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Optimization and Formulation of Maize- Based Composite Flour For Extrusion Of Snacks

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Abstract
Cereal based snacks are high in energy, but low in protein and functional components which can improve its nutritional quality. Therefore this study aimed to determine and optimize the nutritional composition of maize-defatted groundnut-banana flour formulation with enriched protein and fibre content for extrusion of snacks. Maize and green banana were processed into flour; while defatted groundnut flour was obtained by solvent extraction. The variable limits was set for maize, defatted groundnut and banana flours at 60-100%, 0-30%, and 0-10% respectively. Regression analysis was used to model the response variables which were optimized to obtain optimum desirability. Numerical optimization was achieved with the maximization of protein, antioxidant activity and phenol, while energy was minimized and others were set in range. The protein, ash and fibre content of the defatted groundnut was 56.82%, 3.73% and 2.59% with fat content of 6.36% which is good for stability. At the optimal flour blend of 65.30 (maize), 30.00 (defatted groundnut) and 4.70% (banana); and desirability of 62%, predicted response values for phenol, protein, crude fibre, iron, potassium and energy of the optimized flour mixture were 10.29 mg/kg, 4204.91 mg/kg, 16.39%, 4.32%, 1.61 mg/100 g, 725.36 mg/100 g and 434.43 kCal/100 g respectively. The actual value for protein and fibre of the optimized flour was 17.28% and 4.45% with no significant difference at $p<0.05$ between the predicted and actual values of the responses. This study established an optimal enriched flour blend which can be used to enrich the protein content and develop healthy snack foods.

Key words: Optimization, Mixture design, Composite flour, Defatted groundnut flour, Banana, maize

Introduction

High consumption of cereal-based snacks has been reported among adults and children, but these are low protein, high energy snacks referred to as junk foods because of their poor nutritional quality [31, 47, 11]. Increased consumption of snacks is due to increasing urbanization, purchasing power and changing food habits which could lead to the development of diseases in adults; and protein-energy malnutrition and obesity in children [30, 62, 48]. According to [32], more than half of the 25 million children in developing countries are predisposed to early death linked to protein-energy malnutrition by year 2050. Hence the need for development of enriched snacks from high quality protein sources, fibre and bioactive sources that will have significant impact on the nutritional and physical properties of snacks. Maize, groundnut and banana are plant materials which have the potential to be used for food enrichment in developing countries because of their availability and cheap sources of nutrients suitable for the development of snack foods. Maize (*Zea mays*) which is commonly used for the production of maize foods and snacks is a high carbohydrate, low protein material which has resulted in the prevalence of malnutrition in developing countries [37]. However, protein quality of food products is reported to synergistically improve in cereal-legume mixtures which have been demonstrated by many studies [8, 17; 33). Increase in protein content has been reported for maize enriched with high protein sources like oil seeds and pulses which contain 2-3 times more protein than cereals, and are cheap sources of nutrients [5]. They provide proteins, essential amino acids, complex carbohydrates, dietary fibre, unsaturated fats vitamins, minerals and beneficial bioactive compounds [34]. Groundnut is a cheap source of protein and bioactive components with antioxidant properties, while defatted groundnut flour (DG), the by-product of oil extraction has all the properties of groundnut with the advantage of low-fat content desirable for storage and healthy food development [34, 46]. Bananas are the second most important crop accounting for 16% of world fruit production out of which a significant amount is lost, and the remaining underutilized despite their nutritional values [31]. They contain antioxidants, vitamins and mineral components, and have low calorific value useful for the development of snacks and healthy functional food products [5, 31]. The addition of these food materials with good nutritional characteristics for snacks and food development is a method that could be beneficial to health when combined in the right proportion. Obtaining the right combination could be achieved with use of statistical methods such as mixture design of response surface methodology and optimization in order to understand the influence of the new materials on expected responses [33]. The objective of this study was to evaluate and optimize the nutritional composition of an enriched maize-defatted groundnut-banana flour blend for extrusion of snacks and foods.

Materials And Methods

Maize, groundnut and banana used for this study were sourced locally. The yellow maize (*Zea mays*) was obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, groundnut (*Arachis hypogea*) from the Center for Dry Land Agriculture, Bayero Universty (BUK), Kano and banana (*Musa sapientum*) from a local market in Ogbomoso, Oyo State, Nigeria.

Preparation of flours

Maize was cleaned, banana was peeled, sliced and dried, and both materials were milled into flour; while groundnut was roasted, defatted by solvent extraction to obtain the defatted groundnut flour (DG) [18, 26, 19]. All the flour samples were sieved (<450 µm) and packed for further analysis. The composite flour blend was obtained according to the experimental design at three levels of combinations and mixed for analysis.

Experimental design for composite flour formulation

The raw material combination and their proportions were selected by design expert 13.0 software using D-optimal mixture design of response surface methodology. The independent variables were selected based on conclusions from previous studies on extruded flour formulations as 60-100% for maize, 0-30% for defatted groundnut flour and 0-10% banana flour (Table 1). The lower and upper limits were chosen because a minimum range of 60% starchy materials like maize is needed for maximum - expansion of extruded snacks, while a maximum of 30-35% of protein material in extruded snacks is recommended because protein increases the density of snacks due to reduction in expansion [59]. Incorporation of proteins and fibers more than the maximum limit in flour for extrusion is reported to act as diluents which reduce stretchability and expansion of starchy materials [37]. Response surface methodology was used to evaluate the effect of different combinations of ingredients and their interaction on the nutritional qualities parameters. After the constraints were fitted, eighteen (18) experimental runs were generated in randomized order in order to determine repeatability, increase precision and reduce the impact of variability in response variables [33]. The complete experimental design and result of the responses of the flour blend is presented in Table 2. The use of mixture design means that the sum of all the ingredients is 100%, which implies mathematical linear dependence of the variables used [23]. Maize flour, defatted groundnut flour and banana flour were taken as the independent factors (input) and nutritional attributes such as crude protein, fiber, iron, potassium, gross energy, total antioxidant activity and total phenolic content as the dependent parameters (response).

Table 1: Variable Limits for Flour Formulation

Code	Variable	Low limit %	High limit %
A	Maize flour	60	100
B	Defatted groundnut flour (DG)	0	30
C	Banana flour	0	10

The variables used for the design were categorized into independent and dependent variables. The independent variables are related to the composition of the flour blends by the second- order polynomial regression model of RSM with linear, quadratic and interaction relationships. The estimated regression coefficients of the responses were determined using the theoretical polynomial model as shown in the equation

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3 \quad (1)$$

where Y is the responses (crude protein, fiber, iron, potassium, gross energy, total antioxidant activity and total phenolic content); independent variable β_1, β_2 and β_3 are the coefficients estimates for linear, quadratic and interaction coefficients; while X_1, X_2 and X_3 are independent coefficient of variables (maize, groundnut and banana flour).

Analytical Methods

The proximate composition of the raw materials and the responses for the flour mixture was done. The moisture, crude protein, crude fat, crude fiber and ash contents of the maize, defatted groundnut and banana flour were carried out using standard methods [6]. Percentage composition of the carbohydrate was determined by difference by [36]. Response variables for bioactive contents (total phenol and antioxidant activity) were determined by [47 and [16] using the Folin–Ciocalteu method. The mineral content (iron and potassium) was determined according to [62]. Gross energy was determined as described by [36] using Atwater's conversion factors of 4 kcal/g (protein), 9 kcal/g (fat) and 4 kcal/g (carbohydrates).

Statistical Analysis Of Measured Responses

All the responses were obtained as a result of the experimental design and subjected to regression analysis in order to evaluate the effects of the independent variables (maize, DG and banana flour). Response surface methodology was applied to the experimental data using Design Expert version 13.0, while the *f* data was fitted in a high order polynomial model [41]. A linear, quadratic, special cubic and cubic type model was fitted to the experimental data to see the effect of materials on responses [33]. The adequacy of the model was determined from the analysis of variance ANOVA to reveal the F- value ($p<0.05$), lack-of-fit ($p>0.05$) and coefficient of determination R^2. Multiple regression analysis was used to fit the model to the experimental data, and model for the response was written. The estimated regression coefficient for each response was assessed by lack- of- fit test at probability $p > 0.05$. Optimization was done by numerical technique to maximize and minimize the regression models, and optimum flour mixture was obtained from the desirability value.

Results And Discussion

Proximate composition of maize, defatted groundnut and banana flours

The proximate composition of the raw materials for the production of enriched flour formulation is shown in Table 2. The moisture content was highest for maize (9.95%) and least (2.98%) for banana flour, which is less than 10% moisture content suitable for storage [4]. Ash and fibre contents of 3.73% and 2.59% was highest in defatted groundnut which is an indication that it can contribute to the mineral and fibre content of maize-based snack food formulations. The crude fibre contents of the flour samples are within the limit of recommended crude fibre (<5%) content stipulated by codex standard (1991) as reported by [53]. Crude fibre does not contribute nutrients to the body, but it adds bulk to food thus facilitating bowel movements (peristalsis), and preventing many gastrointestinal diseases in man [22]. The highest crude protein content of 56.82% was obtained from defatted groundnut flour which makes it an abundant source of protein that can be used to meet the demand for protein for food product formulation especially in developing countries where majority of the populace may find it hard to afford protein- dense foods due to rising costs [50].

The highest crude protein observed in the defatted groundnut flour could be attributed to the inherently high fat content in groundnuts [62], which was concentrated by the defatting process from 29.18% in raw undefatted groundnut to 56.82%. The crude fat content significantly reduced from 48.43% to 6.36% which is less than 10% fat content suitable for food applications and storage stability [46]. This is lower than 8% and higher than 1.35% which could be due to the method used [46, 60]. The value obtained in this study is low enough to supply fat and prevent spoilage of the flour. Low fat content of maize and banana is typical for cereals and fruits and could contribute to storage stability of the flour by reducing oxidative rancidity [39]. Carbohydrates are the most important source of readily available energy important for brain, heart, nervous, digestive functions and immune system [62]. Low carbohydrate contents observed in the defatted groundnut flour is attributed to the high protein content hence, and the high values (71-8-87.57%) for maize and banana are suffice as rich carbohydrate sources to produce required energy [24, 53]. Result of this study is confirmed from literature that legumes have higher amounts of protein and dietary fibre than cereals [34].

Table 2: **Proximate Composition of Raw Groundnut, Maize, Defatted Groundnut and Banana Flour**

Proximate Composition	Raw groundnut flour	Maize flour	Defatted groundnut flour	Banana flour
Moisture (%)	4.63 ± 0.06^{b}	9.95 ± 0.12^{a}	4.14 ± 0.12^{c}	2.98 ± 0.04^{d}
Ash (%)	3.42 ± 0.03^{b}	1.06 ± 0.07^{d}	3.73 ± 0.01^{a}	3.31 ± 0.09^{c}
Crude fibre (%)	2.33 ± 0.04^{b}	1.01 ± 0.00^{d}	2.59 ± 0.07^{a}	1.26 ± 0.02^{c}
Crude protein (%)	29.18 ± 0.01^{b}	12.31 ± 0.09^{c}	56.82 ± 0.63^{a}	3.47 ± 0.42^{d}
Crude fat (%)	48.43 ± 0.49^{a}	3.82 ± 0.14^{c}	6.36 ± 0.01^{b}	1.41 ± 0.00^{d}
Carbohydrate (%)	12.03 ± 0.42^{d}	71.84 ± 0.26^{b}	26.35 ± 0.64^{c}	87.57 ± 0.41^{a}

Values are mean ± standard deviation. Data with different superscripts along the same row are significantly different at $p < 0.05$

The mixture design from Design Expert 13.0 software was used to formulate the ratios of the flours in the mixture from three components. Eighteen experimental runs of the flour mixtures and responses are shown in Table 3. The regression models and ANOVA used to evaluate the effect of independent factors on the response variables are shown in Table 4. The models for the responses were found significant at $p < 0 .05$ for all the data responses meaning they all contribute significantly to the model.

Table 3: Experimental Values of Independent and Response Variables for Flour blends

Run	Flour blend	TAC mg/k	Phenol mg/kg	Crude protein %	Crude fibre %	Iron mg/100g	Potassium mg/100g	Energy kcal
1	$M_{64.29}DG_{30}B_{5.71}$	11.59	3918.44	17.32	4.71	1.19	727.20	442.52
2	$M_{89.11}DG_{10.65}B_{0.24}$	11.21	3124.00	10.17	5.06	1.43	863.40	436.93
3	$M_{70.95}DG_{29.05}B_{0.00}$	7.11	3930.70	15.48	3.47	1.54	710.11	428.94
4	$M_{83.29}DG_{11.83}B_{4.88}$	7.96	3508.22	12.85	5.53	2.86	871.34	421.15
5	$M_{77.47}DG_{22.53}B_{0.00}$	12.26	3932.74	12.56	4.59	1.73	720.13	420.25
6	$M_{90.80}DG_{0.00}B_{9.20}$	15.56	3904.14	12.72	4.55	2.57	678.80	405.38
7	$M_{100}DG_{0.00}B_{0.00}$	7.41	3922.52	13.10	4.62	1.66	315.42	405.68
8	$M_{84.71}DG_{5.29}B_{10.00}$	7.16	3922.52	13.10	4.62	1.66	705.25	410.00
9	$M_{64.29}DG_{30}B_{5.71}$	12.56	3598.44	16.53	4.45	1.17	726.06	442.52
10	$M_{90.80}DG_{0.00}B_{9.20}$	12.66	3934.80	12.38	5.12	2.18	678.15	401.53
11	$M_{69.04}DG_{20.96}B_{10.00}$	8.46	3939.04	11.39	3.88	1.97	712.24	422.78
12	$M_{83.29}DG_{11.83}B_{4.88}$	7.61	3542.96	11.68	5.09	2.32	870.06	421.27
13	$M_{75.82}DG_{14.71}B_{9.46}$	6.41	3734.78	12.38	4.19	2.22	873.33	411.73
14	$M_{83.29}DG_{11.83}B_{4.88}$	8.76	3738.88	11.38	5.67	2.49	869.43	421.15
15	$M_{69.04}DG_{20.96}B_{10.00}$	8.36	3936.84	1.38	3.98	1.98	713.67	422.64
16	$M_{93.28}DG_{4.10}B_{2.62}$	12.31	3526.62	12.27	5.16	1.43	465.35	398.65
17	$M_{83.29}DG_{11.83}B_{4.88}$	8.31	3708.66	12.34	5.89	2.17	870.75	415.50
18	$M_{82.38}DG_{17.62}B_{0.00}$	15.81	3754.40	12.71	4.89	2.39	715.37	418.87

TAC = Total Antioxidant Capacity; M-Maize flour (%), DG-defatted groundnut flour (%), B-Banana flour (%)

Table 4: Regression Model and ANOVA for responses of flour blends

Coefficients	TAC mg/kg	Phenol mg/kg	Protein %	Fibre %	Energy kcal	Iron mg/100g	Potassium mg/100g
A	6.83	3908.48	12.7*	4.54*	405.4*	1.51*	320.26*
B	-6.35	141.06	23.82*	1.37*	422.15*	1.2*	396.65*
C	-396.29	4.61E+05	-74.61*	-0.990*	1942.21*	43.1*	7108.52*
AB	52.3*	7335.73*	-24.81*	6.91*	77	1.96	1682.42*
AC	564.44*	-7.681E+05*	112.16	8.78	-2010.41	-49.19	-6851.75
BC	629.89*	-8.015E+05*	101.18	31.77	-1431.88	-68.94	-7200.30
A^2BC	-1280.53*	-	26.99	73.47	3168.26	71.41	19832.82
AB^2C	-1071.43*	-	-388.09	-48	-57.95	292.45*	25099.26
ABC^2	1889.27	-	562.69	-366.13	-13594.6	-424.91	-92116.56
ABC	-	7.108E+05*					
AB(A-B)	-	-14162.71*					
AC(A-C)	-	3.239E+05*					
BC(B-C)	-	3.958E+05*					
Model	S	S	S	S	S	S	S
Lack of fit	NS	NS	NS	NS	S	NS	S
P-value	0.0007	0.0141	0.0006	0.0009	0.0079	0.0280	0.0123
F-value	11.26	5.28	11.66	10.62	5.87	3.95	5.14
R^2	0.91	0.86	0.91	0.90	0.84	0.78	0.82
$AdjR^2$	0.8284	0.6940	0.83	0.82	0.69	0.58	0.66
CV %	12.12	3.30	5.79	5.65	1.95	16.40	11.76

Note: A, B and C= Linear term of maize, DG and banana flours, AB, AC and BC = Interactions of maize and defatted groundnut flour, maize and banana flour, and defatted groundnut and banana flour; ABC = Interaction of maize, DG and banana; A^2BC, AB^2C, ABC^2 = Quadratic terms of maize, DG and banana flour, R^2= Regression coefficient, C.V. = Coefficient of variation; *Significant at $p < 0.05$, S = Significant, NS = Not Significant, TAC = Total Antioxidant Capacity, R^2-coefficient of determination, CV-coefficient of variation, lack of fit p>0.05

Total antioxidant activity (TAC)

From Table 3, the total antioxidant activity of the flour blends ranged between 6.41 to 15.81 mg/kg with a mean value of 10.08 mg/kg. The minimum value was obtained for flour blend at Run 13 with maize (75%), defatted groundnut (15%), and banana (10%) while maximum value was obtained for flour blend with maize (82%) and defatted groundnut flour (18%). The high antioxidant activity could be contributed by the yellow maize which is a good source of phenolic compounds and which also contains more antioxidant activity than other cereals like wheat, oats, rice; and other varieties of maize such as white, red, purple and black maize [52]. This could also be due to the high phenolic content in groundnut which remains in defatted flour of groundnut [9]. The ANOVA for the special cubic regression model for TAC showed that model is significant at $p < 0.05$. Lack of fit was not significant at p>0.05 relative to pure error, while the R^2 of 0.91 indicates that 90% of the response data is around its mean indicating the model adequacy. Equation (2) represents the model for total antioxidant activity showing the impact of input on response factors.

$$TAC = 52.30AB + 564.44AC + 629.89BC - 1280.53A^2BC - 1071.43AB^2C \quad (2)$$

At interaction level, AB, AC and BC were all significant on TAC at (p<0.05) and the positive coefficients means that their interaction had favourable significant impact on TAC, with the blend (BC) with the largest coefficient estimate having the most effect on TAC. Positive effect of BC means increase in TAC with increase in flour blend BC thereby contributing more to TAC. Quadratic terms A^2 and B^2 have negative coefficient which negatively impacts the TAC. Larger negative effect of A indicates that very high maize content can significantly reduce TAC. Reduction in TAC from the original antioxidant level in the materials could be due to suppression of antioxidant activity due to heat processing.

Phenol content

The phenol contents of the flour blends ranged from 3124.00 to 3939.04 mg/kg with the mean value of 3754.37 mg/kg. The highest value was obtained for blend with maize (69%), defatted groundnut (21%) and banana (10%). The effect of independent variables (ABC) on the phenol content responses is as presented by the ANOVA in Table 4. Cubic modelling of phenol indicated that the model was significant and adequate for the analysis being significant at ($p < 0.05$). The lack of fit obtained for the responses were found non-significant ($p > 0.05$) relative to pure error indicating adequacy of the model, while the non-significance of the lack of fit revealed that the model fits with the data. The quality of fit of the model was verified by the regression coefficient R^2 of 0.86 showing that 80% of the response data is around its mean and a good fit for the model. CV of 3.30% indicates experimental precision and reliability for phenol. The Adj R^2 of 0.6940 suggest good model fit.

$$\text{Phenol} = 7335.73AB - 7.681E{+}05AC - 8.015E{+}05BC + 7.108E{+}05ABC - 14162.71AB\,(A-B) + 3.239E{+}05AC\,(A-C) + 3.958E{+}05BC\,(B-C) \quad (3)$$

Linear terms were not significant for A, B and C for phenol at $p<0.05$, which could be as a result of effect of processing on the food materials. The interaction term for AB was positive suggesting that the blend of maize and defatted groundnut flour has compounded positive effect on phenol. The interaction AB had the highest coefficient of estimate of 7335.73 indicating greater positive influence on phenol, leading to increases in phenol with the addition of maize and defatted groundnut flour. Similar increases in phenolic contents of maize-groundnut flour composite have been reported [2]. Phenolic complexes serve important role in cells and have the potential to be antioxidants [29]. According to [9], there is strong positive correlation between antioxidant activity and phenolic content of plant materials; hence foods with high phenolic contents will improve TAC. Interaction terms AC and BC have negative coefficients showing that their interaction will cause a reduction in the phenol content. This could be due to the fact that interaction between protein and phenolic compounds could result in complexes which make them unavailable in food systems [9]. The positive coefficient of the special cubic term of ABC means that the interaction between the three variable factors had positive impact on the phenol content of flour.

Protein content

The protein contents of the flour blends varied from 10.17 to 17.32% with the mean value of 12.87%; with the maximum value obtained from blend 64:30:6 (Table 3). The highest protein content at this blend was obtained for defatted groundnut (30%). Table 4 presents the ANOVA for the quadratic regression model for protein which shows that the model is significant ($p < 0.05$) for the responses, and lack of fit (F-value) obtained for the responses were not significant ($p > 0.05$) relative to pure error. The quality of the fit of the model is shown by the regression coefficient R^2 (0.91) which confirms the suitability of the proposed model. According to [1], R^2 value which is at least 0.8 is considered a good fit model and thus indicating that 80% of response data is around its mean. Coefficient of variation (C.V) measures the reproducibility of the model which for protein was 5.79% which must not be greater than 10% for reproducibility. The models fitted the data well (F-value: 11.66), and lack-of-fits was observed to be non-significant $p>0.05$ thereby suggesting that the model can be used to navigate the design.

$$\text{Protein} = 12.70A + 23.82B - 74.61C - 24.81AB \quad (4)$$

The model from the coefficient of regression for protein contents is presented in Eq. (4). The model was significant for protein at linear level, and showed that maize (A) and defatted groundnut (B) had positive effects on protein than banana (C) which was negative [45, 51]. Negative signs in the model coefficients indicate antagonism in the blend which means that banana (C) will reduce protein content more than A or B. Higher coefficient estimate 23.82B for defatted groundnut showed that groundnut had stronger effect on protein than maize; hence increase in the level of defatted groundnut will lead to increase in protein content of the flour. Non-significance of banana flour for protein highlights banana being a poor source of protein but of high energy potential [54].

Crude Fibre

The crude fibre contents of the flour blends ranged from 3.47 to 5.89%, for flour blend at Run 3 (70:29:1) and Run 17 (83:12:5) for maize, defatted groundnut and banana (Table 3). Table 4 presents the ANOVA for the quadratic model for evaluating the impact of the flour blends on crude fibre contents. The regression coefficient (R^2) for crude fibre content was 0.90 which confirms the suitability of the model. An R^2 value which is at least 0.8 is considered a good fit model and thus indicating that 80% of response data is around its mean [1]. Coefficient of variation (C.V) was 5.65% which is less than 10% required for reproducibility of model. The models fitted the data well at F-value 10.62 at $p<0.05$, and lack-of-fit was observed to be non-significant at $p>0.05$ thereby suggesting that the model can be used to navigate the design. The regression model for crude fibre is shown in Eq. 5.

$$\text{Crude fibre} = 4.54A + 1.37B - 0.9903C + 6.91AB \quad (5)$$

The linear coefficients of A (maize) and B (defatted groundnut) positively impacted the crude fibre content of the flour blends with maize having more impact of the crude fibre because of the higher coefficient of 4.5. Only the interaction term for AB was significant showing positive contribution of maize and defatted groundnut to crude fibre content of the flour blend. Crude fibre is obtained through the consumption of foods rich in dietary fibre and is resistant to digestion and absorption in the small intestine [39]. Combination of AB will provide more fibre than either A or B in the diet and cause increase in crude fibre contents of the composite flour [43] and [52]. Whole grains, nuts and fruits are food materials rich in dietary components beneficial to health [39].

Energy content

Energy contents ranged from 398.65 to 442.52 kCal/100g for flour blend 64**:**30**:**6.00 (Table 3). The model F- value of 5.87 implies that the model is significant at linear level at $p<0.05$, with a significant lack of fit ($p>0.05$). However, other indicators such as R^2 of 0.84 was greater than 80% and adjusted R^2 value 0.69 confirms the suitability of the model. Low coefficient of variation (CV) of 1.95% also implies that that the design space can be used to describe the model. The regression model for crude fibre is presented in Eq.6

$$\text{Energy} = 405.40A + 422.15B + 1942.21C \quad (6)$$

The model at quadratic level for linear terms of A, B and C showed that the variables had positive effects on crude fibre. The significance of the linear terms shows that individual factors of A, B and C impacts more on the energy content rather than their blends. The positive coefficient estimates of all the linear terms indicated that linear increases of A, B, and C will lead to increase in energy value. The higher coefficient estimate of C highlights banana being of high energy potential [54]. Although varietal differences may influence energy contents inherent in maize, it has been acknowledged as a rich energy source [52, 44, 12]. Increase in energy contents of the composite flour blends with groundnut flour indicates groundnut being a rich source of energy density [53]. The positive effect of maize and defatted groundnut on the energy content of the composite flour has been documented [58, 53].

Iron contents

From Table 3, the iron contents of the flour blends varied from 1.17 to 2.86 mg/100 g, with mean value of 1.94 mg/100 g, and highest value obtained for blend 83:12:5 (RUN 4). The analysis of variance (ANOVA) for iron content is presented in Table 4 which indicated that the model F-value was found significant ($p < 0.05$), and lack of fit was not significant relative to pure error at $p>0.05$**.** The regression coefficient R^2 obtained for iron is 0.78 indicating that the R^2 is highly compatible and fits the model. According to [1], R^2 value which is at least 0.8 is considered a good fit model which is a pointer to 80% of response data is around its mean. The adjusted R^2 value for iron was 0.58 justifying the model's significance [48] while coefficient of variation (C.V) for iron was 16.40. Furtherance, the statistical analyses indicated that the model fitted the data well at F-value of 3.95. The lack-of-fit was also observed to be non-significant thereby suggesting that the model can be used to navigate the design. The model for iron content is shown in Eq. 7.

$$\text{Iron} = 1.51A + 1.20B + 43.10C + 292.45AB^2C \quad (7)$$

From the model, all the linear terms of A, B and C were positive for iron content of the flours. The interaction term of B^2 also showed positive effect indicating an increase in iron content with B. Iron is a micronutrient required for good health and legumes are considered iron- rich materials with positive effect on cereals [40]. The higher coefficient of estimation of 43.10 for C indicates more positive influence iron content. Inclusion of maize and groundnut flour resulted in significant increase in iron contents of flour blends as groundnut inherently contains higher iron 4.58 mg/100 g than maize 2.3 mg/100 g and banana 0.33

mg/100 g respectively [7, 20, 47]. Iron deficiency often leads to anemia, tissue inflammation and fatigue [51]. Other studies that reported increase in iron contents of flour blends owing to banana and groundnut flour supplementation exist [3, 29, 13, 54]. Iron is essential in human diet for the respiration process, the transport of oxygen in the blood and in the oxygenation of red blood cells.

Potassium content

The potassium contents of the flour blends varied from 315.42 to 873.33mg/100 g, with mean value of 727.00 mg/100 g, and highest value obtained for flour blends at 76:15:9. Potassium protects against sodium in the diet, and although variant dependent, literature had shown that banana has high potassium content 290.95 – 1033.25 mg/100 g as compared to groundnut 705 mg/100 g and maize 286 mg/100 g [7, 30, 51]. The analysis of variance (ANOVA) for potassium is presented in Table 4, which indicated that the model (F-value) was significant ($p < 0 .05$), while lack of fit was significant at $p>0.05$ relative to pure error. However, the R^2 was of 0.82 was found to be higher than 75% which is a good predictor for a fit model.

$$\text{Potassium} = 320.26A + 396.65B + 7108.52C + 1682.42AB \quad (8)$$

All the linear and interaction term AB of the model were positive for potassium content of the flour, meaning that increase in the components A, B and C will result in increase in potassium content. Component with the highest coefficient estimate of 7108.52 indicates that banana has the most positive influence on potassium content of the flour. The interaction term of AB also showed significant effect on potassium content indicated by the supplementation of maize with banana flour.

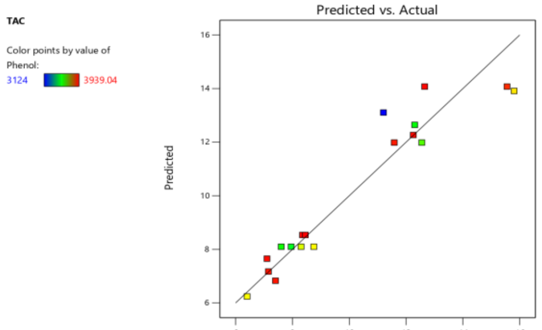
Numerical Optimization and Determination of Predicted Desirability

Numerical optimization was done to determine the composite desirability of the flour by generating the global desirability function which is assigned a value ranging from 0 to 1 where zero (0) indicates no desirability and 1 indicates higher possible desirability with respect to the restraints used [25]. For optimization purposes, response parameters of crude protein, total phenolic and antioxidant activity were maximized, gross energy was minimized while iron and potassium were set in range. The desirability value of 0.621 was selected for optimal flour blend of maize (65%), defatted groundnut (30%) and banana flour (5%) respectively. The predicted and actual values for the response TAC, phenol, protein, crude fibre, iron, potassium and energy contents is shown in Table 5. Validation of the response variables was done by drawing a curve between the expected and actual values as shown in Fig 1a-g. This showed that the expected and actual values were very close to the straight line indicating strong correlation between the two values.

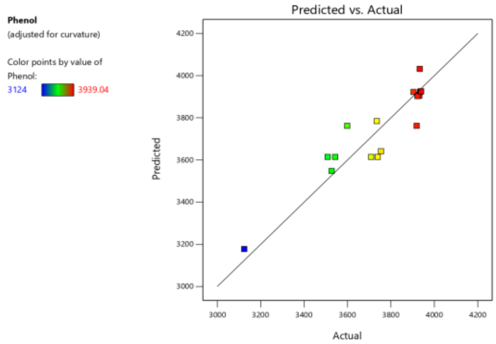
Table 5: Numerical optimization

Response	Goal	PV	AV	Optimized flour ratio
TAC	Maximize	10.296	9.75	-
Phenol	Maximize	4204.63	4108.50	-
Protein	Maximize	16.394	17.28	-
Fibre	In range	4.322	4.45	-
Iron	In range	1.605	1.72	-
Potassium	In range	725.34	745.36	-
Energy	Minimize	434.437	429.35	-
Maize	Minimize	-	-	65.30
DG	Maximize	-	-	30.00
Banana	In range	-	-	4.69
Desirability	-	-	-	0.621

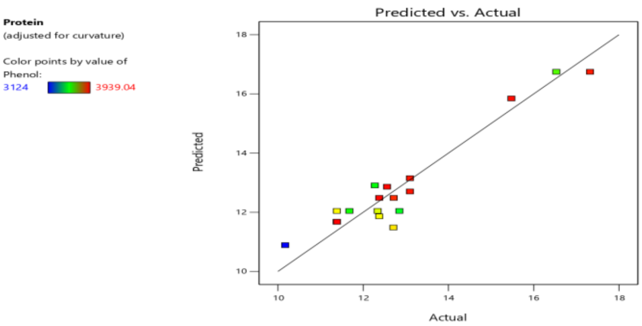
PV-predicted value AV- Actual value DG- defatted groundnut flour



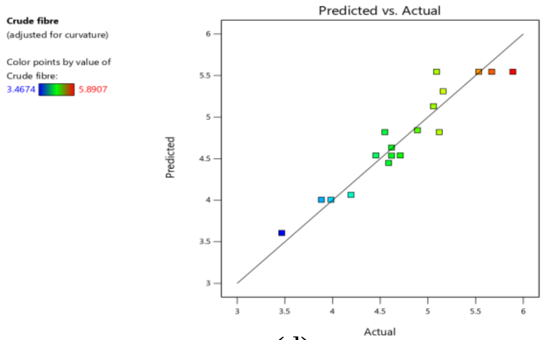
(a)



(b)

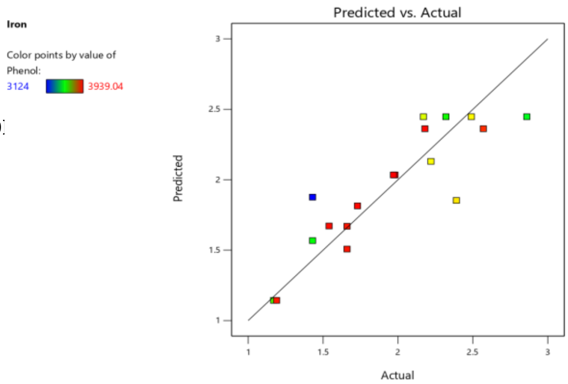


(c)

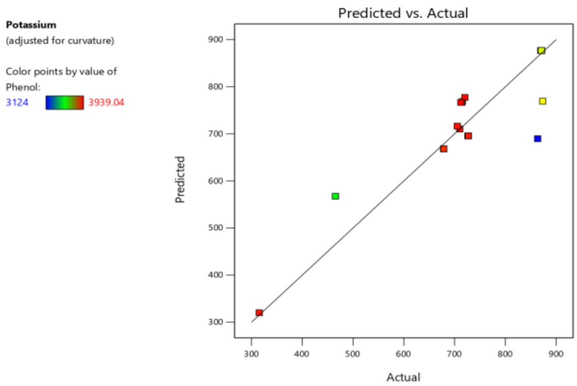


(d)

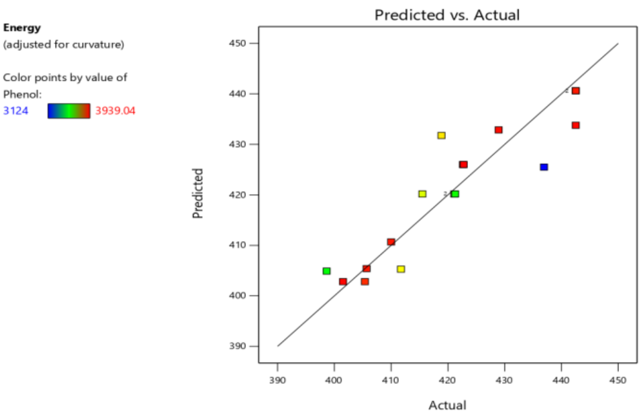
Co



(e)



(f)



(g)

Figure 1 a-g: Model graphs for predicted and actual values for (a) TAC (b) Phenol (c) Protein (d) Fibre (e) Iron (f) Potassium (g) energy

Conclusion

Response surface methodology was successfully applied to determine the optimum formulation of maize flour with defatted groundnut and banana flour. The models provided a strong fit with the experimental data showing that blending the flours can enhance the nutritional composition. The optimized factors all significantly affected the response factors of the flour blends and **t**he predicted values were not significantly different ($p<0.05$) from the experimental values. The experimental value for protein content was 17.28% which indicate that high protein flour blend can be prepared from the optimized mixture of maize (65%), DG (30%) and BF (5%). This shows that the optimal blend is nutritionally adequate and useful for the development of extruded snacks and foods, as it showed better chemical composition which is beneficial for good health. Defatted groundnut flour can provide a cost effective and cheap high protein food material that could be applied in food product formulation. The optimized flour blend can be valuable for enrichment of many foods because of the high protein content and will encourage the utilization of the less utilized DGF in food formulations.

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