperature were maintained during extrusion with constant die and screw geometry. The extruder had a round channel die with separate infolding heater was used. The die used was a cone shaped channel with 45 degrees entrance angle, a 3mm diameter opening and 90mm 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 that was electrically heated. The extruder barrel had a 20mm diameter with lenght to diameter ratio (L:D) of 20:1. The 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 was 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 [23]. The extrusion process consisted of 15 individual runs, and each design point was ran three times and the the result of each parameter averaged.

## 2.8. Average Residence Time (ART)

In any food processing operation, it is important to control the processing time of the food product for optimum and control of end use properties of products. This parameter was determined by dividing the barrel (tube) volume ($Vm^3$) by the volumetric flow rate of extrudate ($m^3\ s^{-1}$), [24].

$$ART = \frac{Volume\ of\ tube}{Volumetric\ flow\ rate} = \frac{V\left(m^3\right)}{Q\left(\left(m^3 s^{-1}\right)\right)}(S) \quad (5)$$

If the internal diameter of the tube is equal to D and the average velocity is $4Q/\pi D^2 s$, then the appropriate expression of volumetric flow rate ($Q\ m^3 s^{-1}$) was obtained or derived from the above equation. The time was measured in seconds.

## 2.9. Mass Flow Rate (MFR)

The mass flow rate ($g\ s^{-1}$) was evaluated by the method described by Zasypkin and Tung - Ching Lee [17] which was calculated as the mass of material extruded per minute. Calculations were made from the data on product output ($Q_E = g\ s^{-1}$), the moisture content of the product extrudate ($w$% wb) and the moisture content of feed material ($W$% wb) was calculated according to the following formula:

$$MFR = Q_E \left[\frac{(100 - w)}{(100 - W)}\right] g\ s^{-1} \quad (6)$$

Water contents of the samples and the product output were determined as mass of the final product was measured about 1 hour after extrusion. Water content was measured by drying the samples to a constant weight at 105°C. The mass flow rate was calculated as the mass in grams of product delivered per time in seconds.

## 2.10. Specific Mechanical Energy (SME)

The specific mechanical energy was determined as described by Binoy et al. [25] from the torque on the drive motor at constant screw speed and mass flow rate. In the extruder, this energy was provided by a 4.1Kw electric motor, which is coupled to the screw. SME (kj/kg) was calculated using the following equation:

$$SME = \frac{n(actual) \times \%\, net\ torque \times P(rated)}{n(rated) \times 100 \times m} \qquad (7)$$

where n = screw speed (rpm); the net torque = the measured torque less the lot frictional torque due to bearings and gear drive assembly; P = motor power (kj /s); and m = feed rate (kg /s).

## 2.11. Expansion Ratio (Puff Ratio)

Expansion ratio can be of two indices, diametric and longitudinal as described by Sopade and Le Grys [26]. Diametric 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.

## 2.12. Bulk Density of Extrudates

The bulk density (ρ) of extrudates was calculated using the methods described by Qing-Bo et al. [27] as follows:

$$Density(\rho) = \frac{4 \times m}{\pi \times D^2 \times L} \qquad (8)$$

where ṁ is the mass in gram of extrudate with length L and diameter D both in meters. The samples were randomly selected and replicated 10 times and the average value taken.

## 2.13. Water Absorption Index (WAI) and Water Solubility Index (WSI)

The WAI and WSI were determined using the method described by Qing - Bo et al. [27]. The ground extrudate samples were suspended in water at temperature of 30°C for 30 minutes; it was then stirred gently and immediately 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 (g $H_20$/1g sample). Determinations were made in triplicate and the average result taken.

## 2.14. Viscosity

Viscosity of extrudates were determined with the aid of a 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 ($Nms^{-2}$) was carried out at 30°C. Triplicate determination was carried out and the result averaged.

## 2.15. Statistical Analysis

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 [28].

# 3. Results and Discussions

## 3.1. Model Description

In this study, response surface methodology was used to describe the process model, physical and functional properties of Millet – Bambara groundnut based fura extrudate with respect to the independent variables. Table 4 shows the coefficient of equations obtained by fitting of the experimental data obtained. The coefficient of determinations of regression equations changed from 0.71 to 0.80 with significant probability values ($p < 0.05$) and non-significant lack of fit values (Table 4). These models could be adequately used as predictor models, for getting optimum values regardless of the coefficient of determinations. Only coefficients making a significant contribution to the model were used in the model. Furthermore, non-significant lack of fit in the models makes them as predictive models (Table 4) such that the lack of fit error was significantly larger than the pure error which indicates something remain in the residuals can be removed by an appropriate model. If a model has a significant lack of fit, it is considered not a good indicator of the response and should not be used for prediction [29]. Hence, it can be concluded that the proposed models approximates the response surfaces and can be used suitably for prediction at any values of the parameters within experimental range.

## 3.2. Average Residence Time (ART), Mass Flow Rate (MFR) and Specific Mechanical Energy (SME)

The ART observed values from this study ranged from 24.65 – 44.22 seconds for design points 14 and 11 representing (20% feed composition, 25% feed moisture, 284rpm) and (20% feed composition, 16.6% feed moisture, 200 rpm screw speed) respectively as shown in Table 3. The MFR values ranged from 1.73 – 0.93$gs^{-1}$ for design points 15 and 5 representing (20% feed composition, 25% feed moisture, 200rpm screw speed) and (30% feed composition, 20% feed moisture, 150rpm screw speed) respectively as indicated in Table 3. The SME which is the specific mechanical energy that is transferred to each particle during extrusion recorded the highest value of 765.8 Kj/Kg for design point 13 representing (20% feed composition, 25% feed moisture and 116rpm screw speed). The lowest value of mechanical energy 380.5Kj/Kg, however was recorded by design point 8 (30% feed composition, 30% and 250rpm screw speed) as shown in Table 3. The response equation coefficients for ART, MFR and SME are presented in Table 4. Examination of these parameters indicated that linear, quadratic and interaction terms were significant ($p<0.05$) for ART and SME, however interaction term was not significant ($p>0.05$) for MFR but the linear and quadratic terms were significant ($p<0.05$) for the MFR as shown in Table 4.

**Table 3. Observed and predicted values for process parameters, functional and physical properties**

| Runs | [1]MFR Obsd .Prdt. | [2]ART Obsd. Prdct. | [3]SME Obsd. Prdct. | [4]ER Obsd.Prdt. | [5]BD Obsd.Prdt. | [6]WAI Obsd. Prdct. | [7]WSI Obsd. Prdct. | [7]VSCSITY Obsd. Prdct. |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.16 1.14 | 30.45 29.25 | 471.1 476.3 | 2.74 2.76 | 0.16 0.15 | 6.45 6.43 | 4.81 4.84 | 10.98 10.34 |
| 2 | 1.25 1.27 | 30.23 29.23 | 478.3 480.4 | 2.34 2.44 | 0.26 0.27 | 5.23 5.13 | 5.74 5.56 | 15.97 15.33 |
| 3 | 1.13 1.09 | 28.16 28.58 | 468.4 471.3 | 3.72 3.47 | 0.12 0.18 | 6.76 6.84 | 6.23 6.19 | 12.23 11.39 |
| 4 | 1.51 1.41 | 27.12 27.57 | 480.6 485.1 | 2.54 2.44 | 0.17 0.18 | 5.56 5.63 | 5.43 5.38 | 15.01 15.63 |
| 5 | 0.93 0.95 | 33.24 32.25 | 761.7 768.3 | 3.42 3.86 | 0.06 0.07 | 6.34 6.54 | 5.87 6.04 | 16.96 16.64 |
| 6 | 1.16 1.12 | 30.24 30.75 | 428.3 432.1 | 1.93 1.83 | 0.37 0.35 | 6.58 6.63 | 6.43 6.35 | 15.87 15.34 |
| 7 | 1.65 1.46 | 43.34 43.73 | 471.3 475.6 | 5.57 5.14 | 0.07 0.08 | 6.63 6.73 | 6.74 6.84 | 10.89 10.12 |
| 8 | 0.94 0.96 | 25.85 25.56 | 380.5 385.3 | 3.46 3.92 | 0.12 0.12 | 6.54 6.34 | 6.46 6.66 | 12.97 12.13 |
| 9 | 1.57 1.46 | 25.12 24.59 | 400.3 396.4 | 2.83 2.67 | 0.18 0.17 | 5.44 5.56 | 4.42 4.37 | 8.45 8.36 |
| 10 | 1.43 1.36 | 28.76 28.33 | 470.2 475.6 | 2.42 2.35 | 0.24 0.26 | 6.64 6.73 | 6.61 6.78 | 12.12 11.73 |
| 11 | 1.12 1.08 | 44.22 43.34 | 430.8 426.7 | 3.48 3.63 | 0.09 0.08 | 5.87 5.84 | 6.72 6.74 | 13.11 13.67 |
| 12 | 1.51 1.46 | 28.84 28.45 | 425.7 427.4 | 1.65 1.52 | 0.43 0.45 | 4.67 4.83 | 5.34 5.23 | 13.86 14.66 |
| 13 | 1.34 1.28 | 29.87 30.75 | 765.8 760.9 | 1.75 1.87 | 0.24 0.23 | 5.77 5.86 | 4.42 4.38 | 15.21 15.67 |
| 14 | 1.05 1.08 | 24.65 25.75 | 476.9 473.4 | 2.71 2.65 | 0.17 0.16 | 6.65 6.74 | 6.89 7.01 | 10.23 9.43 |
| 15 | 1.73 1.74 | 34.88 34.55 | 650.6 640.3 | 2.76 2.55 | 0.21 0.19 | 5.44 5.34 | 6.56 6.76 | 15.24 15.72 |

Key1=Mass flow rate ($gs^{-1}$); 2=Average Residence Time (s); 3=Specific Mechanical Energy (kj/kg); 4=Expansion ratio; 5= Bulk Density ($g\ m^{-3}$); 6=Water absorption index ($g_{water}/g_{sample}$); 7=Water solubility index; 8=Viscosity ($Nsm^{-2}$)

**Table 4. Regression equation coefficients for objective responses[a, b]**

| Coefficient | [1]MFR | [2]ART | [3]SME | [4]ER | [5]BD | [6]WAI | [7]WSI | [8]VSCTY |
|---|---|---|---|---|---|---|---|---|
| Linear | | | | | | | | |
| $B_0$ | 1.2634* | 0.4907* | 0.8978* | -0.1967 | 0.9745* | -0.7581* | 0.5620* | 0.6764* |
| $B_1$ | -0.1634 | 0.3445* | 0.1669 | 0.2510 | 0.3218 | 0.4888* | 0.7171* | 0.2074 |
| $B_2$ | 0.1507 | -0.6610* | -0.2411* | -0.8169* | 0.3245 | -0.5276* | -0.2191 | 0.3342* |
| $B_3$ | 0.0111 | -0.0749 | -0.4880* | 0.3762* | -0.4321 | 0.2679* | 0.5752* | -0.5432* |
| Quadratic | | | | | | | | |
| $B_{11}$ | -0.4547* | -0.4957* | -0.6028* | 0.1242 | -0.4321 | 0.4940* | -0.3498* | -0.6379* |
| $B_{22}$ | -0.6620* | 0.1431 | -0.6298* | 0.1538 | -0.5643 | 0.0356 | -0.1752 | -0.0643 |
| $B_{33}$ | -0.7351* | -0.3666* | -0.0834 | 0.0103 | -0.2564 | 0.5817* | -0.2987 | -0.2892* |
| Interaction | | | | | | | | |
| $B_{12}$ | -0.3613 | -0.4403* | -0.4496* | -0.5145* | 0.3215 | 0.4413* | 0.0316 | -0.4185* |
| $B_{13}$ | 0.0860 | 0.1922 | -0.3431* | 0.3537 | 0.4378 | -0.2017 | 0.0165 | -0.5442* |
| $B_{23}$ | -0.2323 | -0.4155* | 0.2587 | -0.0450 | 0.2768 | -0.0779 | -0.3020 | 0.1257 |
| $R^2$ | 0.8741 | 0.8732 | 0.9194 | 0.8182 | 0.3409 | 0.9290 | 0.8367 | 0.8752 |
| Adjusted $R^2$ | 0.7607 | 0.7590 | 0.8469 | 0.6547 | -0.2522 | 0.8652 | 0.6897 | 0.7630 |
| Lack of fit | NS | * | NS | * | NS | * | * | * |
| Model | * | * | * | * | * | * | * | * |

[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 $P < 0.05$; NS, not significant. Key1=Mass flow rate;2=Average Residence Time; 3=Specific Mechanical Energy; 4=Expansion ratio; 5= Bulk Density; 6=Water absorption index, 7=Water solubility index, 8=Viscosity

The error analysis showed that lack of fit was not significant ($p<0.05$) for ART. The regression models for the data were significant ($p<0.05$) with satisfactory coefficients $R^2$ of 0.87, 0.87 and 0.92 for ART, MFR and SME respectively which is indicating a good fit. The coefficients of variation (CV) were less than <10% suggesting that the models could be reproducible [30]. The models indicated that feed composition had the most linear effects on SME while feed moisture and screw speed had the most effects on the interaction terms. The SME in this study was dependent in an order of ranking of feed moisture content, screw speed and feed composition (amount of Bambara groundnut flour). The model for ART indicated that feed composition had the most effect on the average residence time (ART). The result further revealed that feed moisture content showed more quadratic effect on the ART. The independent variables feed composition and screw speed showed more influence on the ART. The 3D plot was drawn to illustrate the main and interactive effects of the independent variables on the dependent ones and the response surface, whose coefficients were given in Table 3, was shown in Figure 1. In order to make this design work, one of the variables was kept at the optimum level while the remaining two variables were changed within experimental range. The 3D plot shows that screw speed had significant influence on the ART, that is increasing screw speed as expected reduced the ART, while increasing the feed moisture increased the ART as shown in Figure 1. Lower screw speed resulted in a longer residence time of extrudates in the extruder [31]. The models for MFR showed that feed moisture content had the most linear effect on the MFR. These results suggest that the linear effect and interaction effects of the three independent variables were the primary determining factors of the responses and no significant influence ($p>0.05$) was shown by the interaction term. The response plot for the MFR against screw speed and feed moisture was a maximum, suggesting a maximum value for the three factors is the middle points Figure 2.

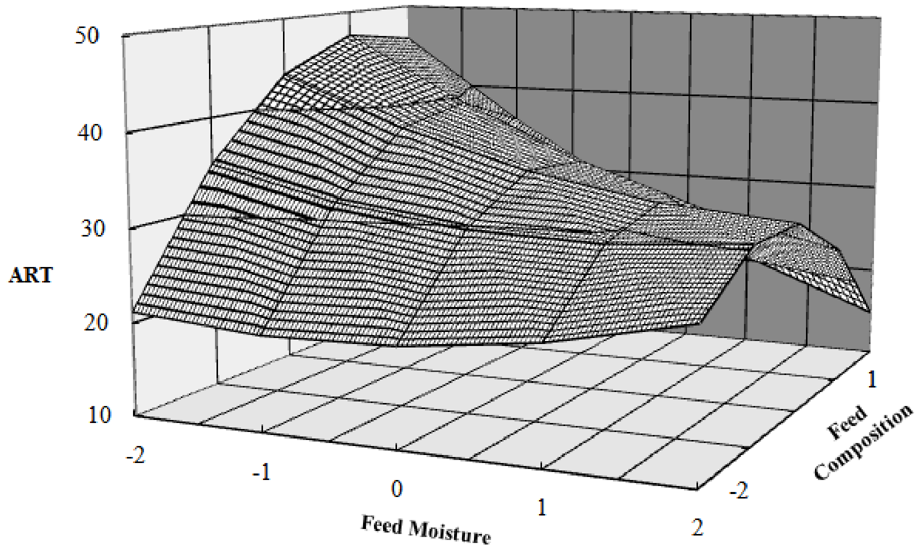


**Figure 1.** Response for the effect of Feed moisture and Feed composition on ART

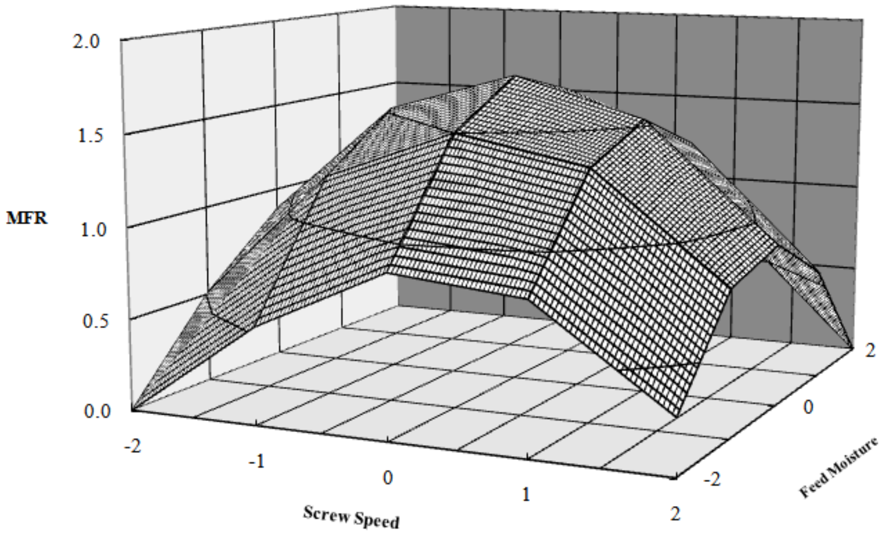


**Figure 2.** Response Effect of Feed Moisture and screw Speed on MFR

The specific mechanical energy (SME) has been used by Meuser and van Lengerich [32] as a system to model the extrudate property [27]. Higher SME usually results in greater degree of starch gelatinization and extrudate expansion. Hence, increased SME is desired for expanding products. The independent variables, feed moisture content and feed composition strongly influenced the SME, as expected decreasing feed moisture resulted in increased SME [6]. Choudhury and Gautan [33] reported that increasing the amount of fish solids in the hydrolyzated fish muscle and rice blend resulted in lowering the SME input, reducing mixing and increasing the mean residence time.

### 3.3. Expansion Ratio (ER) and Bulk Density (BD) of Extrudates

The ER values ranged between 5.57 and 1.65 for design points 7 and 12 representing (30% feed composition, 20% feed moisture, 250rpm screw speed) and (20% feed composition, 33.4% feed moisture, 200rpm screw speed) respectively as shown in Table 3. The BD observed values ranged between 0.06gcm$^{-3}$ and 0.43 for design points 5 and 12 representing (30% feed composition, 20% feed moisture, 150rpm screw speed) and (20% feed composition, 33.4% feed moisture, 200rpm screw speed) respectively as shown in Table 3. The result of regression coefficient for expansion ratio ER and bulk density BD is presented in Table 4. The ER was influenced significantly ($p<0.05$) by both the linear and interaction terms. The 3-D surface plot shows that the independent variables, feed moisture and feed composition both influenced the ER as shown in Figure 3. This is a commonly observed phenomenon in many extruded snack 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. Feed materials with lower moisture contents tend to be more viscous than those having higher moisture contents and therefore the pressure differential is smaller for higher moisture foods leading to a less expanded product. The result shows that, increasing feed moisture content caused a decrease in ER Figure 3.

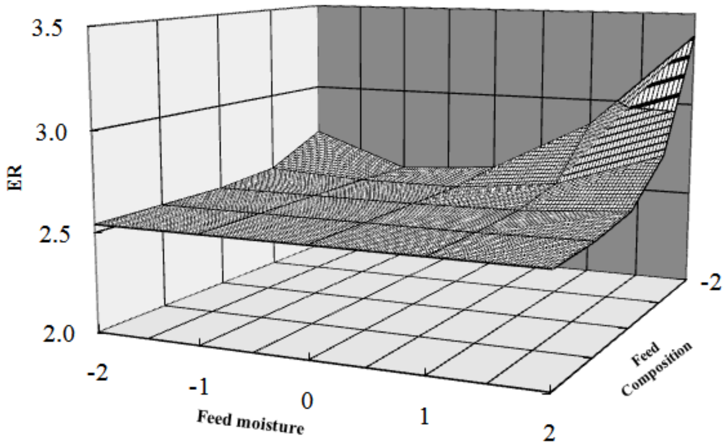


**Figure 3.** Response Effect of feed moisture and feed composition on ER

The BD was influenced by only the linear term (p<0.05) as explained by the regression equation. The $R^2$ were 0.82 and 0.84 for ER and BD respectively, suggesting good fit of the model. 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 which results in an expanded structure with large alveoli and low bulk density. On the other hand, if enough heat is not 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 will usually disintegrates on cooling.

Generally, extruded snacks possess the typical texture of puffed, light and crispy properties, some physical properties of extruded snack were reported including bulk density that ranged from 48-64 g/L, 50-160g/L [35]and 59 10g/L [36] and expansion ratio which ranged from 3.06 - 3.83 [37] and 4.03 [36]. Seker, [38] reported that increasing screw speed improved sectional expansion and reduced bulk density of extrudates during extrusion of soy protein and corn starch. He further reported that mixtures of soy protein isolate/modified starch had higher sectional expansion indices than those of native starch/soy protein isolate, indicating that feed materials (in addition to phase transition) may contribute to the reduced expansion of extrudates containing soy protein.

Modified starch/soy protein isolate mixtures had lower bulk densities than native starch/soy protein isolate mixtures and it is suggested that bulk densities of extrudates containing high levels of soy protein can be reduced by inclusion of cross linked starch in the extrusion mix [34]. Filli and Nkama [39] 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. Samples with high fat content appear to have lower puff ratio. In another report a puffer extrudate resulted by decreasing the lipid content in the feed mix [34].

Phillips and Falcone [40] also reported that increasing feed moisture content from 13 to 18% increased expansion of sorghum extrudates but further increase caused a decrease in expansion. Thymi, et al. [41] showed that apparent density, porosity and expansion ratio of extrudates from corn grits were dependent more upon the feed moisture, residence time and temperature, but screw speed had no effects. Pelembe et al. [42] reported decreased expansion as the percentage of cowpea flour increased in the mix. They attributed this due to the higher starch content of sorghum and/or the far higher protein content of cowpea than sorghum. Paton and Spratt [43] showed that increasing protein content in the feed mixture may decrease expansion ratio during extrusion. Binoy et al. [25] reported that bulk density was less affected by addition of fish solids to rice flour up to 30%, but when the amount of fish solids was increased to 60% bulk density increased more than twofold. They also reported that as the severity of screw configuration increased the product bulk density decreased. According to Areas [44], addition of proteins to high starch flours could change the behavior of transformation into a ‘protein-type’ extrudate when less expansion occurs and the products are harder and more resistant to water dispersion. Only starch granules that have been gelatinized can participate in the formation of a stable expanded structure [45]. Chinnaswamy and Hanna [46] noted that the expanded volume of cereal flour decreases with increasing amounts of protein and lipid but increases with starch content. Harmann and Harper [47] 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 and high temperature [48]. Increasing feed moisture caused a decrease in ER.

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 [49]. Qing – Bo et al. [27] reported extrudate density to be most depended on feed moisture content. Increased feed moisture content lead to sharp increase of extrudate density. Screw speed was observed to have slight impact on the density of extrudate. Feed moisture has a significant effect on the expansion ratio. Increased feed rate significantly increased the extrudate expansion. Increasing feed moisture content resulted in sharp decrease in expansion value. Qing–Bo et al. [27] reported no significant effect of feed rate on the expansion ratio was observed during extrusion of rice –

based expanded snacks. Increasing the feed moisture content from 18 to 22% caused a decrease in expansion ratio for tapioca and corn starch [50]. Proteins do not expand as well as starch. Increasing soybean protein from 0 to 25% resulted in decreased expansion of extruded corn starch, according to the report lipids also affected expansion of extrudates. The results of Mohamed [37] showed that expansion of corn grits was little affected by addition of oil up to 3%. Faubion and Hosney [51] showed that flour lipid reduced extrudate expansion.

## 3.4. Water Absorption Index (WAI) and Water Solubility Index (WSI)

For any extruded snack product, WAI is one of the critical quality characteristics taken into consideration. This is owing to its important implications on hydration properties of such products, because it is consumed inform of gruel. The highest recorded WAI observed value was 6.76 62g$H_2O$/1g for design point 3 representing (10% feed composition, 20% feed moisture and 150 rpm screw speed). The least value of 4.67 62g$H_2O$/1g was observed for design point 12 representing (20% feed composition, 33.4% feed moisture and 200 rpm screw speed) as shown in Table 3. The WSI values ranged between 4.42 and 6.89 for design points 9; 13 and 14 representing (3.2% feed composition, 25% feed moisture, 200 rpm screw speed); (20% feed composition, 25% feed moisture, 116 rpm) and (20% feed composition, 25% feed moisture, 284 rpm) respectively as shown in Table 3. The regression equation coefficients for objective responses are presented in Table 4. The result shows that, the effect of extrusion conditions on WAI was significant ($p<0.05$) as shown in Table 4. The linear, quadratic and interaction terms affected the WAI. Examination of the result however, indicated that only linear and quadratic terms showed influence on the WSI. The $R^2$ observed were 0.93 and 0.84 for WAI and WSI respectively suggesting good fit of the regression model.

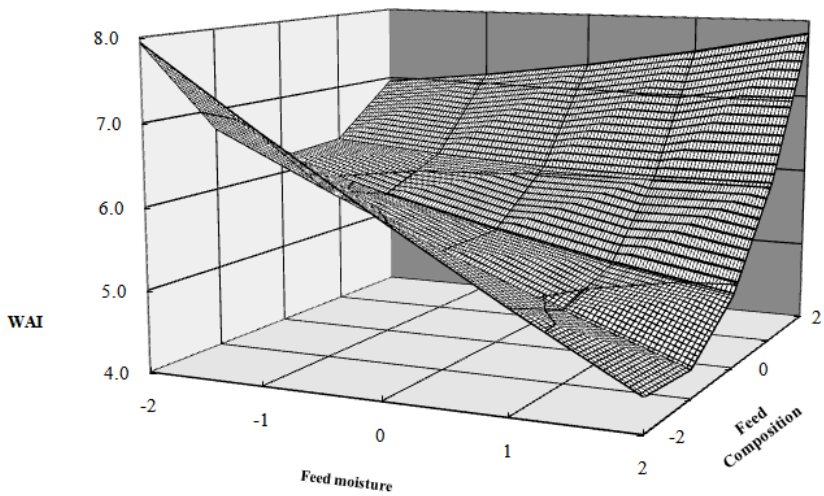


**Figure 4.** Response for the effect of Feed moisture and Feed composition on WAI

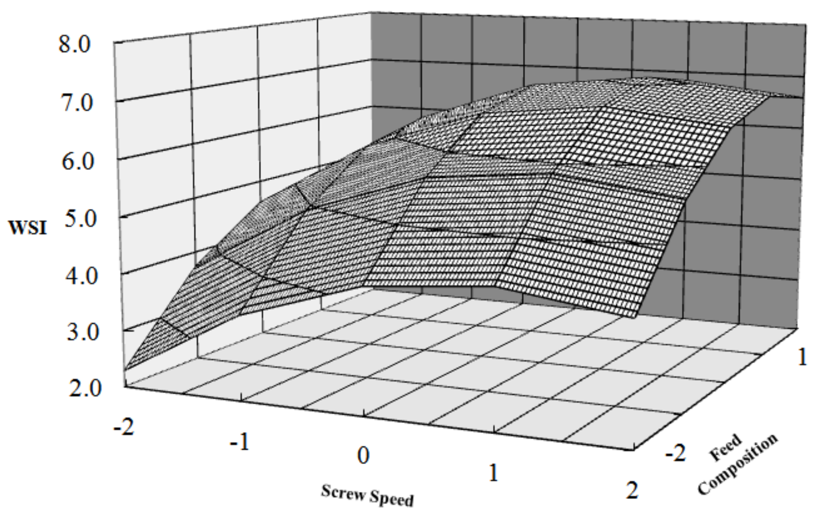


**Figure 5.** Response for the effect of Screw speed and Feed composition on WSI

Examination of 3D-plot for the result of fura extrudates shows that increasing feed moisture significantly decreased the water absorption index (WAI) of fura extrudate, while increase in the level of Bambara groundnut flour resulted in increased WAI as shown in Figure 4. The water absorption index (WAI) is the measure of the volume occupied by the extrudate starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion, which can be used as an index of gelatinization [27]. Increasing screw speed and level of Bambara groundnut flour were found to increase the WSI as shown in Figure 5. Solubility describes the rate and extent to which the component of a powdered material or particles dissolves in water. WSI, often is used as an indicator of degradation of molecular components, this to a certain extent measures the amount of soluble components released from the starch after extrusion process. However, this will also depend mainly on the chemical composition of the powder and the physical state of the material. Mercier and Feillet, [52] reported the increase in soluble starch with increasing extrusion temperature and decreasing feed moisture which was similar to what was observed in this study with respect to feed moisture content. There was a report of WAI increasing as the proportion of cowpea flour increased during extrusion of sorghum-cowpea porridge, [42]; according to the report it may be attributed to the higher amylose/amylopectin ratio of cowpea**.** Balandran-Quintana et al. [54], reported that high protein content (20 - 22%) in the raw material they used were responsible in the increase in water absorption as a result of nonconvalent interactions between polypeptide chains and other constituents and also to the formation of new disulfide bonds. It is important to note at this point that the protein content of some of the samples used in this work was up to the above range mentioned.

Mercier and Feillet [52] observed that higher amylase content resulted in a higher WAI. If temperature increased beyond a certain limit, WAI reached a maximum and then decreased as a result of starch dextrinisation, as reported by Anderson et al. [54,55]; Anderson, [56]. The reported work also found that maximum values of WAI for cereals during extrusion exercise with 15-25% feed moisture attributed this increase in WAI to starch breakdown which was verified by the viscosity profiles according to their report. Colonna et al. [57] indicated that WAI decreases with the onset of dextrinization. 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 has on the starch component of foods. It may be expected that as the starch granule structure is disrupted more water is bound to the extrudate properties [27]. They reported that Barrel temperature and feed moisture exerted the greatest influence on gelatinization. Mercia and Feillet, [52] reported that soluble starch increased with increasing extrusion temperature and decreasing feed moisture. They found out that as extrusion temperature increased at the feed moisture of 18.2%, water solubility index increased. Water absorption index achieved a maximum value at extrusion temperatures 180 – 200°C. Increase in the amount Bambara groundnut in this work resulted in increase in WAI this might be attributed to increased level of protein as a result of increase in the level of Bambara groundnut. Hagenimana, et al. [58] reported that regression analyses showed that water absorption index was significant ($P<0.05$) and was affected by all linear, quadratic and interaction terms in extrusion of flour from rice with (screw speed, extrusion temperature and feed moisture) as independent variables. Augustniano-Osornio, et al. [59] reported increased water absorption index with decrease in the feed moisture during extrusion of mango starch.

Pelembe et al. [42] reported increased extrudate WAI as the percentage of cowpea increased in sorghum. 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 [60]. 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 cowpeas. Cowpea proteins have relatively higher water solubility than sorghum proteins [61,62]. WSI often is used as an indicator of degradation of molecular components [63], which measures the degree of starch conversion during extrusion process, this is to a certain extent is the amount of soluble polysaccharide released from the starch component after extrusion. 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, [27]. Binoy et al. [25] reported that water solubility index increased with severity of screw configuration. This trend was observed for rice flour as well as to its blends with 30% and 60% fish solids during extrusion process. An increase in shear energy inputs as well as residence time by incorporation of reverse screw elements can cause both depolymerisation and degradation of food components. High shearing can also cause fragmentation of products from both starch and proteins during extrusion cooking. The degradation products which are mostly small molecules are generally water soluble in nature [25]. During extrusion process water is usually absorbed and bound to the starch molecules with resulting change in the starch granule structure. It has been established [64]; [65] that, proteins are the most reactant components in foods and some of their reactions are essential for functionality role in extrudates. Pelembe et al. [42] reported an increased nitrogen solubility index in extruded sorghum-cowpea porridge. Among functional properties water holding capacity is important because of the hydrogen bonds formed between water and polar residues of protein molecules. An increase in shear energy inputs can cause depolymerisation and degradation of food components. The function of extrusion moisture content in WAI was reported by Anderson et al. [54]. An increasing WAI is advantageous since this parameter determines the suitability of extruded products for use in situations that involve water bonding [66].

## 3.5. Viscosity

The result of viscosity shows that, increasing the levels of Bambara groundnut flours marginally increased the viscosities of the extrudates as shown in Table 3. The viscosity values were observed to range between 8.45 and 16.96Nsm$^{-2}$ for design points 9 and 5 representing (3.2% feed composition, 25% feed moisture, 200rpm screw speed) and (30% feed composition, 20% feed moisture, 150rpm) respectively as shown in Table 3. The samples shows that, linear, quadratic and interaction terms influenced the viscosity significantly ($p<0.05$) with the linear term showing more effect on the viscosity. The coefficient of determinant $R^2$ was 0.88 for viscosity, indicating good fit of the regression model Table 4. The effect of the independent variable screw speed was not clearly defined in the results of viscosities of the fura extrudates. Examination of 3D-plot for fura extrudates showed that increase in the amount of Bambara groundnut flour increased apparent viscosity of extrudate, Figure 6.

The viscosity of extruded products will depend generally on solubility and water holding capacity of the constituents as well as the structural changes of the extrudate components. It has been reported that viscosity profile can be thought of as a reflection of the granular changes in the starch granule that occur during gelatinization in a extrusion process, [67]. Extrusion usually will induce starch dextrinization which resulted in reduction of viscosity in all gruels and a concomitant increase in caloric and nutrient density of extrudates [68]. Bhattacharya et al. [69] reported that, viscosity of protein would depend on solubility and water holding capacity as well as the structural nature of extrudates. The report indicated that, globular structures can be expected to be more viscous than the linear structures. Hagenimana et al. [58] 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).

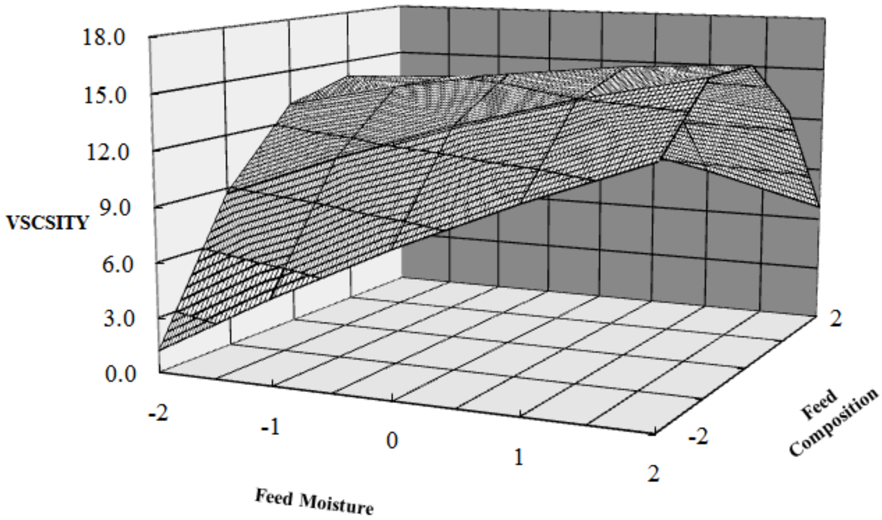


**Figure 6.** Response Effect of feed moisture and feed composition on VSCSTY

Ozcan and Jackson [70] 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 process. The report 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. [71] reported decreased apparent viscosity of extruded instant corn flour when temperature was increased. Likimani et al. [23] 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) of the extrudates. Davidson, et al. [72] 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 in extrudates. 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. [42] reported that, reduced viscosity of protein – rich sorghum – cowpea extrudate could be very beneficial for infant feeding. The high bulk dietary nature (low nutrient density) of cereal weaning porridges is a major cause of infant malnutrition in Africa, since it limits enough nutrient intakes [73]. According to the report, 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. Adeyemi and Beckley, [74] 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 of very high temperature and low moisture where shear effects were severe and significant [60]. General increase in water absorption of sorghum extrudates was reported by Gomez et al. [75]. Maximum water absorption values of extrudates were previously reported by Williams et al. [76], and Gomez and Aguilera [45], their report suggested that maximum gelatinization during extrusion cooking of corn grits and corn starch occurred at 27-29% moisture content**.** Likimani et al. [23], reported that water absorption index of starch paste could be used as indices of extent of starch hydrolysis under different extrusion conditions. El-Dash et al. [77] further reported that gelatinized starch readily absorb water to form paste that had higher final viscosity at room temperature than native starch. Mouquet, et al. [78] reported that gelatinization and dextrinization of starch occurred during extrusion of corn starch; this factor will allow preparation of product with a higher energy density.

### 3.6. Optimization

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 independent and dependent variables were analyzed to get regression equation, which was an empirical relationship between the responses and the test variable in coded units, which could predict the response under the given range. The quadratic regression model for the influenced variables are presented below where $X_1$, $X_2$, and $X_3$ are the independent variables values for feed composition, feed moisture and screw speed levels respectively. The equations were used to generate the coefficients for all the depended variables. The regression equation obtained was used to find optimum conditions for the desired parameter of millet – Bambara groundnut based fura within the range of conditions applied in this study which are shown in Table 5.

**Table 5. Summary of optimum levels of independent variables**

| Dependable variable | Feed Composition (%) | Feed Moisture (%) | Screw Speed (rpm) | Predicted value |
|---|---|---|---|---|
| WAI | 41.10 | 4.8 | 186.9 | 5.1124 $g_{water}/g_{sample}$ |
| WSI | 30.20 | 27.4 | 141.1 | 5.9326 |
| VSCSTY | 22.10 | 30.2 | 154.8 | 16.4908 $Nsm^{-2}$ |
| ER | 9.88 | 31.1 | 289.5 | 2.3499. |
| BD | 11.6 | 15.87 | 167.56 | 0.3400 $g\ m^{-3}$ |
| ART | 17.9 | 29.8 | 164.9 | 32.3277s |
| SME | 17.1 | 40.4 | 674.4 | 277.21 kj/kg |
| MFR | 17.4 | 26.0 | 198.1 | 1.7480 $gs^{-1}$ |

$$WAI = -0.7581 + 0.4888X_1 - 0.5276X_2 + 0.2679X_3 + 0.4940X_1^2 + 0.0356X_2^2 + 0.5817X_3^2 + 0.4413X_1X_2 - 0.2017X_1X_3 - 0.0779X_2X_3$$

$$WSI = 0.5620 + 0.7171X_1 - 0.2191X_2 + 0.5752X_3 – 0.3498X_1^2 - 0.1752X_2^2 -0.2987X_3^2 - 0.0316X_1X_2 + 0.0165X_1X_3 – 0.3020X_2X_3$$

$$VSCSITY = 0.6764 + 0.2074X_1 + 0.3342X_2 – 0.5432X_3 – 0.6379X_1^2 - 0.0643X_2^2 -0.2892X_3^2 - 0.4185X_1X_2 - 0.5442X_1X_3 + 0.1257X_2X_3$$

$$ART = 0.4907 + 0.3445X_1 – 0.6610X_2 - 0.0749X_3 - 0.4957X_1^2 + 0.1431X_2^2 - 0.3666X_3^2 - 0.4403X_1X_2 + 0.1922X_1X_3 - 0.4155X_2X_3$$

$$SME = 0.8978 + 0.1669X_1 – 0.2411X_2 - 0.4880X_3 - 0.6028X_1^2 – 0.6298X_2^2 - 0.0834X_3^2 - 0.4496X_1X_2 - 0.3431X_1X_3 + 0.2587X_2X_3$$

$$MFR = 1.2634 – 0.1634X_1 + 0.1507X_2 + 0.0111X_3 – 0.4547X_1^2 – 0.6620X_2^2 - 0.7351X_3^2 - 0.3613X_1X_2 + 0.0860X_1X_3 - 0.2323X_2X_3$$


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

# 4. Conclusion

Information about the physical and functional properties of foods is very useful for the purpose of process design and the production of high-value foods with desirable properties. Extrusion being a high temperature short time process characterized by reduced physical effort/energy consumption showed a great potential for adoption for commercial fura production. This technology has the possibility of producing a high quality, easily reconstitutable and hygienic product as revealed by the research. Extrusion parameters significantly affected the properties of the extruded millet – Bambara groundnut based fura. The model for the average residence time indicated that level of Bambara groundnut had the most effect on the average residence time. Feed moisture content showed more quadratic effect on the average residence time. The extrudates' expansion decreased as the moisture content increased, while a screw speed rise resulted in products with higher expansion ratio. The result shows that feed moisture and level of Bambara groundnut both influenced the expansion ratio. Fura extrudates shows that increasing feed moisture significantly decreased the water absorption index of extrudate, while increase in the level of Bambara groundnut flour resulted in increased water absorption index. Increasing screw speed and level of Bambara groundnut flour were found to increase the water solubility index. The extrudates showed that increase in the amount of bambara groundnut flour increased apparent viscosity of extrudate. RSM was successfully used to pinpoint the best combination of different factors for a processing window for a typical extrusion cooking of fura from blends pearl millet and Bambara groundnut flour mixtures. The objective of the research was to obtain suitable process that could be adopted for fura production with standardized quality characteristics and with a longer shelf life than the original ones, avoiding those negative effects which take place during manufacture. The statistical approach allowed the achievement of the optimum processing condition within the investigated experimental region defined by the (-1 and +1 level). In addition, the modelling of experimental data allowed the generation of useful equations for general use, to predict the behavior of the system under different factor combinations as may be required.

The essential amino acids (result not shown) were present in adequate levels if compared with the recommended values of FAO/WHO [79]. Bambara groundnut fortification can therefore be used to increase the nutritive value of millet with acceptable product quality characteristics for fura production.

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