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Modelling And Optimization Of Aerial Yam, Finger Millet And Pro-Vitamin A Cassava Flour Blends.

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Abstract
The study x-rays the modelling and optimization of flours from blend of aerial yam, finger millet and pro vitamin A cassava flour. The experiments were conducted using the simplex centroid design, 14 formulations was obtained using mixture response surface methodology as the optimization technique. The formulated flour blends showed that there was significant difference ($P<0.05$) between observed (52.60) and predicted (54.57) values for glycemic index. There were no significant difference ($P>0.05$) for predicted and observed values for tannin, phytate, oxalate, and phenol content. High values of determination (R^2) suggests that the models developed had a good fit. The optimized flour blends fufu (12.97AYF:10.20FMF:76.83PVACF) had a lower value for glycemic index, tannin, stickiness and lower phytate, oxalate, phenol, appearance, taste, mouldability, consistency, colour and overall acceptability. The study showed that high regression coefficients $R^2>0.09$ were obtained, showing that the models can be used to navigate the design space. 12.97AYF:10.20FMF:76.83PVACF would produce fufu of moderate glycemic index, low Antinutrients and sensory attributes.
Keywords: *modelling, optimization, glycemic index, response surface, aerial yam flour*

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I. Introduction

Modelling and optimization of food processes has been done through focusing on the effect of changes in one parameter on a response, keeping all other factors constant. This is called one-variable-at-a-time technique (Acosta *et al.,* 2008). The major limitation of this method is that the interactive effects of the factors on the accounted for lack explanation of the complete effect of the factors on the response, and on the variables' behaviour within the entire experimental space. However, one variable at a time method increase the number of experimental runs required to conduct the research. Optimization studies should be conducted using procedures like response surface methodology (RSM) where multiple factors are considered at a time, and has been found to be an effective method for food product modelling and optimization (Acosta *et al.,* 2008).

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques suitable for developing, improving, and boosting processes. It also has important application in the design, development, and formulation of new products as well as in the improvement of existing product designs (Alam *et al.,* 2010). The most extensive application of RSM is in the industrial world, including the food industry, particularly in situations where multiple input variables potentially influence the quality characteristics of the product or the process. RSM has been extensively used in modelling and optimizing food processing operations and formulation of products. Major food process operations like drying, extrusion, fermentation, baking and cooking. (Ade-Omowaye *et al.,* 2002). Several experimental designs including factorial central composite design with its variants, D-optimal design and mixture designs have been used with RSM (Acosta *et al.,* 2008).Besides analysing the effects of the independents variables. Acosta *et al.,* (2008) reported that there are several experimental designs such as factorial central composite design with variants, D-optimal design, mixture design, which has been used by RSM. The process under study generates an empirical model of Response surface methodology.

Aerial yam (*Dioscorea bulbifera*) is a specie of yam in the family of *Dioscoreacea* (Kay, 1987). It is cultivated in Africa, Asia, and Northern Australia where it is used for food and it provides substantial amount of calories and minerals such as iron, calcium, potassium, magnesium and phosphorus (Abara, *et al.,* 2000).The aerial yam flour can be used as composite flour in the production of fufu. Princewill-Ogbonna and Ezembaukwu (2015), reported that aerial yam (*Dioscorea bulbiferra*) has an array of good starch contents, functional and rheological properties which indicates a wider potential for utility of Aerial yam flour in the food industry as thickners, flour, drug/tablets binders in the pharmaceutical industries.

Finger millet (*Eleusine coracana L.*) is a cereal grown in Africa where the climatic conditions are adverse (Syeunda *et al*., 2020). Its nutritional value increases with increased extreme climatic conditions (Ambuko *et al.,* 2014). Finger millet is rich in minerals, nutrients like Calcium, Iron, Pottassium and Zinc. It is a very good source of natural iron and its consumption helps in recovery from anaemia (Syeunda *et al*., 2020) and in relaxing body naturally. It is beneficial in conditions from anxiety, depression, insomnia and migraines. Finger millets phyto-chemicals help in slowing digestion process, controlling blood sugar level in conditions of diabetes (Syeunda *et al*., 2020). Finger millets-based diet helps diabectic patients as it contains higher fibre than rice and wheat (Syeunda *et al*., 2020).

Cassava (*Manihot esculenta* Crantz) is a staple food for over 500 million people in the developing world. Where it is a major source of low cost carbohydrate (O' Hair, 1990). Cassava is valued for its outstanding ecological adaptation, low labour requirement, ease of cultivation and high yield. It is widely cultivated because it can grow in poor soils under marginal rainfall. It grows well where many other crops hardily survive. It gives good yield under marginal conditions, and when conditions are optimal, it produces more calories per hectare than most tropical crops (Nweke *et al.,* 1999; I1TA, 1990).

This study is aimed at comparing the observed and predicted quality attributes of the optimized flour formulation from the blend ratios of aerial yam (AYF), finger millet (FMF) and pro vitamin A cassava flour (PVACF).

II. Materials And Methods

Source of Raw materials

Aerial yam (*Dioscorea bulbifera*) and finger millet (*Eleusine coracana L.*) was purchased from kpirikpiri Market, Ebonyi L.G.A of Ebonyi State, Nigeria. Vitamin A cassava (*Manihot esculenta "Yellow Cassava"*) was purchased from Ebonyi State University, Biotechnology Research Centre, Ebonyi State, Nigeria.

Sample Preparation

Production of Aerial Yam Flour

The tubers of aerial yam *(D. bulbifera*) (plate 1) were sorted, washed with clean water to remove adhering soil and other undesirable materials as described by Umoh *et al.* (2021). The aerial yam samples were sorted and hand peeled using stainless steel knives and then sliced into sizes of 2 to 3 cm in thickness. The sliced yam was soaked in water at 50 ^{o}C, while peeling to avoid enzymatic browning and also to remove the bitter compound from the sliced samples. The slices were blanched with hot water at 80 ^{o}C for 10 mins. The blanched yam slices (treatment sample) were returned to the steep water and allowed to undergo natural fermentation for 48 hours before it was drained. The blanched fermented sample was sun dried to constant weight within 120 hours. The dried yam slices were milled using locally fabricated hammer mill and screened (1mm sieve) to produce aerial yam flour and then stored in an air tight high density polyethylene (HDPE) prior to analysis.

Production of Germinated Finger Millet Flour

The malting of the finger millet (plate 2) was carried out as described by Mbithi-Mwikya *et al*. (2000). The finger millet grains were cleaned and sorted, (1 kg) was washed three times and steeped in 2 Litres of water for 24 h, which was changed after every 6 h. The grains were washed after steeping and germinated in ventilated cupboards for 48 h at an ambient temperature of 28 ± 2°C. Portable water was sprinkled on the germinating seeds regularly and then occasionally mixed. The germinated finger millet grains were removed and dried in an oven (escalibur dehydrator) oven at 48 ± 2 °C for 24 h. The grains were milled using a locally fabricated hammer mill, 0.3 aparture opening screen was used. The finger millets flour was stored at room temperature in an air tight HDPE until further analysis.

Production of Pro-Vitamin A Cassava Flour

The Pro-vitamin A cassava roots (plate 3) were sorted, washed with potable water, manually peeled with stainless steel knife, washed and sliced with stainless steel knife into 1mm thickness as described by Adeshina and Bolaji (2013). The slices were soaked in portable water for 24 hours, after which the water was drained using a palm frond weaved basket to reduce the process of fermentation. The drained cassava chips were removed and sun-dried during winter weather at average temp of 34.7 ºC and relative humidity of 46 % for 72 h. The dried cassava chips were milled using a locally fabricated machine and was stored in HDPE at room temperature until further analysis.



Plate 1: Aerial yam specie **Plate 2: Finger Millets** **Plate 3: Vitamin A cassava**

Experimental Design

A three-component augmented simplex centroid design was used in the study (Scheffe, 1965). The three components used were aerial yam (x_1), finger millet (x_2) and cassava (x_3) flours (see Table 3). The proportions for each ingredient were expressed as a fraction of the mixture and for each treatment combination, the sum of the component proportions was equal to 100% where as shown in Table 1:

$$\Sigma X_i = x_1 + x_2 + x_3 = 100 \tag{1}$$

Ten experimental combinations will be produced with four runs replicated to generate a total of fourteen (14) runs. The four runs to be replicated will give an internal estimate of error. The experiments were run in random order to minimize the effects of unexplained variability in the observed response due to extraneous factors (Capanzana and Buckle, 1997).

The second order model proposed for predicting the response variable is given as:

$$Y = b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{123}X_1X_2X_3 \tag{2}$$

Where;

b_1, b_2, b_3 represent regression coefficients of linear blends

$b_{12}, b_{13}, b_{23}, b_{123}$ represent regression coefficients of non-linear blends.

X_1= aerial yam,

X_2= finger millet,

X_3= cassava

Y represents the response.

Table 1: Experimental Runs for Aerial Yam, Finger Millet and Pro-Vitamin A Cassava Flour Blends

	Component 1	Component 2	Component 3
Run	A: Aerial Yam	B: Finger Millet	C: Pro Vitamin A-Cassava
1	100	0	0
2	0	100	0
3	0	0	100
4	50	0	50
5	0	50	50
6	50	50	0
7	33.3333	33.3333	33.3333
8	66.6667	16.6667	16.6667
9	16.6667	16.6667	66.6667
10	16.6667	66.6667	16.6667
11	50	50	0
12	0	0	100
13	100	0	0
14	0	100	0

Optimization

The low glycemic index, sensory qualities and antinutritional properties of the flour blends were chosen as criteria to optimize the blending ratio of the flour mix. The numerical optimization techniques of the Design Expert Software version 9 (State-Ease, Inc. Minneapolis, 2015) was used to carryout simultaneous optimization of the desirability function (Table 1).

III. Results And Discussion

Optimization

Table 2, Figures 1, 2 and 3 showed results for seven optimum percentages of flour sample model formulation (blends) with the predicted values of responses for flour produced from aerial yam (AYF), finger millet (FMF), and pro vitamin A cassava (PVACF) flour blends. From the results, the highest level of desirability was 0.57. The optimized flour blends at this level (0.57*) of desirability were made up of 12.97% AYF, 10.19 % FMF, and 76.83 % PVAC (Plate 4). Contour plots generated as a result of the optimization procedure at their different levels of desirability are shown in fig 1, 2 and 3. The antinutrients were high in the optimized sample in some of the parameters. It had borderline low- medium glycaemic index (GI) contents, with low sensory attributes compared with others. The optimized flour sample fufu is shown in plate 4.

Figure 1: Glycemic index Optimization Contours

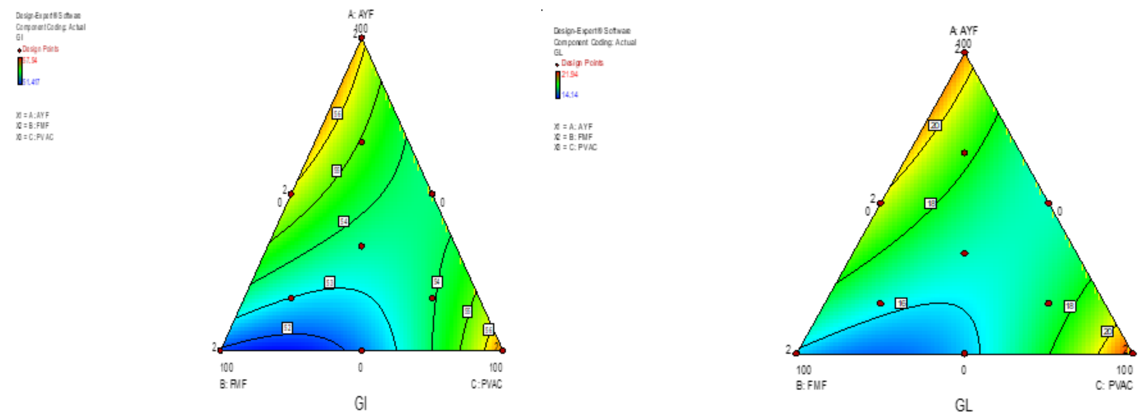


Figure 2: Antinutrients Optimization contour

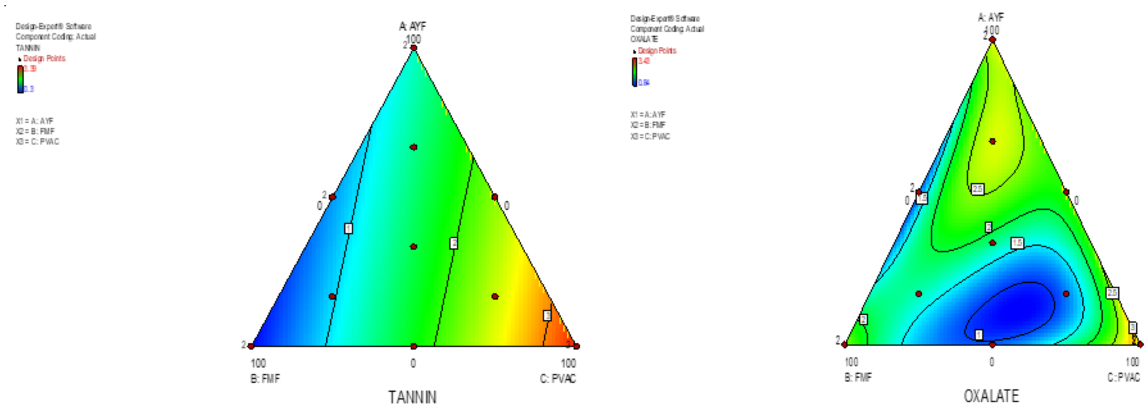
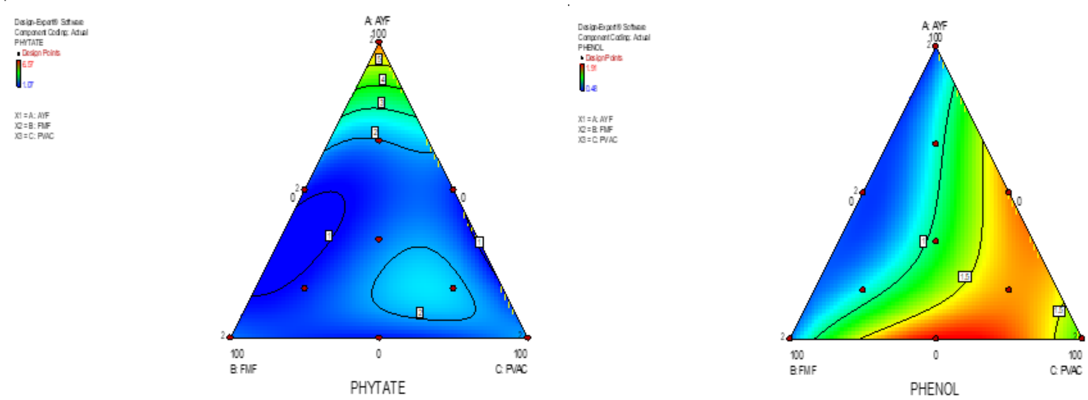
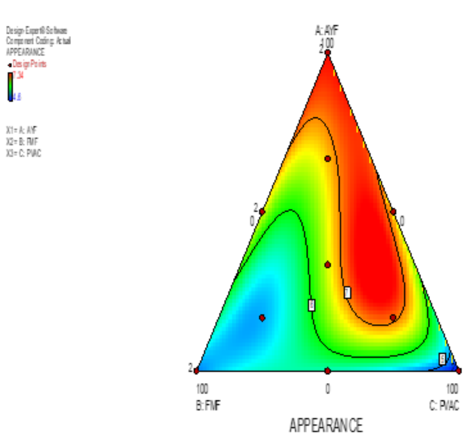
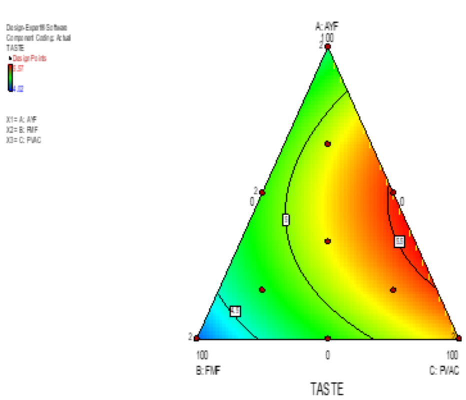


Figure 3: Sensory Optimization Contour







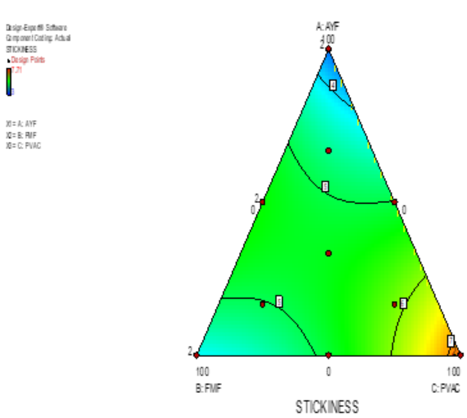


Plate 4: Shows Fufu from Reconstituted Optimized Flour Blends at (12.97AYF:10.20 FMF: 76.83 PVACF) ratios.

Model Verification / Optimal Conditions values

Flours were produced from the ratio given for the optimized flour at 0.57 level of desirability (12.97 % AYF, 10.20 %FMF and 76.83 % PVAC) and analysed to check model verification. The observed values were compared to the predicted values and are presented in Table 3. Lower values (≤ 10 %) of MAD (Mean Absolute Deviation) and MRPD (Mean Relative Percent Deviation) for all the variables with the exception of the phytate suggest the validity of the model for flour from AYF, FMF and PVAC flour formulation.

Solutions number 1 was selected among the seven solution numbers. The optimal conditions of 12.97 %, 10.20 % and 76.83 % were obtained for aerial yam flour, finger millet flour and pro vitamin A cassava flour respectively (Table 2). The predicted values of the dependant variables for the optimized flour blends were low for antinutrients. The tannin (2.74), phytate (1.93) and phenol (1.66) contents of the optimized flour blends were within safe levels respectively. The predicted value for the optimized flour blend were higher in glycemic index (54.57) content; making it a good source of control for diabetes and other cardiovascular diseases. The predicted had poor sensory attributes except in stickiness content.

Table 2: Solution for Optimum level of flour Formulation from Aerial Yam (AYF), Finger Millets (FMF) and Pro Vitamin A Cassava (PVAC) Flour Blends.

PARAMETER		SOLUTIONS					
Independent Variables	1	2	3	4	5	6	7
AYF	12.97	22.29	0	76.73	19.81	0	69.80
FMF	10.20	0	19.91	0	80.19	84.40	30.21
PVAC *Dependent Variables*	76.83	77.71	80.09	23.27	0	15.60	0
GI	54.57	54.76	54.51	54.38	53.87	51.55	56.42
TANNIN	2.74	2.85	2.71	1.72	0.50	0.78	0.96
PHYTATE	1.93	0.97	1.57	3.20	0.85	1.42	2.54
OXALATE	1.70	2.60	1.92	2.37	1.51	1.63	1.37
PHENOL	1.66	1.65	1.73	1.30	0.61	1.25	0.55

APPEARANCE	6.45	5.74	5.17	7.21	5.73	5.29	7.01
TASTE	5.37	5.54	5.12	5.18	4.56	4.40	4.87
MOULDABILITY	6.60	6.58	7.02	6.61	7.20	7.11	7.05
STICKNESS	6.21	6.18	6.28	4.11	5.04	4.38	4.98
CONSISTENCY	7.20	7.14	7.09	6.82	6.97	7.03	6.58
COLOUR	6.85	6.62	5.43	6.82	4.76	3.53	6.74
OVERALACCEPTABILITY	7.13	7.35	7.10	6.85	6.90	6.67	6.77
DESIRABILITY	0.57*	0.52	0.51	0.49	0.46	0.44	0.41

A-AYF- Aerial Yam flour, B-FMF- Finger Millet Flour, C-PVAC- Pro-Vitamin A Cassava Flour, GI-Glycaemic Index*-Solution number selected
MRPD-Mean Relative Percent Deviation
MAD- Mean Absolute Deviation
R^2 – Coefficient of Determination

Comparison of Observed and Predicted Values of Optimized Flours

The results of the sensory attributes of the predicted and observed values are presented in Table 3. The scores for appearance, taste, mould ability, stickiness, consistency, colour and overall acceptability for predicted value showed that there were significant differences ($P<0.05$) between the observed value and the predicted values (Table 3). The results of the antinutrients showed that there were no significant differences ($P>0.05$) from the predicted and observed values (Table 3). Also, the results for GI (glycemic index) showed that there were significant differences ($P<0.05$) between the observed and the predicted values for glycemic index content (Table 3). The precision between predicted and actual values were measured by MRPD, MAD and R^2. The MRPD ranged from -4.80 to 10.12, MAD ranged from 0.01 to 0.95 and R^2 ranged from 0.24 to 3.92.

Model Validation

The corresponding optimal values for the predicted and actual are presented in Table 3. The actual and predicted values were validated using mean relative percent deviation (MRPD), absolute average deviation (MAAD) and determination coefficient (R^2). The observed values were compared to the predicted values and are presented in Table 3. Lower values ($\leq$ 10%) obtained for MAD and MRPD with high R^2 ($\geq$ 80%) for all the variables with the exception of the antinutrients parameters (oxalate and phenol) suggests the validity of the model for formulation of the flour blends from AYF, FMF and PVACF. The actual values were close to the predicted values in most of the parameters; with the exception of sensory parameters for taste and stickiness, antinutrients for oxalate and phenol. The much difference between the predicted and the actual values for antinutrients could be attributed to the blending ratios, processing, the difference in moisture content, and analytical methods while sensory could be attributed to the panellist variability, and personal preferences of fufu from the AYF, FMF and PVACF flour blend.

Table 3: Comparison of Observed and Predicted Quality Attributes of Optimized Flour Formulation from Aerial Yam (AYF), Finger Millets (FMF) and Pro Vitamin A Cassava (PVAC) Blends.

PARAMETER	PREDICTED VALUE	ACTUAL VALUE± SD	STANDARD ERROR	MEAN DIFFERENCE	MRPD %	MAD	R^2
Independent Variables AYF	12.97						
FMF	10.20						
PVAC *Dependent Variables*	76.83						
GI	54.57	52.60±1.35	0.96	-1.97	2.04	0.95	3.92
TANNIN	2.74	2.50±0.03	0.02	-0.24	-4.80	1.02	0.06
PHYTATE	1.93	2.42±0.14	0.10	0.49	10.12	0.01	0.24
OXALATE	1.70	2.10±0.34	0.24	0.40	9.52	0.24	0.16
PHENOL	1.66	1.47±0.01	0.01	-0.19	-6.46	0.02	0.04
APPEARANCE	6.45	7.78±0.96	0.68	1.33	8.55	0.68	1.77
TASTE	5.37	6.16±0.35	0.25	0.79	6.41	0.25	0.62
MOULDABILITY	6.60	7.70±0.28	0.20	1.10	7.14	0.20	1.21
STICKNESS	6.21	4.80±0.14	0.10	-1.41	-14.69	0.10	1.99
CONSISTENCY	7.20	8.00±0.28	0.20	0.8	5.00	0.20	0.64
COLOUR	6.85	7.85±0.21	0.15	1.00	6.37	0.15	1.00
OVERALACCEPTABILITY	7.13	8.15±0.35	0.25	1.02	6.26	0.25	1.04
DESIRABILITY	0.57*						

A-AYF- Aerial Yam flour, B-FMF- Finger Millets Flour, C-PVAC- Pro-Vitamin A Cassava Flour, GI-Glycaemic Index
*-Solution number selected, MRPD-Mean Relative Percent Deviation, MAD- Mean Absolute Deviation
R^2 – Coefficient of Determination

Model Equations / Fitting from Mixture Response Surface Methodology of AYF, FMF and PVACF Blends.
Glycemic index

The results for glycemic index Table 5 and 6 (Equation 3) showed a significant quadratic mixture models ($P<0.05$) in all the regression models, significant lack of fit and high determination coefficient (R^2). Hence, indicating the suitability of the quadratic model in predicting the glycemic index of the flour blends. The ANOVA for the quadratic mixture (Table 4) showed a significant model and the R^2 value was 0.8098, Adj R^2 was 0.6909. The model equation developed for predicting Glycemic Index was shown in equation (3).

$$G.I=56.2616AYF+51.8875FMF+56.8513PVAC+7.0415AYF*FMF \quad 3$$

Table 4 and 5: Analysis of variance (ANOVA) and Estimated Regression Coefficients for Glycemic index (GI) value of Aerial Yam, Finger Millet and Pro vitamin A Cassava Fufu Blends.

Table 4 ANOVA for Quadratic Mixture Model Component

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	43.8063	5	8.7613	6.8106	0.0092 sig
Linear Mixture	24.8788	2	12.4394	9.6699	0.0073
AYF*PVAC	4.5987	1	4.5987	3.5748	0.0953
AYF*FMF	8.2665	1	8.2665	6.4261	0.0350
PVAC*FMF	4.6254	1	4.6254	3.5956	0.0945
Residual	10.2913	8	1.2864		
Lack of Fit	5.8279	4	1.4569	1.3057	0.4011 n.sig
R^2	0.8098				
Adj R^2	0.6909				

A-AYF- Aerial Yam flour, B-FMF- Finger Millet Flour, C-PVAC- Pro-Vitamin A Cassava Flour, Df- Degree of freedom
*Sig-Significant, n.sig –not significant.

Table 5 Estimated Regression Coefficients

Component	Coefficient Estimate	Df	Standard Error	95% CI Low	95% CI High	VIF
A-AYF	56.2616	1	0.7872	54.4462	58.0769	1.6192
B-FMF	51.8875	1	0.78723	50.0722	53.7029	1.6192
C-PVAC	56.8513	1	0.7865	55.0378	58.6649	1.4958
AYF*FMF	7.0415	1	3.7242	-1.5466	15.6296	1.7554
AYF*PVAC	-11.3159	1	4.4639	-21.6098	-1.0221	1.5538
FMF*PVAC	-8.4645	1	4.4639	-18.7583	1.8294	1.5538

A-AYF- Aerial Yam flour, B-FMF- Finger Millet Flour, C-PVAC- Pro-Vitamin A Cassava Flour., Df-Degree of freedom

Antinutrients
Tannin

The ANOVA for Linear Mixture Model (Table 6) showed a non-significant lack of fit P-value of 0.0877 level and R^2 value of 0.985941, Adj R^2 was 0.9834. The model equation developed for predicting Tannin cannot predict as none of the parameters for testing adequacy of the model were, as such no model equation to predict tannin was developed as shown in Table 7.

Table 6 ANOVA for Linear Mixture Model

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	12.4111	2	6.2055	385.7127	0.0000	Sig
Linear Mixture	12.4111	2	6.2055	385.7127	0.0000	
Residual	0.1770	11	0.0161			
Lack of Fit	0.1563	7	0.0223	4.3258	0.0877	n.sig
R^2	0.9859					
Adj R^2	0.9834					

Df- Degree of freedom, *Sig-Significant, *n.sig- Significant

The special quartic mixture model predicted phytate, oxalate, and phenol. The fitted models were significant, presented non-significant lack of fit for all except oxalate which is significant, had a significant lack of fit and high determination coefficient R^2 were recorded for all. This implies that the empirical models for the antinutrients were suitable for prediction purposes. The special quartic mixture model for oxalate although significant, had a significant lack of fit. Therefore, the model is not suitable for predicting oxalate.

Phytate =6.1990AYF+1.6840FMF+2.004PVAC-10.8941AYF*FMF-11.3423AYF*PVAC2.3523FMF*AYF* FMF*PVAC^2 4

Oxalate =2.8056AYF+2.4406FMF+3.1856PVAC-6.2877AYF*FMF-2.9331AYF*PVAC-7.0031FMF*PVAC 5

Phenol=0.5355AYF+0.6455FMF+1.2155PVAC+3.3855AYF*PVAC+3.9255FMF*PVAC11.95092AYF^2*FMF * PVAC-29.23092AYF*FMF^2*PVAC 6

Sensory properties

Quadratic mixture model predicted the sensory attributes for taste (Equation 8), mouldability (Equation 9), stickiness (Equation 10) and overall acceptability (Equation 13). All the fitted models were significant ($P<0.05$) and presented a non-significant lack of fit with the exceptions of appearance (Equation5), consistency (Equation 9), and colour (Equation 10) which were predicted by special quartic models. The models were significant ($P<0.05$) but only appearance showed non- significant lack of fit. Although the model for consistency and colour were significant, the adjusted determination coefficients Adj. R^2 (0.9383790) consistency and (0.621919) colour were well below 80 %; Also, a significant lack of fit which indicated the inadequacy of the model to predict consistency and colour content. The quadratic models were significant and presented non-significant lack of fit showing the adequacy for predictive purposes.

Appearance=7.3107AYF+4.9607FMF+4.6407PVAC+1.9229AYF*FMF+2.9087AYF*PVAC+2.8887FMF*PVAC -92.8914AYF*FMF^2 PVAC+130.4364AYF*FMF*PVAC^2 7

Taste=4.6072AYF+4.1848FMF+5.2867PVAC+1.8571AYF*FMF+2.3097AYF*PVAC 8

Mouldability=8.4246AYF+8.0808FMF+8.2650PVAC-6.0040AYF*FMF-9.9320AYF*PVAC-7.5949FMF*PVAC 9

Stickiness=3.4802AYF+4.2221FMF+7.2624PVAC+6.0541AYF*FMF 10

Consistency=8.0063AYF+8.0663FMF+8.5113PVAC-6.8350AYF*FMF-7.2950AYF*PVAC-8.3750FMF*PVAC 11

Colour=6.2962AYF+3.0262FMF+5.9612PVAC+6.8049AYF*FMF-9.0224AYF^{2*}FMF*PVAC-201.2624*AYF*FMF^{2}PVAC 12

OverallAcceptability=7.3276AYF+7.29950FMF+8.2063PVAC-2.5812AYF*FMF-3.8277AYF*PVAC-5.8362FMF*PVAC ` 13

IV. Conclusion

The optimized flour blend had lower viscosity and setback values as a result fufu produced from this flour can retain its texture for a longer period without cracking. The study established model equations that can predict glycemic index, antinutritional and sensory properties like taste, appearance, colour, texture, mouldability and overall acceptability. This study has also contributed meaningfully to the knowledge of nutrition therapy as a management tool for blood glucose level especially for diabetics.

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