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Research Article

Development and Statistical Optimization of Flakes from Selected Local Food Ingredients

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Abstract
Flakes are instant breakfast meals, primarily produced from mono-cereals (corn, wheat, rice, and/or oats), processed with added flavor and fortified with vitamins and minerals. They are one of the several forms of cold cereals that are consumed immediately after mixing with milk, yogurt, or fruit. In this study, value-added instant flakes were developed, characterized and optimized; from blends of corn, millet, and soybean. A three-component constrained optimal (custom) mixture experimental design, with 30 randomized experimental runs, was employed for the formulation. The formulation design constraints were: corn flour (30% - 45%), millet flour (10% - 25%), and soybean flour (5% - 20%). Other components of the formulation, which were kept constant, were: water (19%), sugar (8%), malt (2%), egg (3%), sweet potato extract (3%), ginger (2%), and moringa seed powder (3%). The formulated flakes were analyzed and evaluated for the proximate, physicochemical and sensory characteristics using standard procedures. The result of the numerical optimization gave optimized instant flakes with an overall desirability index of 0.637, based on the set optimization goals and individual quality desirability indices. The optimal instant flake was obtained from 30.5 % corn flour, 11.2 % millet flour, 18.3 % soybean meal. The quality properties of this optimal instant flake were: 1.83 % moisture content, 9.05 % fat content, 1.74 % ash content, 2.66 % crude fibre, 38.0 % crude protein, 46.7 % carbohydrate, 420 kcal energy value and 6.28 overall acceptability. The result of the study showed that the formulated instant flakes were of high quality and that improving the nutritional quality of flakes is possible through grain-to-grain composite formulation. It is recommended that further study be carried out on the formulation of nutritionally improved instant flakes using other nutritionally rich grains and legumes such as groundnut, sesame seed, melon seed etc. Enrichment of flakes with protein-rich sources will result in flakes product with improved nutrient quality that meets the consumer's dietary needs.

1. Introduction

Several forms of cold breakfast cereals are available: (1) toasted flaked cereals (corn flakes, wheat flakes, and rice flakes), including extruded flakes, (2) puffed intact grains or extruded pellets, (3) baked shredded whole grains or extruded grain fractions, (4) granola and muesli-type cereals, and (5) pre-processed hot cereals [1-3].

Corn flakes, wheat flakes, and rice flakes are typical examples of convenient and relatively shelf-stable flaked cereals. Traditionally, flaked cereals come from regular field corn and the cooking method for its preparation involves direct cooking of intact grain kernels or parts of kernels with water and flavour in a steam cooker. Another method involves cooking finer materials, such as grain flour, in an extruder where mechanical energy is applied for the formation of the grits for flaking. Extruded flakes differ from those made by the traditional process in that the grit for flaking is formed by extruding mixed flour ingredients through extruder die and cutting off pellets of the dough in the desired size [4-8]. Scientific research into the use of multigrain and fiber for the production of flakes is on the increase [9-13].

Composite food formulation is a viable and sustainable means of tackling nutrient deficiencies, particularly protein-energy malnutrition and it will go a long way in reducing malnutrition and food insecurity in developing countries. Furthermore, there is a general demand for food developed to meet dietary requirements of consumers. Increasing the

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nutritional value of flakes will increase its market value. This study was aimed at the development, characterization and optimization of value-added instant flakes, via mixture experimental design, from blends of corn, millet, and soybean.

2. Materials and Methods

2.1. Materials

The major raw materials used in this study were corn, millet, and soybean. The three grains comprise 60% of the total mixture with the remaining 40% reserved for other ingredients (kept constant throughout the experiment). These ingredients include: water (19%), sugar (8%), malt (2%), egg (3%), sweet potato extract (3%), ginger (2%), and moringa seed powder (3%). All these materials were gotten from Kure Market, Minna, Nigeria.

2.2. Processing of the corn, millet, and soya beans flours

Clean grains of corn and millet were properly milled until a fine flour is achieved using a bore mill. Cleaned, sorted soybeans were roasted until a golden brown color was observed, and the roasted soybeans were dehulled in a commercial attrition mill, winnowed manually, milled into flour. The flours were sieved using a laboratory sieve mesh of 0.75–1 mm.

2.3. Methods

2.3.1. Experimental Design for Flakes Grits Formulation

A three-component constrained, optimal (custom) mixture experimental design, with 30 randomized experimental runs, was employed. The formulation design constraints were: corn flour (30% - 45%), millet flour (10% - 25%), and soybean flour (5% - 20%). Other components of the formulation, which were kept constant, were: water (19%), sugar (8%), malt (2%), egg (3%), sweet potato extract (3%), ginger (2%), and moringa seed powder (3%). The formulation design constraints were: corn flour (30% - 45%), millet flour (10% - 25%), and soybean flour (5% - 20%). Other components of the formulation, which were kept constant, were: water (19%), sugar (8%), malt (2%), egg (3%), sweet potato extract (3%), ginger (2%), and moringa seed powder (3%).The formulation design constraints were: corn flour, millet flour and soybean flour Other constant components and/or ingredients of the formulation were water (19%), sugar (8%), malt (2%), egg (3%), sweet potato extract (3%), ginger (2%), and moringa seed powder (3%). The design matrix used for the formulation experiment were presented in Table 1. The samples or runs were prepared based on the design matrix. The other minor components were added to each of the thirty samples and mixed thoroughly, to obtain a homogeneous mixture. The samples were then subjected to an electrical steam pressure cooking at a temperature of 80°C for 1hours and then the samples were removed and allowed to cool down for 5 minutes. Each of the samples were then rolled or pressed into flat, thin flakes using a rolling pin, and then were subjected to an electric oven drying at temperature of 66°C for 1hours. On removal from the toasting machine, the flakes were allowed to cool down and later packaged in different clean transparent, plastic packaging containers.

2.3.2. Proximate analysis and sensory evaluations

The proximate and quality characteristics of the multigrain flakes were carried out using the method described by the Association of Analytical Chemist [14]. These include moisture content, lipid, ash content, crude fibre, crude protein, carbohydrate, and energy value. Sensory evaluations of the formulated flakes were also conducted using thirty trained panellists. A 9-point hedonic scale ranging from 9 = like extremely and 1= dislike extremely was used to evaluate the samples for taste, flavour, sweetness, colour, texture and overall acceptability. Table water was used for mouth rinsing intermittently to minimize the carry-over effects.

3. Results and Discussion

3.1. Results

The proximate compositions and the sensory evaluation scores of the formulated flakes were presented in Table 1.

3.2. Statistical analysis of experimental results

The experimental results were analyzed and appropriate Scheffe canonical models were fitted to the mean proximate property data. The statistical significance of the terms in the Scheffe canonical regression models were examined by ANOVA for each response, and the adequacy of the models were evaluated by the coefficient of determination, F-value, and model p-values at the 0.05 level of significance. The models were also subjected to lack-of-fit and adequacy tests. The fitted models for all the responses were used to generate 3-D response surfaces as well as their contour plots using the DESIGN EXPERT 11.0 statistical software.

A Numerical optimization approach, exploiting the desirability function technique, was utilized to generate the optimal formulation with the anticipated responses. Optimization goals are assigned to parameters and these goals were used to construct desirability indices (di). In multi-response optimization, the desirabilities of all the individual responses are combined into a single number known as the overall desirability index. A value of one represents the case where all goals are met perfectly. A zero indicates that one or more responses fall outside desirable limits. Numerical optimization solutions are given as a list in the order of desirability, detailing the component's proportions and process variables values that satisfy the set criteria and the overall desirability (Raymond et al., 2009).

Table 1. Formulated flakes design matrix, proximate compositions and the sensory evaluation scores

	x_1	x_2	x_3	y_{mc}	y_{fat}	y_{ac}	y_{fc}	y_{pc}	y_{cho}	y_{ev}	y_t	y_f	y_s	y_c	y_{tx}	y_o
Run	%	%	%	%	%	%	%	%	%	k/cal						
1	37.5	10	12.5	3.2	9	5	1.33	48	33.5	407	5.7	6.8	6.7	6.3	5.6	6.9
2	37.5	10	12.5	3.22	9.05	4.98	1.34	48	33.4	407	5.2	6.7	7	6	5.9	5.5
3	37.5	10	12.5	3.21	9	4.99	1.33	48	33.5	407	5.1	6	5.7	5.8	5.7	5.4
4	40	12.5	7.5	2.5	6	1	2.67	31.9	55	405	6.3	6.5	6.2	5.4	6.1	6.4
5	40	12.5	7.5	2.53	6.01	0.99	2.65	31.9	56	405	5.8	5.9	5.9	5.7	6	6.1
6	40	12.5	7.5	2.51	6.04	1.01	2.69	31.9	55.9	405	5.5	6.9	6.5	5.9	6.2	6.2
7	45	10	5	2.62	6.01	2	2	35	52.4	404	6.8	6.8	6.7	6	6.1	7
8	45	10	5	2.61	6	2.01	2	35	52.4	404	5.7	5.8	6.3	5.9	5.8	5.5
9	45	10	5	2.6	6.03	2	2.03	35	52.3	404	7.1	6.9	6.1	5.9	6.5	7.3
10	32.5	20	7.5	2.04	7.1	3.1	2	35	50.8	407	6	5.4	6.4	5.8	5.9	6.5
11	32.5	20	7.5	2.4	7	3	2.01	35	50.6	406	5.7	6.8	6.7	6.3	5.6	6.9
12	32.5	20	7.5	2.4	7.1	3.1	2	35	50.4	406	5.2	6.7	7	6	5.9	5.5
13	35	15	10	1.85	7.51	2.03	2.67	32.5	53.4	411	5.1	6	5.7	5.8	5.7	5.4
14	35	15	10	1.88	7.5	2	2.65	32.6	53.4	411	6.3	6.5	6.2	5.4	6.1	6.4
15	35	15	10	1.86	7.5	2.01	2.67	32.5	53.4	411	5.8	5.9	5.9	5.7	6	6.1
16	30	10	20	1.86	9	1.01	3.75	42	42.4	419	5.5	6.9	6.5	5.9	6.2	6.2
17	30	10	20	1.88	9.05	0.99	3.77	42	42.3	419	6.8	6.8	6.7	6	6.1	7
18	30	10	20	1.86	9.01	1.01	3.78	42	42.3	418	5.7	5.8	6.3	5.9	5.8	5.5
19	32.5	12.5	15	1.66	9	2.01	1.25	30.4	55.6	425	7.1	6.9	6.1	5.9	6.5	7.3
20	32.5	12.5	15	1.65	9.01	2.01	1.3	30.5	55.5	425	6	5.4	6.4	5.8	5.9	6.5
21	32.5	12.5	15	1.66	9	2	1.27	30.5	55.2	424	5.7	6.8	6.7	6.3	5.6	6.9
22	34.5	14.5	11	1.66	6.01	1.01	1.88	26.3	63.2	412	5.2	6.7	7	6	5.9	5.5
23	34.5	14.5	11	1.66	6.03	1	1.9	26.3	63.1	412	5.1	6	5.7	5.8	5.7	5.4
24	34.5	14.5	11	1.65	6	1	1.88	26.3	63.2	412	6.3	6.5	6.2	5.4	6.1	6.4
25	30	17.5	12.5	1.5	8.51	3.01	1.25	28	57.7	420	5.8	5.9	5.9	5.7	6	6.1
26	30	17.5	12.5	1.52	8.5	3	1.3	28	57.6	419	5.5	6.9	6.5	5.9	6.2	6.2
27	30	17.5	12.5	1.52	8.51	3	1.29	28	57.7	419	6.8	6.8	6.7	6	6.1	7
28	30	25	5	1.5	8.51	2.01	3.13	29.1	55.8	413	5.7	5.8	6.3	5.9	5.8	5.5
29	30	25	5	1.51	8.51	2.01	3.1	29.1	55.8	416	7.1	6.9	6.1	5.9	6.5	7.3
30	30	25	5	1.52	8.5	2	3.11	29	55.9	416	6	5.4	6.4	5.8	5.9	6.5

$x_1 = Corn\ flour\ (\%)$, $x_2 = Millet\ flour\ (\%)$, $x_3 = Soybean\ flour\ (\%)$, $y_{mc} = Moisture\ Content\ (\%)$,

$y_{pc} = Protein\ Content\ (\%)$; $y_{fat} = Fat\ Content\ (\%)$, $y_{ac} = Ash\ Content\ (\%)$; $y_{cho} = Carbohydrate\ (\%)$

$y_{ev} = Energy\ value\ (k/cal)$, $y_{fc} = Fibre\ Content\ (\%)$; $y_t = Taste$; $y_f = Flavor$; $y_s = Sweetness$;

$y_c = Colour$; $y_{tx} = Texture$; $y_o = Overall\ acceptability$

3.2. Results of statistical analysis of experimental data

The summary of the analysis of variance (ANOVA) for the formulated flake's proximate compositions and the energy value are presented in Tables 2-8.

Table 2. ANOVA for moisture content of formulated multigrain instant flakes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	8.64	8	1.08	244.53	< 0.0001	significant
Linear Mixture	4.58	2	2.29	518.84	< 0.0001	significant
x_{12}	0.1117	1	0.1117	25.30	< 0.0001	significant
x_{13}	1.89	1	1.89	427.34	< 0.0001	significant
x_2x_3	0.0615	1	0.0615	13.92	0.0012	significant
$x_1^2x_2x_3$	0.2220	1	0.2220	50.27	< 0.0001	significant
$x_1x_2^2x_3$	0.0349	1	0.0349	7.90	0.0105	significant
$x_1x_2x_3^2$	0.5748	1	0.5748	130.17	< 0.0001	significant
Residual	0.0927	21	0.0044			
Lack of Fit	0.0041	1	0.0041	0.9341	0.3453	not significant
Pure Error	0.0886	20	0.0044			
Cor Total	8.73	29				
Std. Dev.	0.0665	R^2	0.9894			
Mean	2.07	Adjusted R^2	0.9853			
C.V. %	3.21	Predicted R^2	0.9766		Adeq Precision	46.7302

The moisture content fitted model in terms of L_Pseudo Components is:

$$\left.\begin{aligned} y_{mc} &= 2.61x_1 + 1.51x_2 + 1.87x_3 + 5.15x_1x_2 + 3.89x_1x_3 \\ &\quad - 0.701x_2x_3 - 54.1x_1^2x_2x_3 + 21.4x_1x_2^2x_3 - 55.0x_1x_2x_3^2 \end{aligned}\right\} \qquad (1)$$

The results of the analysis showed that the moisture content model of the formulated multigrain instant flakes is significant with F-value of 245 and p-value of 5.91E-19. The moisture content is significantly influenced, at 5% level of significance, by the proportions of corn, millet, and soybean flours in the formulations (with linear mixture F- and p-values of 519 and 1.33E-18, respectively). The moisture content is also significantly influenced, at 5% level of significance by the corn/millet flours interaction (with F-value of 25.3 and p-value of 5.59E-05); the corn/soybean flours interaction (with F-value of 427 and p-value of 1.93E-15); the millet / soybean flours interaction (with F-value of 13.9 and p-value of 0.00123); the second order of corn/millet/soybean flours interaction (with F-value of 50.3 and p-value of 5.39E-07); corn / the second order of millet / soybean flours interaction (with F-value of 7.90 and p-value of 0.0105); and corn / millet / the second order of soybean flours interaction (with F-value of 130 and p-value of 1.84E-10). The Lack of Fit F- and p-value of 0.93 and 0.345 implies that the Lack of Fit is not significant. There is a 34.53% chance that a Lack of Fit F-value this large could occur due to extraneous factors. Non-significant lack of fit is expected for a significant fitted model. The moisture content model R^2 and the Adjusted R^2 are 0.9894 and 0.9853, respectively. The predicted R^2 of 0.9766 is in reasonable agreement with the adjusted R^2 of 0.9853; i.e., the difference is less than 0.2. Adequacy of precision ratio of 46.7 indicates an adequate signal and that the fitted model can be used to navigate the design space and to make predictions about moisture content for given levels of each factor.

The results of the analysis showed that the fat content model of the formulated multigrain instant flakes is significant with F-value of 17.4 and p-value of 1.17E-07. The fat content is significantly influenced, at 5% level of significance, by the proportions of corn, millet, and soybean flours in the formulations (with linear mixture F- and p-values of 43.2 and 3.60E-08, respectively). The fat content is also significantly influenced, at 5% level of significance by the corn/soybean flours interaction (with F-value of 15.4 and p-value of 0.00078). There is only a 0.01% chance that a lack of fit F-value this large could occur due to extraneous factors. The Lack of Fit F- and p-value of 1.02E+04 and 1.39E-28 implies that the Lack of Fit is significant. The fat content model R^2 and the Adjusted R^2 are 0.8692 and 0.8194, respectively. The predicted R^2 of 0.8023 is in reasonable agreement with the adjusted R^2 of 0.8194; i.e. the difference is less than 0.2. Adequacy of precision ratio of 10.53 indicates an adequate signal. The model can be used to navigate the design space and to make predictions about fat content for given levels of each factor.

Table 3. ANOVA for fat content of formulated multigrain instant flakes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	40.2	8	5.03	17.4	1.17E-07	significant
Linear Mixture	24.9	2	12.5	43.2	3.60E-08	significant
x_{12}	0.00582	1	0.00582	0.0202	0.888	
x_{13}	4.43	1	4.43	15.4	0.00078	significant
x_2x_3	0.144	1	0.144	0.499	0.488	
$x_1^2x_2x_3$	0.711	1	0.711	2.46	0.131	
$x_1x_2^2x_3$	0.227	1	0.227	0.789	0.385	
$x_1x_2x_3^2$	0.0415	1	0.0415	0.144	0.708	
Residual	6.06	21	0.288			
Lack of Fit	6.04	1	6.04	1.02E+04	1.39E-28	significant
Pure Error	0.0118	20	0.00059			
Cor Total	46.3	29				
Std. Dev.	0.5370	R²	0.8692			
Mean	7.6667	Adjusted R²	0.8194			
C.V. %	7.00437	Predicted R²	0.8023		Adeq Precision	10.53

The fat content fitted model in terms of L_Pseudo Components is:

$$\left.\begin{aligned} y_{fat} &= 5.99x_1 + 8.48x_2 + 9.09x_3 - 1.17x_1x_2 + 5.95x_1x_3 \\ &- 1.07x_2x_3 - 96.7x_1^2x_2x_3 - 54.7x_1x_2^2x_3 + 14.8x_1x_2x_3^2 \end{aligned}\right\} \quad (2)$$

Table 4. ANOVA for ash content formulated multigrain instant flakes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	39.24	8	4.91	62.05	< 0.0001	significant
[(1)]Linear Mixture	0.0910	2	0.0455	0.5754	0.5711	
x_{12}	0.1279	1	0.1279	1.62	0.2174	
x_{13}	24.23	1	24.23	306.49	< 0.0001	significant
x_2x_3	4.45	1	4.45	56.34	< 0.0001	significant
$x_1^2x_2x_3$	1.87	1	1.87	23.62	< 0.0001	significant
$x_1x_2^2x_3$	1.44	1	1.44	18.26	0.0003	significant
$x_1x_2x_3^2$	2.84	1	2.84	35.89	< 0.0001	significant
Residual	1.66	21	0.0791			
Lack of Fit	1.65	1	1.65	4062.66	< 0.0001	significant
Pure Error	0.0081	20	0.0004			
Cor Total	40.90	29				
Std. Dev.	0.2812	R²	0.9594			
Mean	2.21	Adjusted R²	0.9439			
C.V. %	12.72	Predicted R²	0.9386	Adeq Precision	25.6922	

The ash content fitted model in terms of L_Pseudo Components is:

$$\left.\begin{aligned} y_{ac} &= 1.99x_1 + 1.99x_2 + 1.04x_3 - 5.15x_1x_2 + 13.9x_1x_3 \\ &+ 5.97x_2x_3 - 157x_1^2x_2x_3 + 138x_1x_2^2x_3 - 122x_1x_2x_3^2 \end{aligned}\right\} \quad (3)$$

The results of the analysis showed that the ash content model of the formulated multigrain instant flakes is significant with F-value of 62.05 and p-value of 7.06E-13. The fat content is not significantly influenced, at 5% level of significance, by the proportions of corn, millet, and soybean flours in the formulations (with linear mixture F- and p-values of 0.575 and 0.571, respectively). The ash content is significantly influenced, at 5% level of significance by the corn / soybean flours interaction (with F-value of 306 and p-value of 5.28E-14); millet/soybean flours interaction (with F-value of 56.3 and p-value of 2.25E-07); the second order of corn/millet/ soybean flours interaction (with F-value of 23.6 and p-value of 8.35E-05); corn / the second order of millet/soybean flours interaction (with F-value of 18.3 and p-value of 0.000338); and corn/millet/ the second order of soybean flours interaction (with F-value of 35.9 and p-value of 6.03E-06). The Lack of Fit F- and p-value of 4.06E+03 and 1.41E-24 implies that the Lack of Fit is significant. The ash content model R^2 and the Adjusted R^2 are 0.9594 and 0.94395, respectively. The Predicted R^2 of 0.9386 is in reasonable agreement with the Adjusted R^2 of 0.9439; i.e., the difference is less than 0.2. Adequacy of precision ratio of 25.692 indicates an adequate signal. The model can be used to navigate the design space and to make predictions about ash content for given levels of each factor.

Table 5. ANOVA for crude fibre formulated multigrain instant flakes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	18.86	8	2.36	237.59	< 0.0001	significant
Linear Mixture	0.6105	2	0.3053	30.77	< 0.0001	significant
x_{12}	0.6382	1	0.6382	64.33	< 0.0001	significant
x_{13}	4.85	1	4.85	488.77	< 0.0001	significant
x_2x_3	9.35	1	9.35	942.38	< 0.0001	significant
$x_1^2x_2x_3$	3.08	1	3.08	310.08	< 0.0001	significant
$x_1x_2^2x_3$	0.6349	1	0.6349	64.00	< 0.0001	significant
$x_1x_2x_3^2$	1.41	1	1.41	141.85	< 0.0001	significant
Residual	0.2083	21	0.0099			
Lack of Fit	0.2027	1	0.2027	715.35	< 0.0001	significant
Pure Error	0.0057	20	0.0003			
Cor Total	19.07	29				
Std. Dev.	0.0996	R^2	0.9891			
Mean	2.20	Adjusted R^2	0.9849			
C.V. %	4.53	Predicted R^2	0.9833	Adeq Precision	46.9623	

The crude fibre fitted model in terms of L_Pseudo Components is:

$$\left.\begin{aligned} y_{fc} &= 2.01x_1 + 3.11x_2 + 3.78x_3 - 12.3x_1x_2 - 6.23x_1x_3 \\ &- 8.65x_2x_3 + 201x_1^2x_2x_3 + 91.4x_1x_2^2x_3 - 86.1x_1x_2x_3^2 \end{aligned}\right\} \quad (4)$$

The results of the analysis showed that the crude fibre model of the formulated multigrain instant flakes is significant with F-value of 238 and p-value of 7.97E-19. The crude fibre is significantly influenced, at 5% level of significance, by the proportions of corn, millet, and soybean flours in the formulations (with linear mixture F- and p-values of 30.8 and 5.73E-07, respectively). The crude fibre is also significantly influenced, at 5% level of significance by the corn / millet flours interaction (with F-value of 64.3 and p-value of 7.91E-08); corn/soybean flours interaction (with F-value of 489 and p-value of 5.01E-16); millet/soybean flours interaction (with F-value of 942 and p-value of 6.22E-19); the second order of corn/millet/soybean flours interaction (with F-value of 310 and p-value of 4.71E-14); corn/the second order of millet/soybean flours interaction (with F-value of 64.0 and p-value of 8.24E-08); and corn/millet/the second order of soybean flours interaction (with F-value of 142 and p-value of 8.37E-11). The Lack of Fit F-and p-value of 715 and 3.95E-17 implies that the Lack of Fit is significant. The ash content model R^2 and the Adjusted R^2 are 0.9891 and 0.9849, respectively. The model Predicted R^2 of 0.9833 is in reasonable agreement with the Adjusted R^2 of 0.9849. Adequacy of precision ratio of 46.96 indicates an adequate signal. The model can be used to navigate the design space and to make predictions about crude fibre for given levels of each factor.

Table 6. ANOVA for crude protein formulated multigrain instant flakes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1166.87	8	145.86	89.39	< 0.0001	significant
Linear Mixture	353.11	2	176.55	108.20	< 0.0001	significant
x_{12}	2.77	1	2.77	1.70	0.2069	
x_{13}	179.48	1	179.48	109.99	< 0.0001	significant
x_2x_3	114.33	1	114.33	70.06	< 0.0001	significant
$x_1^2x_2x_3$	6.99	1	6.99	4.28	0.0510	
$x_1x_2^2x_3$	70.77	1	70.77	43.37	< 0.0001	significant
$x_1x_2x_3^2$	156.51	1	156.51	95.91	< 0.0001	significant
Residual	34.27	21	1.63			
Lack of Fit	34.25	1	34.25	34247.58	< 0.0001	significant
Pure Error	0.0200	20	0.0010			
Cor Total	1201.14	29	R²	0.9715		
Std. Dev.	1.28		Adjusted R²	0.9606		
Mean	33.83		Predicted R²	0.9569		
C.V. %	3.78		Adeq Precision	28.5849		

The crude protein fitted model in terms of L_Pseudo Components is:

$$\left.\begin{aligned} y_{pc} &= 34.9x_1 + 29.0x_2 + 42.2x_3 - 25.6x_1x_2 + 37.9x_1x_3 \\ &\quad - 30.2x_2x_3 - 303x_1^2x_2x_3 + 965x_1x_2^2x_3 - 908x_1x_2x_3^2 \end{aligned}\right\} \quad (5)$$

The results of the analysis showed that the crude protein model of the formulated multigrain instant flakes is significant with F-value of 89.4 and p-value of 1.80E-14. The crude protein is significantly influenced, at 5% level of significance, by the proportions of corn, millet, and soybean flours in the formulations (with linear mixture F- and p-values of 108 and 8.73E-12, respectively). The crude protein is also significantly influenced, at 5% level of significance by the corn/soybean flours interaction (with F-value of 110 and p-value of 8.37E-10); millet/soybean flours interaction (with F-value of 70.1 and p-value of 3.96E-08); corn/the second order of millet/soybean flours interaction (with F-value of 43.4 and p-value of 1.60E-06); and corn/millet/the second order of soybean flours interaction (with F-value of 95.9 and p-value of 2.79E-09). The Lack of Fit F-and p-value of 3.42E+04 and 8.08E-34 implies that the Lack of Fit is significant. The crude protein model R^2 and the Adjusted R^2 are 0.97147 and 0.9606, respectively. The model Predicted R^2 of 0.9569 is in reasonable agreement with the Adjusted R^2 of 0.9606; i.e., the difference is less than 0.2. Adequacy of precision ratio of 28.585 indicates an adequate signal. The model can be used to navigate the design space and to make predictions about crude protein for given levels of each factor.

The carbohydrate fitted model in terms of L_Pseudo Components is:

$$\left.\begin{aligned} y_{cho} &= 52.5x_1 + 55.9x_2 + 42.1x_3 + 34.3x_1x_2 - 55.3x_1x_3 \\ &\quad + 34.5x_2x_3 + 425x_1^2x_2x_3 - 1110x_1x_2^2x_3 + 1140x_1x_2x_3^2 \end{aligned}\right\} \quad (6)$$

The results of the analysis showed that the carbohydrate model of the formulated multigrain instant flakes is significant with F-value of 45.3and p-value of 1.59E-11. The carbohydrate is significantly influenced, at 5% level of significance, by the proportions of corn, millet, and soybean flours in the formulations (with linear mixture F- and p-values of 41.6 and

4.96E-08, respectively). The carbohydrate is also significantly influenced, at 5% level of significance by the corn / soybean flours interaction (with F-value of 76.7 and p-value of 1.88E-08); millet / soybean flours interaction (with F-value of 29.8 and p-value of 2.03E-05); corn / the second order of millet / soybean flours interaction (with F-value of 18.9 and p-value of 0.000284); and corn/millet/the second order of soybean flours interaction (with F-value of 49.5 and p-value of 6.03E-07). The Lack of Fit F-and p-value of 2.56E+03 and 1.39E-22 implies that the Lack of Fit is significant. The carbohydrate model R^2 and the Adjusted R^2 are 0.9452 and 0.9243, respectively. The Predicted R^2 of 0.9169 is in reasonable agreement with the Adjusted R^2 of 0.9243; i.e. the difference is less than 0.2. Adequacy of precision ratio of 20.838 indicates an adequate signal. The model can be used to navigate the design space and to make predictions about carbohydrates for given levels of each factor.

Table 7. ANOVA for carbohydrate formulated multigrain instant flakes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1808.35	8	226.04	45.26	< 0.0001	significant
Linear Mixture	415.51	2	207.76	41.60	< 0.0001	significant
x_{12}	4.96	1	4.96	0.9941	0.3301	
x_{13}	382.88	1	382.88	76.67	< 0.0001	significant
x_2x_3	148.99	1	148.99	29.83	< 0.0001	significant
$x_1^2x_2x_3$	13.74	1	13.74	2.75	0.1120	
$x_1x_2^2x_3$	94.36	1	94.36	18.89	0.0003	significant
$x_1x_2x_3^2$	247.35	1	247.35	49.53	< 0.0001	significant
Residual	104.88	21	4.99			
Lack of Fit	104.06	1	104.06	2558.97	< 0.0001	significant
Pure Error	0.8133	20	0.0407			
Cor Total	1913.23	29	R^2	0.9452		
Std. Dev.	2.23		Adjusted R^2	0.9243		
Mean	51.99		Predicted R^2	0.9169		
C.V. %	4.30		Adeq Precision	20.8382		

The energy value fitted model in terms of L_Pseudo Components is:

$$\left.\begin{aligned} y_{ev} = {} & 404x_1+415x_2+419x_3+41.6x_1x_2-17.4x_1x_3 \\ & +9.92x_2x_3-467x_1^2x_2x_3-1160x_1x_2^2x_3+1070x_1x_2x_3^2 \end{aligned}\right\} \qquad (7)$$

The results of the analysis showed that the energy value model of the formulated multigrain instant flakes is significant with F-value of 126 and p-value of 5.48E-16. The energy value is significantly influenced, at 5% level of significance, by the proportions of corn, millet, and soybean flours in the formulations (with linear mixture F- and p-values of 339 and 1.05E-16, respectively). The energy value is also significantly influenced, at 5% level of significance by the corn / millet flours interaction (with F-value of 5.67 and p-value of 0.0269); corn/soybean flours interaction (with F-value of 29.5 and p-value of 2.18E-05); millet/soybean flours interaction (with F-value of 9.57 and p-value of 0.0055); corn/millet/soybean flours interaction (with F-value of 12.9 and p-value of 0.00172); the second order of corn/millet/soybean flours interaction (with F-value of 80 and p-value of 1.32E-08); and corn/millet /the second order of soybean flours interaction (with F-value of 168 and p-value of 1.75E-11). The Lack of Fit F-and p-value of 42.3 and 2.44E-06 implies that the Lack of Fit is significant. The energy value model R^2 and the Adjusted R^2 are 0.9796 and 0.9718, respectively. The Predicted R^2 of 0.9644 is in reasonable agreement with the Adjusted R^2 of 0.9718; i.e., the difference is less than 0.2. Adequacy of precision ratio of 32.486 indicates an adequate signal. The model can be used to navigate the design space and to make predictions about energy value for given levels of each factor. The contour and 3-D plots for the formulated flake's proximate compositions and the energy value are summarized in Figs. 1-2. Table 9 presents the summary of the optimization constraints employed in the optimization module. The three desirability solutions that were found were summarized in Table 10.

Table 8. ANOVA for energy value formulated multigrain instant flakes

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	1295.31	8	161.91	125.98	< 0.0001	significant
Linear Mixture	870.71	2	435.35	338.73	< 0.0001	significant
x_{12}	7.28	1	7.28	5.67	0.0269	significant
x_{13}	37.90	1	37.90	29.49	< 0.0001	significant
x_2x_3	12.30	1	12.30	9.57	0.0055	significant
$x_1x_2x_3$	16.58	1	16.58	12.90	0.0017	significant
$x_1^2x_2x_3$	102.81	1	102.81	79.99	< 0.0001	significant
$x_1x_2x_3^2$	215.73	1	215.73	167.85	< 0.0001	significant
Residual	26.99	21	1.29			
Lack of Fit	18.32	1	18.32	42.29	< 0.0001	significant
Pure Error	8.67	20	0.4333			
Cor Total	1322.30	29	R²	0.9796		
Std. Dev.	1.13		Adjusted R²	0.9718		
Mean	412.30		Predicted R²	0.9644		
C.V. %	0.2750		Adeq Precision	32.4859		

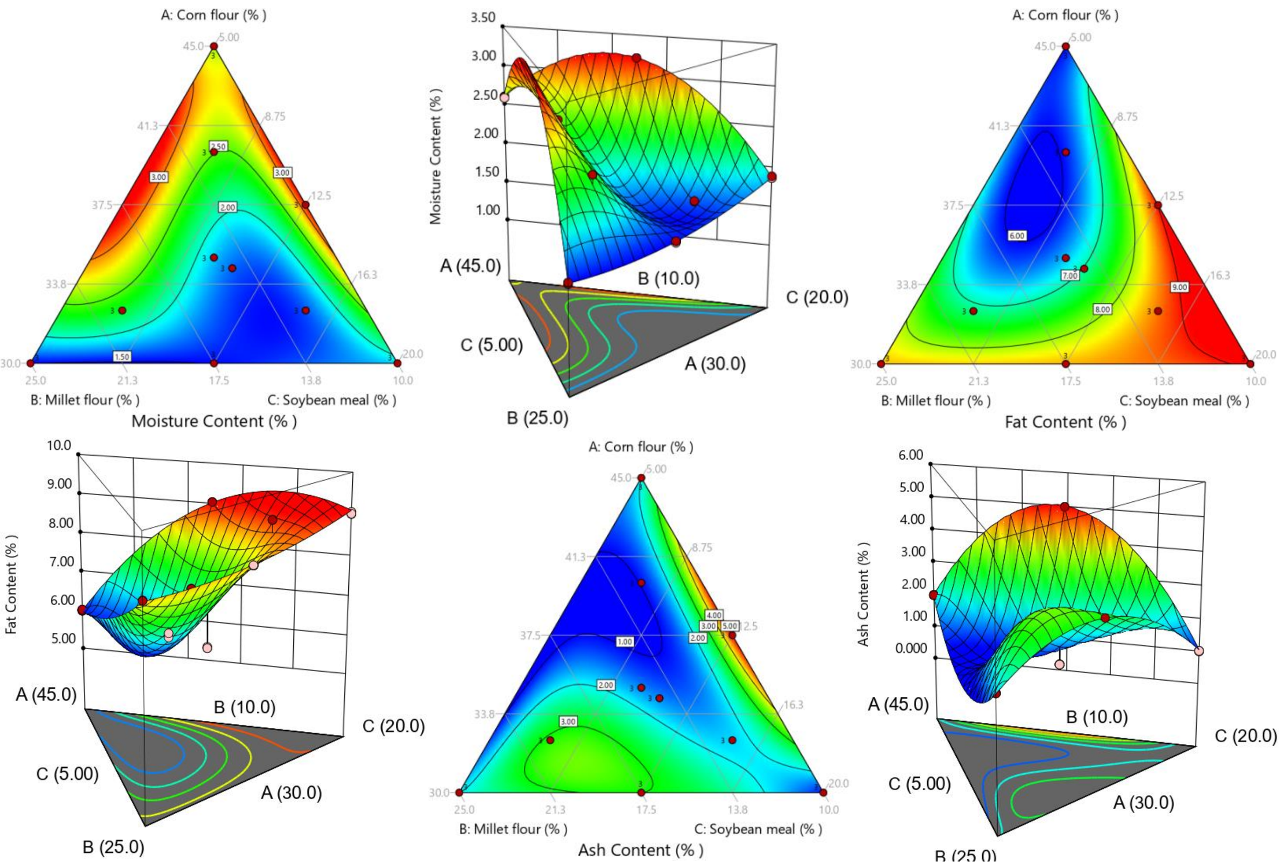


Figure 1. The contour and 3-D plots for the formulated flake's proximate compositions and the energy value

The numerical solution desirability contour and 3-D Surface graphs were presented in Figure 3. The numerical solution, presented in the form of optimal instant flakes bar graph and the graphical optimization overlay contour plot, showing the optimized formulation compositions with the respective quality parameters, were presented in Figure 4. The box in the overlay contour plot indicates the properties of the optimal instant flake and the component proportions to obtain it.

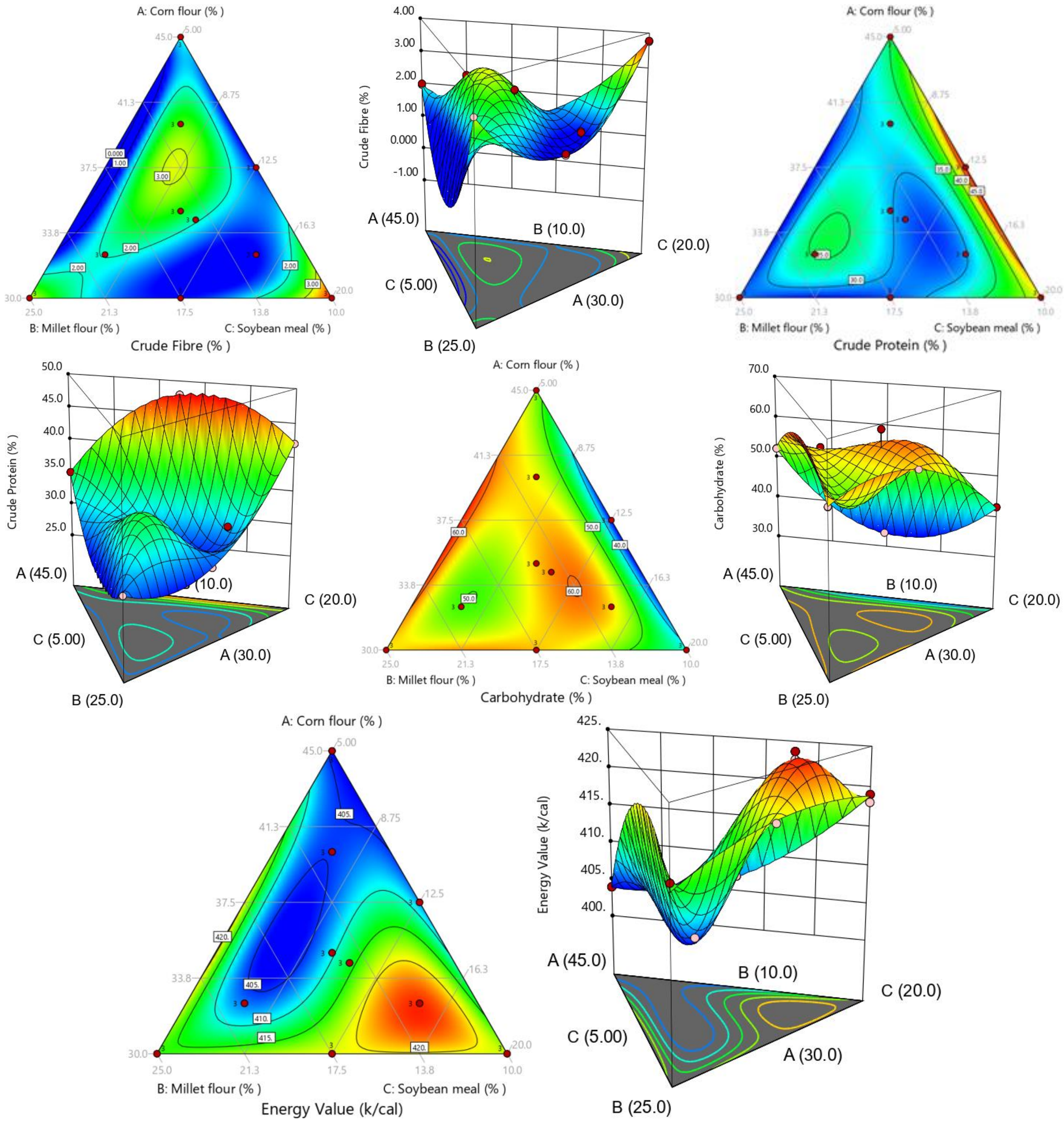


Figure 2. The contour and 3-D plots for the formulated flake's proximate compositions and the energy value

Table 9. Optimization constraints for instant flakes formulation

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Corn flour	is in range	30	45	1	1	3
Millet flour	is in range	10	25	5	1	3
Soybean meal	is target = 20	5	20	1	10	5
Moisture Content	is target = 2.5	1.5	3	1	10	3
Fat Content	is in range	6	9.05	10	10	3
Ash Content	is target = 3	1	5	1	1	3
Crude Fibre	is target = 2.5	1.25	3.78	1	1	5
Crude Protein	is target = 45	26.3	48	1	10	5
Carbohydrate	minimize	45	50	1	1	3
Energy Value	is target = 425	410	425	1	10	5

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Taste	is in range	5.1	7.1	5	1	3
Flavor	is in range	5.4	6.9	5	1	3
Sweetness	is in range	5.7	7	5	1	3
Colour	is in range	5.4	6.3	5	1	3
Texture	is in range	5.6	6.5	5	1	3
Overall acceptability	is in range	5.4	7.3	5	1	5

Table 10. Desirability solutions found for the optimal formulations

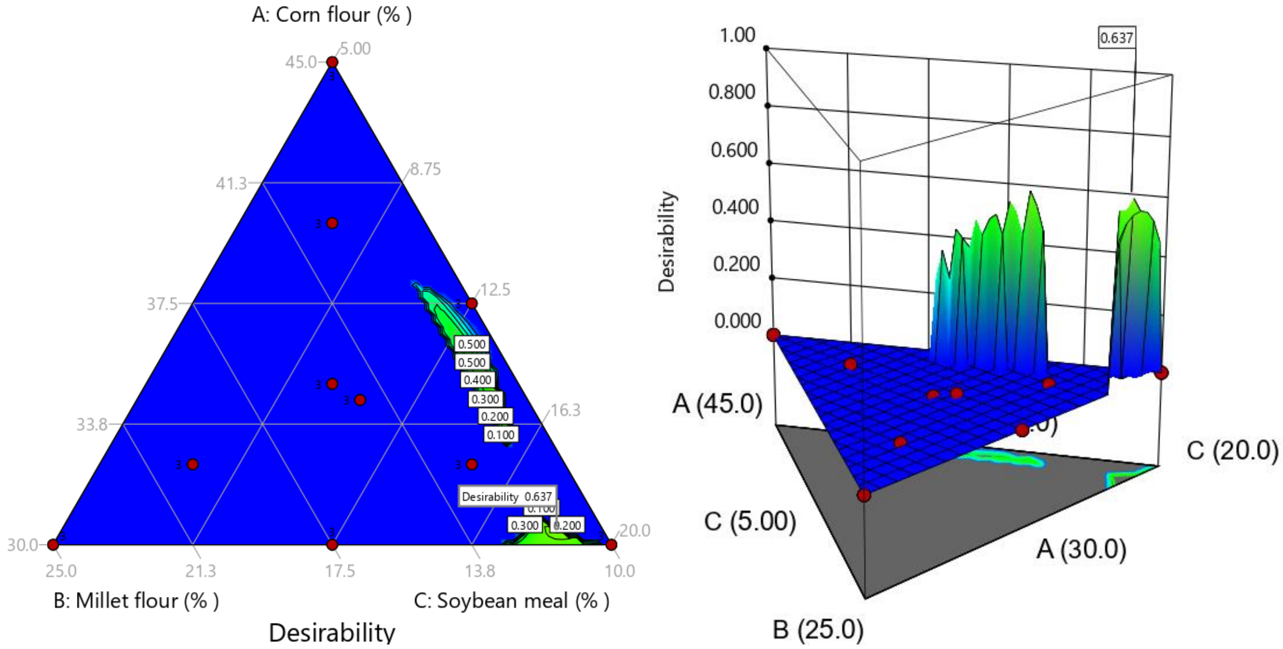
No	x_1	x_2	x_3	y_{mc}	y_{fat}	y_{ac}	y_{fc}	y_{pc}	y_{cho}	y_{ev}	y_t	y_f	y_s	y_c	y_{tx}	y_o	D_i	
1	**30.54**	**11.20**	**18.26**	**1.83**	**9.05**	**1.737**	**2.658**	**37.953**	**46.716**	**420.34**	**6.03**	**6.37**	**6.35**	**5.97**	**5.98**	**6.28**	**0.637**	**Selected**
2	34.32	10.75	14.93	2.37	9.05	3.000	1.637	39.196	44.646	416.81	5.61	6.37	6.35	5.97	5.98	6.28	0.614	
3	30.00	11.56	18.44	1.77	8.92	1.695	2.902	37.966	46.725	419.31	6.13	6.37	6.35	5.91	5.98	6.28	0.584	

$y_{mc} = Moisture\ Content\ (\%),\ y_{pc} = Protein\ Content\ (\%),\ y_{fat} = Fat\ Content\ (\%)$

$y_{ac} = Ash\ Content\ (\%),\ y_{cho} = Carbohydrate\ (\%),\ y_{ev} = Energy\ value,\ \ y_{cl} = Colour$

$y_{fc} = Fibre\ Content\ (\%),\ y_{flav} = Flavour,\ y_{sw} = Sweetness,\ y_{ta} = Taste,\ y_{tx} = Texture$

$y_{oa} = Overall\ Acceptability,\ D_i = Overall\ Desirability\ Index$



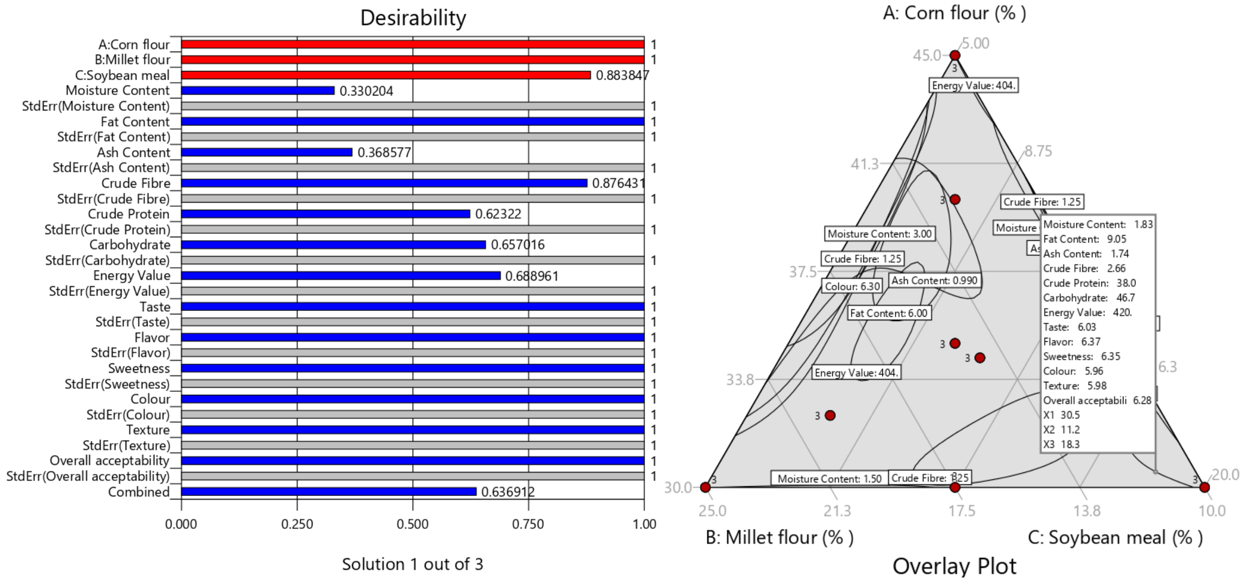
Figures 3. The numerical solution desirability contour plot and 3-D Surface

The result of the flakes optimization gave optimized multigrain instant flakes with overall desirability index of 0.637, based on the set optimization goals and individual quality desirability indices. Formulating instant flake with 30.5 % corn flour, 11.2 % millet flour, 18.3 % soybean meal yielded an improved instant flake with the following optimal quality properties:1.83 % moisture content, 9.05 % fat content, 1.74 % ash content, 2.66 % crude fibre, 38.0 % crude protein, 46.7 % carbohydrate, 420 kcal energy value and 6.28 overall acceptability. This result of the study showed that the formulated multigrain instant flake was found to be of high quality.

4. Conclusion

It can be concluded that the nutritional qualities of instant flake can be improved through food ingredients composite formulations. The formulated instant flake from blends of corn flour, millet flour, and soybean meal has high nutritional, and sensory qualities suitable for improving and solving the problems of malnutrition, especially in the African continent.

This research has shown that locally available food ingredients can be blended to produce flakes with high nutritional value. However, this study encouraged that further study is carried out on the formulation of instant flakes using other blends. There is need to improve the nutritional quality by substituting other nutritionally rich grains and legumes. Soy beans, groundnut, sesame seed, melon seed etc.; are rich sources of protein, essential amino and fatty acids, minerals and vitamins. Enrichment of flakes with these protein-rich plant foods will result in flakes with improved nutrient quality that meets the consumer's dietary needs and of acceptable sensory properties.



Figures 4. The optimal instant flakes bar graph and the graphical optimization overlay contour plot

Declaration of interest

The authors declare no conflicts of interest. The authors alone are responsible for the content and writing of the manuscript.

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