Modeling Mineral Profile of Extruded Sorghum Bambara Groundnut Breakfast Cereals

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Authors’ contributions

This work was carried out in collaboration between all authors. Author DIG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript and managed literature searches. Authors IN and MHB managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study was designed to assess the effect of Bambara groundnut flour, feed moisture and barrel temperature on the mineral profile of extruded sorghum-Bambara groundnut blends and the possible mineral contribution of the products to human nutrition.

Study Design: A central composite face-centered design (CCFCD) with response surface methodology (RSM) was used. Feed composition, feed moisture and barrel temperature at three levels of -1, 0 and +1 for each variable, was used to model the mineral composition of the sorghum-Bambara groundnut extrudates. A second order polynomial was used to fit the regression equation.

Methodology: Sorghum flour was blended with Bambara groundnut flour in varying proportions. Samples were extruded at 20 to 25% feed moisture and 120 to 160°C barrel temperature. Mineral analysis was performed using atomic absorption spectrophotometer (AAS). Statistical analysis was done using MINITAB version 14 statistical software.

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Results: The calcium, zinc, phosphorus and potassium contents of all extrudates increased as the amount of Bambara groundnut flour in the feed increased. Feed composition had a significantly positive effect on the mineral content of the sorghum-Bambara groundnut extrudates. The coefficients of determination \( R^2 \) were 0.92, 0.81, 0.98, 0.96 and 0.97 for calcium, iron, zinc, phosphorus and potassium respectively with high values of adjusted \( R^2 \) values. Plots of residuals against fitted values indicated adequacy of the empirical models.

Conclusion: The mineral contents of the extrudates generally increased with increases in Bambara groundnut flour in the feed. It was therefore concluded that blends of sorghum and Bambara groundnut flour can be used for production of instant (extruded) breakfast cereals to improve their mineral contents. The second order model was found appropriate for the prediction of the mineral profile of the extrudates.

Keywords: Minerals; response surface; modeling; sorghum; extrusion; Bambara groundnut.

1. INTRODUCTION

Nigeria is the largest producer of sorghum in West Africa, accounting for about 71% of the total regional sorghum output [1]. Nigeria’s sorghum production also accounted for 35% of the African production in 2007 [2]. The country (Nigeria) is the largest world producer after the United States and India [3]. About 90% of sorghum produced in the United States and India is used for animal feed, making Nigeria the world leading country in food grain sorghum utilization. It is the primary food crop in the northern part of Nigeria [4]. There are two uses of sorghum in Nigeria: traditional and industrial uses. The traditional uses include a variety of foods, beverages and drinks. The cereal is also used in the industrial brewing of beers and malt drinks. Majority of domestic production is used for household consumption and fodder [4]. Over the last two decades, sorghum contributed to about 30% of calorie intake per capita among all cereal crops consumed in Nigeria [3]. Likewise, in terms of quantity, sorghum consumption represents in average, 30% of the total cereal consumption (excluding beer).

Bambara groundnut is regarded as the third most important legume crop after groundnut (Arachis hypogaea) and cowpea (Vigna unguiculata) in Africa but due to its low status, it is seen as a snack or food supplement but not a lucrative cash crop [5,6,7]. It originated in the Sahelian region of present day West Africa, from the Bambara tribe near Timbuktu, who now live mainly in central Mali [8], hence its name Bambara groundnut. Though, grown extensively in Nigeria, [9, 10], it is still one of the less utilized and unexploited legume. The crop has the potential to improve malnutrition and boost food availability. Bambara groundnut is primarily grown for human consumption, but it has other uses as well. The seeds of the crop make it a complete food, with sufficient and well balanced quantities of carbohydrate, protein and fats [11,12]. On average, the grains contain 63% carbohydrates, 19% protein and 6.5% oil. The gross energy value of Bambara groundnut is said to be greater than that of other common pulses such as cowpea and pigeon pea [13]. It has a high content of nitrogen, fairly well supplied with calcium and iron though poor in phosphorus and magnesium.

Extrusion cooking is a process which pushes a food material through a specially engineered narrow opening to give the desired shape and texture through increases in temperature, pressure, and shear forces. The pushing force is applied using a screw [14]. Thermoplastic extrusion is considered a High Temperature Short Time (HTST) process in the food industry, and permits, the production of a great variety of food and feed products [15,16,17]. This technique has been widely used with raw materials such as corn, wheat, rice and, especially in recent years, with soybean [16,18,19,20,21]. Examples of traditional extruded foods are pasta, noodles, vermicelli, and breakfast cereals. Other extruded foods include flat bread and snack foods such as corn curls, chips, crackers, chewing gum, chocolate, and soft/chewy candy [14]. In the formulation of extruded breakfast cereals, a mixture of these cereals can be used, in the form of flours, grits or whole grain flours, and they can also be mixed with other ingredients such as starches, sugar, salt, malt extract or other liquid sweeteners, heat stable vitamins and minerals, flavourings, colorants and water, to vary appearance, texture, taste, aroma and other product characteristics [22].
Breakfast cereals can be categorized as products such as oatmeal, which are served hot and therefore, are expected to be cooked before serving, and fully cooked ready-to-eat cereals such as corn flakes which are rarely, if ever, heated before serving. The former class is probably as old as civilization, since it is very likely that gruels and porridges made from grains cooked with water were among the first cereal foods of mankind. Bellis [23] however defined breakfast cereals (or just cereal) as a food made from processed grains that is often eaten with the first meal of the day. It is often eaten cold, usually mixed with milk (e.g. cow’s milk, soy milk, rice milk, almond milk), juice, water, or yogurt, and sometimes fruit, but may be eaten dry. Some products are produced from high fibre cereals. Many breakfast cereals are produced via extrusion.

Ready-to-eat breakfast cereals have become recognized by persons in all walks of life as economical, convenient, and flavourful foods suitable for daily consumption by all age groups. Addition of vitamins, minerals, and protein as well as fibre supplementation have been developed to give finished products a nutritional adequacy which is equaled by only a few other foods. Many consumers especially the working class, find the cooking time required for preparing meals using ingredients containing unaltered grain products to be excessive. To increase convenience and therefore consumer acceptance, it is desirable to decrease cooking time required for kitchen preparation. Ideally it should be possible to pour boiling water on the cereal, stir the mixture a few times and then consume it [24].

The traditional breakfast cereals in Nigeria are ogi or akamu from maize, millet and sorghum, kunun-gyada from rice, masa from rice [25] and porridge (Iber-Tiv), from millet or sorghum flour. Commercially processed breakfast cereals which are presented in modern packages in the Nigerian market include Quaker Oats, Golden morn (from maize), Corn Flakes (from maize) and Fast-O-Meal, also from maize.

A Central Composite Design (CCD) is a response surface design wherein a process of sequential experiments using independent variables leads to an optimum response [26]. It is another version of a general $2^k$ factorial design where $k$ denotes the number of factors and the number 2 denotes two levels (high or low) of the factors. The difference between a $2^k$ factorial design and CCD is that, the CCD includes the central point. Also the CCD takes into account the changes in the response due to interaction of the factors and the quadratic effects [26].

Despite the importance of minerals for good health, relatively few studies have examined mineral stability during extrusion because they are reported stable and unaffected by other food processes [15]. Minerals are heat stable and unlikely to become lost in the steam distillate at the die [27]. Extrusion cooking can improve the absorption of minerals by reducing other factors, such as antinutrients, that inhibit absorption [28]. This study was designed to assess the effect of Bambara groundnut flour (feed composition), feed moisture and barrel temperature on the mineral profile of sorghum-Bambara groundnut extrudates.

2. MATERIALS AND METHODS

2.1 Procurement of Raw Materials

The sorghum variety (Chakalari red), was obtained from Maiduguri Monday market. Bambara groundnut (cream-coloured variety) was purchased from the Mubi main market, Adamawa State, Nigeria.

2.2 Preparation of Sorghum Flour

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

2.3 Blending of Sorghum with Bambara Groundnut Flour and Moisture Adjustment

Sorghum flour was blended with Bambara groundnut flour in varying proportions (10%, 20% and 30% Bambara groundnut). The total moisture content of the blends was adjusted to the desired level according to Zasypkin and Tung-Ching [29]. The blends were then mixed
using a laboratory mixer and the moisture allowed to equilibrate as earlier reported [20].

2.4 Extrusion of Sorghum-Bambara Groundnut Blends

Extrusion cooking was done in a single-screw extruder (Model: Brabender Duisburg DCE-330), equipped with a variable speed DC drive unit and strain gauge type torque meter. The extruder was fed manually through a screw operated conical hopper using a plastic bowl. The hopper which is mounted vertically above the end of the extruder is equipped with a screw rotated at variable speed. Experimental samples were collected when steady state (constant torque and temperature) was achieved. Variables considered were feed composition, feed moisture content and temperature of extrusion. Extrudates were kept on work benches in the workshop for about 24 hr to dry. They were then packaged in polythene bags prior to analysis.

2.5 Mineral Analysis

2.5.1 Sample preparation for mineral analysis

The extrudates samples were treated according to the elemental analysis procedures described by Vogen [30]. These samples were taken and aspirated into the atomic absorption spectrophotometer (AAS Model: PERKINS ELMER 2380). Corresponding concentrations and absorbances were read from the digital display unit.

2.6 Experimental Design

A central composite face-centered (CCFC) non-rotatable design with three independent variables: Feed composition (%), feed moisture (%) and extruder barrel temperature (°C) at three levels of -1, 0 and +1 for each variable [31] was used to predict the optimum processing conditions for the extrusion of the breakfast cereals (Table 1). The feed which was made up of sorghum and cowpea flours was blended in the ratios of 10, 20 and 30% cowpea to sorghum flour respectively. Extrusion runs were performed as presented in Table 2. The levels of the various independent variables were arrived at after preliminary extrusion runs. The Central Composite Face-Centered Design used in this work was produced using MINITAB 14 [32] statistical software. The design was made up of 8 cube points, 6 centre points in the cube and 6 axial points giving a total of 20 design points. The general second-order equation was used in the experimental design of this work thus:

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

(1)

Where \( X_1, X_2 \) and \( X_3 \) are feed composition, feed moisture and barrel temperature, respectively; \( b_0 \) is the regression constant; \( b_1, b_2 \) and \( b_3 \) are linear regression terms; \( b_{11}, b_{22} \) and \( b_{33} \) are quadratic regression terms; \( b_{12}, b_{13} \) and \( b_{23} \) are the cross-product regression terms; \( \varepsilon \) is the error term.

| Table 1. Process variables and their levels used in the central composite face centered design (CCFC) |
|-----------------------------------------------|
| Independent variable | Code | -1 | 0 | +1 |
| Feed composition (%) | \( X_1 \) | 10 | 20 | 30 |
| Feed moisture (%) | \( X_2 \) | 20 | 22.5 | 25 |
| Extrusion temperature (°C) | \( X_3 \) | 120 | 140 | 160 |

| Table 2. Central composite face centered (CCFC) design matrix and the independent variables in their coded and natural forms |
|-----------------------------------------------|
| Experimental runs | Cowpea flour (%) \( X_1 \) | Feed moisture (%) \( X_2 \) | Barrell temperature (°C) \( X_3 \) |
| 1. | 10 (-1) | 20 (-1) | 120 (-1) |
| 2. | 30 (+1) | 20 (-1) | 120 (-1) |
| 3. | 10 (-1) | 25 (+1) | 120 (-1) |
| 4. | 30 (+1) | 25 (+1) | 120 (-1) |
| 5. | 10 (-1) | 20 (-1) | 160 (+1) |
| 6. | 30 (+1) | 20 (-1) | 160 (+1) |
| 7. | 10 (-1) | 25 (+1) | 160 (+1) |
| 8. | 30 (+1) | 25 (+1) | 160 (+1) |
| 9. | 10 (-1) | 22.5 (0) | 140 (0) |
| 10. | 30 (+1) | 22.5 (0) | 140 (0) |
| 11. | 20 (0) | 20 (-1) | 140 (0) |
| 12. | 20 (0) | 25 (+1) | 140 (0) |
| 13. | 20 (0) | 22.5 (0) | 120 (-1) |
| 14. | 20 (0) | 22.5 (0) | 160 (+1) |
| 15. | 20 (0) | 22.5 (0) | 140 (0) |
| 16. | 20 (0) | 22.5 (0) | 140 (0) |
| 17. | 20 (0) | 22.5 (0) | 140 (0) |
| 18. | 20 (0) | 22.5 (0) | 140 (0) |
| 19. | 20 (0) | 22.5 (0) | 140 (0) |
| 20. | 20 (0) | 22.5 (0) | 140 (0) |

2.7 Statistical Analysis

MINITAB version 14 statistical analysis software [32] was used for the statistical analysis. Multiple regression analysis was conducted and results fitted to second-order polynomial equation to
develop a model equation that will establish the relationship between the independent and response variables. Analysis of variance (ANOVA) was conducted on the data to establish statistical level of significance of the model, while coefficient of determination test ($R^2$), test of lack of fit and residual analysis were used to determine the adequacy of the fitted models.

3. RESULTS AND DISCUSSION

3.1 Mineral Composition of Sorghum-Bambara Groundnut Extrudates

Minerals are inorganic substances, present in all body tissues and fluids and their presence is necessary for maintenance of certain physicochemical processes which are essential for life. Although they yield no energy, they have important roles to play in many activities in the body [33,34]. The mineral composition of sorghum-Bambara groundnut extrudates is shown in Table 3. Calcium content increased from 21.23 mg/100 g for design point 6 (30% Bambara groundnut flour, 20% feed moisture and 160°C barrel temperature) to 38.60 mg/100 g for design point 8 (30% Bambara groundnut flour, 25% feed moisture and 160°C barrel temperature). There was significant ($p \leq 0.05$) variation in the calcium content of samples. Extrudates with higher Bambara groundnut flour incorporated in them showed higher values of calcium while lower values were observed for samples with lower amounts of Bambara groundnut flour. The calcium content of extrudates was lower than the recommended dietary allowance of 300 mg per day for humans [35]. The breakfast cereals would have to be consumed along with other sources of calcium such as milk to meet the dietary requirements. The iron content of samples varied from 2.39 mg/100 g for design points 12 (20% Bambara groundnut flour, 25% feed moisture and 140°C barrel temperature) to 4.21 mg/100 g for design point 4 (30% Bambara groundnut flour, 25% feed moisture and 120°C barrel temperature). There was significant ($p < 0.05$) variation in the iron content of extrudates. This may be due to variation in the Bambara groundnut flour in the samples prior to extrusion. Iron is an important component of the cytochromes that function in cellular respiration. Red blood cells cannot function properly without iron in haemoglobin, the oxygen-carrying pigment of red blood cells [36]. The iron requirements for children of 1 to 3 years is 7 mg/day. Adult males of 14 to 18 years of age require 15 mg per day [37]. The zinc content of extrudates ranged from 10.84 mg/100 g for design point 5 (10% Bambara groundnut flour, 20% feed moisture and 160°C barrel temperature) to 26.50 mg/100 g for design point 4 (30% Bambara groundnut flour, 25% feed moisture, 120°C barrel temperature). There was significant ($p < 0.05$) difference in the zinc contents of extrudates. This may be because of the same reason of variation in Bambara groundnut flour in samples earlier stated. The recommended zinc requirements for males of 65 kg body weight is 14 mg/day while females of 55 kg body weight require 9.8 mg per day [35]. The phosphorus content of samples varied from 372.0 mg/100 g for design point 13 (20% Bambara groundnut flour, 22.5% feed moisture and 120°C barrel temperature) to 381.13 mg/100 g for design point 9 (10% Bambara groundnut flour, 22.5 feed moisture and 140°C barrel temperature). There was significant ($p < 0.05$) difference in the phosphorus content of samples. Adults require 700 mg phosphorus per day while children of 1 to 3 years require 460 mg phosphorus per day [38]. The potassium content of extrudates increased from 561.89 mg/100 g for design point 1 (20% Bambara groundnut flour, 22.5% feed moisture and 140°C barrel temperature) to 650.60 mg/100 g for design point 4 (30% Bambara groundnut flour, 25% feed moisture, 120°C barrel temperature). There was significant ($p < 0.05$) difference in the potassium content of samples. Potassium is important in the maintenance of osmotic balance between cells and the interstitial fluid [36]. The potassium requirements for children of 1 to 3 years is 3000 mg per day while the requirements for children between 9 to 13 years is 4,500 mg per day [39]. Although, the mineral contents of the extrudates (breakfast cereals) increased significantly due to supplementation with Bambara groundnut flour, it is necessary for consumers of the products to eat other sources of minerals to meet their daily nutritional needs.

3.2 Response Surface Plots of Sorghum-Bambara Groundnut Extrudates

The response surface plots for calcium content of sorghum-Bambara groundnut extrudates is presented in Fig. 1(a). The calcium content of the extrudates increased sharply as the Bambara groundnut flour in the feed was increased (Fig. 1a). This could be explained by the lower amounts of calcium in sorghum (6 to 53 mg/100 g) [40,41] than Bambara groundnut (51 to 68 mg/100 g) [41,42]. The interactive effects of feed components in extrudates increased significantly with increased Bambara groundnut flour in the feed. The response surface plots for iron content of extrudates showed an increase in iron content of extrudates as the Bambara groundnut flour in the feed was increased (Fig. 1b). The iron content of extrudates increased significantly with increased Bambara groundnut flour in the feed. The response surface plots for zinc content of extrudates showed an increase in zinc content of extrudates as the Bambara groundnut flour in the feed was increased (Fig. 1c). The zinc content of extrudates increased significantly with increased Bambara groundnut flour in the feed. The response surface plots for phosphorus content of extrudates showed an increase in phosphorus content of extrudates as the Bambara groundnut flour in the feed was increased (Fig. 1d). The phosphorus content of extrudates increased significantly with increased Bambara groundnut flour in the feed. The response surface plots for potassium content of extrudates showed an increase in potassium content of extrudates as the Bambara groundnut flour in the feed was increased (Fig. 1e). The potassium content of extrudates increased significantly with increased Bambara groundnut flour in the feed.
composition and feed moisture produced a saddle-shaped response surface. The minimum for iron content of the extrudates was located along the feed composition axis while the maximum was located on the feed moisture axis. Sorghum contains higher amounts of iron [40] than Bambara groundnut which may explain the reduction with increase in Bambara groundnut flour. Minerals are heat stable and unlikely to become lost in the steam distillate at the die [27]. Camire et al. [15] reported increase in iron content of extrudates which was attributed to wear from the extruder screw. More work is required here to explain the reduction in iron content in this report.

The zinc content of the extrudates increased sharply with increased in Bambara groundnut flour in the feed (Fig. 3a). Bambara groundnut is richer than sorghum in zinc which explains this increase. The response surface plot for phosphorus is presented in Fig. 4(a). The saddle shape shows the probability of the variable (phosphorus) at either the maximum or minimum point. In this case, the minimum is located midway along the feed composition axis while the maximum points are located midway along the temperature axis. The potassium content of the extrudates increased progressively (Fig. 5(a) as the Bambara groundnut flour increased in the feed.

Fig. 1(a) Response surface plots on effect of extrusion conditions on the calcium content of extrudates

![Response surface plot](image)

**Residuals Versus the Fitted Values**

(response is Calcium)

![Residuals plot](image)

Fig. 1(b). Plot of residuals and fitted values for calcium
The increase in the potassium content of extrudates may be due to the higher (1,578 mg/100 g) potassium content of Bambara groundnut than sorghum (363 mg/100 g) [42,43,44] observed similar increases in mineral content when rice-cowpea blends were extruded and partly attributed it to wear from the extruder screw as earlier reported by Camire et al. [15]. Bambara groundnut appears richer than sorghum in most of the minerals studied in this work. It is therefore appropriate to extrude blends of sorghum and sorghum for production of instant food products from sorghum to improve their mineral contents.

3.3 Model Fitting and Validation

Estimated regression coefficients for minerals in sorghum-Bambara groundnut extrudates are presented in Table 4. Barrel temperature showed a negative linear effect on the calcium content of the extrudates. Calcium content tended to increase as the Bambara groundnut flour was increased in the feed. Feed composition had a positive quadratic effects as well as interactive effect when combined with feed moisture. All the cross product effects had significant effects on the calcium content of the extrudates blends. The coefficient of determination ($R^2$) was 0.92 with adjusted $R^2$ value of 0.85. Although there was a significant lack of fit, plots of residuals against fitted values (Fig. 1) for calcium showed a scattered distribution of the points about the central line thus validating the model. The analysis of variance (ANOVA) of the regression analysis for calcium, iron and zinc is presented in Table 5. Because the F-statistic is the ratio of two sample variances, when the two sample variances are close to equal, the F-score is close to one. If the F-score is computed, and it is close to one, you accept the hypothesis that the samples come from populations with the same variance. The larger the F-value, the better for the researcher to find a significant effect. That is the higher the F-value, the better the model [45]. The F-value for calcium was $F(p < 0.01) = 12.92$, thus validating the second order model. The iron content of the extrudates was significantly ($p < 0.01$) influenced by the negative linear effect of feed composition and feed moisture and the negative influence of barrel temperature and the quadratic effects of barrel temperature. It was also significantly affected by feed composition and feed moisture. The $R^2$ and adjusted $R^2$ were 0.81 and 0.63 respectively with a non-significant lack of fit suggesting a good fit. A plot of the residuals against fitted values (Fig. 2) for iron shows a validation of the model for the process. The F-value for iron was $F(p < 0.01) = 4.76$, thus validating the reliability of the second order model. The zinc content of the extrudates was positively influenced by the feed composition and the negative cross-product effect of feed composition and barrel temperature.

### Table 3. Mineral composition of sorghum-Bambara groundnut extrudates (mg/100 g)$^1$

| Runs | Feed composition (%) | Feed moisture (%) | Barrel temp. ($^\circ$C) | Calcium | Iron | Zinc | Phosphorus | Potassium |
|------|----------------------|-------------------|---------------------------|---------|------|------|------------|----------|
| 1.   | 10                   | 20                | 120                       | 23.70c  | 4.21a | 10.95i| 376.15gh  | 561.89hi |
| 2.   | 30                   | 20                | 120                       | 38.46a  | 3.98bcd | 26.2b | 375fg     | 634.6b   |
| 3.   | 10                   | 25                | 120                       | 22.8cd  | 4.05abc| 10.85i| 377.8ode  | 608.6gh  |
| 4.   | 30                   | 25                | 120                       | 37.7ab  | 4.11ab | 26.5a | 376def    | 650.6a   |
| 5.   | 10                   | 20                | 160                       | 22.16de | 4.11ab | 10.84i| 377ef     | 635.9b   |
| 6.   | 30                   | 20                | 160                       | 21.23de | 3.94de | 25.7c | 377.5def  | 610.4de  |
| 7.   | 10                   | 25                | 160                       | 26.45bc | 3.91e | 17.93h| 379.4abc  | 622.18c  |
| 8.   | 30                   | 25                | 160                       | 38.6a   | 3.91e  | 25.74c| 379.2ode  | 586.71h  |
| 9.   | 10                   | 22.5               | 140                       | 22.51cd | 4.05abc| 10.94i| 381.13a   | 614.68d  |
| 10.  | 30                   | 22.5               | 140                       | 36.81ab | 4.08abc| 26.11b| 380ab     | 634.5b   |
| 11.  | 20                   | 22.5               | 140                       | 27.96abc| 3.93de | 18.45def| 375.7g    | 586.9g   |
| 12.  | 20                   | 25                | 140                       | 26.6bc  | 3.90e  | 18.6def| 377.5def  | 610.05de |
| 13.  | 20                   | 22.5               | 120                       | 27.2abc | 4.1a   | 18.5def| 374.2i    | 610de    |
| 14.  | 20                   | 22.5               | 160                       | 26.47bc | 4.1a   | 17.91h| 377.8de   | 610.55de |
| 15.  | 20                   | 22.5               | 140                       | 26.3bcd | 3.95de | 18.4fg | 377.87de  | 610.1de  |
| 16.  | 20                   | 22.5               | 140                       | 26.8bc  | 3.91e  | 18.6def| 378.5ode  | 610.13de |
| 17.  | 20                   | 22.5               | 140                       | 26.6bc  | 3.92e  | 18.6def| 378.5ode  | 610.2de  |
| 18.  | 20                   | 22.5               | 140                       | 26.8bc  | 3.95de | 18.7de | 378.5ode  | 610de   |
| 19.  | 20                   | 22.5               | 140                       | 26.7bc  | 3.97de | 18.73de| 379cd     | 610.1de  |
| 20.  | 20                   | 22.5               | 140                       | 26.75bc | 3.95de | 18.65de| 378.5ode  | 610.2de  |

*Any two means in a column not accompanied by the same letter(s) are significantly ($p<0.05$) different*
Increasing Bambara groundnut flour in the feed caused a sharp increase in the zinc content of the extrudates. The $R^2$ and adjusted $R^2$ were 0.98 and 0.96 respectively. The $R^2$ values near unity are considered a good indication of the suitability of the model for prediction of the responses being studied. The F-value for zinc was $F(p<0.01) = 47.21$, thus validating the second order model.
Fig. 3(b). Plot of residuals and fitted values for zinc

Fig. 4 (a). Response surface plots on effect of extrusion conditions on the phosphorus content of extrudates

Fig. 4(b). Plot of residuals and fitted values for phosphorus
Fig. 5 (a). Response surface plots on effect of extrusion conditions on the potassium content of extrudates

Table 4. Estimated regression coefficients for minerals in sorghum-Bambara groundnut extrudates

| Coefficient | Calcium   | Iron       | Zinc       | Phosphorus | Potassium   |
|-------------|-----------|------------|------------|------------|-------------|
| Linear      |           |            |            |            |             |
| $b_0$       | 174.87    | 2.0534     | 59.01      | 163.06     | -1476.78    |
| $b_1$       | -0.338    | -0.0799**  | 1.991**    | -1.157*    | 14.78**     |
| $b_2$       | -7.703    | 0.6408*    | -4.4264    | 10.750     | 122.92      |
| $b_3$       | -0.956**  | -0.0696**  | -0.3256    | 1.405**    | 7.53**      |
| Quadratic   |           |            |            |            |             |
| $b_{11}$    | 0.025**   | -0.0006    | 0.0041     | 0.025**    | 0.15        |
| $b_{22}$    | -0.022    | -0.014     | 0.0659     | -0.240     | -1.82**     |
| $b_{33}$    | -0.001    | 0.0002**   | 0.0002     | -0.005**   | ****        |
| Interaction |           |            |            |            |             |
| $b_{12}$    | 0.066**   | 0.0023**   | -0.0333    | -0.007     | -0.20**     |
| $b_{13}$    | -0.012**  | ****       | -0.0051*   | 0.002      | -0.11**     |
| $b_{23}$    | 0.058**   | -0.0005    | 0.0173*    | 0.004      | -0.25**     |
| R²          | 0.921     | 0.811      | 0.977      | 0.961      | 0.974       |
| Adjusted R² | 0.850     | 0.641      | 0.956      | 0.925      | 0.95        |

$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}(X_1)^2 + b_{13}(X_1)X_2 + b_{23}(X_2)^2 + b_{123}X_1X_2 + b_{234}X_2X_3 + \varepsilon$; $X_1 =$ Feed composition, $X_2 =$ Feed moisture, $X_3 =$ Barrel temperature; * Significant at $p \leq 0.05$, and **$p \leq 0.01$ respectively, NS = not significant.
Table 5. Results of analysis of variance (ANOVA) for calcium, iron and zinc

| Source   | df | Seq SS  | Adj SS | Adj MS  | F     | P     |
|----------|----|---------|--------|---------|-------|-------|
| **Calcium** |    |         |        |         |       |       |
| Regression | 9  | 522.68  | 522.68 | 58.08   | 12.92 | 0.000 |
| Linear    | 3  | 363.85  | 12.262 | 4.09    | 0.91  | 0.471 |
| Square    | 3  | 26.50   | 26.50  | 8.84    | 1.97  | 0.183 |
| Interaction| 3  | 132.33  | 44.11  | 9.82    | 0.003 |
| Residual Error | 10 | 44.94   | 44.94  | 4.49    | ------ | ------ |
| Lack of fit| 5  | 44.76   | 44.76  | 8.95    | 245.81| 0.000 |
| Pure error | 5  | 0.182   | 0.182  | 0.04    | ------ | ------ |
| Total     | 19 | 567.62  | 567.62 | ------- | ------ | ------ |
| **Iron**  |    |         |        |         |       |       |
| Regression | 9  | 0.131   | 0.131  | 0.0145  | 4.76  | 0.011 |
| Linear    | 3  | 0.041   | 0.0595 | 0.0198  | 6.50  | 0.01  |
| Square    | 3  | 0.058   | 0.0582 | 0.0194  | 6.37  | 0.011 |
| Interaction| 3  | 0.031   | 0.0315 | 0.0105  | 3.44  | 0.06  |
| Residual Error | 10 | 0.031   | 0.0305 | 0.00305 | ------ | ------ |
| Lack of fit| 5  | 0.0268  | 0.0268 | 0.0054  | 7.28  | 0.024 |
| Pure error | 5  | 0.0037  | 0.0037 | 0.0007  | ------ | ------ |
| Total     | 19 | 0.515.8 | ------- |         | ------ | ------ |

| Source   | df | Seq SS  | Adj SS | Adj MS  | F     | P     |
|----------|----|---------|--------|---------|-------|-------|
| **Zinc** |    |         |        |         |       |       |
| Regression | 9  | 503.94  | 503.94 | 55.99   | 47.21 | 0.000 |
| Linear    | 3  | 480.74  | 18.1   | 6.03    | 5.09  | 0.022 |
| Square    | 3  | 3.21    | 3.21   | 1.07    | 0.90  | 0.474 |
| Interaction| 3  | 20      | 20     | 6.67    | 5.62  | 0.016 |
| Residual Error | 10 | 11.86   | 11.86  | 1.19    | ------ | ------ |
| Lack of fit| 5  | 11.53   | 11.53  | 2.31    | 34.48 | 0.001 |
| Pure error | 5  | 0.334   | 0.334  | 0.067   | ------ | ------ |
| Total     | 19 | 515.8   | ------- |         | ------ | ------ |

The estimated regression coefficient for phosphorus is presented in Table 4. The phosphorus content of the extrudates was negatively affected by the linear effect of Feed composition (Bambara groundnut flour inclusion) and barrel temperature. It was also affected by the positive quadratic effect of feed composition and the negative effects of extrusion temperature. The $R^2$ and adjusted $R^2$ values were 0.96 and 0.93 respectively with a non-
significant lack of fit. The F-value for phosphorus was $F(p<0.01) = 27.17$, thus validating the second order model. Potassium content of all the extrudates was influenced by the linear effect of feed composition and barrel temperature. Feed moisture showed a quadratic effect while all the cross-product effects indicated a negative influence on the potassium content of the extrudates. The $R^2$ was 0.97 while the adjusted $R^2$ was 0.95. There was a significant lack of fit for the model. Figures 3 to 5 which shows the plots of residuals against fitted values for zinc, phosphorus and potassium clearly show that the models appropriately describe these minerals in the system. The F-value for potassium was $F(p<0.01) = 41.31$, thus validating the second order model.

4. CONCLUSION

Bambara groundnut was found richer than sorghum in most of the minerals reported in this work hence the increases in the mineral content of the extrudates. It is therefore concluded that, blends of sorghum and Bambara groundnut flours can be used for production of instant (extruded) breakfast cereals to improve their mineral (composition) content. The second order model was found appropriate for the prediction of the mineral profile of the extrudates. Feed composition showed the most effect on mineral content of extrudates followed by barrel temperature while feed moisture showed the least effect.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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