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Ready-To-Eat Flakes from Acha, Partially Defatted Sesame Meal and Modified Corn Starch: Modeling, Optimization and Characterization

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Abstract

In this research, ready-to-eat flake from a blend of acha, partially defatted sesame, and modified corn starch was modeled, optimized and characterized. The study aimed to develop a design model that would give a healthy ready-to-eat flake. The formulated flour mixtures were developed into ready-to-eat flakes. Mixture experimental design of the response surface methodology was employed. Characterization of the flake showed protein (14.01g/100g), fat (8.69g), fibre (1.23g), ash (5.03g), moisture (9.45g), carbohydrate (61.50g), sodium (92.03mg), calcium (142.50mg), potassium (201.11mg), iron (110.01mg), zinc (85.32mg), thiamine (0.12mg), niacin (9.81mg), folic acid (2.16mg), pyridoxine (1.81mg), and acceptability index (90.10%). The high essential amino acid index (>90%) showed that the product is a good protein-source. The study showed the feasibility of formulating ready-to-flakes with good protein and high acceptability index using acha, partially defatted sesame, and modified corn starch. The production process is scalable and could be employed for both domestic and industrial purposes.

Keywords: Acha; Sesame; Modified Corn Starch; Optimization; Ready-To-Eat Flakes; Mixture Response Surface Methodology

Introduction

Ready-to-eat (RTE) flakes are typically produced using cereals and are commonly known as breakfast cereals. However, legumes and oilseeds are increasingly being added as a composite in the production of flakes to augment for the nutritional deficiency in cereal crops to have a healthier diet. Breakfast cereals play a vital role in the human diet [1]. The products were initially sold as milled grains of wheat and oats, which require further cooking in the home before consumption. However, in an attempt to reduce the time needed in homes during preparation, some technologies have evolved, from a simple procedure to the manufacture of ready-to-eat products that are convenient and easily prepared [2]. Ready-to-eat cereals are processed from corn, wheat, oats, or rice usually with added flavour and fortifying ingredients. They are processed through variation of several technological unit operations such as cooking, shape-forming, drying, flavouring, sweetening, enrichment with vitamins, and minerals (Caldwell, McKeehen & Kadan). They contain low fat, readily available, convenient, filling, and are easy to digest. Ready-to-eat breakfast cereals in flake form are flakes that contain cereal grains such as wheat, rice, millet, sorghum, oats, and corn, among others. The cereal flakes also contain some ancillary ingredients for enrichment (such as vitamins), sugars, salts, natural and artificial flavoring agents, and other agents such as oils, coloring agents, and natural and artificial preservatives. Other ingredients can also be included to impart desirable flavour and texture properties to the breakfast cereal. In this work, acha, defatted sesame meal, and modified corn starch were used in the production ready-to-eat flakes.

Acha (Digitaria exilis), commonly called hungry rice, hungry millet, fonio, is one of the oldest African cereals; it was once a major crop cultivated across several African countries. It is a crop of great antiquity and the most ancient indigenous cereal of West Africa with cultivation history dating back to 7000 years [3]. Acha is grown in many parts of the world such as the Republic of Benin, Burkina Faso, Gambia, Mali, Niger, Nigeria, Togo, Senegal, and other West African countries. In Nigeria, for instance, it is used as a staple or a major part of a diet. Considering its importance to the rural economy and the potential of increasing food security, it is unfortunate that it has received little attention. Acha has the potential to improve human nutrition, boost food security, foster development, and support land use, being one of the world's fastest-growing cereals that can mature in three to four months [4]. The crop is reported to have a lower glycemic index than sorghum, corn, and white rice which are intermediary in glycemic indexes [5]. Because of the lack of attention, acha is still agronomically primitive. It suffers from small seeds, low yields, and some seed shattering. Acha has the potentials to explore.

Sesame (*Sesamum indicum* L), also known as gingelly, beniseed, sim sim, and til is an important annual oilseed crop. It was a highly prized oil crop of Babylon and Assyria at least 4000 years ago [6]. It is called "sesame" internationally while it is called "benisseed" in West Africa. In Nigeria, it goes by different local names; it is called "Ridi" by the Hausa-Fulani in the North; Igbos call it "Isasa", while the Yorubas call it "Ekuku" [7]. Sesame is a drought-tolerant crop adapted to many soil types [8]. Sesame meal after oil extraction is excellent sources of edible nutrients [9]. According to Mauputu & Buhr [10], the amino acid composition is similar to that of soybean meal except for lower lysine. Defatted sesame meal is also reported to contain more sugar and has a great potential in combating the protein-calorie malnutrition because of the high quantity and quality protein.

Starch is a very important ingredient in the food processing industry. Native starch is used in food preparation mainly due to the functional properties it imparts. It provides properties such as thickening, emulsification, gelling, and binding. However, native starches provide viscous, cohesive, and sticky pastes when they are heated and gels when these pastes cool off [11]. Its instability in the treatment of acid, heat, or shear has limited its application and should be improved to extend its use. Starch in its innate state is a highly functional carbohydrate consisting of a high number of glucose units joined together by a glycosidic bond. Its use in the food industry before modification is limited. The innate starches can be modified to produce starches with better behavioural properties. The purpose is to enhance rhe properties of the paste in specific applications; it may be to improve the water holding capacity, heat resistant behaviour, to reinforce its binding, minimize syneresis of starch and improve thickening [12,13]. Starch modification could be done using physical or chemical methods. Physical modification is carried out using heat and moisture (gelatinization); while chemical treatments involve the introduction of functional groups into the starch molecules using reactions of derivitization (etherification, esterification, and crosslinking) or decomposition (acid or enzymatic hydrolysis and oxidation) [14].

This work aimed to optimize the process of production and develop significant models for ready-to-eat flake using acha, defatted sesame, and modified corn starch that would be nutritionally balanced.

Materials and Methods

Collection of Sample and Preparation

The mature and wholesome sesame (*Sesamum indicum*) grains and corn (*Zea mays*) grains were obtained from commercial stores at Afikpo, (latitude 5˚53' 33.3" N and longitude 7˚56' 7.2" E) Nigeria while acha (*Digitaria exilis*) grains were obtained from a commercial store in Lokoja, Kogi State in Nigeria. The grains were sorted, washed, and dried in a hot air oven (SM9053, Uniscope, England) at 50˚C for 12 h. The dried sesame grains were roasted on an electric hot plate at 100±5˚C, milled into flour, partially defatted using a screw press, dried in a hot air oven (SM9053, Uniscope, England) at 50˚C for 6 h and passed through a sieve with mesh size 212 μm. The dried corn grains were soaked in distilled water (1:10, w/v) at ambient temperature for 6 h, after which it was rinsed using distilled water (1:10, w/v) thrice, wet-milled in an attrition mill, sieved using a muslin cloth and centrifuged at 3,664 3 x g using a centrifuge (0502-1 Hospibrand, USA) for 20 min at ambient temperature. The residue obtained was oven-dried (SM9053, Uniscope, England) at 50˚C for 6 h and the starch pulverized into flour. Acha grains were also milled into flour. The powders from sesame, corn starch, and acha were kept under refrigeration condition for further use.

Modification of Corn Starch Using Heat Moisture Treatment

Heat-moisture treatment was done as described by Sui, et al. [15] with modifications. The innate corn starch (1 kg, db) was measured and placed in a screw-capped glass jar. The moisture content of the starch was adjusted to 25% by adding distilled water and homogenized. The glass jar was sealed and equilibrated at 4°C for 24 h. Thereafter, the starch sample was heated at 85°C for 6 h in a hot-air oven (SM9053, Uniscope, England). The obtained modified starch was then dried at 50°C for 12 h to obtain moisture content of 8%.

Experimental Design and Modeling

The mixture experimental design of the response surface methodology (MRSM) was employed as the design technique in this work. A three-component augmented simplex centroid design was used as described by Okpala & Okoli [16]. The three mixture components evaluated in this study were acha flour (a), sesame flour (s), and modified corn starch (m) while the dependent variables were protein, fat, fibre, colour, taste and acceptability index. The proportions for each ingredient were expressed as a fraction of the mixture and form each treatment combination; the sum of the component proportions was equal to 100, where:

$$\Sigma X = a + s + m = 100 \qquad (1)$$

In this design, the number of points (n) necessary to run a mixture experiment was calculated using Eq. (2).

$$n = 2^{q-1} + q + e \qquad (2)$$

Where q is the number of components being studied (3), e is the replicated experiment to give an internal estimate of error (Table 1). Each mixture component was varied between 0 and 100 g (Table 1). A completely randomized experimental order was adopted to avoid systematic errors. The coefficient of determination (R^2), adjusted coefficient of determination (Adj. R^2), probability value at 95% confidence interval, predicted R^2, coefficient of variation, lack-of-fit, and analysis of variance (ANOVA) were used as statistical indices. Mathematical modeling and optimization were carried out using MRSM of the Design-Expert software version 10.0 (Stat-ease Inc., MN, USA).

Expt. No.	Expt. Order	Acha	Sesame	Modified Corn Starch	Protein	Fat	Fibre	Colour	Taste	Acceptability Index
		(g)	(g)	(g)	(g/100g)	(g/100g)	(g/100g)	(%)	(%)	(%)
1	2	100	0	0	10.53±0.12	2.70±0.01	1.90±0.00	77.00±1.60	79.00±0.89	80.00±1.32
2	12	0	100	0	23.00±0.45	15.40±0.17	3.51±0.01	75.45±1.45	84.00±0.75	75.00±0.74
3	5	0	0	100	0.03±0.00	0.01±0.01	0.01±0.00	74.00±1.64	80.00±1.46	70.00±1.12
4	1	50	50	0	18.30±0.13	17.38±0.08	1.81±0.00	80.31±1.82	90.21±1.62	90.38±1.45
5	11	50	0	50	4.80±0.02	3.60±0.02	0.59±0.00	84.69±1.78	88.17±1.74	75.25±1.80
6	3	0	50	50	11.42±0.10	2.90±0.01	1.45±0.00	83.70±1.95	85.75±0.99	87.92±0.82
7	6	66.67	16.67	16.67	11.22±0.03	8.44±0.04	1.26±0.01	83.36±1.92	88.26±0.23	85.00±0.52
8	10	16.67	66.67	16.67	17.54±0.52	12.52±0.05	2.09±0.01	82.02±1.88	89.05±1.58	88.00±1.21
9	4	16.67	16.67	66.67	5.45±0.02	2.92±0.01	0.55±0.00	83.33±1.89	86.83±1.21	80.54±1.30
10	13	33.33	33.33	33.33	11.31±0.09	8.50±0.03	1.12±0.01	85.34±1.47	90.24±0.98	87.64±0.91
11	7	100	0	0	10.68±0.11	2.71±0.00	1.88±0.01	77.00±1.98	79.81±0.68	80.01±0.94
12	14	0	100	0	22.96±0.09	15.40±0.16	3.51±0.01	75.49±1.78	85.00±1.43	76.00±1.02
13	9	0	0	100	0.04±0.00	0.02±0.00	0.02±0.00	74.00±1.89	80.00±0.99	71.00±1.16
14	8	50	50	0	18.30±0.21	17.10±0.11	1.80±0.00	79.00±1.24	89.00±1.25	89.00±0.97

Table 1: Experimental design and chemo-sensory attributes of enriched ready-to-eat flakes from acha, sesame and modified corn starch.
Nutritional data are presented as mean ± standard deviation (n = 5). Sensory data are presented as mean ± standard deviation (n = 50).

Formulation and Production of Ready-To-Eat Flakes

Flour mixtures were formulated from partially defatted sesame flour, acha flour, and corn starch as shown in Table 1. Each mixture was sieved using a sieve with mesh size 212 µm to obtain a homogenous mixture. The formulated flour mixtures were developed into ready-to-eat flakes.

Ready-to-eat flakes were prepared as described by Lii & Walker with some modifications. Composite flour (400 g) blend was mixed with 28 g of sugar, 3 g of salt, and 160 ml of distilled water in a potable mixer for 4 min at number 2 speeds. The batter obtained was placed in a pasta extractor and formed through the disc (3 mm thick with 5 mm bole). The extruded batter was cut into approximately 1.5 m long pellets, trayed, and stemmed at 18 psi for 70 min. After cooking, the pellets were tempered for 12 h at 5˚C, and then placed in a circulatory air oven at 45˚C to reduce the moisture content to 20%. The partially dried pellets were flaked using a portable flaking machine. The resultant flakes were toasted at 100˚C for 30 mins, cooled, and packaged in an airtight container.

Optimization

The data generated were subjected to multiple regression analysis using Design-Expert software 10.0. The optimal values of the independent variables were obtained by solving the generated quadratic expression. The predicted optimal values were verified by conducting five confirmation experiments to compare the experimental results with the predicted. The observed values from experimental runs were used to test the validity of the optimum points using Absolute Average Deviation (*AAD*) (eq.3).

$$ADD\,(\%) = \left\{\frac{1}{n} \sum_{i-1}^{n} \left(\frac{y_{i,expt} - y_{i,pred}}{y_{i,expt}}\right)\right\} x\,100 \quad (3)$$

Where n is the number of experimental values, $y_{i,expet}$ is the experimental value for ith term, $y_{i,\,pred}$ is the predicted value for ith term.

Nutritional Composition

Moisture, ash, protein, fat, and fibre were evaluated as described by AOAC [17]. Carbohydrate was determined by difference. Water-soluble vitamins were evaluated according to the method of Sami, et al. [18]. Mineral elements of the samples (calcium, magnesium, iron, zinc, magnesium, potassium, and sodium) were analyzed with the aid of an atomic absorption spectrophotometer, Buck Scientific (210VG) after digestion. The water absorption capacity was determined as described by Gbadamosi Fasuan & Omobuwajo [19]. Amino acid profile was carried out as described by Fasuan, Gbadamosi & Omobuwajo [20]. Amino acid scores were obtained as elucidated by Olaofe Adeyeye & Ojugbo [21] using the whole hen's egg amino acid. Predicted protein efficiency ratio (p-PER) was estimated as described by Shi et al. [22] depicted in equations (4)-(5).

$$P - PER_1 = -0.468 + 0.454\,(Leu) - 0.105\,(Tyr) \quad (4)$$

$$P - PER_2 = -0.684 + 0.456\,(Leu) - 0.047\,(Pro)$$

$$P - PER_2 = -0.684 + 0.456\,(Leu) - 0.047\,(Pro) \quad (5)$$

The essential amino acid index (EAAI) was obtained as described by Adeyeye whereas, the biological value (BV) was evaluated using the expression described by Shi et al. (2020) as shown in equation (6) with the amino acids of casein used as the standard.

$$P - BV = 1.09(EAAI) - 11.70P - BV = 1.09(EAAI) - 11.70$$

(6)

All experimental data were average of five replicates.

Results and Discussion

Modeling and Parameter Optimization

The experimental design and chemosensory attributes of the enriched ready-to-eat flakes from acha, partially defatted sesame and modified corn starch are presented in Table 1. The effects of the treatment variables interaction coefficient on response variables were tested for adequacy and fitness by regression analysis. Regression models relating to the response parameters (protein, fat and fibre, colour, taste, and acceptability index) to the independent variables (acha, partially defatted sesame, modified corn starch) are shown in Table 2. The results showed that the quadratic model best explains the relationship between the processing variables and dependent variables. When the p-values were compared to the significant levels, the regression model was seen to be significant, hence a rejection of the null hypothesis that there is a non-zero correlation. The coefficient of determination of the model parameters was very high. The R^2 is a measure of the degree of fitness that illustrates the ratio of the explained variation to the total variation. A suitable model is expected to have the value of R^2 nearer to unity; and an empirical model fits better when it has R^2 value approaching unity. The coefficient of determination, R^2 ranged between 0.9924 to 0.9999 which are very close to perfect. This guarantees good fitness of the model when applied. The coefficients of the model parameters indicate the magnitude and significance of each model parameter with regards to their effects on the response variables. The higher the coefficient of the model parameter, the higher the significance of such a parameter. The non-significant lack-of-fit of the regression models, a high adjusted coefficient of determination (adj. R^2) substantiated the adequacy of the regression models in describing the ready-to-eat flakes parameters. Consequently, the generated quadratic models were ample to depict the processing process for the ready-to-eat flakes.

Model Terms	Protein				Fibre		Colour		Taste		Acceptability Index	
	p-value	RC	p-value	RC	p-value	RC	p-value	RC	p-value	RC	p-value	RC
Model	<0.0001	-	<0.0001	-	<0.0001	-	<0.0001	-	<0.0001	-	<0.0001	-
Linear mixture	<0.0001	-	<0.0001	-	<0.0001	-	0.0014	-	<0.0001	-	<0.0001	-
a	-	10.61	-	2.7	-	1.89	-	77.04	-	79.42	-	80.02
s	-	22.99	-	15.4	-	3.51	-	75.44	-	84.5	-	75.55
m	-	0.05	-	0.03	-	0.02	-	73.98	-	79.96	-	70.4
as	<0.0001	5.77	<0.0001	32.73	<0.0001	-3.57	<0.0001	14.03	<0.0001	30.97	<0.0001	48.35
am	0.0002	-2.5	<0.0001	8.98	<0.0001	-1.42	<0.0001	37.56	<0.0001	34.38	0.8579	0.41
sm	0.0774	-0.78	<0.0001	-19.11	<0.0001	-1.19	<0.0001	36.19	<0.0001	14.42	<0.0001	60.33
Lack-of-fit	0.0698	-	0.7654	-	0.1725	-	0.8998	-	0.9812	-	0.857	-
R^2	0.9999	-	0.9999	-	0.9999	-	0.9951	-	0.9924	-	0.9959	-
Adj. R^2	0.9998	-	0.9998	-	0.9999	-	0.9921	-	0.9876	-	0.9933	-
Pred. R^2	0.9995	-	0.9997	-	0.9997	-	0.9844	-	0.9742	-	0.9873	-
Ad. Pred.	357.63	-	314.95	-	433.28	-	46.89	-	35.57	-	52.52	-
St. Dev.	0.1	-	0.08	-	0.01	-	0.37	-	0.46	-	0.57	-
CV (%)	0.83	-	1.07	-	0.8	-	0.46	-	0.54	-	0.7	-

Table 2: Regression analysis of enriched ready-to-eat flakes from acha, sesame and modified corn starch.
RC-Regression coefficient; a-acha; s-sesame; m-modified corn starch; R2-coefficient of determination; Adj. R2- adjusted coefficient of determination; Pred. R2-predicted coefficient of determination; Ad. Pred.-adequate prediction; CV-coefficient of variation.

The coefficient of variation (CV) illustrates the reproducibility of a model. The CV value is expected to be below 10%; and the lower the CV value, the better the model. The CV value of 0.46-1.07% of the generated models upheld the repeatability of the obtained models. The adequate prediction (Ad. Pred.), which evaluates signal to noise ratio was very high for all the regression models. It is expected that the value of Ad. Pred. be greater than 4. In this study, the values of Ad. Pred. ranged from 35.57 to 433.28, which were significantly higher than 4. The mathematical illustrations for the ready-to-eat flakes are presented in equations (7)-(12).

$$Protein = 10.61a + 22.99s + 0.05c + 5.77as - 2.50ac - 0.78sc \quad (7)$$

$$Fat = 2.70a + 15.40s + 0.03c + 32.73as\ 8.98ac - 19.11sc \quad (8)$$

$$Fibre = 1.89a + 3.51s + 0.02c - 3.57as - 1.42ac - 1.19sc \quad (9)$$

$$Colour = 77.04a + 75.44s + 73.98c\ 14.03as\ 37.56ac + 36.19\ sc \quad (10)$$

$$Taste = 79.42a + 84.50s + 79.96c + 30.97as + 34.38ac\ 14.42sc \quad (11)$$

$$Acceptability\ Index = 80.02a + 75.55s + 70.40as + 48.35ac + 60.33sc \quad (12)$$

Where a is the quantity of acha flour, s is the quantity of defatted sesame flour and c is the quantity of modified corn starch.

Optimal Values and Models Evaluations

The empirical expressions in equations (7) to (12) were solved using Design Expert Software while the values of protein, fibre, colour, taste, and acceptability index were set for maximum values whereas, the fat was set to a minimum. The regression models were validated using the predicted optimum formulation conditions (29.53g, 38.02g and 32.45g of acha, partially defatted sesame and modified corn starch, respectively) with the corresponding protein of 13.20 g/100g, fat (8.84g/100g), fibre (1.21g/100g), colour (85.08%), taste (90.08%) and acceptability index (88.11). With these values of the independent variables as optimized conditions, the selected proximate and sensory parameters evaluated showed that the optimized enriched ready-to-eat flakes were rated high. As shown in Table 3, the experimental values for the response variables were higher than the predicted values, except for fat whose experimented value was 1.73% lower than the predicted value. The percentage increase recorded by experimental values over predicted values by the response variables were 5.78%, 1.63%, 1.23%, 1.01%, and 2.21% for protein, fibre, colour, taste, and acceptability index, respectively. Overall, the measured responses of the sensory and proximate contents compared favourably to the predicted values and were acceptable. The low values of the absolute average deviation (AAD) showed the accuracy of the predictive models. The lower the value of AAD, the better the predictive model. Typically, the value of AAD is expected to be below 10%. Conclusively, the above-described modeling and optimization process is suitable and adequate as a typical representation of the ready-to-eat flakes from acha, partially defatted sesame, and modified corn starch.

Parameter	Actual Value	Predicted Value	Residual	AAD (%)
Desirability		0.718	-	-
Independent variables				
Acha, a (g/100g)	-	29.53	-	-
Sesame, s (g/100g)	-	38.02	-	-
Modified corn starch, m (g/100g)	-	32.45	-	-
Dependent variable				
Protein (g/100g)	14.01±0.11	13.20±0.10	0.81	5.78
Fat (g/100g)	8.69±0.06	8.84±0.08	-0.15	1.73
Fibre (g/100g)	1.23±0.02	1.21±0.01	0.02	1.63
Colour (%)	86.14±0.74	85.08±0.37	1.06	1.23
Taste (%)	91.00±0.95	90.08±0.46	0.92	1.01
Acceptability index (%)	90.10±1.38	88.11±0.57	1.99	2.21

Table 3: Optimal condition for enriched ready-to-eat flakes from acha, sesame and modified corn starch.
Nutritional data are presented as mean ± standard deviation (n = 5). Sensory data are presented as mean ± standard deviation (n = 50). AAD-Absolute average deviation.

Proximate, Mineral and Vitamin Compositions

The results of the proximate, mineral and vitamin analyses conducted on the optimized ready-to-eat flakes from acha, defatted sesame, and modified corn starch are shown in Table 4. The results showed that the protein was 14.01 g/100g. That was higher than the 2 g reference standard protein value for ready-to-eat flakes according to USDA [23]. It was equally higher than the 13 g protein found in commercial corn flake (Golden morn). The high amount of protein could be a result of sesame which is rich in protein. This is particularly good as protein plays a prominent role in bodybuilding. The fat content was found to be 8.69 g/100g. That value was comparable to the value reported by Mbaeyi & Uchendu [2] which ranged between 1.57 and 16.29% in different samples of breakfast cereals produced from blends of acha and fermented soybean paste. The figure was however lower but comparable to the value reported in commercial corn flake which was 10.0 g. The processing methods as well as the modifications employed are thought to be the reason for the slight reduction. The crude fibre in the optimized enriched ready-to-eat flakes was 1.23 g/100g. The value was higher than what Mbaeyi [24] reported for breakfast cereal from maize meal and coconut. Similarly, it was higher but reasonably comparable to the reference fibre content of 0.8 g according to USDA [23]. The figure was however lower than 7.0 g of fibre recorded for commercial corn flakes. Consumption of fibre helps to improve digestive functions and the amount of fibre found in the enriched ready-to-eat flake makes it a healthy diet. The moisture content of the processed flakes was 9.45%. This value was found to be in the same range as the 4.71%-9.88% range reported by Mbaeyi & Uchendu [2]. It was also very much below the maximum 12.5% water content for shelf-stable storage and viability of food grains. Conversely, the processed flakes would be shelf-stable. The carbohydrate content was found to be 61.50 g/100g. It was found to be lower than the 65.0 g reported as the amount in commercial corn flakes. It was however found to be higher the 24 g which is the reference value for carbohydrate according to USDA [23]. The high carbohydrate content is thought to be as a result of the richness of both acha and corn in carbohydrates. The ash content was 5.03 g/100g. The high quantity could be an indication of the richness of the flakes in minerals.

Parameter	Amount
Proximate (g/100g)	
Protein	14.01±0.11
Fat	8.69±0.06
Fibre	1.23±0.02
Ash	5.03±0.21
Moisture	9.45±0.36
Carbohydrate	61.50±0.74
Mineral (g/100g)	
Sodium	92.03±1.41
Calcium	142.50±1.32
Potassium	120.47±1.25
Magnesium	201.11±1.14
Iron	110.01±1.02
Phosphorus	306.14±1.83
Zinc	85.32±0.89
Vitamin	
Thiamin (B_1) (mg/100g)	0.12±0.00
Riboflavin (B_2) (mg/100g)	0.57±0.00
Niacin (B_3) (mg/100g)	9.81±0.05
Folic Acid (B_9) (µg/100g)	2.16±0.01
Pyridoxine (B_6) (mg/100g)	1.81±0.01
Pantothenic Acid (B_5) (mg/100g)	1.59±0.00

Table 4: Nutritional properties of enriched ready-to-eat flakes from acha, sesame and modified corn starch produced under optimal condition Data are presented as mean ± standard deviation (n=5).

The minerals of the ready-to-eat are equally presented in Table 4. The mineral information revealed a lower level of sodium when compared with what was reported for commercial samples; it yielded 92.03 mg/100g of sodium while in a commercial sample, the amount ranged from 111 mg to 196.5 mg. It was also lower than the 298 mg reference standard according to USDA [23]. The not too high amount could be desirable because the excess of sodium in industrialized food could be dangerous to health [25]. The calcium content was 142.50 mg/100g. That was higher than the standard reference according to USDA which is 100 mg. The amount was comparable to the value reported by Okafor & Usman [26] and value reported by Agunbiade & Ojezele for breakfast cereals made from maize, sorghum, soybean, and African yam bean flour. Calcium is a vital constituent of bone and teeth as well as regulation of nerve and muscle [15]. Potassium was found to be 201.11 mg/100g. This figure is comparable to the value reported by Mbaeyi [24] for breakfast cereal from sorghum and pigeon pea; and potassium content of 107.0-238.0 mg/100 g. It also compared favourably with the 153.80-210.20 mg/100g range of potassium reported by Anne. The potassium maintains a balance between acid and base content in the body [27]. The iron content was 110.0 mg/100g. This amount compared favourably with that reported by Anne; they reported an iron content of 68.30-130.47 mg/100g in their breakfast cereal samples. The quantity of phosphorus was equally high; the enriched flake yielded 306.14 mg/100g. The zinc content was 85.32 mg/100 g.

Thiamin, riboflavin, niacin, folic acid, pyridoxine (B_6), and pantothenic acid contents of the enriched optimized flake recorded significant values. The vitamins evaluated are generally unstable during processing and this could have affected their yield. The values were 0.12 mg/100g, 0.57 mg/100g, 9.81 mg/100g, 2.16 mg/100g, 1.81 mg/100g and 1.59 mg/100g, respectively. Riboflavin supports growth, reproduction, and vision. Niacin is attributed to neurological functions whereas; pantothenic acid supports the skin, hair, healing of a wound, and blood lipid profile. Pyridoxine enhances nerve functioning and formation of blood [28].

Physico-Functional and Sensory Attributes

The results of the physico-functional and sensory attributes of the enriched ready-to-eat flakes are presented in Table 5. The bulk density of flakes products is important to their packaging requirement and the ability to float or sink when poured into milk. Loose bulk density (LBD) is a reflection of the load the sample can carry if allowed to rest directly on one another. It represents the lowest attainable density with compression. The loose density of the enriched ready-to-eat flakes was 0.502 g/ml. This value is considered low and is a good attribute concerning its packaging and storage. According to Emmanuel, et al. [29], a product with lower values of loose bulk density is more desirable, as the samples would pack better during storage without losing volume. The value of the packed bulk density (PBD) of the enriched flakes was 0.733 g/ml. It represents the highest attainable density with compression. The porosity of the enriched flake was 28.79%. Porosity is a measure of the voids between the solid particles of a material. It is a fraction of the empty volume (void) and it is usually estimated from the apparent and the true density of the material. Water absorption capacity represents the ability of a product to associate with water under conditions where water is limiting [30]. It is an indication of the extent to which protein can be incorporated into food formulation. The water absorption capacity (WAC) of the enriched flour analyzed at 30°C, 50°C and 70°C were 20.13 g/g, 59.74 g/g, and 76.81 g/g, respectively. The result showed that as the temperature increased, the water absorption capacity of the flake increased.

Parameter	Amount
Physico-functional	
Loose bulk density (g/ml)	0.502±0.002
Packed bulk density (g/ml)	0.733±0.010
Porosity (%)	28.79±0.30
Water absorption capacity 30°C	20.13±0.11
50°C	59.74±0.83
70°C	76.81±0.19
Sensory attributes (%)	
Colour	86.14±0.74
Aroma	90.70±1.29
Taste	91.00±0.95
Acceptability index	90.10±1.38

Table 5: Physico-functional and sensory characteristics of enriched ready-to-eat flakes from acha, sesame and modified corn starch produced under optimal condition.

Physico-functional data are presented as mean ± standard deviation (n = 5). Sensory data are presented as mean ± standard deviation (n = 40).

The colour characteristic of flakes product is important in the sensory characteristics of a product and plays an important role in determining the final acceptance by consumers [31]. In Table 5 the colour of the enriched ready-to-eat flake was scored 86.14%. Considering the high score, it indicated that the flake had a very high eye appeal and was highly accepted by the panelists. The result may be a result of the effect of acha flour which had been reported by Chukwu & Abdulkadir [32] to have smooth and bright colour. The taste of the flake was equally scored high; it had 91.0%. Taste is the main attribute consumers take into account when purchasing a product [33]. The aroma of the flake got a score of 90.7% from the panelists. It showed that the product had a great chemical interaction between taste and smell. The flake had a reasonably high acceptability index of 90.1%. That was an indication that the flake had an overall sensory appeal and acceptability.

Amino Acids Profile

The amino acid profiles of the optimized enriched flake are presented in Table 6. There was a general good yield of the amino acids, especially the essential amino acids such as methionine, Histidine, lysine, threonine, and phenylalanine. Histidine is generally produced in the liver in small quantities; it facilitates growth, the creation of body cells and tissues and this necessitates the intake of food rich in histidine. Its deficiency causes anemia, and low blood levels appear to be more common among people with arthritis and kidney disease. Phenylalanine is required by the body for the synthesis of important signaling molecules [21].

Amino Acid	Ready-to-eat flakes	Hen's Egg[a] (g/100 g)	Amino Acid Score with Reference to Hen's (%) (%)
Arginine	7.95±0.19	6.1	130.33
Cysteine	0.82±0.00	1.8	45.56
Methionine	1.09±0.01	3.2	34.06
Histidine	3.14±0.08	2.4	130.83
Isoleucine	5.82±0.31	5.6	103.93
Leucine	7.25±0.11	8.3	87.35
Lysine	4.82±0.06	6.2	77.74
Tyrosine	7.04±0.09	4	176
Phenylalanine	7.83±0.05	5.1	153.53

Threonine	4.96±0.07	5.1	97.25
Tryptophan	2.03±0.01	-	-
Valine	6.09±0.21	7.5	81.2
Glycine	3.04±0.02	3	101.33
Glutamic Acid	10.54±0.15	12	87.83
Aspartic Acid	10.01±0.14	10.7	93.55
Serine	3.23±0.16	7.9	40.87
Proline	4.95±0.20	3.8	130.26
Alanine	4.21±0.08	5.4	77.96
TAA	94.82	98.1	-
TNEAA	48.66	59.6	-
TEAA with histidine	46.16	40.4	-
TEAA without histidine	43.02	38	-
EAAI (%)	99.65	-	-
p-BV (%)	96.93	-	-
$p\text{-}PER_1$	2.08	-	-
$p\text{-}PER_2$	2.39	-	-

Table 6: Amino acids profile of enriched ready-to-eat flakes from acha, sesame and modified corn starch produced under optimal condition.

Data are presented as mean ± standard deviation (n = 5). TAA-Total amino acids. TNEAA-Total non-essential amino acids. TEAA-Total essential amino acids. EAAI-Essential amino acids index with reference to egg's protein. p-BV-Predicted biological value with reference to casein protein. P-PER-Predicted protein efficiency ratio with reference to casein's protein (methods 1 & 2).

The biological value (BV) is an evaluation of the amount (in percentage) of the protein in a food-material that can be incorporated into the proteins of the body. Consuming foods with high BV is usually recommended. A protein with essential amino acids in an amount similar to what the body required is said to have high biological value. The p-BV of the ready-to-eat flake was 96.93%. The result indicated that the ready-to-eat flake had a high biological value.

Protein efficiency ratio (PER) is the ratio of weight gained by the body to the amount of the ingested protein; a measure of the ability of the protein to promote growth [34]. The p-PER was 2.08 for the ready-to-eat flake.

Essential amino acid index (EAAI) is the geometrical-mean of the ratio of the essential amino acids in a protein compared to their content in a highly-nutritive reference-protein. The EAAI for the ready-to-eat flake was 99.65%. According to Shi, et al. [35], a good nutritional value is a representation of high EAAI and a protein-material is regarded as good protein-source if it has EAAI greater than 90; conversely, the value below 70 is regarded as low protein-source. This implies that the ready-to-eat flake produced from blends of acha, partially defatted sesame, and modified corn starch at optimized conditions is a good protein source [36-47].

The biological value (BV) illustrates the amount (in percentage) of the protein in a food-material that could be incorporated into the proteins of the body. Food with high BV is usually recommended. A protein with essential amino acids in an amount similar to what the body required is said to have high biological value. The p-BV of the flakes was 96.93%. The flakes also have a good protein efficiency ratio score.

Conclusion

The study modeled and optimized the development of ready-to-eat flakes using acha, partially defatted sesame, and modified corn starch by employing MRSM and characterization of the products. The flour mixture composition of acha (29.53%), sesame (38.02%), and modified corn starch (32.45%) were identified as optimal parameters with the protein content of 14.01%, fibre (1.23%) and acceptability index (90.10%). The developed product is rich in mineral, vitamins, and amino acids. The high essential amino acid index (>90%) showed that the product is a good protein source. The study showed the feasibility of formulating ready-to-flakes with good protein content and high acceptability index using acha flour, partially defatted sesame flour, and modified corn starch. The production process is scalable and could be employed for both domestic and industrial purposes.

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Conflicts of Interest

The authors declare there were no conflicts of interest.

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