Chapter

Development and Optimization of Flakes from Some Selected Locally Available Food Materials

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Abstract

Flakes are one of the most popular ready-to-eat breakfast cereals meals. Most traditional instant breakfast meals are from mono-cereals. This work aims to develop, characterize and optimize value-added instant cereal breakfast flakes using flours of rice, sorghum, and soybean. A three-component constrained optimal (custom) mixture experimental design was employed for the formulation. The formulation design constraints were: rice flour (30%–35%), sorghum flour (20%–25%), and soybean flour (5%–10%). Other ingredients were water (19%), sugar (8%), malt (2%), egg (3%), sweet potato (3%), ginger (2%) and moringa seed powder (3%). The formulated samples were analysed and evaluated based on standard procedures for quality characteristics. Numerical optimization gave the optimal product's overall desirability index of 0.519 obtained from 31.9 % rice flour, 22% sorghum flour, and 6.05% soybean flour; with quality properties as follows: 3.67% moisture content, 3.18% fat content, 3.08% ash content, 1.44% crude fibre, 30.0% crude protein, 58.6% nitrogen-free extract, 384 kcal energy value, and 7.28 overall acceptability. The result of the study showed that the nutritional qualities of cereal flakes can be improved through food-to-food composite formulations, employing numerical optimization technique.

Keywords: instant flakes, multigrain, breakfast cereals, optimization, development

1. Introduction

The food manufacturing process is the transformation of raw ingredients into edible end products for human consumption. It has been a popular method of producing convenient and accessible food since ancient times. Knowing the formulation and processing profile of a food or beverage and how it quantitatively relates to consumer perceptions opens up a world of development, quality, and marketing opportunities for a food manufacturer. Methodical exploration of product features, known commonly as "response surface methodology" (RSM) is vital to manufacturing of quality products.

Cereals are the basis of many staple foods and have been used in flaking for over a century. They provide over half of the dietary energy globally and are a major source of carbohydrates in the diet. Most traditional instant breakfast meals are produced from mono-cereals and these mono-cereals consist of carbohydrate as its major constituent. The nutritional and energy level gotten from the consumption of these mono-cereals is minimal. Besides, the production involves many processes and during these processes, nutrient losses occur therefore reducing its nutritional content. Major constituents of breakfast cereals are whole or broken cereal kernels (flaked, cracked) or ground (flours or meals). Importantly, new technology, like extrusion, enabled higher production rates and lowered manufacturing costs, but ended up having an impact on where cereals are today [1, 2].

Flakes are convenient and relatively shelf stable breakfast cereals, primarily produced from corn, wheat, rice, and/or oats, and processed with added flavor and fortified with vitamins and minerals. Flaking process is a relatively simple process of cooking fragments of cereal grains (or in some cases whole grains) with water, flattening the particles between large steel rollers and toasting the resultant flake at high temperature. In flaking the starch in gelatinized and probably slightly hydrolyzed. The particle then undergoes dextrinization and caramelization.

There are other grains that can be used but are presently unexploited. Soybean contains about 40% protein; it is higher than other legumes in protein. Sorghum is rich in carbohydrates and fiber. Moringa greens (leaves) are an excellent source of protein. Dry, powdered leaves indeed are a much-concentrated source of many quality amino acids. Sweet potatoes contain a wealth of orange-hued carotenoid pigments, it has been shown to be a better source of bioavailable beta-carotene than green leafy vegetables, has a high amount of Vitamin A, Vitamin B5, Vitamin B6, Thiamin and Riboflavin. Corn flakes, wheat flakes, and rice flakes are typical examples of flaked cereals. Extruded flakes differ from those made by the traditional process in that the grit for flaking is formed by extruding mixed flour ingredients through a die hole and cutting off pellets of the dough in the desired size [1, 2].

Ready-to-eat breakfast cereals are increasingly gaining acceptance in most developing countries due to their convenience, ease of preparation, and nutritional values. There is an increasing demand for convenient foods and variety as well as nutritional quality and affordability. Nutritional properties and health relevance are a key driving force in flakes manufacturing, the nutritional quality depends both on their composition and structure. The market is further driven by changing food habits, consumers want more transparency on food sourcing, and are increasingly looking for more convenience and healthier options that are instant, high in fiber or protein, low in carbohydrates, and free of artificial colors and flavors. Governments globally are also tightening regulations on nutrition. The flaked cereals business needs to meet consumer expectations in terms of nutrition, health, and taste. Population growth continues and the rate of consumption of instant breakfast is on the increase. New ways will need to be discovered to sustainably grow more breakfast cereals that promotes health, convenient, and meet consumer's nutritional needs [2].

The traditional method used to prepare flaked cereals involves direct cooking of intact grain kernels or parts of kernels with water and flavor in a steam cooker. The basic raw material for the traditionally cooked corn flake comes from the dry milling of regular field corn. The second method involves cooking of finer materials, such as grain flour, in an extruder where mechanical energy is applied for the formation of the grits for flaking [3–7]. There is a current trend of using non-traditional grains, novel ingredients for production of flakes; scientific research into the use of multigrain and fiber is on the increase [8–12]. Unfortunately, practical application in these areas remains proprietary information to each food manufacturer.

Due to changes in lifestyle and urbanization, the consumption of instant flaked cereals has increased in Nigeria. There is the need to formulate value added flakes so as to eliminate the issue of nutrient imbalance in flakes. Formulation of flakes from different grains is one of the ways to improve flasks quality. Hundreds of people have worked on the development of new cereals and the improvement of older ones. There have been new types of raw materials for cereal making introduced over the years [2]. In this study, nutritionally improved, value-added instant flakes were developed, characterized and optimized, via constrained optimal (custom) mixture experimental design, from blends of rice, sorghum, soybean, sweet potato, moringa seed powder and ginger.

2. Materials and methods

2.1 Materials

The major components used for the formulation of the flakes were rice, sorghum and soybean which comprises 60% of the mixture. The other ingredients were water, sugar, malt, egg, sweet potato, ginger and moringa seed powder. All these materials were purchased from Kure Market, Minna, Nigeria.

2.1.1 Processing of the rice, sorghum, and soya beans into flours

Properly clean rice and sorghum grains were milled until fine flour is achieved using a bore mill. Cleaned, sorted soybeans grains 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.

2.2 Methods

2.2.1 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: rice flour ($30\% \le x_1 \le 35\%$), sorghum flour ($20\% \le x_1 \le 25\%$), and soybean flour ($5\% \le x_1 \le 10\%$). These major components comprise 60% of the total mixture and other ingredients were water (19%), sugar (8%), malt (2%), egg (3%), sweet potato (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 30 samples and mixed together thoroughly, to obtained homogeneous mixture. The samples were then subjected to an electrical steam pressure cooking at temperature of 80°C for 1 hours 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 electrical oven drying at temperature of 66°C for 1 hours. On removal from the toasting machine, the flakes were allowed to cool down and later packaged in different clean transparent, plastic packaging containers.

	x_1	x_2	x_3	y_{mc}	y_{fat}	y_{ac}	y_{fc}	y_{pc}	y_{nfe}	y_{ev}	y_t	y_f	y_s	y_c	y_{tx}	y_o
Run	%	%	%	%	%	%	%	%	%	k/cal						
1	33.4	20.8	5.8	3.20	3.50	2.50	1.25	29.1	60.5	381	6.8	7.0	7.1	7.4	7.0	7.1
2	33.4	20.8	5.8	3.22	3.51	2.50	1.23	29.0	60.5	381	7.2	7.2	7.3	7.5	7.1	7.3
3	33.4	20.8	5.8	3.20	3.51	2.51	1.25	29.0	60.5	381	7.4	7.3	7.5	7.6	7.5	7.5
4	32.5	20.0	7.5	4.00	2.00	1.50	1.88	30.4	60.2	376	7.8	7.3	7.4	7.2	7.6	7.5
5	32.5	20.0	7.5	4.01	2.02	1.51	1.89	30.5	60.1	376	6.5	6.9	7.0	7.2	6.9	6.9
6	32.5	20.0	7.5	4.00	2.01	1.50	1.87	30.4	60.2	376	7.2	7.1	7.1	7.3	7.1	7.2
7	30.0	25.0	5.0	2.20	3.50	2.50	1.25	29.2	61.3	385	8.0	7.4	7.2	7.5	7.7	7.6
8	30.0	25.0	5.0	2.20	3.51	2.52	1.25	29.2	61.3	385	7.1	7.0	7.3	7.8	7.6	7.4
9	30.0	25.0	5.0	2.21	3.50	2.51	1.26	29.2	61.3	385	6.8	7.1	7.4	7.5	7.1	7.2
10	30.0	22.5	7.5	2.40	4.00	3.00	1.88	28.0	60.7	382	7.0	7.1	7.2	7.6	7.3	7.2
11	30.0	22.5	7.5	2.40	4.01	3.01	1.89	28.0	60.7	382	6.8	7.0	7.1	7.4	7.0	7.1
12	30.0	22.5	7.5	2.42	4.00	3.03	1.88	28.0	60.6	382	7.2	7.2	7.3	7.5	7.1	7.1
13	35.0	20.0	5.0	5.00	3.50	3.50	1.88	28.9	57.2	376	7.4	7.3	7.5	7.6	7.5	7.5
14	35.0	20.0	5.0	5.02	3.50	3.51	1.87	28.9	57.2	376	7.8	7.3	7.4	7.2	7.6	7.5
15	35.0	20.0	5.0	5.01	3.51	3.50	1.88	28.9	57.2	376	6.5	6.9	7.0	7.2	6.9	6.9
16	32.5	22.5	5.0	3.40	3.50	2.50	1.88	26.3	62.5	377	7.2	7.1	7.1	7.3	7.1	7.2
17	32.5	22.5	5.0	3.42	3.51	2.50	1.88	26.2	62.5	377	8.0	7.4	7.2	7.5	7.7	7.6
18	32.5	22.5	5.0	3.41	3.50	2.52	1.87	26.3	62.5	377	7.1	7.0	7.3	7.8	7.6	7.4
19	30.8	20.8	8.4	2.60	4.00	4.00	1.25	17.5	70.7	389	6.8	7.1	7.4	7.5	7.1	7.2
20	30.8	20.8	8.4	2.61	4.00	4.02	1.24	17.5	70.6	389	7.0	7.1	7.2	7.6	7.3	7.2
21	30.8	20.8	8.4	2.60	4.01	4.01	1.25	17.5	70.6	389	6.8	7.0	7.1	7.4	7.0	7.1
22	30.8	23.4	5.8	2.80	3.50	4.00	1.25	26.3	62.2	390	7.2	7.2	7.3	7.5	7.1	7.3
23	30.8	23.4	5.8	2.80	3.53	4.00	1.24	26.3	62.2	390	7.4	7.3	7.5	7.6	7.5	7.5
24	30.8	23.4	5.8	2.82	3.51	4.03	1.25	26.2	62.1	390	7.8	7.3	7.4	7.2	7.6	7.5
25	31.7	21.7	6.6	4.20	3.00	3.00	1.88	29.2	58.7	379	6.5	6.9	7.0	7.2	6.9	6.9
26	31.7	21.7	6.6	4.23	3.01	3.02	1.87	29.2	58.6	379	7.2	7.1	7.1	7.3	7.1	7.2
27	31.7	21.7	6.6	4.22	3.00	3.01	1.88	29.2	58.6	379	8.0	7.4	7.2	7.5	7.7	7.6
28	30.0	20.0	10.0	3.80	2.00	3.00	1.25	328.9	61.1	387	7.1	7.0	7.3	7.8	7.6	7.4
29	30.0	20.0	10.0	3.82	2.01	3.00	1.24	28.9	61.1	387	6.8	7.1	7.4	7.5	7.1	7.2
30	30.0	20.0	10.0	3.81	2.01	3.01	1.25	28.9	61.1	387	7.0	7.1	7.2	7.6	7.3	7.2

x_1 = *Rice flour* (%), x_2 = *Sorghum flour* (%), x_3 = *Soybean flour* (%)
y_{mc} = *Moisture Content* (%); y_{pc} = *Protein Content* (%); y_{fat} = *Fat Content* (%), y_{ac} = *Ash Content* (%)
y_{nfe} = *Nitrogen Free Extract* (%); 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*

Table 1.
The design matrix, proximate compositions and the sensory evaluation average scores of the formulated flakes.

2.2.2 Proximate analysis and sensory evaluations

The quality characteristic of the flakes which were determined using the method described by the Association of Analytical Chemist [13] include moisture content, ash content, fat content, crude fiber, crude protein, nitrogen free extract, and energy value. Sensory evaluations of the formulated flakes were also conducted using 30 trained panelists. A 9-point hedonic scale ranging from 9 = like extremely and 1 = dislike extremely was used to evaluate the samples for taste, flavor, sweetness, color, texture and overall acceptability. Table water was used for mouth rinsing intermittently to minimize the carry over effects.

3. Experimental results

The proximate composition of the formulated flakes from rice, sorghum, and soy beans were presented in **Table 1**.

The photos of some of the formulated instant cereal breakfast flakes are presented in **Figure 1**.

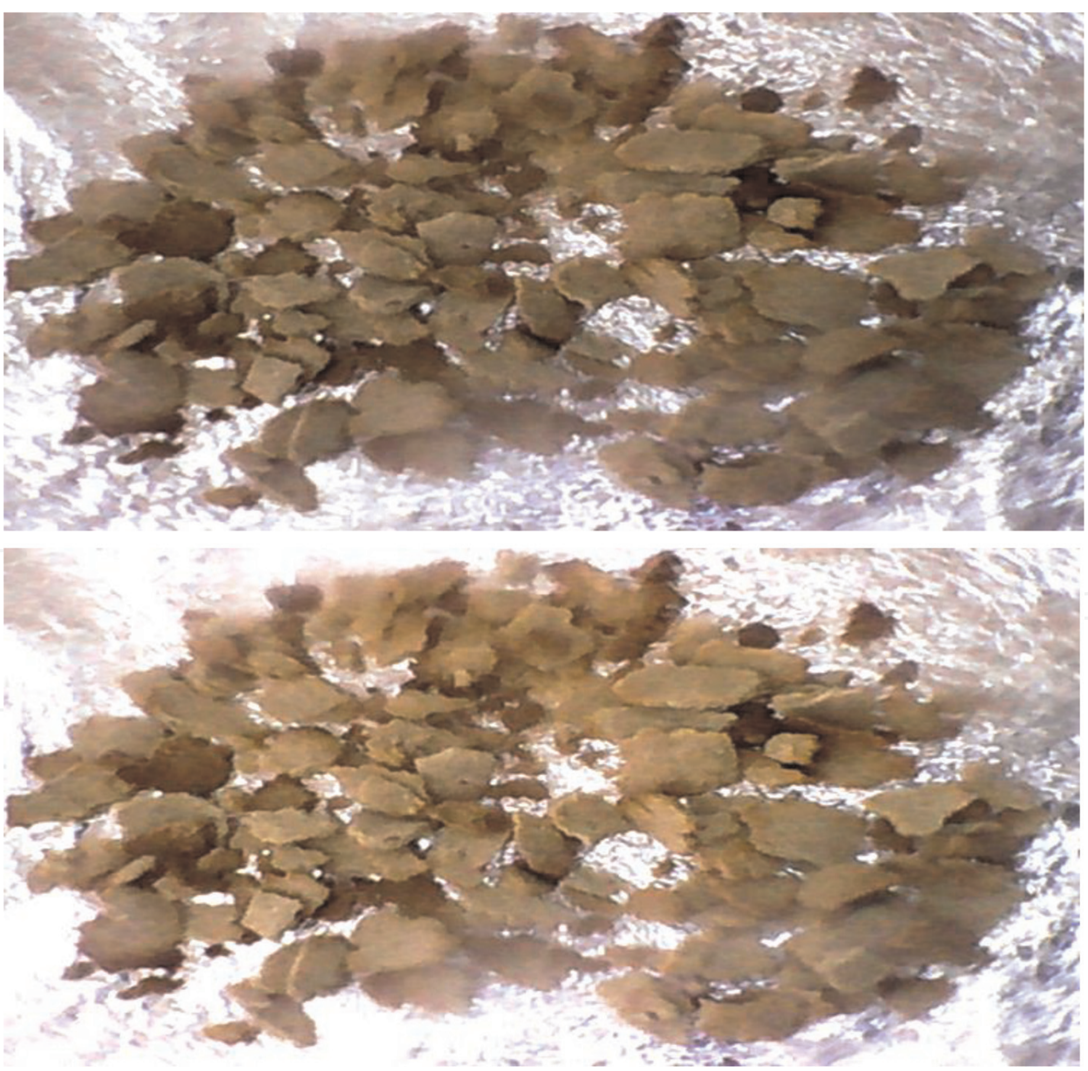


Figure 1.
Figure of formulated flakes.

3.1 Statistical analysis of experimental results

The experimental data 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 tested using analysis of variance (ANOVA) for each response, and the adequacy of the models were evaluated by coefficient of determination, F-value, and model p-values at the 5% level of significance. The models were also subjected to lack-of-fit and adequacy tests. The fitted models for each of the response was used to generate 3-D response surface as well as the contour plots using the DESIGN EXPERT 13.0 statistical software.

3.2 Generating the optimal formulation

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). Desirability index range from zero to one for any given response and individual desirability for all the responses, in the case of multi-response optimization, are combined into a single number known as 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 the set desirable limits. Under this approach, each *ith* response is assigned a desirability function, d_i, where the value of $d_i$varies between 0 and 1. The function, is defined differently based on the objective of the response.

If the response is to be maximized, then d_i is defined by equation1. If the response is to be minimized, as in the case when the response is cost, is then d_i is defined by Eq. 2. There may be times when the experimenter wants the response to be neither maximized nor minimized, but instead stay as close to a specified target as possible. In such cases, the desirability function is defined by Eq. 3. Once a desirability function is defined for each of the responses, assuming that there are m responses, an overall desirability function is obtained by Eq. 4. The objective is to now find the settings that return the maximum value of D. The rationale for using a geometric rather than an arithmetic mean is that if any individual desirability di is equal to zero, then the overall desirability will also be equal to zero.

$$d_i = \left\{ \begin{array}{cc} 0 & y_i < L \\ \left(\frac{y_i - L}{T - L}\right)^w & L \le y_i \le T \\ 1 & y_i > T \end{array} \right\} \tag{1}$$

where T represents the target value of the *ith* response, y_i, L, represents the acceptable lower limit value for this response and w represents the weight. When $w = 1$ the function is linear. If $w > 1$ then more importance is placed on achieving the target for the response, y_i. When $w < 1$, less weight is assigned to achieving the target for the response, y_i.

$$d_i = \left\{ \begin{array}{cc} 1 & y_i < T \\ \left(\frac{U - y_i}{U - T}\right)^w & T \le y_i \le U \\ 0 & y_i > U \end{array} \right\} \tag{2}$$

where U represents the acceptable upper limit for the response.

$$d_i = \begin{Bmatrix} 0 & y_i < L \\ \left(\frac{y_i - L}{T - L}\right)^{w_1} & L \le y_i \le T \\ \left(\frac{U - y_i}{U - T}\right)^{w_2} & T \le y_i \le U \\ 0 & y_i > U \end{Bmatrix} \tag{3}$$

$$D = \left(d_1^{r_1}.d_2^{r_2}.d_3^{r_3} \dots \dots \dots d_m^{r_m}\right)^{1/(r_1 + r_2 + r_3 + \dots \dots \dots + r_m)} \tag{4}$$

where the r_i's represent the importance of each response. The greater the value of r_i, the more important the response with respect to the other responses.

Numerical optimization solutions are given as a list, in their order of desirability, detailing the components proportions and process variables values that satisfies the set criteria and the overall desirability. The numerical solution can be presented in the form of desirability contour and 3-D Surface plots, optimal bar graph and graphical optimization overlay contour plot; showing the optimized formulation compositions and/or regions that meet specifications [14–17].

4. Results of statistical analysis of experimental data and discussion

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**.

Source	Sum of Mean Squares	df	Square	F-value	p-value	
Model	17.5	8	2.19	11.1	5.22E-06	significant
Linear Mixture	14.4	2	7.22	36.6	1.45E-07	significant
x_1x_2	0.148	1	0.148	0.749	0.397	
x_1x_3	0.487	1	0.487	2.47	0.131	
x_2x_3	0.943	1	0.943	4.78	0.0403	significant
$x_1^2x_2x_3$	0.240	1	0.240	1.22	0.283	
$x_1x_2^2x_3$	2.25	1	2.25	11.4	0.00287	significant
$x_1x_2x_3^2$	0.0835	1	0.0835	0.423	0.523	
Residual	4.15	21	0.197			
Lack of Fit	4.14	4	1.04	9.87E+03	2.31E-28	significant
Pure Error	0.00178	17	0.000105			
Cor Total	21.7	29				
Std. Dev.	0.4443	R^2		0.8087		
Mean	3.3677	Adjusted	R^2	0.7359		
C.V. %	13.19295	Predicted	R^2	0.6566	Adeq Precision	11.5341

Table 2.
ANOVA for moisture content of multigrain flakes.

	Sum of Mean Source	Squares	df	Square	F-value	p-value
Model	13.3	8	1.66	14.2	7.02E-07	significant
Linear Mixture	0.359	2	0.179	1.53	0.240	
x_{12}	0.392	1	0.392	3.35	0.0815	
x_{13}	5.69	1	5.69	48.6	6.98E-07	significant
x_2x_3	0.209	1	0.209	1.78	0.196	
$x_1^2x_2x_3$	1.28	1	1.28	10.9	0.00339	significant
$x_1x_2^2x_3$	1.68	1	1.68	14.3	0.00108	significant
$x_1x_2x_3^2$	2.66	1	2.66	22.7	0.000105	significant
Residual	2.46	21	0.117			
Lack of Fit	2.46	4	0.615	4.90E+03	8.93E-26	significant
Pure Error	0.00213	17	0.000125			
Cor Total	15.7	29				
Std. Dev.	0.3423	R^2	0.8437			
Mean	2.9573	Adjusted R^2	0.7841			
C.V. %	11.5740	Predicted R^2	0.7193	Adeq Precision	10.7149	

Table 3.
ANOVA for fat content of multigrain flakes.

Source	Sum of Mean Squares	df	Square	F-value	p-value	
Model	12.1	8	1.51	18.3	7.84E-08	significant
Linear Mixture	3.99	2	1.99	24.1	3.67E-06	
x_{12}	0.00472	1	0.00472	0.0570	0.814	
x_{13}	0.954	1	0.954	11.5	0.00273	significant
x_2x_3	3.41	1	3.41	41.2	2.30E-06	significant
$x_1^2x_2x_3$	0.00182	1	0.00182	0.0220	0.883	
$x_1x_2^2x_3$	1.58	1	1.58	19.1	0.000269	significant
$x_1x_2x_3^2$	2.22	1	2.22	26.8	3.94E-05	significant
Residual	1.74	21	0.0827			
Lack of Fit	1.74	4	0.434	6.61E+03	7.01E-27	significant
Pure Error	0.00112	17	6.57E-05			
Cor Total	13.8	29				
Std. Dev.	0.2876	R^2	0.8743			
Mean	3.2557	Adjusted R^2	0.8264			
C.V. %	8.8350	Predicted R^2	0.7743	Adeq Precision	13.0502	

Table 4.
ANOVA for ash content of multigrain flakes.

	Sum of Mean					
Source	Squares	df	Square	F-value	p-value	
Model	1.47	8	0.183	2.53	0.0422	significant
Linear Mixture	0.515	2	0.258	3.55	0.0469	significant
x_{12}	0.142	1	0.142	1.96	0.176	
x_{13}	0.142	1	0.142	1.96	0.176	
x_2x_3	0.679	1	0.679	9.36	0.00596	significant
$x_1^2x_2x_3$	0.214	1	0.214	2.95	0.101	
$x_1x_2^2x_3$	0.00529	1	0.00529	0.0730	0.790	
$x_1x_2x_3^2$	0.0108	1	0.0108	0.148	0.704	
Residual	1.52	21	0.0725			
Lack of Fit	1.52	4	0.381	9.03E+03	4.95E-28	significant
Pure Error	0.000717	17	4.22E-05			
Cor Total	2.99	29				
Std. Dev.	0.2693	R^2	0.4908			
Mean	1.563	Adjusted R^2	0.29675			
C.V. %	17.2298	Predicted R^2	0.0855	Adeq Precision	4.2265	

Table 5.
ANOVA for crude fiber of multigrain flakes.

Source	**Sum of Mean Squares**	**df**	**Square**	**F-value**	**p-value**	
Model	276	8	34.5	7.56	9.49E-05	significant
Linear Mixture	24.1	2	12.1	2.65	0.0943	
x_{12}	19.8	1	19.8	4.35	0.0494	significant
x_{13}	2.52	1	2.52	0.553	0.465	
x_2x_3	4.28	1	4.28	0.939	0.344	
$x_1^2x_2x_3$	63.3	1	63.3	13.9	0.00125	significant
$x_1x_2^2x_3$	17.9	1	17.9	3.92	0.0610	
$x_1x_2x_3^2$	204	1	204	44.8	1.28E-06	significant
Residual	95.7		21	4.56		
Lack of Fit	95.7	4	23.9	2.03E+04	5.00E-31	significant
Pure Error 0.0200	17		0.00118			
Cor Total	371		29			
Std. Dev.	2.1346		R^2	0.7423		
Mean	27.37		Adjusted R^2	0.6442		
C.V. %	7.7989		Predicted R^2	0.5375	Adeq Precision	9.9719

Table 6.
ANOVA for crude protein of multigrain flakes.

Source	Sum of Mean Squares	df	Square	F-value	p-value	
Model	241	8	30.2	6.07	0.000426	significant
Linear Mixture	66.7	2	33.4	6.71	0.00558	significant
x_{12}	26.4	1	26.4	5.31	0.0316	significant
x_{13}	4.21	1	4.21	0.847	0.368	
x_2x_3	0.0221	1	0.0221	0.00445	0.947	
$x_1^2x_2x_3$	34.6	1	34.6	6.96	0.0154	significant
$x_1x_2^2x_3$	32.3	1	32.3	6.50	0.0187	significant
$x_1x_2x_3^2$	133	1	133	26.7	4.04E-05	significant
Residual	104	21	4.97			
Lack of Fit	104	4	26.1	1.40E+04	1.19E-29	significant
Pure Error	0.0317	17	0.00186			
Cor Total	346	29				
Std. Dev.	2.2294	R^2	0.6981			
Mean	61.4867	Adjusted R^2	0.5831			
C.V. %	3.6259	Predicted R^2	0.4580	Adeq Precision	8.6721	

Table 7.
ANOVA for nitrogen free extract of multigrain flakes.

Source	Sum of Mean Squares	df	Square	F-value	p-value	
Model	488	6	81.3	6.85	0.000288	significant
Linear Mixture	387	2	194	16.3	3.86E-05	significant
x_{12}	18.1	1	18.1	1.52	0.230	
x_{13}	51.9	1	51.9	4.37	0.0478	significant
x_2x_3	18.6	1	18.6	1.57	0.223	
$x_1x_2x_3$	85.6	1	85.6	7.22	0.0132	significant
Residual	273	23	11.9			
Lack of Fit	273	6	45.5			
Pure Error	0.000	17	0.000			
Cor Total	761	29				
Std. Dev.	3.4447	R^2	0.6413			
Mean	382.2	Adjusted R^2	0.5477			
C.V. %	0.9013	Predicted R^2	0.4912	Adeq Precision	7.0182	

Table 8.
ANOVA for Energy Value of multigrain flakes.

The moisture content fitted model in terms of L_Pseudo Components is presented in Eq. (5):

$$\left.\begin{aligned} y_{mc} = {} & 4.92x_1 + 2.11x_2 + 3.73x_3 - 1.09x_1x_2 - 1.97x_1x_3 \\ & -2.74x_2x_3 - 29.2x_1^2x_2x_3 + 89.3x_1x_2^2x_3 - 17.2x_1x_2x_3^2 \end{aligned}\right\} \tag{5}$$

The results of the analysis showed that the moisture content model of the formulated instant flakes is significant with F-value of 11.1 and p-value of 5.22E-06. The moisture content is significantly influenced, at 5% level of significance, by the proportions of rice, sorghum, and soybean flours in the formulations (with linear mixture F- and p-values of 36.6 and 1.45E-07, respectively). The moisture content is also significantly influenced, at 5% level of significance by the sorghum/soybean flours interaction (with F-value of 4.78 and p-value of 0.0403); and rice/the second order of sorghum/soybean flours interaction (with F-value of 11.4 and p-value of 0.00287). The Lack of Fit F-and p-value of 9.87E+03 and 2.31E-28 implies that the Lack of Fit is significant. The moisture content model R^2 and the Adjusted R^2 are 0.8087 and 0.7359, respectively. The predicted R^2 of 0.6566 is in reasonable agreement with the adjusted R^2 of 0.7359; i.e. the difference is less than 0.2. Adequacy of precision ratio of 11.534 indicates an adequate signal. This model can be used to navigate the design space and can be used to make predictions about moisture content for given levels of each factor.

The fat content fitted model in terms of L_Pseudo Components is presented in Eq. (6):

$$\left.\begin{aligned} y_{fat} = {} & 3.57x_1 + 2.58x_2 + 3.06x_3 - 1.77x_1x_2 - 6.73x_1x_3 \\ & +1.29x_2x_3 - 67.4x_1^2x_2x_3 + 77.2x_1x_2^2x_3 + 97.0x_1x_2x_3^2 \end{aligned}\right\} \tag{6}$$

The results of the analysis showed that the fat content model of the formulated instant flakes is significant with F-value of 14.2 and p-value of 7.02E-07. The fat content is not significantly influenced, at 5% level of significance, by the proportions of rice, sorghum, and soybean flours in the formulations (with linear mixture F- and p-values of 1.53 and 0.240, respectively). The fat content is significantly influenced, at 5% level of significance by the rice/soybean flours interaction (with F- value of 48.6 and p-value of 6.98E-07); the second order of rice/sorghum/soybean flours interaction (with F-value of 10.9 and p-value of 0.00339); rice/the second order of sorghum/soybean flours interaction (with F-value of 14.3 and p-value of 0.00108), and rice/sorghum/the second order of soybean flours interaction (with F-value of 22.7 and p-value of 0.000105). The Lack of Fit F-and p-value of 4.90E+03 and 8.93E-26 implies that the Lack of Fit is significant. The fat content model R^2 and the Adjusted R^2 are 0.8437 and 0.7841, respectively. The predicted R^2 of 0.7193 is in reasonable agreement with the adjusted R^2 of 0.7841; i.e. the difference is less than 0.2. Adequacy of precision ratio of 10.715 indicates an adequate signal. This model can be used to navigate the design space and can be used to make predictions about the fat content for given levels of each factor.

The ash content fitted model in terms of L_Pseudo Components is presented in eq. (7):

$$\left.\begin{aligned} y_{ac} = {} & 3.56x_1 + +3.56x_2 + 2.06x_3 + 0.194x_1x_2 - 2.76x_1x_3 \\ & +5.21x_2x_3 - 2.54x_1^2x_2x_3 - 74.9x_1x_2^2x_3 + 88.7x_1x_2x_3^2 \end{aligned}\right\} \tag{7}$$

The results of the analysis showed that the ash content model of the formulated instant flakes is significant with F-value of 18.3 and p-value of 7.84E-08. The ash content is significantly influenced, at 5% level of significance, by the proportions of rice, sorghum, and soybean flours in the formulations (with linear mixture F- and p-values of 24.1 and 3.67E-06, respectively). The ash content is also significantly influenced, at 5% level of significance by the rice/soybean flours interaction (with F-value of 11.5 and p-value of 0.00273); sorghum/soybean flours interaction (with F-value of 41.2 and p-value of 2.30E-06); rice/the second order of sorghum/soybean flours interaction (with F-value of 19.1 and p-value of 0.000269); and rice/sorghum/the second order of soybean flours interaction (with F-value of 26.8 and p-value of 3.94E-05). The Lack of Fit F-and p-value of 6.61E+03 and 7.01E-27 implies that the Lack of Fit is significant. The ash content model R^2 and the Adjusted R^2 are 0.8743 and 0.8264, respectively. The predicted R^2 of 0.7743 is in reasonable agreement with the adjusted R^2 of 0.8264; i.e. the difference is less than 0.2. Adequacy of precision ratio of 13.05 indicates an adequate signal. This model can be used to navigate the design space and can be used to make predictions about ash content for given levels of each factor.

The crude fiber fitted model in terms of L_Pseudo Components is presented in eq. (8):

$$\left.\begin{aligned} y_{fc} &= 1.82x_1 + 1.20x_2 + 1.20x_3 + 1.07x_1x_2 + 1.06x_1x_3 \\ &\quad + 2.33x_2x_3 - 27.6x_1^2x_2x_3 - 4.33x_1x_2^2x_3 - 6.17x_1x_2x_3^2 \end{aligned}\right\} \tag{8}$$

The results of the analysis showed that the crude fiber model of the formulated instant flakes is significant with F-value of 2.53 and p-value of 0.0422. The crude fiber is significantly influenced, at 5% level of significance, by the proportions of rice, sorghum, and soybean flours in the formulations (with linear mixture F- and p-values of 3.55 and 0.0469, respectively). The crude fiber is also significantly influenced, at 5% level of significance by sorghum/soybean flours interaction (with F-value of 9.36 and p-value of 0.00596); The Lack of Fit F- and p-value of 9.03E+03 and 4.95E-28 implies that the Lack of Fit is significant. The crude fiber model R^2 and the Adjusted R^2 are 0.4908 and 0.29675, respectively. The predicted R^2 of 0.0855 is not close to the adjusted R^2 of 0.2967; i.e., the difference is more than 0.2. This indicates a possible problem with the fitted model. Adequacy of precision ratio of 4.227 still indicates an adequate signal. Thus, the model can still be used to navigate the design space and to make predictions about crude fiber for given levels of each factor.

The crude protein fitted model in terms of L_Pseudo Components is presented in Eq. (9):

$$\left.\begin{aligned} y_{pc} &= 28.5x_1 + 28.8x_2 + 28.5x_3 - 12.6x_1x_2 + 4.48x_1x_3 \\ &\quad - 5.84x_2x_3 + 474.x_1^2x_2x_3 + 252.x_1x_2^2x_3 - 850.x_1x_2x_3^2 \end{aligned}\right\} \tag{9}$$

The results of the analysis showed that the crude protein model of the formulated instant flakes is significant with F-value of 7.56 and p-value of 9.49E-05. The crude protein is not significantly influenced, at 5% level of significance, by the proportions of rice, sorghum, and soybean flours in the formulations (with linear mixture F- and p-values of 2.65 and 0.0943, respectively). The crude protein is significantly influenced, at 5% level of significance by rice/sorghum flours interaction (with F- value of 4.35 and p-value of 0.0494); second order of rice/sorghum/soybean flours interaction (with F-value of 13.9 and p-value of 0.00125); and rice/sorghum/the second order of soybean flours interaction (with F-value of 44.8 and p-value of 1.28E-06). The Lack of Fit F-and p-value of 2.03E+04 and 5.00E-31 implies that the Lack of Fit is significant. The crude protein model R^2 and the Adjusted R^2 are 0.7423 and 0.6442, respectively. The predicted R^2 of 0.5375 is in reasonable agreement with the adjusted R^2 of 0.6442; i.e. the difference is less than 0.2. Adequacy of precision ratio of 9.972 indicates an adequate signal. This model can be used to navigate the design and can be used to make predictions about the crude protein for given levels of each factor.

The nitrogen free extract fitted model in terms of L_Pseudo Components is presented in Eq. (10):

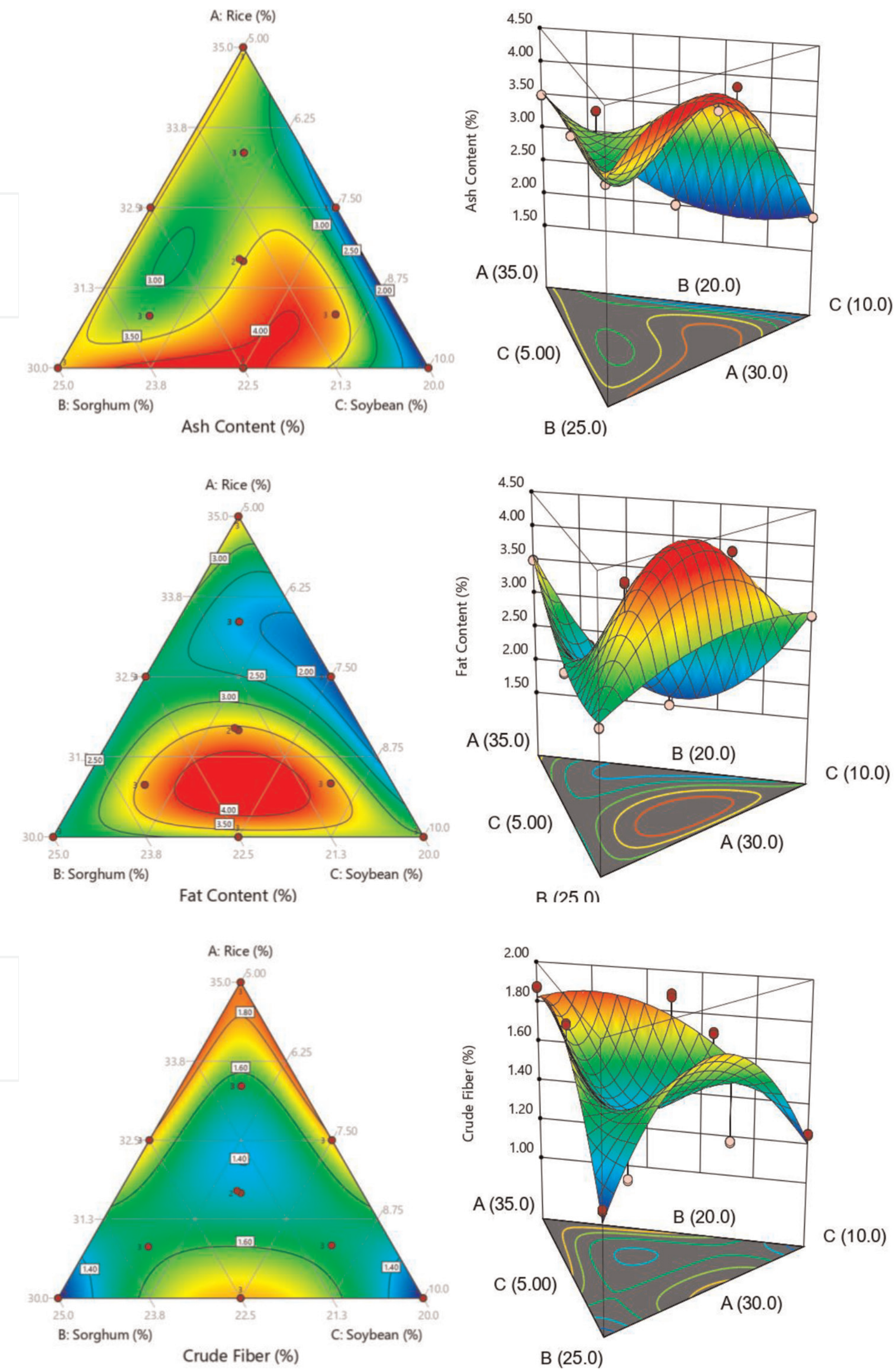
$$\left.\begin{array}{l} y_{nfe} = 57.6x_1 + 61.7x_2 + 61.5x_3 + 14.5x_1x_2 + 5.79x_1x_3 \\ \quad -0.42x_2x_3 - 351.\,x_1^2x_2x_3 - 339.\,x_1x_2^2x_3 + 686.\,x_1x_2x_3^2 \end{array}\right\} \tag{10}$$

The results of the analysis showed that the nitrogen free extract model of the formulated instant flakes is significant with F-value of 6.07 and p-value of 0.000426. The nitrogen free extract is significantly influenced, at 5% level of significance, by the proportions of rice, sorghum, and soybean flours in the formulations (with linear mixture F- and p-values of 6.71 and 0.00558, respectively). The nitrogen free extract is also significantly influenced, at 5% level of significance by rice/sorghum flours interaction (with F-value of 5.31 and p-value of 0.0316); second order of rice/sorghum/soybean flours interaction (with F-value of 6.96 and p-value of 0.0154); rice/second order of sorghum/soybean flours interaction (with F-value of 6.50 and p-value of 0.0187); and rice/sorghum/the second order of soybean flours interaction (with F-value of 26.7 and p-value of 4.04E-05). The Lack of Fit F-and p-value of 1.40E+04 and 1.19E-29 implies that the Lack of Fit is significant. The nitrogen free extract model R^2 and the Adjusted R^2 are 0.6981 and 0.5831, respectively. The predicted R^2 of 0.4580 is in reasonable agreement with the adjusted R^2 of 0.5831; i.e. the difference is less than 0.2. Adequacy of precision ratio of 8.672 indicates an adequate signal. This model can be used to navigate the design space and can be used to make predictions about nitrogen free extract for given levels of each factor.

The energy value fitted model in terms of L_Pseudo Components is presented in Eq. (11):

$$\left.\begin{array}{l} y_{ev} = 376x_1 + 386.x_2 + 388.x_3 - 11.9x_1x_2 - 20.2x_1x_3 \\ \quad -12.1x_2x_3 + 172x_1x_2x_3 \end{array}\right\} \tag{11}$$

The results of the analysis showed that the energy value model of the formulated instant flakes is significant with F-value of 6.85 and p-value of 0.000288. The energy value is significantly influenced, at 5% level of significance, by the proportions of rice, sorghum, and soybean flours in the formulations (with linear mixture F- and p-values of 16.3 and 3.86E-05, respectively). The energy value is also significantly influenced, at 5% level of significance by rice/soybean flours interaction (with F-value of 4.37 and p-value of 0.0478); and rice/sorghum/soybean flours interaction (with F-value of 7.22 and p-value of 0.0132). The energy value model R^2 and the Adjusted R^2 are 0.6413 and 0.5477, respectively. The predicted R^2 of 0.4912 is in reasonable agreement with the adjusted R^2 of 0.5477; i.e. the difference is less than 0.2. Adequacy of precision ratio of 7.018 indicates an adequate signal. This model can be used to navigate the design space and can be used to make predictions about energy value for given levels of each factor.


A: Rice (%)
B: Sorghum (%)
C: Soybean (%)
Ash Content (%)
Fat Content (%)
Crude Fiber (%)
A (35.0)
B (20.0)
C (10.0)
C (5.00)
A (30.0)
B (25.0)

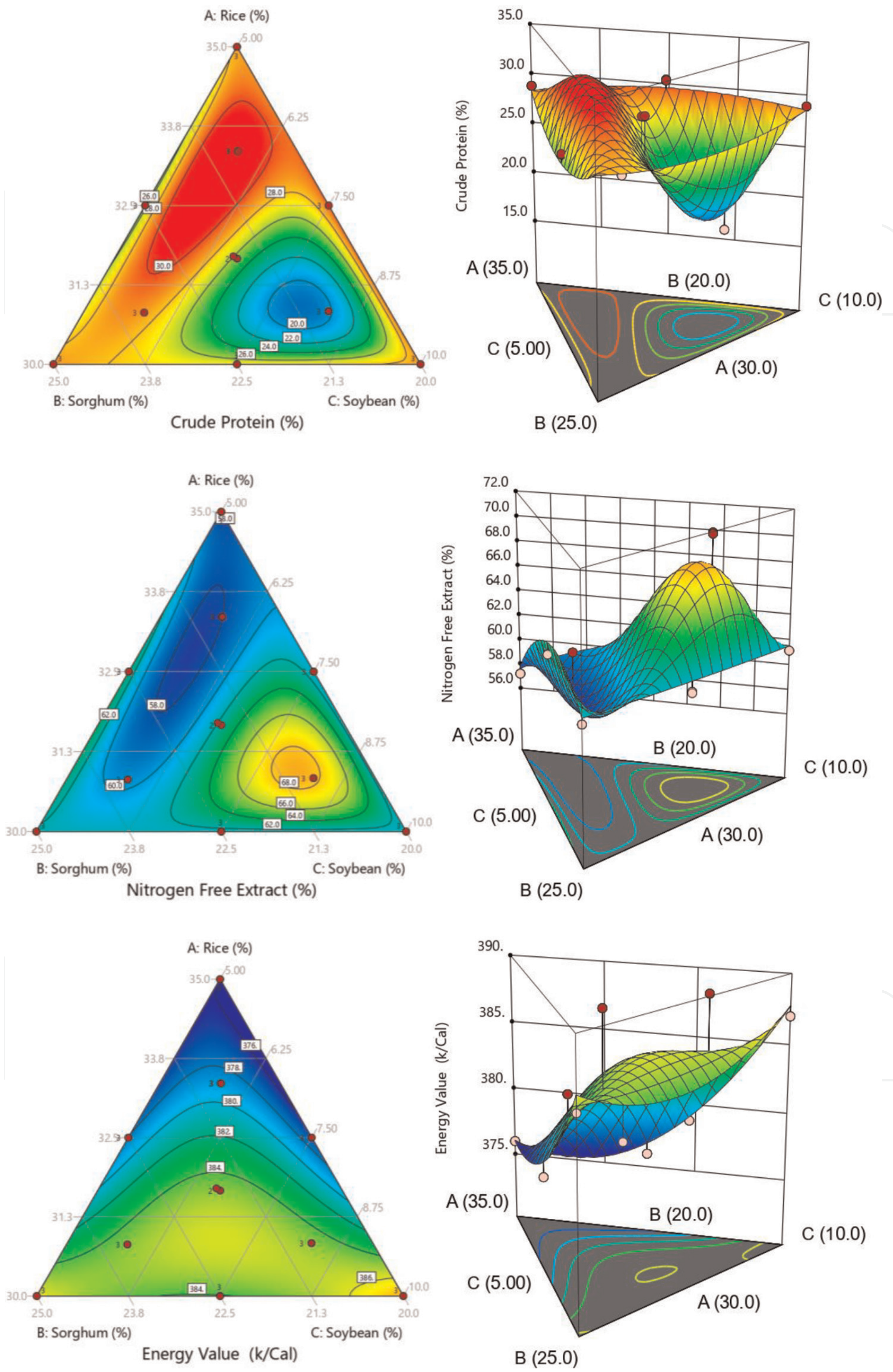


Figure 2.
The contours and 3-D plots for the proximate compositions, nitrogen free extract, and energy value of multigrain flakes.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Rice	in range	30	35	1	1	3
Sorghum	in range	20	25	1	1	3
Soybean	target = 10	5	10	1	10	5
Moisture Content	target = 2.5	2.2	5	1	1	3
Ash Content	target = 3	2	4	1	1	3
Fat Content	in range	1.5	4	1	1	3
Crude Fiber	target = 1.8	1.23	1.89	1	1	3
Crude Protein	target = 30	20	30.5	1	10	5
Nitrogen Free Extract	minimize	57.2	60	1	1	3
Energy Value	target = 390	376	390	1	10	5
Taste	in range	6.5	8	1	1	3
Flavor	in range	6.9	7.4	1	1	3
Texture	in range	7	7.5	1	1	3
Color	in range	7.2	7.8	1	1	3
Sweetness	in range	6.9	7.7	1	1	3
Overall Acceptability	maximize	6.9	7.56	1	1	3

Table 9.
Optimization constraints for instant flakes formulation.

The contours and 3-D plots for the proximate compositions (moisture content, fat content, ash content, crude fiber, crude protein, nitrogen free extract, and energy value) are summarized in **Figure 2**.

Table 9 presents the summary of the optimization constraints employed in the optimization module. The five desirability solutions that were found are presented in **Table 10**. The numerical solution desirability contour plot and 3-D Surface were presented in **Figure 3**. The numerical solution, presented in the form of optimal flake's bar graph and the graphical optimization overlay contour plot, showing the optimized formulation compositions with the respective quality parameters, are summarized in **Figure 4**.

The result of the flakes optimization gave optimized multigrain instant flakes with overall desirability index of 0.519, based on the set optimization goals and individual quality desirability indices. Formulating instant flake with 31.9% rice flour, 22% sorghum flour, 6.05% soybean flour yielded an improved instant flake with optimal quality properties.

5. Conclusions

Instant flakes were developed, characterized and optimized, via constrained optimal (custom) mixture experimental design, from blends of rice, sorghum and soybean. Some concluding observations from the investigation are given below.

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No	y_{mc}	y_{ac}	y_{fat}	y_{fc}	y_{pc}	y_{nfe}	y_{ev}	y_{ta}	y_{flav}	y_{tx}	y_{cl}	y_{sw}	y_{oa}	D_i	
1	**3.668**	**3.083**	**3.178**	**1.441**	**30.000**	**58.611**	**383.678**	**7.238**	**7.157**	**7.500**	**7.435**	**7.288**	**7.284**	**0.519**	**Selected**
2	3.493	3.142	3.781	1.552	28.486	59.539	384.864	7.265	7.166	7.500	7.484	7.307	7.309	0.483	
3	3.474	3.256	2.483	1.413	30.000	59.336	381.965	7.206	7.147	7.000	7.377	7.249	7.263	0.463	
4	3.543	3.132	2.686	1.602	29.999	59.071	380.513	7.303	7.177	7.500	7.498	7.401	7.306	0.404	
5	4.224	3.278	2.587	1.738	30.000	58.169	376.628	7.257	7.162	7.000	7.364	7.295	7.261	0.305	
6	4.082	3.239	2.413	1.695	30.500	58.064	377.048	7.250	7.160	7.372	7.363	7.290	7.261	0.035	

y_{mc} = *Moisture Content* (%), y_{pc} = *Protein Content* (%), y_{fat} = *Fat Content* (%), y_{ac} = *Ash Content* (%), y_{nfe} = *Nitrogen Free Extract*(%), y_{ev} = *Energy value*, y_{fc} = *Fibre Content* (%), y_{ta} = *Taste*, y_{flav} = *Flavour*, y_{sw} = *Sweetness*, y_{cl} = *Colour*, y_{tx} = *Texture*, y_{oa} = *Overall Acceptability*, D_i = *Overall Desirability*

Table 10.
The desirability solutions found.

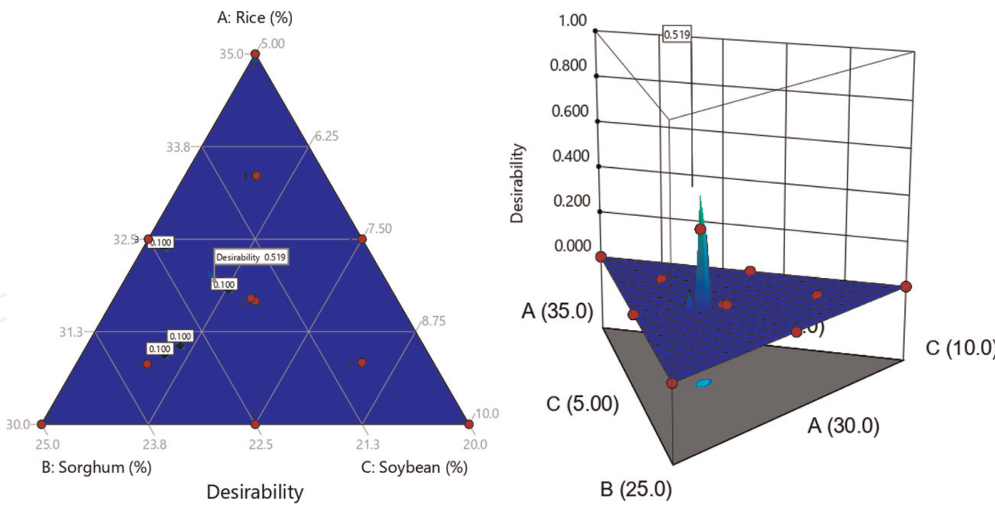

Figure 3.
The numerical solution desirability contour plot and 3-D surface.

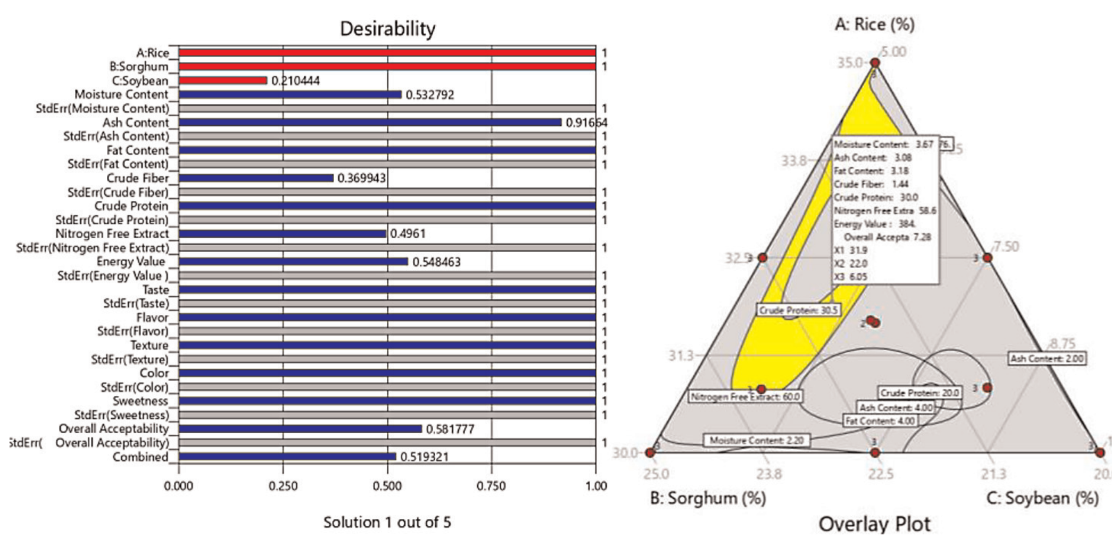

Figure 4.
The bar graph and the graphical optimization overlay contour plot for the optimal formulated flake.

- The optimal flake was obtained from 31.9% rice flour, 22% sorghum flour, 6.05% soybean flour.

- The quality properties of the optimal flake were: 3.67% moisture content, 3.18% fat content, 3.08% ash content, 1.44% crude fiber, 30.0% crude protein, 58.6% nitrogen free extract, 384 kcal energy value and 7.28 overall acceptability

- A The optimal flake from blends of rice flour, sorghum flour, and soybean meal has high nutritional qualities suitable for improving and solving the problems of malnutrition especially in the African continent.

The research has shown that composite food formulation is an excellent way to achieve nutrition revolution, the road to healthier diets and optimal nutrition in Africa: The continent is blessed with vast varieties of agricultural produce seasonally (tubers, roots, cereals, pulses, fruits, vegetables, etc.), yet hunger, malnutrition, dietary deficit, concurrent diseases and food insecurity persists. Additive food manufacturing and/or composite food formulation, dietary diversification, food fortification and increasing access to varieties of nutritionally adequate foods are vital strategies to tackle these lingering problems. However, this study encouraged that further study be carried out on formulation of instant flakes using other nutritionally rich blends (grains and legumes).

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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