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# Optimization of African breadfruit based complementary food using mixture response surface methodology

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## ABSTRACT

**Aims:** To model and optimize complementary foods based on their mixture ingredients viz. African breadfruit, soybean and maize, and their depending quality characteristics namely, energy, carbohydrate, fat, ash, protein, flavor, taste, general acceptability and paste viscosity, and determine the amino acid qualities of the optimized formula.

**Study design:** Experimental research (controlled experiment).

**Place and Duration of Study:** The Department of Food Science and Technology, Michael Okpara University of Agriculture, Umudike between 2011 and 2015.

**Methodology:** The D-optimal three factor mixture design fitted into the second order canonical model was adopted, and the factor ranges were set at 64-80% (African breadfruit), 19-35% (soybean) and 1-9% (maize) which yielded twenty blends (including replications) based on the mixture design combination. Each mixture component was expressed as a proportion of the mixture such that the sum was equal to 100%.

**Results:** The results of the analyses were: 379.51-411kcal/100g (energy), 53.59-63.62% (carbohydrate), 8-6% (fat), 3.03-4.28% (ash), 10.31-14.64% (protein), 6-like slightly to 8-like very much (flavor, taste and general acceptability) and 5770-5800mPa.s (paste viscosity). Protein and energy were exceptionally high with all the values of protein exceeding the minimum standard recommended for complementary foods. The models for energy, fat, taste and paste viscosity were excellent for prediction due to the quality of their PRESS and predicted r-squared hence their selection for the numerical optimization which resulted in the prediction of 69:24:7 (African breadfruit: soybean: maize) as the optimized formula. Amino acid evaluation of this optimized formula showed that the values compared favourably with standards (WHO/FAO/UNU reference pattern and egg reference protein). **Conclusion:** The selection of 69:24:7 as the optimized formula indicates that complementary food can be produced with the African breadfruit as a base at 69% inclusion, while its amino acid profile suggests that its protein could be nutritionally adequate.

*Keywords: African breadfruit, complementary food, response surface methodology, optimization, protein energy malnutrition.*

## 1. INTRODUCTION

The problem of protein energy malnutrition which has been associated with as much as 50-60% of under-five mortality in poor countries, has for long been pronounced a public health problem in most developing countries such as Nigeria (Ijarotimi and Olopade, 2009; Faruque et al., 2008). Recent reports show that the problem is still prevalent in Nigeria especially among infants and children, and most common in low socioeconomic families who are barely surviving with low purchasing power (Abubakar, 2017). Due to such socioeconomic factors, households resort to the feeding of infants with portions of family diets which are mainly cereal based and grossly inadequate as the nutritional and physiological conditions of the child are not usually considered during preparation. Legumes are usually avoided due to the problem of indigestibility resulting in gruels with low protein, high bulk and low energy

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25 density. Food and nutrition education has also not made the right impact as it ends up in  
26 teaching people to eat what they cannot afford or do not have (Gurung, 2010).

27 The feeding of suitably prepared complementary foods from mixtures of locally available  
28 foods to infants alongside breast milk is being considered in many scientific circles as a  
29 potential solution. Food mixtures from legumes and carbohydrate sources processed using  
30 appropriate traditional technologies have also been established to possess the right balance  
31 of nutrients and functional properties useful as complementary foods. The choice of the  
32 African breadfruit which is a tree legume as the main ingredient is quite strategic in  
33 alleviating hunger as it is available during the period when most staples are under  
34 cultivation. The seeds are edible and are eaten in different forms especially as porridge and  
35 mainly as a main dish in homes and in ceremonies in different parts of Africa. Moreover, it is  
36 grown widely in the rain forest zone of Nigeria and other African countries, and is accepted  
37 by all classes of people in the rural and urban areas of Nigeria as well as African consumers  
38 in the diaspora.

39 Optimization can be defined as a series of steps for obtaining the best result under a given  
40 set of constraints. Most mathematical and statistical methods available for optimization are  
41 not effective in a multivariate system, and the conventional technique which follows one  
42 factor at a time, demands more time and requires more data to determine optimal level and  
43 results are likely to be unreliable. The response surface methodology which is a collection of  
44 mathematical and statistical techniques used in optimization, provides designs that are  
45 appropriate for optimization in a multivariate system. This experiment was on food mixture  
46 hence the choice of the mixture response surface methodology which is widely used in food  
47 mixture modeling and optimization. In mixture RSM, the independent factors are the  
48 proportions of the mixture ingredients which must always sum to 1 or 100% (Li et al., 2016).  
49 Meanwhile the blending surface is modeled with empirical equation models that are useful in  
50 predicting the optimized mixture as well as determining the influence of the factors on the  
51 responses.

52 This study is part of a larger research, and the objective was to optimize the African  
53 breadfruit based complementary food using the mixture response surface methodology.

## 54 **2. MATERIAL AND METHODS**

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### 56 **2.1 MATERIAL COLLECTION AND PREPARATION**

57 African breadfruit seeds were purchased from local producers at while soybean and maize  
58 were obtained from a sales outlet in Umuahia town all in Abia state, Nigeria. The seeds were  
59 manually sorted and cleaned. Maize and African breadfruit were steeped with potable water  
60 at room temperature ( $25 \pm 2^{\circ}\text{C}$ ) for 16h and the water changed at 8h, then drained and  
61 spread on wet jut bags and covered with muslin clothes and allowed to sprout. The bed was  
62 kept wet by spraying water at 12h interval and the grains turned at 8h interval to discourage  
63 mould growth. At the end of the germination period (40h for maize and 6 days for the African  
64 breadfruit), the sprouts were dried in hot air oven at  $50^{\circ}\text{C}$  for 24h, then toasted at  $180^{\circ}\text{C}$  for  
65 20 minutes and the rootlets removed. Soybean was parboiled at  $100^{\circ}\text{C}$  for 15 minutes, then  
66 dehulled manually and dry-fermented for 48h. It was then washed, drained, dried at  $50^{\circ}\text{C}$  for  
67 24h in a hot air oven, and then toasted at  $180^{\circ}\text{C}$  for 20 minutes in the same oven.

68 The grains were milled and sieved using a  $300\mu\text{m}$  mesh size then blended into composite  
69 flours based on the RSM mixture design layout which yielded 20 blends. These composite  
70 flours were then used in the formulation of the complementary foods based on the formula:

71 composite flour containing 10% protein (Xg), sugar (sucrose) (12g), salt (2g), oil (9g),  
72 vitamin-mineral mix (2g), and corn starch [100-(25 +X)]g.

## 73 2.2 Experimental design and optimization

74 The D-optimal mixture design was adopted as the experimental design. The factor ranges  
75 for the 3 mixture components, African breadfruit- $x_1$ , soybean- $x_2$  and maize- $x_3$  were 64-80%,  
76 19-35% and 1-9% respectively while the responses were energy, carbohydrate, fat, ash,  
77 protein, flavour, taste, general acceptability and paste viscosity. Each mixture component  
78 was expressed as a fraction of the mixture such that the sum was equal to 100%. Twenty  
79 formulations (including replications) of the complementary foods were prepared based on  
80 the mixture design ratios (Table1). The second order canonical model (Eqn. 1) was used to  
81 approximate the unknown function.

$$Y = \sum_{i=1}^3 \beta_i x_i + \sum_{i=1}^3 \sum_{i < j} \beta_{ij} x_i x_j \quad \text{Eqn. 1}$$

Where Y is the response,  $\beta_i$  and  $\beta_{ij}$  are the coefficients of the linear ( $x_i$ ) and quadratic ( $x_i x_j$ ) effects respectively (where  $i = 1-3$ ,  $j = 1-3$  and  $i \neq j$ ).

82 The response surface plots were used to provide visualization of the responses.  
83 Optimization of the responses was carried out via the desirability function approach. Only  
84 predictive models with good predictive capacity namely energy, carbohydrate, fat, taste and  
85 paste viscosity were used for the numerical optimization of which carbohydrate and fat were  
86 maximized while others were left in range. The factors, African breadfruit and maize, were  
87 also placed in range while soy alone was maximized.

## 88 2.3 Chemical, sensory and physical analysis

89 The methods of AOAC (1984) were used for the determination of fat and ash while the  
90 methods described in Onwuka (2005) were used for the determination of the paste viscosity,  
91 crude protein, carbohydrate and crude fibre. Energy determination was by multiplying the  
92 number of carbohydrate, protein, and fat by 4, 4, and 9 respectively and taking the sum of  
93 the result as the energy value of the food expressed in kilocalories per 100g (kcal/100g).

94 Flavour, taste and general acceptability were determined using 20 panelists evaluating  
95 alongside a reference sample (Nutrend) based on a nine point hedonic scale with the  
96 highest point (9) representing like extremely and the lowest point (1) representing dislike  
97 extremely.

98 Amino acid determination was carried out by drying the samples to constant weight,  
99 defatting using the soxhlet extraction procedure as described by AOAC (2006), hydrolyzing  
100 to dryness (Ogunwende and Omowole, 2012), and loading the hydrolysate into the TSM  
101 analyser designed for the separation and analysis of free acidic, neutral and basic amino  
102 acids (Ekeanyanwu, 2013). The amino acids were then calculated from the chromatogram  
103 peaks and expressed as **g/100g** of protein (Gabriel *et al.*, 2010).

## 104 3. RESULTS AND DISCUSSION

105 The predictive models for energy, carbohydrate, fat and paste viscosity have certain things  
106 in common which include the significance ( $P = .05$ ) of the model type and the linear model,  
107 and the non-significance ( $P = .05$ ) of the lack of fit. The significance ( $P = .05$ ) of the linear  
108 model implies that the main effects (individual ingredients) rather than the interactions

109 (blends) had significant ( $P = .05$ ) effects on the corresponding responses. This fact is  
 110 conveyed in their predictive model equations (eqn. 2, 3, 4, and 5) as the blends are not  
 111 included in the equations.

$$\text{Energy} = 385.11x_1 + 406.08x_2 + 401x_3 \quad \text{Eqn. 2}$$

112 The value of energy ranged between 379.51 and 411kcal/100g (Table 1) with most of the  
 113 products exceeding the 400kcal per 100g energy benchmark for complementary foods as  
 114 recommended by FAO/WHO (2013). This compares with those of Onoja *et al.* (2014),  
 115 211.34 – 420.98 kcal/100g, and Yohannes *et al.* (2020), 394 – 560 kcal/100g. The high  
 116 energy (411.3kcal/100g) content of 64:35:1 (African breadfruit: soybean: maize)  
 117 complementary food may be attributed to high fat content which was probably contributed by  
 118 soybean of which the product had the highest proportion.

119 Table1: Mixture design layout: factors and responses

COM	Factors			Responses								
	ABF	Soy	Mz	Energy kcal/100g	Carb %	Fat %	Ash %	Prot %	Flav	Tas	GA	Visco mPa.s
1	67	30	3	407.13	53.59	15.25	3.53	13.88	6	7	7	5780
2	70	25	5	398.41	57.22	13.25	3.33	12.57	7	8	7	5790
3	70	25	5	400.88	56.51	14.00	3.58	12.21	7	7	7	5780
4	72	19	9	390.77	61.44	11.25	3.28	10.94	7	7	7	5800
5	64	27	9	410.05	55.29	15.25	3.38	12.91	6	6	7	5790
6	70	25	5	401.27	56.44	13.75	3.38	12.94	7	8	6	5790
7	80	19	1	379.51	60.55	8.00	3.28	14.64	6	6	6	5800
8	80	19	1	388.09	59.65	10.25	3.03	14.31	6	7	6	5800
9	70	25	5	401.79	56.87	13.75	3.36	12.64	7	7	7	5800
10	73	22	5	403.01	58.28	14.25	3.53	10.41	7	7	7	5790
11	70	25	5	397.76	55.65	14.00	3.53	12.29	7	7	7	5780
12	64	27	9	389.2	58.8	11.00	3.28	13.75	6	6	7	5790
13	72	27	1	384.39	61.18	10.75	4.28	10.73	7	8	8	5790
14	64	35	1	411.31	55.06	15.75	3.28	12.33	6	7	7	5770
15	70	25	5	381.77	59.38	10.25	3.50	13.00	8	8	7	5790
16	76	19	5	387.71	63.62	10.25	3.03	10.31	6	7	7	5800
17	69	24	7	381.71	59.42	10.75	3.48	11.82	7	7	7	5790
18	64	31	5	402.86	55.49	15.50	4.03	10.35	6	7	7	5790
19	72	19	9	410.25	55.31	15.25	3.33	12.94	7	7	7	5800
20	64	35	1	411.00	55.01	16.00	3.35	11.74	7	6	6	5790

<sup>a</sup>Com = Complementary Food; <sup>b</sup>ABF = African breadfruit; <sup>c</sup>Mz = Maize; <sup>d</sup>Soy = Soybean;  
<sup>e</sup>Carb = Carbohydrate; <sup>f</sup>Flav = Flavour; <sup>g</sup>GA = General Acceptability; <sup>h</sup>Visco = Paste Viscosity.

120 The energy model with a C.V.% as low as 2.32 (Table 2) which implies reproducibility of the  
 121 model, and adequate precision of 5.870 which was greater than 4 - the limit, was adequate  
 122 for the analysis. The surface plot (Figure1) shows that African breadfruit and soybean  
 123 increased with increasing values of energy.

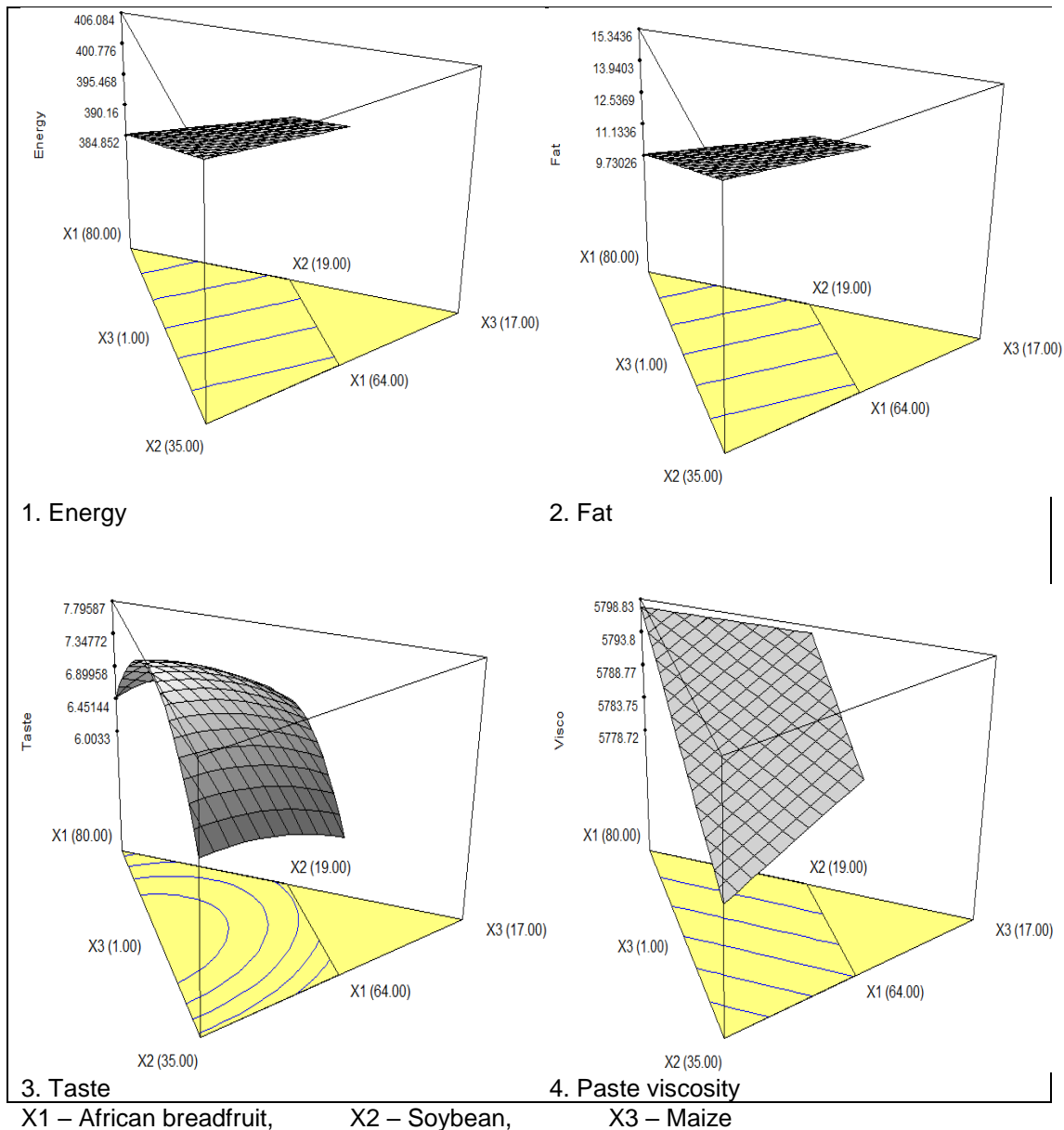


Fig.1 Energy, fat, taste and paste viscosity surface plots

124 Carbohydrate has now overtaken fat as the chief energy source in complementary foods.  
125 The range of 53.59 – 63.62% (Table 1) in the products compared with 57.3 - 66.1% of  
126 Gebrezgi (2019). This was quite moderate as compared to 30.10 – 32.87 of Onoja *et al.*  
127 (2014) and 78.55 – 80.87% of Ojinnaka *et al.* (2013). The class of carbohydrates in the  
128 products are essential for infants especially those with cow-milk allergy as it is lactose free  
129 since being of plant origin. Also, it is highly digestible due to partial hydrolysis through  
130 fermentation and germination. The predictive model for carbohydrate (Eqn. 3) shows the  
131 significance ( $P = .05$ ) of the African breadfruit, soybean and maize. Fat, a main source of  
132 energy of infants of less than 6 months of age (about 50% in breast milk) ranged between 8  
133 to 16% in the complementary foods constituting between 23.79 and 35.04% of proportions of  
134 energy from fat in these diets. The range of values of fat of 30-45% (proportions of energy)

135 has been suggested for complementary foods within which most of these products lay.  
 136 Ikujenlola *et al.* (2013) reported a range of 2.07 – 8.34%, much lower than the range of fat  
 137 recorded in this study. The predictive model for fat (Eqn. 4) though with a low R-squared,  
 138 had adequate precision of 7.839 (Table 2) a value greater than 4, implying that the model  
 139 was adequate. The surface plot for fat (Figure1) shows a linear decrease in fat along the  
 140 African breadfruit axis against a linear increase in fat along the soybean axis.

$$\text{Carbohydrate} = 60.87x_1 + 54.78x_2 + 57.53x_3 \quad \text{Eqn. 3}$$

$$\text{Fat} = 9.80x_1 + 15.34x_2 + 13.99x_3 \quad \text{Eqn. 4}$$

141 Table 2: Diagnostic parameters for the fitted model

Parameters	C.V.	PRESS	R-squared	Pred. R-Squared	Adeq. Precision
Energy	2.32	2012.71	0.3344	0.0744	5.870
Carbohydrate	3.39	2225.67	0.6997	-16.3234	6.948
Fat	14.13	80.80	0.4725	0.2485	7.839
Ash	3.15	107.36	0.9262	-66.6371	16.083
Protein	4.92	2544.37	0.8857	-78.1123	9.971
Flavour	5.88	6.79	0.6966	-0.0363	6.483
Taste	6.80	7.07	0.6040	0.1158	6.355
General					
Acceptability	5.00	4.67	0.6651	-0.0256	9.233
Paste Viscosity	0.11	917.06	0.5078	0.2918	8.085

142 Paste viscosity is essential in complementary foods as infants prefer foods of low viscosity  
 143 unlike adult. The products ranging from 5770 to 5800 mPa.s (Table 1) were within the range  
 144 of gruels with thick spoonable, poor-batter consistency which mothers prefer to feed their  
 145 children. Also, the narrow range of viscosity may be attributed to malting and air-dry  
 146 fermentation used in the processing of the flours which are close in terms of impact on  
 147 viscosity reduction. The predictive model for paste viscosity (Eqn. 3) had a very high  
 148 adequate precision of 8.085 (Table 2) indicating an adequate model. The absence of  
 149 interactive terms in the predictive model suggests that blending did not have any significant  
 150 effect ( $P = .05$ ) on paste viscosity. The surface plot for paste viscosity (Figure 1) shows that  
 151 the most significant ( $P = .05$ ) factors were the African breadfruit and soybean which  
 152 increased with increasing paste viscosity. Although this suggests that the lower proportions  
 153 of these ingredients are needed to achieve low paste viscosity, this is not be a problem as  
 154 the range of paste viscosity (Table 1) falls within the requirement for complementary foods.

$$\text{Paste viscosity} = 9837.74x_1 + 9818.72x_2 + 9838.04x_3 \quad \text{Eqn. 5}$$

156 Taste ranged between like slightly (6) to like very much (8) (Table 1), the same range  
 157 reported by Turfa *et al.* (2016). The taste model (Eqn. 3) had R-squared of 0.6040 and  
 158 adequate precision of 6.355 (Table 2) indicating a good predictive model. The binary  
 159 mixture, African breadfruit\*soybean ( $X_1X_2$ ), was the only significant ( $P = .05$ ) term in the  
 160 model which implies synergy (blending improved the taste of the products). The relationship  
 161 is shown in the response surface plot for visualization (Fig. 1).

$$\text{Taste} = 4.93x_1x_2 \quad \text{Eqn. 6}$$

163 Flavour and general acceptability (Eqn. 7) models both had insignificant ( $P = .05$ ) lack of fit,  
 164 significant ( $P = .05$ ) model type and insignificant ( $P = .05$ ) linear model. Flavour ranged

165 between like slightly-6 and like very much-8 (Table 1) with the 70:25:5 African breadfruit:  
166 soybean: maize complementary food having the highest score. Flavour had no model term  
167 significant besides the significance ( $P = .05$ ) of the model type hence the exclusion of its  
168 predictive model. A good number of the model terms of general acceptability were significant  
169 ( $P = .05$ ). These include the binary mixture, African breadfruit\*soybean ( $X_1X_2$ ), with a  
170 positive coefficient implying synergy and the tertiary mixture, African  
171 breadfruit\*soybean\*maize ( $X_1X_2X_3$ ) with a negative coefficient implying antagonism. These  
172 suggests that the blend of African breadfruit and soybean significantly ( $P = .05$ ) improved the  
173 general acceptability of the products.

174 
$$\text{General acceptability} = 6.60x_1x_2 - 27.99x_1x_2x_3$$
 Eqn. 7

175 Ash and protein both had insignificant ( $P = .05$ ) lack of fit and significant ( $P = .05$ ) quadratic  
176 terms. Ash, an important nutritional indicator of mineral content, ranged between 3.03 to  
177 4.28% (Table 1). This was higher than the ash composition of traditional complementary  
178 foods reported by Alamu *et al.* (2018) which was 1.03 – 2.54%. The model for ash had a  
179 very high R-squared (0.9262) and adequate precision (16.08) (Table 2); the R-squared quite  
180 close to 1 indicates repeatability of the model. The highest value of protein in the  
181 complementary foods was 14.64% (Table 1) corresponding to 3.66g/100kcal while the  
182 lowest value was 10.31% corresponding to 2.58g/100kcal which were above the minimum  
183 standards of 6-15g/100g and 6-11g/100g stipulated by FAO/WHO (2013), and WFP (2015)  
184 respectively for complementary foods. Turfa *et al.* (2016) reported a range of 7.34 – 16.73%  
185 protein for complementary foods in Ethiopia. The model for protein with R-squared as high  
186 as 0.8857, and adequate precision of 9.971 showed that the model was adequate. The  
187 negative signs of the binary mixtures, African breadfruit\*soybean ( $X_1X_2$ ), African  
188 breadfruit\*maize ( $X_1X_3$ ) and soybean\*maize ( $X_2X_3$ ) imply antagonism. It is notable that the  
189 African breadfruit\*soybean\*maize ( $X_1X_2X_3$ ) had positive coefficient which shows that this  
190 blend could improve the protein value of the complementary foods.

191 
$$\text{Protein} = -10.12x_1x_2 - 231.84x_1x_3 - 221.27x_2x_3 + 348.42x_1x_2x_3$$
  
$$+ 122.63x_1x_3(x_1 - x_3) + 122.69x_2x_3(x_2 - x_3)$$
 Eqn. 8

192 The result of the simultaneous optimization showed that 69:24:7 (African breadfruit:  
193 soybean: maize) was selected as the optimized complementary food implying that the  
194 optimal conditions were 69% for the African breadfruit, 24% for the soybean and 7% for  
195 bread. Also shown was that at this optimal condition, the energy, carbohydrate, fat, taste,  
196 and paste viscosity were 397.62, 59.70, 13.10, 7.17, and 5791.91 respectively.

197 Amino acid composition is a principal factor in the quality of a protein. The amino acid profile  
198 of the optimized formula (Table 3), 69:24:7 African breadfruit: soybean: maize, competed  
199 favourably with the WHO/FAO/UNU (2007) amino acid reference pattern for the infant with  
200 some exceeding these values. Arginine, histidine, and phenylalanine, all essential amino  
201 acids for infant, all had values higher than the amino acid reference pattern. This is important  
202 as the capacity of arginine synthesis is low in infants. Also phenylalanine is a precursor for  
203 tyrosine and infants lack the capacity to synthesize histidine. Also observed, was the  
204 increasing values of the amino acids with increasing levels of soybean which may be  
205 attributed to the excellent quality of soybean as a complete protein. The sulphur containing  
206 amino acids though lower than the reference pattern, equally increased with increasing  
207 levels of maize which may be associated with the high levels of sulphur containing amino  
208 acids in maize – a cereal, suggesting the possibility of increase with proportionate increase  
209 of maize in the formula.

Table 3: Amino acid profile and nutritional indices calculated from amino acids

Amino Acids (g/100g)	69:24:7 (Optimized complementary food)	Reference Pattern (WHO/FAO/UNU, 2007)
Amino acid profile		
Lysine	6.66 ±0.050	6.9
Histidine	3.01 ±0.014	2.1
Arginine	6.64 ±0.127	2.3
Aspartic acid	10.91±0.014	9.0
Threonine	3.55±0.070	4.4
Serine	5.10±0.141	5.0
Glutamic acid	17.07±0.199	17.8
Proline	3.93±0.042	8.0
Glycine	3.40±0.28	2.3
Alanine	4.05±0.070	3.8
Cysteine	1.46±0.084	1.7
Valine	4.39±0.280	5.5
Methionine	1.30±0.141	1.6
Isoleucine	4.02±0.228	5.5
Leucine	7.85±0.212	9.6
Tyrosine	3.38±0.170	5.2
Phenylalanine	5.58±0.169	4.2
Nutritional Indices Calculated from Amino Acids		
Total Amino Acid (TAA)	92.30±1.004	-
Total Sulphur Amino Acid (SAA)	2.76±0.1670	-
Total Essential Amino Acids(EAA)	36.36±0.933	-
EAA/TAA %	39.4±0.566	-
ArAA (Phy + Tyro)	8.96±0.849	-

Values are mean ± standard deviation of duplicate determination.

#### 210 **4. CONCLUSION**

211 The predictive models for taste, general acceptability and protein seem to suggest by the  
 212 significance of their blends that the blending of ingredients for the production of the  
 213 complementary food was successful. Also the selection of 69:24:7 African breadfruit:  
 214 soybean: maize as the optimized formula indicates that 69% inclusion of the African  
 215 breadfruit was appropriate for the formulation of African breadfruit based complementary  
 216 food. The presence of such levels of amino acid suggests that its protein has the right  
 217 balance to sustain the life of an infant; however, a biological studies of the protein is  
 218 recommended to ascertain this.

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## 225 **COMPETING INTERESTS**

226 The authors of this manuscript hereby declare that no competing interests exist.

## 227 **AUTHORS' CONTRIBUTIONS**

228 This manuscript is a collaborative effort of all the authors. All authors read and approved the  
229 final manuscript.

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