British Journal of Applied Science & Technology
17(4): 1-14, 2016, Article no.BJAST.28700
ISSN: 2231-0843, NLM ID: 101664541

SCIENCEDOMAIN *international*
www.sciencedomain.org

Modeling Mineral Profile of Extruded Sorghum Bambara Groundnut Breakfast Cereals

David Iordehiin Gbenyi[1*], Iro Nkama[2] and Mamudu Halidu Badau[3]

[1]Department of Food Science and Technology, The Federal Polytechnic, P.M.B. 35, Mubi, Nigeria.
[2]Department of Food Science and Technology, University of Nigeria, Nsukka, Nigeria.
[3]Department of Food Science and Technology, University of Maiduguri, P.M.B 1069, Maiduguri, Nigeria.

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.

Article Information

DOI: 10.9734/BJAST/2016/28700
Editor(s):
(1) Ming-Chih Shih, Department of Health and Nutrition Science, Chinese Culture University, Taiwan.
Reviewers:
(1) Sherif Ramzy, National Research Centre, Egypt.
(2) Bamidele O. Peter, Obafemi Awolowo University Ile-Ife, Nigeria.
(3) Patrícia Matos Scheuer, Federal University of Santa Catarina, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history/16280

Original Research Article

Received 31st July 2016
Accepted 14th September 2016
Published 21st September 2016

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℃ barrel temperature. Mineral analysis was performed using atomic absorption spectrophotometer (AAS). Statistical analysis was done using MINITAB version 14 statistical software.

**Corresponding author: E-mail: digbenyi@yahoo.com;*

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 hypogea*) 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℃ 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 (℃) 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:

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

Where X_1, X_2 and X_3 are feed composition, feed moisture and barrel temperature, respectively; b_o 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; ε 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	Barrel temperature (°C); X_2
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℃ barrel temperature) to 38.60 mg/100 g for design point 8 (30% Bambara groundnut flour, 25% feed moisture and 160℃ barrel temperature). There was significant (p≤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 3.90 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 1 (10% Bambara groundnut flour, 20% feed moisture and 120℃ 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 11 mg per day while females of the same age require 15mg 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℃ 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℃ barrel temperature) to 381.13 mg/100 g for design point 9 (10% Bambara groundnut flour, 22.5 feed moisture and 140℃ 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℃ barrel temperature) to 650.60 mg/100 g for design point 4 (30% Bambara groundnut flour, 25% feed moisture, 120℃ 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 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.

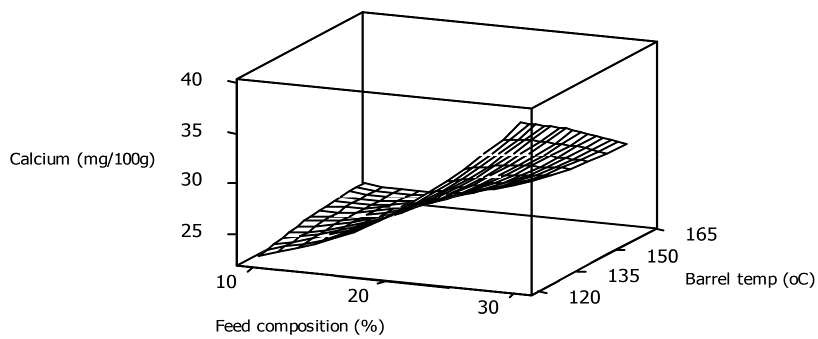

Fig. 1(a) Response surface plots on effect of extrusion conditions on the calcium content of extrudates

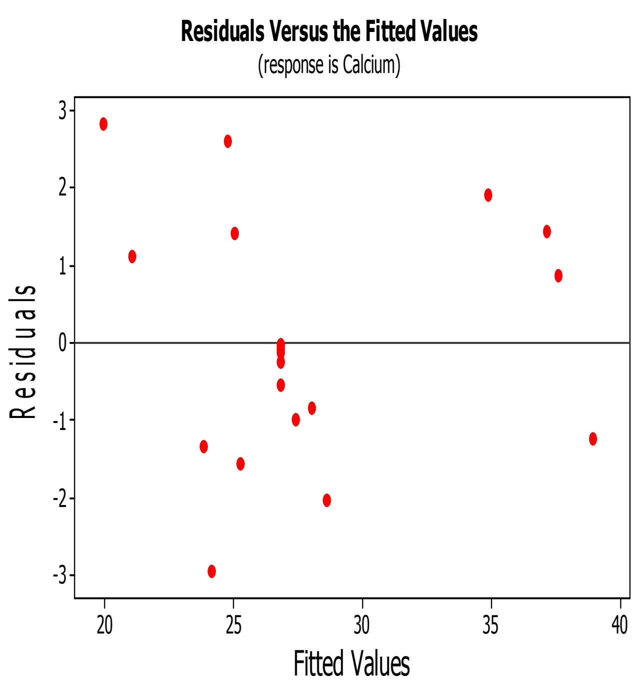

Fig. 1(b). Plot of residuals and fitted values for calcium

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. (°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	377.8cde	608.6gh
4.	30	25	120	37.7ab	4.11ab	26.5a	376def	650.6a
5.	10	20	160	22.16cde	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	379.2cde	586.71h
9.	10	22.5	140	22.51cd	4.05abc	10.94i	381.13a	614.69d
10.	30	22.5	140	36.81ab	4.08abc	26.11b	380ab	634.5b
11.	20	20	140	27.36abc	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	4.1ab	18.5def	374.2i	610de
14.	20	22.5	160	26.47bc	4.1ab	17.91h	377.8de	610.55def
15.	20	22.5	140	26.3bcd	3.95de	18.4efg	377.87de	610.1de
16.	20	22.5	140	26.8bc	3.91e	18.6def	378.5cde	610.13de
17.	20	22.5	140	26.6bc	3.92e	18.6def	378.5cde	610.2de
18.	20	22.5	140	26.8bc	3.95de	18.7de	378.5cde	610de
19.	20	22.5	140	26.7bc	3.97cde	18.75de	379cd	610.1de
20.	20	22.5	140	26.75bc	3.95de	18.65de	378.5cde	610.2de

[1]Any two means in a column not accompanied by the same letter(s) are significantly ($p\leq0.05$) different

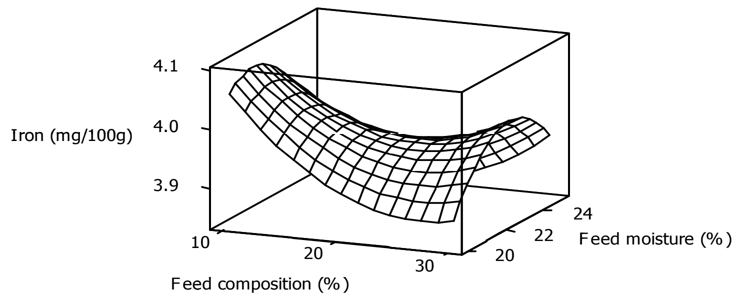

Fig. 2(a). Response surface plots on effect of extrusion conditions on the iron content of extrudates

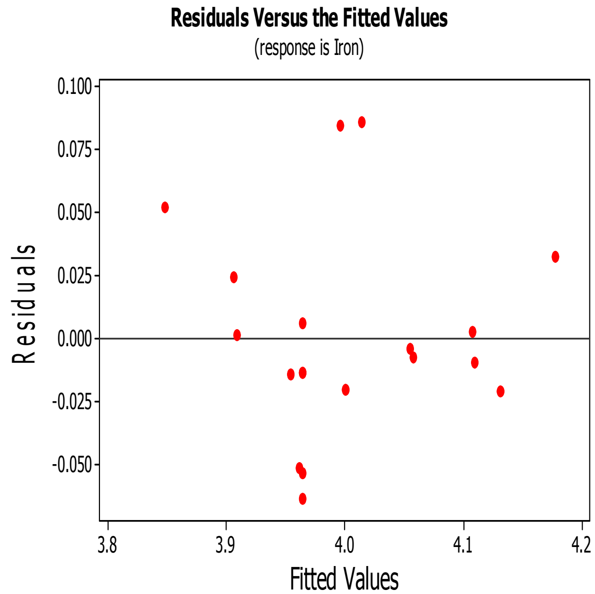

Fig. 2(b). Plot of residuals and fitted values for iron

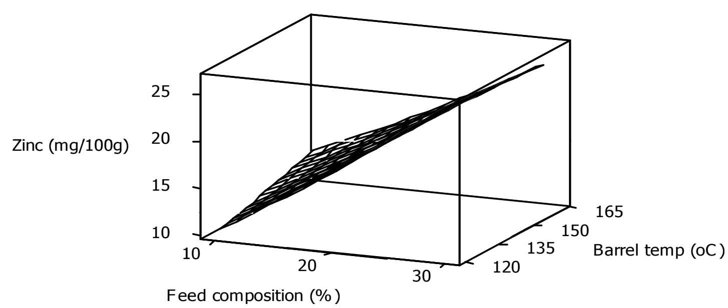

Fig. 3 (a). Response surface plots on effect of extrusion conditions on the zinc content of extrudates

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.

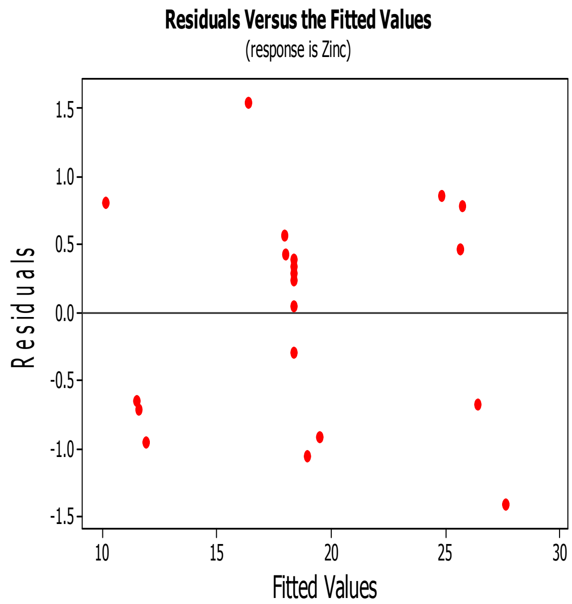

Fig. 3(b). Plot of residuals and fitted values for zinc

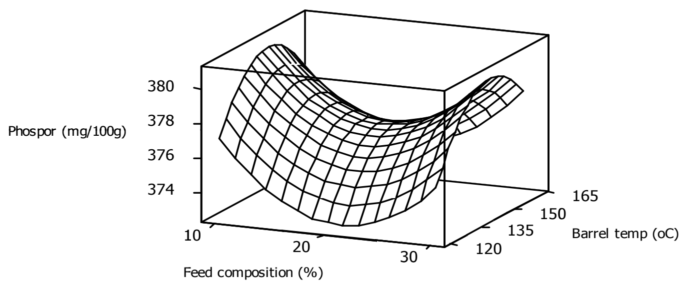

Fig. 4 (a). Response surface plots on effect of extrusion conditions on the phosphorus content of extrudates

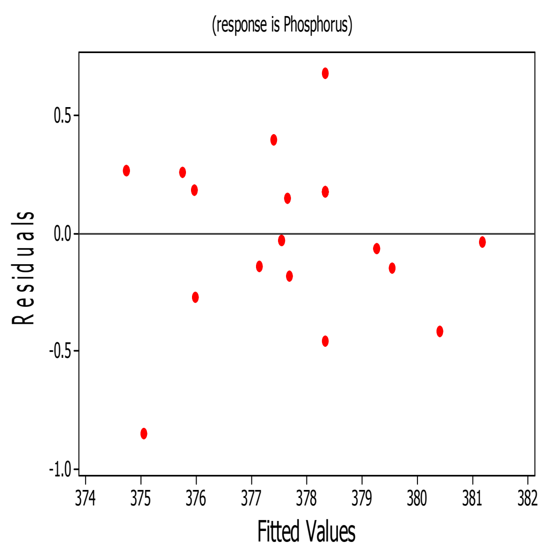

Fig. 4(b). Plot of residuals and fitted values for phosphorus

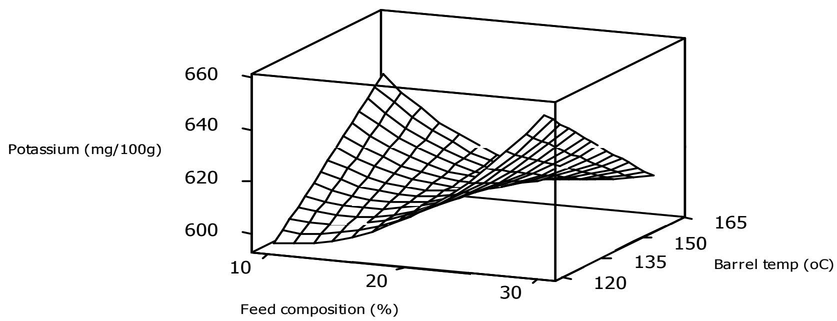

Fig. 5 (a). Response surface plots on effect of extrusion conditions on the potassium content of extrudates

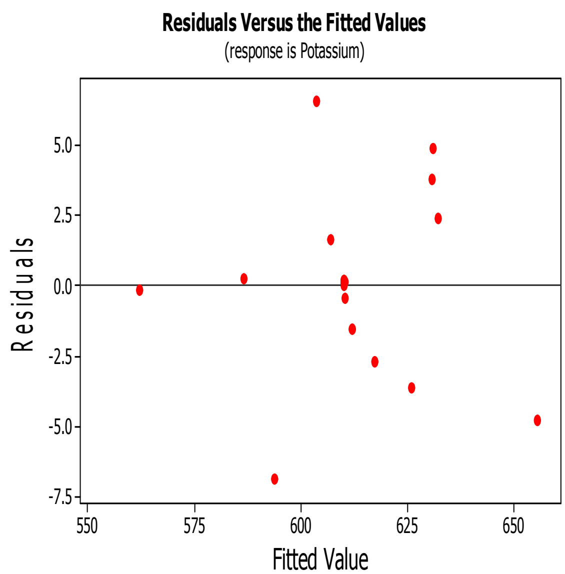

Fig. 5 (b). Plot of residuals and fitted values for potassium

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

Coefficient	Calcium	Iron	Zinc	Phosphorus	Potassium
Linear					
b_o	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**	-0.0596**	-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**
R^2	0.921	0.811	0.977	0.961	0.974
Adjusted R^2	0.850	0.641	0.956	0.925	0.95
Lack of Fit	*	NS	*	NS	*

*$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}(X_1)^2 + b_{22}(X_2)^2 + b_{33}(X_3)^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + \varepsilon$; 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	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					
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				

df = degree of freedom, SS = sum of squares, MS = mean sum of squares, F = variance ratio, P = probability.

Table 6. Results of analysis of variance (ANOVA) for phosphorus and potassium

Source	df	Seq SS	Adj SS	Adj MS	F	P
Phosphorus						
Regression	9	53.63	53.63	5.96	27.17	0.000
Linear	3	22.55	22.86	7.62	34.75	0.000
Square	3	29.27	29.27	9.76	44.5	0.000
Interaction	3	1.81	1.81	0.60	2.75	0.098
Residual Error	10	2.19	2.19	0.219	------	------
Lack of fit	5	1.55	1.55	0.310	2.40	0.179
Pure error	5	0.644	0.644	0.129	------	------
Total	19	55.82				
Potassium						
Regression	9	6831.01	6831.01	759	41.31	0.000
Linear	3	775.7	3048.77	1016.26	55.32	0.000
Square	3	737.52	737.52	245.84	13.38	0.001
Interaction	3	5317.79	5317.79	1772.6	96.48	0.000
Residual Error	10	183.72	183.72	18.37	------	------
Lack of fit	5	183.69	183.69	36.74	6540.9	0.000
Pure error	5	0.03	0.03	0.01	------	------
Total	19	7014.73				

df = degree of freedom, SS = sum of squares, MS = mean sum of squares, F = variance ratio, P = probability.

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.

REFERENCES

1. Ogbonna AC. Current developments in malting and brewing trials with sorghum in Nigeria: A review. 2011;117(3):394-400.
2. African Agricultural Technology Foundation (AATG). Feasibility Study on Striga Control in Sorghum; 2011.
3. Food and Agriculture organization (FAO). Trade Database, Production Database; 2012.
   Available:http://faostat.org/
   (Retrieved 28th June, 2016)
4. Gaurichon H. Analysis of incentives and disincentives for sorghum in Nigeria. Technical Notes Series, MAFAP, FAO, Rome. 2013;6-9.
5. Doku EV, Karikari SK. Flowering and pod production of Bambara groundnut. Ghana Journal of Agricultural Science. 1970;3:17-26.
6. Racie KO, Silvestre P. Grain Legumes. In: CL Leakey, JB Wills (Eds.). Food crops of the lowland tropics. Oxford University Press, London. 1977;41-47.
7. Linnemann AR. Bambara groundnut (*Vigna subterranean*) literature: A revised and updated bibliography. Tropical Crops Communication 7. Department of Tropical Crop Science, Wageningen Agricultural University, Netherlands. 1992;124.
8. Nwanna LC, Enujiugha VN, Oseni AO, Nwanna EE. Possible effects of fungal fermentation on Bambara groundnut (*Vigna subterranean* (L.) Verde) as a feedstuff resource. J. Food Tech. 2005;3(4):572-575.
9. Oguntunde AO. Development of new food products from readily available raw materials. Paper presented at the Nigerian Institute of Food Science and Technology Training Workshop. Ibadan, Nigeria; 1985.
10. Enwere NJ. Foods of plant origin*:* Processing and utilization with recipes and technology profiles*,* afro-orbis Pub., Nsukka, Nigeria. 1998;59 -61.
11. Oliveira JS. Grain Legumes of Mozambique. Tropical Grain Legume Bulletin. 1976;3:13-15.
12. Linnemann AR. Bambara Groundnut (*Vigna subterranea* (L) Verde.): A Review. Abstract Trop. Agric. 1987;12:7.
13. FAO*.* Legumes in human nutrition, Food and Nutrition Paper No. 20, FAO. Rome; 1982*.*
14. Floros JD, Newsome R, Fisher W, Barbosa-Canovas GV, Chen H, Dunne CP et al. Feeding the world today and tomorrow: The importance of Food Science and Technology. Comprehensive Reviews in Food Science and Food Safety, An IFT Scientific Review. 2010;13-14.
    DOI: 10.1111/j.1541.4337.2010.00127.x.
15. Camire ME, Camire AL, Krumhar K. Chemical and nutritional changes in foods during extrusion. *Critical* Reviews in Food Sci. and Nutr. 1990;29:35-57.
16. Chang YK, Hashimoto JM, Moura-Alcioli M, Martinez-Bustos F. Twin-screw extrusion of cassava starch and isolated soybean protein blends. Molecular

Nutrition and Food Research. 2001;45(4): 234-240.
ISSN 1613-4133

17. El-Dash AA. Application and control of thermoplastic extrusion of cereals for food and industrial uses. In: Cereals: A renewable resource, theory and practice. Y. Pomeranz, L. Munich, (Eds.). American Association of Cereal Chemists, Saint Paul, USA. 1981;165-216.
18. Kadan R, Pepperman A. Physicochemical properties of starch in extruded rice flours. Cereal Chemistry. 2002;79(4):476-480.
19. Filli KB, Nkama I, Abubakar UM, Jideani VA. Influence of extrusion variables on some functional properties of extruded millet-soybean for the manufacture of "Fura": A Nigerian traditional food. African J. of Food Sci. 2010;4(6):342–352.
20. Gbenyi DI, Nkama I, Badau MH. Optimization of extrusion conditions for production of breakfast cereal from sorghum-soybean blends using sensory evaluation. International Journal of Food Science and Nutrition. 2016;1(3):10-19.
21. Gbenyi DI, Nkama I, Badau MH. Optimization of functional properties of sorghum-Bambara groundnut extrudates. Journal of Food Research. 2016;5(2):81-97.
22. Riaz MN. Introduction to Extruders and their principles. In: Extruders in Food Applications, MN Riaz (Ed.). CRC Press, Boca Raton, USA. 2000;1-23.
23. Bellis M. The History of Breakfast Cereals; 2013.
Available:www.about.com/library/inventors/b/cereals.htm
(Retrieved 22/04/2013)
24. Matz SA. Chemistry and technology of cereals as food and feed, 2nd ed. CBS Pub. 1996;645-659.
25. Nkama I, Angarawai I, Badau MH. Bank data production commercialization, transportation and consumption survey report. ROCAFREMI-WCAMRN Project P5 – Food Technology of Millet; 1998.
26. Montgomery DC. Design and analysis of experiments. 6th ed. John Wiley and Sons Inc. NJ 07030; 2005.
27. Singh S, Gamlath S, Wakeling L. Nutritional aspects of food extrusion: A review. Int. J. Food Sci. Tech. 2007; 42:916-929.
28. Alonso R, Rubio LA, Muzquiz M, Marzo F. The effect of extrusion cooking on mineral bioavailability in pea and kidney bean seed meals. Animal Feed Sci. and Technol. 2001;94:1-13.
29. Zasypkin DV, Tung-Ching L. Extrusion of soybean and wheat flour as affected by moisture content. J. Food Sci. 1998;63(6):1058 – 1061.
30. Vogen A I. Vogen textbook of quantitative chemical analysis, 6th ed. Revised by Mendham J, Denny RC, Barnef JD, Thomas MJK, Pearson Ltd. India. 2000; 104-107,602-607.
31. Meyers HR. Response surface methodology, Boston M.A. USA: Allyn and Bacon. 1976;246.
32. MINITAB 14. Meet MINITAB Release 14 for Windows Manual. Minitab Inc; 2003. ISBN 0-925636-48-7.
33. Malhotra VK. Biochemistry for Students. 10th edition, Jaypee Brothers Medical Publishers (P) Ltd., New Delhi, India; 1998.
34. Eruvbetine D. Canine nutrition and health. A paper presented at the seminar organized by Kensington Pharmaceuticals Nig. Ltd., Lagos on August, 21; 2003.
35. FAO/IAEA/WHO. Trace elements in human nutrition and health. Geneva, World Health Organization; 1996.
36. Soetan KO, Olaiya CO, Oyewole OE. The importance of mineral elements for humans, domestic animals and plants: A review. African Journal of Food Science, 2010;4(5):200-222.
37. National Institute of Health (NIH). Iron: dietary supplement fact sheet; 2016.
Available:https://ods.od.nih.gov/factsheets/iron-healthprofessional
38. Food and Nutrition Board (FNB). Phosphorus in diet. Institute of Medicine. Dietary Reference Intakes (DRI) of Calcium, Phosphorus, Magnesium, Vitamin D, and Flouride. Washington DC: National Academy Press; 1977. PMID: 23115811.
Available:www.ncbi.nlm.nih.gov/pubmed/23115811
39. World Health Organization (WHO). Potassium intake for adults and children. Geneva, World Health Organization; 2012.
40. Serna-saldivar S, Rooney LW. Structure and chemistry of sorghum and millets. In: Sorghum and Millets Chemistry and Technology, Dendy, D.A.V., ed.; American Association of Cereal Chemists: St. Paul, MN. 1995;69-124.

41. Jambunathan R, Subramanian V. Grain quality and utilization of sorghum and pearl millet. In: Biotechnology in Tropical Crop Improvement. Proceedings of the International Biotechnology Workshop, Patancheru, India, 12-15 Janvier. 1987; 133-139. Patancheru, ICRISAT; 1988.
42. United State Department of Agriculture (USDA). USDA National nutrient for standard reference, release 27; 2014. Available:https://ndb.nal.usda.gov/ndb/foods/show/6477. (Retrieved January, 8, 2015)
43. Amateifio JO, Tibe O, Njogu RM. The mineral composition of Bambara groundnut (*Vigna unguiculata* (L) Verdc) grown in Southern Africa. African Journal of Biotechnology. 2006;5(23):2408-2411.
44. Danbaba N, Nkama I, Badau MH. Application of response surface methodology (RSM) and central composite design (CCD) to optimize minerals composition of rice-cowpea composite blends during extrusion cooking. Int. Journal of Food Science and Nutrition Engineering, 2015;5(1):40-52. `
45. Winter B. The F distribution and the basic principle behind ANOVAs. Tutorial; 2015. Available:www.bodowinter.com. (Retrieved 26th July, 2016)

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/16280