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Bioactive and nutritional characterization of modeled and optimized consumer-ready flakes from pseudocereal (*Amaranthus viridis*), high-protein soymeal and modified corn starch

Temitope Omolayo Fasuan[1*], Kenneth Chigozie Asadu[1], Cynthia Chioma Anyiam[2], Linda Obianuju Ojokoh[1], Titilope Modupe Olagunju[3], Judith Uchenna Chima[1] and Kingsley Osita Okpara[1]

Abstract

Flake is consumed in many parts of the world. Flakes are majorly prepared from cereals. However, most flakes are deficient in protein and some other healthful substances. High-protein soymeal is rich in protein, mineral, amino acids, antioxidants, and other healthful substances. Formulating flakes with high-protein soymeal would improve the health status of consumers. This work investigated consumer-ready flake from amaranth, high-protein soymeal, and modified corn starch produced under the optimized condition and characterized with the aim to develop models that would give a healthful consumer-ready flake. *Amaranthus viridis,* corn, and soybean grains were sorted, wet-cleaned, and dried. Soybean grains were processed into high-protein soymeal, starch was extracted from corn grains while *A. viridis* grains were processed into flour. Formulated flour mixtures were developed into flakes using three-level factorial categoric factor design of response surface methodology. The flakes were analyzed using standard procedures. Optimal flour mixtures of high-protein soymeal (34.78 g/100 g), amaranth (56.52 g/100 g), and modified corn starch (8.70 g/100 g) were established. Results showed the optimized flakes contained per 100 g: 29.05 g protein, 6.00 g fat, 4.10 g fibre, 3.84 g ash, 8.96 g moisture, 249.74 mg calcium, 272.35 mg magnesium, 12.08 mg iron, 618.42 mg phosphorus, 6.41 mg niacin, 4.85 mg pyridoxine, 0.21 g tannin, 1.85 mg phytate, 2.96 mg alkaloids, 908.24GAE total phenolics and 12.75mgRE flavonoids with good quality characteristics in amino acids. The study illustrated the feasibility of formulating quality consumer-ready flakes from amaranth, high-protein soymeal, and modified corn starch. The production process is scalable and could be employed for both domestic and industrial purposes.

Keywords: High-protein soymeal, Modified corn starch, Amaranth, Optimized consumer-ready flakes, Modeling, Characterization

* Correspondence: temitopeomolayo@yahoo.com
[1]Department of Food Technology, Akanu Ibiam Federal Polytechnic, Unwana, Ebonyi State, Nigeria
Full list of author information is available at the end of the article

Introduction

Pseudocereals are the class of dicotyledonous plants that resemble in function and composition with true cereals. They are plants that produce fruits or seeds which are used and consumed as grains; though botanically, pseudocereals are neither grasses nor true cereal grains. They are typically high in protein and other nutrients, gluten-free, and are considered whole grains (Anubhuti 2017). Because they are gluten-free, they have wide applications in gluten-free formulations. Pseudocereals are sources of high-quality protein, fibre, minerals, and also have bioactive and health-promoting effects (Alvarez-Jubert et al. 2010a, 2010b). Currently, there is a much bigger interest in the use of pseudocereals for developing nutritious food products. Amaranth (*Amaranthus spp*) buckwheat (*Fagopyrum spp*), and quinoa (*Chenopodium spp*) are the three major pseudocereals in terms of world production (Janssen et al. 2017).

Amaranth, buckwheat, and quinoa are not true cereals; they are dicotyledonous plants as opposed to most cereals (example wheat, rice, barley) which are monocotyledons but they produce seeds that can be milled into flour and used as cereal crop (Alvarez-Jubert et al. 2010a, 2010b). There has been an increasing interest in gluten-free foodstuffs in recent years (Gimenez-Bastida et al. 2015). The use of gluten-free products is increasing since a growing number of people are suffering from celiac disease and they need a gluten-free diet. Many gluten-free products have been put into production including gluten-free bread, pasta, cookies, and other snacks (Padalino et al. 2016). For this work, amaranth was used as the pseudocereal. Amaranths are cultivated from temperate to tropical zone. It has a great amount of genetic diversity, phenotypic plasticity, and is extremely adaptable to adverse growing conditions, resists heat and drought, has no major disease problem, and is among the easiest of plants to grow in agriculturally marginal lands (Anubhuti 2017). Amaranth is known for its excellent nutritional value and therapeutic nature (Balasubramanian and Karthikeyan 2016). It is rich in protein (17–19% of dry weight) with double the amount of essential amino acids in wheat grain protein (Bressani et al. 1987). Amaranth is an important alternative for cereals due to its high nutritive values and interesting functional properties. Amaranth, an underutilized crop and a cheap source of proteins, minerals, vitamins A and C, seems to be a future crop that can substantiate this demand due to its tremendous yield potential and nutritional qualities, also recently gained worldwide attention (Anubhuti 2017).

Soybeans are the most widely grown oilseed in the world. Soybean meal is the most commonly used protein supplement in the daily ration and is the standard used for determining the value of other protein supplements. The most common forms of soybean meal are solvent extracted (44% CP, as-fed basis) and dehulled, solvent extracted (48% CP, as-fed basis). Soybean meal is very palatable and contains large quantities of essential amino acids.

Flakes are extruded products majorly produced from cereals. However, due to the low nutrients contents of cereal grains, the recent developments in flakes production involved the incorporation of other nutrients dense crops to improve the nutrients and non-nutrients components. Therefore, this work aimed to investigate and optimize the development of consumer-ready flakes from amaranth grains, high-protein soymeal, and modified corn starch in an attempt to reduce protein-energy malnutrition and enhance food security.

Materials and methods

Collection of sample and preparation

The wholesome soybean (*Glycine max*) 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 amaranth (*Amaranthus viridis*) grains were obtained from National Horticultural Research Institute (NIHORT, Kano, Nigeria. The grains were sorted, washed, and dried in a hot air oven (SM9053, Uniscope, England) at 50 °C for 6 h. The dried soybean grains were boiled for 20 min, dehulled, crushed to form grits using an attrition mill, steamed for 30 min, and partially deoiled using a screw press. The deoiled cake was toasted on an electric hot plate at 80 ± 5 °C, milled into flour, 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 3664 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. Amaranth grains were also milled into flour. The powders from high-protein soybean meal (HPSM), corn starch, and amaranth were kept under refrigeration conditions for further use.

Modification of corn starch using heat moisture treatment

Heat–moisture treatment was done as described by Sui et al. (2015) with modifications. The innate corn starch (1 kg, dry basis) 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 three-level factorial categoric factor design (3LFCFD) of the response surface methodology (RSM) was used as the design technique in this study. The quantities of high-protein soymeal (q), and amaranth (a) with modified corn starch as a categoric factor (at two levels) were used as independent variables while protein, fat, fibre, appearance, taste, and acceptability index were used as dependent variables. A total of 26 experiments were conducted. Fifty panelists were used for the sensory variables (appearance, taste, and acceptability index) while protein, fat, and fibre contents were replicated five times. 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 employed as statistical indices.

Formulation and production of consumer-ready flakes

Flour mixtures were formulated from high-protein soymeal, amaranth flour, and modified 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 consumer-ready flakes. Consumer-ready flakes were prepared as described by Ratnawati and Afifah (2017) with some modifications. Composite flour blend was mixed with 7% of sugar, 0.75% of salt, and 40% of distilled water in a potable mixer for 4 min at number 2 speed. 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. The produced flake is shown in Fig. 1. A commercial product (NASCO Cornflakes) was used as the control.

Optimization and validation

The replicated data 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.1).

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

where n is the number of experimental values, $y_{i,expet}$ is the experimental value for the 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 (2000). Carbohydrate was determined by a difference as illustrated in eq. (2).

$$Carbohydrate\ (\%) = 100 - (moisture + ash + fat + fibre + protein) \qquad (2)$$

Water-soluble vitamins were evaluated according to the method of Sami et al. (2014). 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 et al. (2017). The amino acid profile was carried out as described by Fasuan et al. (2018). Amino acid scores were obtained as elucidated by Olaofe et al. (2013) using the whole hen's egg amino acid as a reference (Olaofe et al. 2013). The predicted protein efficiency ratio (p-PER) was estimated as described by Adeyeye (2017) and Shi et al. (2020), and depicted in eqs. (3)–(4).

$$P-PER_1 = -0.468 + 0.454\ (Leu) - 0.105\ (Tyr) \qquad (3)$$

$$P-PER_2 = -0.684 + 0.456\ (Leu) - 0.047\ (Pro) \qquad (4)$$

The essential amino acid index (EAAI) was obtained as described by Adeyeye (2017) whereas, the biological value (BV) was evaluated using the expression described by Shi et al. (2020) as shown in eq. (5) with the amino acids of casein used as the standard.

$$P-BV = 1.09(EAAI) - 11.70 \qquad (5)$$

Phytochemical and antioxidants activities

Total flavonoids were evaluated as described by Naheed et al. (2017). DPPH was evaluated as described by Naheed et al. (2017). FRAP was carried out as described by Alvarez et al. (2016) and the result was expressed as mmol of iron II ion per 100 g of sample. The alkaloids, saponins, and tannins were evaluated as described by Raji et al. (2019). Total

Table 1 Experimental design and quality attributes of consumer ready flakes from amaranth, high-protein soymeal and modified corn starch

Std	Run	High-protein Soymeal	Amaranth Flour	Modified Corn Starch	Protein	Fat	Fibre	Taste	Apperance	Acceptability Index
					(g/100 g)	(g/100 g)	(g/100 g)	(%)	(%)	(%)
1	10	30(− 1)	50(− 1)	10(− 1)	17.20 ± 0.13	6.93 ± 0.01	4.78 ± 0.01	89.74 ± 0.18	89.00 ± 2.05	75.00 ± 0.58
2	5	40(0)	50(−1)	10(− 1)	34.00 ± 0.42	6.90 ± 0.11	3.88 ± 0.00	87.00 ± 0.74	88.10 ± 1.78	79.68 ± 0.74
3	14	50(1)	50(−1)	10(−1)	40.00 ± 0.15	7.02 ± 0.02	3.34 ± 0.02	85.20 ± 0.54	85.20 ± 1.93	87.79 ± 1.98
4	16	30(−1)	65(0)	10(−1)	18.00 ± 0.29	6.82 ± 0.01	5.53 ± 0.05	92.10 ± 0.89	86.35 ± 1.45	90.07 ± 1.47
5	18	40(0)	65(0)	10(−1)	29.00 ± 0.41	6.85 ± 0.01	4.85 ± 0.03	90.00 ± 1.02	85.95 ± 2.09	91.50 ± 0.31
6	8	50(1)	65(0)	10(−1)	35.00 ± 0.09	7.02 ± 0.03	4.54 ± 0.04	85.30 ± 1.95	87.67 ± 2.48	96.27 ± 0.78
7	7	30(−1)	80(1)	10(−1)	15.00 ± 0.17	7.25 ± 0.11	6.00 ± 0.00	95.40 ± 2.01	85.40 ± 1.86	95.89 ± 2.19
8	12	40(0)	80(1)	10(−1)	19.00 ± 0.31	7.32 ± 0.07	5.54 ± 0.08	93.00 ± 1.89	86.66 ± 0.99	93.98 ± 2.45
9	21	50(1)	80(1)	10(−1)	22.00 ± 0.08	7.55 ± 0.04	5.45 ± 0.02	93.00 ± 2.13	90.00 ± 1.74	95.41 ± 2.19
10	22	40(0)	65(0)	10(−1)	37.00 ± 0.06	6.85 ± 0.03	4.84 ± 0.00	89.20 ± 0.75	85.95 ± 1.35	91.00 ± 1.84
11	20	40(0)	65(0)	10(−1)	37.00 ± 0.18	6.85 ± 0.03	4.84 ± 0.02	89.00 ± 1.71	85.90 ± 1.48	91.50 ± 1.78
12	3	40(0)	65(0)	10(−1)	37.00 ± 0.11	6.85 ± 0.01	4.84 ± 0.07	90.00 ± 1.95	84.00 ± 0.74	92.00 ± 1.96
13	19	40(0)	65(0)	10(−1)	37.00 ± 0.61	6.80 ± 0.01	4.84 ± 0.09	90.00 ± 2.70	85.77 ± 1.21	91.00 ± 1.39
14	9	30(−1)	50(−1)	20(1)	15.00 ± 0.04	6.88 ± 0.03	4.73 ± 0.11	89.00 ± 2.50	91.28 ± 2.18	72.00 ± 1.05
15	24	40(0)	50(−1)	20(1)	30.00 ± 0.08	6.94 ± 0.02	3.75 ± 0.00	88.00 ± 0.96	87.371.72	75.90 ± 1.74
16	13	50(1)	50(−1)	20(1)	36.00 ± 0.81	6.99 ± 0.04	3.140.02	85.00 ± 1.48	84.09 ± 1.77	84.00 ± 0.84
17	26	30(−1)	65(0)	20(1)	16.00 ± 0.45	6.82 ± 0.00	5.50 ± 0.12	86.35 ± 1.98	91.98 ± 0.78	89.50 ± 0.69
18	15	40(0)	65(0)	20(1)	28.00 ± 0.11	6.83 ± 0.01	4.74 ± 0.01	85.95 ± 1.75	89.41 ± 0.95	90.02 ± 1.85
19	25	50(1)	65(0)	20(1)	34.00 ± 0.21	7.00 ± 0.05	4.33 ± 0.13	87.68 ± 0.84	87.47 ± 0.39	94.87 ± 1.36
20	17	30(−1)	80(1)	20(1)	12.90 ± 0.03	7.24 ± 0.01	6.00 ± 0.21	85.42 ± 1.35	95.40 ± 1.25	94.00 ± 2.09
21	6	40(0)	80(1)	20(1)	18.00 ± 0.08	7.30 ± 0.02	5.45 ± 0.11	86.66 ± 1.47	93.05 ± 2.04	92.40 ± 1.78
22	1	50(1)	80(1)	20(1)	18.90 ± 0.14	7.46 ± 0.06	5.26 ± 0.02	90.03 ± 1.64	93.20 ± 1.22	92.00 ± 1.64
23	4	40(0)	65(0)	20(1)	36.00 ± 0.09	6.79 ± 0.03	4.75 ± 0.05	85.95 ± 1.69	89.20 ± 0.27	89.10 ± 1.27
24	23	40(0)	65(0)	20(1)	36.00 ± 0.10	6.78 ± 0.01	4.75 ± 0.14	85.95 ± 1.73	89.10 ± 0.75	89.50 ± 0.82
25	11	40(0)	65(0)	20(1)	36.00 ± 0.23	6.78 ± 0.00	4.75 ± 0.03	84.00 ± 2.11	91.00 ± 1.83	89.50 ± 0.97
26	2	40(0)	65(0)	20(1)	36.00 ± 0.15	6.79 ± 0.15	4.74 ± 0.28	84.00 ± 1.49	91.00 ± 2.62	89.00 ± 1.91

Nutritional data are presented as mean ± standard deviation (n = 5). Sensory data are presented as mean ± standard deviation (n = 50)
Experimental design was done using three-level factorial-response surface methodology (3LF-RSM) and regression analysis using Design Expert software 10.0
Items in parenthesis (for high protein soymeal, amaranth flour, and modified corn starch) are values of independent variables in coded form whereas, those not in parenthesis are the actual values of the independent variables

phenolic content was obtained using Folin-Ciocalteu colourimetric as illustrated by Pang et al. (2018) while gallic acid was used as the standard.

Colour

The colour of the grain was measured using chroma meter (CR-400/410, Konica Minolta). The grains were evaluated for L* (which indicates lightness and ranged from 0 to 100 representing dark to light), a* (indicates the degree of redness to greenness), and b* (which indicates the degree of yellowness to blueness).

Statistical analysis

All experimental data except sensory attributes were replicated five times ($n = 5$) whereas sensory characteristics were carried out using fifty ($n = 50$) semi-trained panelists. Mathematical modeling and optimization of the flaking process were carried out using a three-level factorial-response surface methodology (3LF-RSM) of the Design-Expert software version 10.0 (Stat-ease Inc., MN, USA). Means differences were evaluated at a 5% significant level using Independent *T*-Test of SPSS version 17.

Results and discussion

Modeling and parameter optimization

The experimental design and chemosensory attributes of the consumer-ready flakes from pseudocereal, modified corn starch, and high-protein soybean meal are presented in Table 1. The regression models relating the response parameters (protein, fat fibre, appearance, taste,

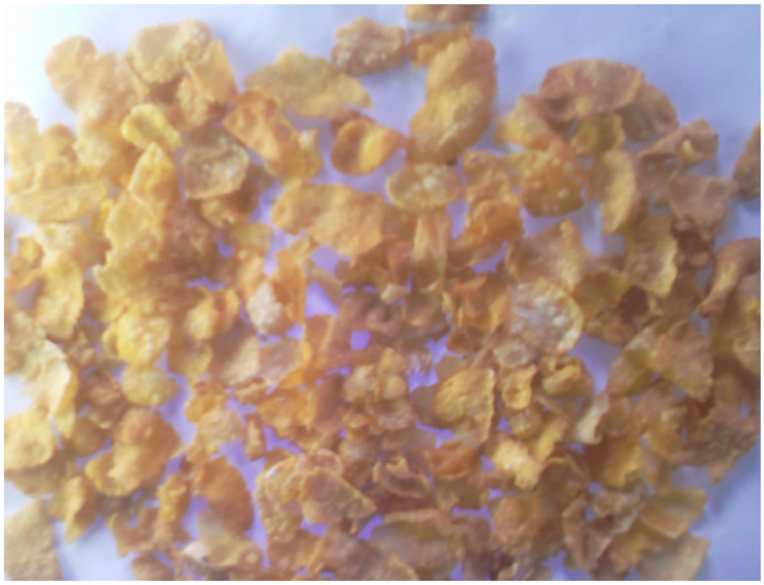

Fig. 1 Consumer-ready flakes produced at optimal condition

and acceptability index) to the independent variables (high protein soymeal, amaranth flour, and 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 (5%), 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 (R^2) of the model parameters was very high. A suitable model is expected to have the value of R^2 nearer to unity; an empirical model fits better when it has an R^2 value approaching unity. The coefficient of determination, R^2 ranged between 0.8985 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 (Jideani 2010). 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 consumer-ready flakes parameters. Consequently, the generated quadratic models were ample to depict the processing process for the consumer-ready flakes.

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 14.96 to 679.45, which were significantly higher than 4. Figure 2 shows the response surface plots for the chemo-sensory parameters. Figure 2a, b, and e show that an increase in the amount of high-protein soymeal in the formulation improved the protein, fat, and appearance of the consumer-ready flakes. Figure 2c, d, and f show that the fibre, taste, and acceptability index of the flakes were favoured by the addition of more amaranth flour in the formulation.

The mathematical illustrations for the consumer-ready flakes are presented in eqs. (6)–(11).

$$\begin{aligned} Protein = {} & 34.07\beta + 7.65h \\ & + 0.33ac - 5.53a - 0.94c - 3.85ha \\ & - 0.15hc - 6.24\text{h}2 - 6.74\text{a}2 \end{aligned} \tag{6}$$

$$\begin{aligned} Fat = {} & 6.82\beta + 0.09h + 0.21a + 0.04ha \\ & + 0.07h2 \\ & + 0.28a2 - 0.02c - 6.68E - 3hc - 6.57E - 3ac \end{aligned} \tag{7}$$

$$\begin{aligned} Fibre = {} & 4.79\beta + 0.84a + 0.22ha + 0.18h2 + 8.14E \\ & - 3ac - 0.54h - 0.05c - 0.04hc - 0.14a \end{aligned} \tag{8}$$

$$\begin{aligned} Appearance = {} & 87.41\beta + 1.56a + 1.83c + 1.67ha \\ & + 1.60ac + 0.52h2 \\ & + 0.95a2 - 0.98h - 1.34hc \end{aligned} \tag{9}$$

$$\begin{aligned} Taste = {} & 87.41\beta + 1.63a + 1.34ha + 1.31hc \\ & + 0.44h2 \\ & + 1.25a2 - 0.98h - 1.73c - 1.61ac \end{aligned} \tag{10}$$

Table 2 Regression analysis of consumer-ready flakes from high-protein soymeal, amaranth and modified corn starch

Model Terms	Protein		Fat		Fibre		Appearance		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	–
β	–	34.07	–	6.82	–	4.79	–	87.76	–	87.41	–	90.51
h	< 0.0001	7.65	< 0.0001	0.09	< 0.0001	−0.54	0.0013	− 0.98	0.0091	− 0.98	< 0.0001	2.82
a	< 0.0001	−5.53	< 0.0001	0.21	< 0.0001	0.84	< 0.0001	1.56	0.0001	1.63	< 0.0001	7.44
c	0.1542	− 0.94	0.0076	−0.02	< 0.0001	− 0.05	< 0.0001	1.83	< 0.0001	−1.73	< 0.0001	−1.13
ha	0.0035	−3.85	0.0008	0.04	< 0.0001	0.22	< 0.0001	1.67	0.0043	1.34	< 0.0001	−3.41
hc	0.8733	−0.15	0.4054	−6.68E-3	< 0.0001	−0.04	< 0.0001	−1.34	0.0011	1.31	0.1496	−0.26
ac	0.7234	0.33	0.4125	−6.57E-3	0.0011	8.14E-3	< 0.0001	1.60	0.0002	−1.61	0.0944	0.31
h^2	0.0003	−6.24	< 0.0001	0.07	< 0.0001	0.18	0.1808	0.52	0.3815	0.44	< 0.0001	1.91
a^2	0.0001	−6.74	< 0.0001	0.28	< 0.0001	−0.14	0.0212	0.95	0.0210	1.25	< 0.0001	−5.28
Lack-of-fit	0.7471	–	0.1946	–	0.0587	–	0.5807	–	0.0844	–	0.0604	–
R^2	0.9182	–	0.9901	–	0.9999	–	0.9413	–	0.8985	–	0.9941	–
Adj. R^2	0.8797	–	0.9855	–	0.9999	–	0.9137	–	0.8508	–	0.9914	–
Pred. R^2	0.8282	–	0.9731	–	0.9998	–	0.8609	–	0.6698	–	0.9813	–
Ad. Pred.	14.96	–	46.43	–	679.45	–	21.07	–	16.26	–	68.84	–

B – Intercept; RC – Regression coefficient; h – high-protein soymeal; a – amaranth; m – modified corn starch; R^2 – coefficient of determination; Adj. R^2- adjusted coefficient of determination; Pred. R^2 – predicted coefficient of determination; Ad. Pred. – adequate prediction

$$Acceptability\ Index = 90.51\beta + 2.82h + 7.44a + 0.31ac + 1.91h2 - 1.13c - 3.41ha - 0.26hc - 5.28a2 \quad (11)$$

Where h is the quantity of high protein soymeal, a is the quantity of amaranth flour, and c is the quantity of modified corn starch.

Optimal values and models evaluations

The empirical expressions in eqs. (6) to (11) were solved using Design Expert Software while the values of protein, fibre, appearance, 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 (34.78 g, 56.52 g, and 8.70 g of high protein soymeal, amaranth flour, and modified corn starch, respectively) with the corresponding protein of 29.05 g/100 g, fat (6.00 g/100 g), fibre (4.10 g/100 g), appearance (87.10%), taste (92.00%) and acceptability index (92.75 g/100 g) (Table 3). With these values of the independent variables at optimized conditions, the selected proximate and sensory parameters evaluated showed that the optimized enriched consumer-ready flakes were rated high. The low values of the absolute average deviation (AAD) showed the

Table 3 Optimal condition for high-protein consumer-ready flakes from high-protein soymeal, amaranth and modified corn starch

Parameter	Actual Value	Predicted Value	Residual	AAD (%)
Independent variables				
High-protein soymeal, h (g/100 g)	–	34.78	–	–
Amaranth flour, a (g/100 g)	–	56.52	–	–
Modified corn starch, m (g/100 g)	–	8.70	–	–
Dependent variable				
Protein (g/100 g)	29.05 ± 0.91	30.43 ± 1.10	−1.41	4.85
Fat (g/100 g)	6.00 ± 0.11	5.95 ± 0.03	0.05	0.83
Fibre (g/100 g)	4.10 ± 0.04	4.22 ± 0.01	−0.12	2.93
Appearance (%)	87.10 ± 1.24	85.93 ± 0.88	1.17	1.34
Taste (%)	92.00 ± 1.34	89.14 ± 1.16	2.86	3.11
Acceptability index (%)	92.75 ± 1.72	91.64 ± 0.60	1.11	1.20

Nutritional data are presented as mean ± standard deviation (n = 5). Sensory data are presented as mean ± standard deviation (*n* = 50). *AAD* Absolute average deviation

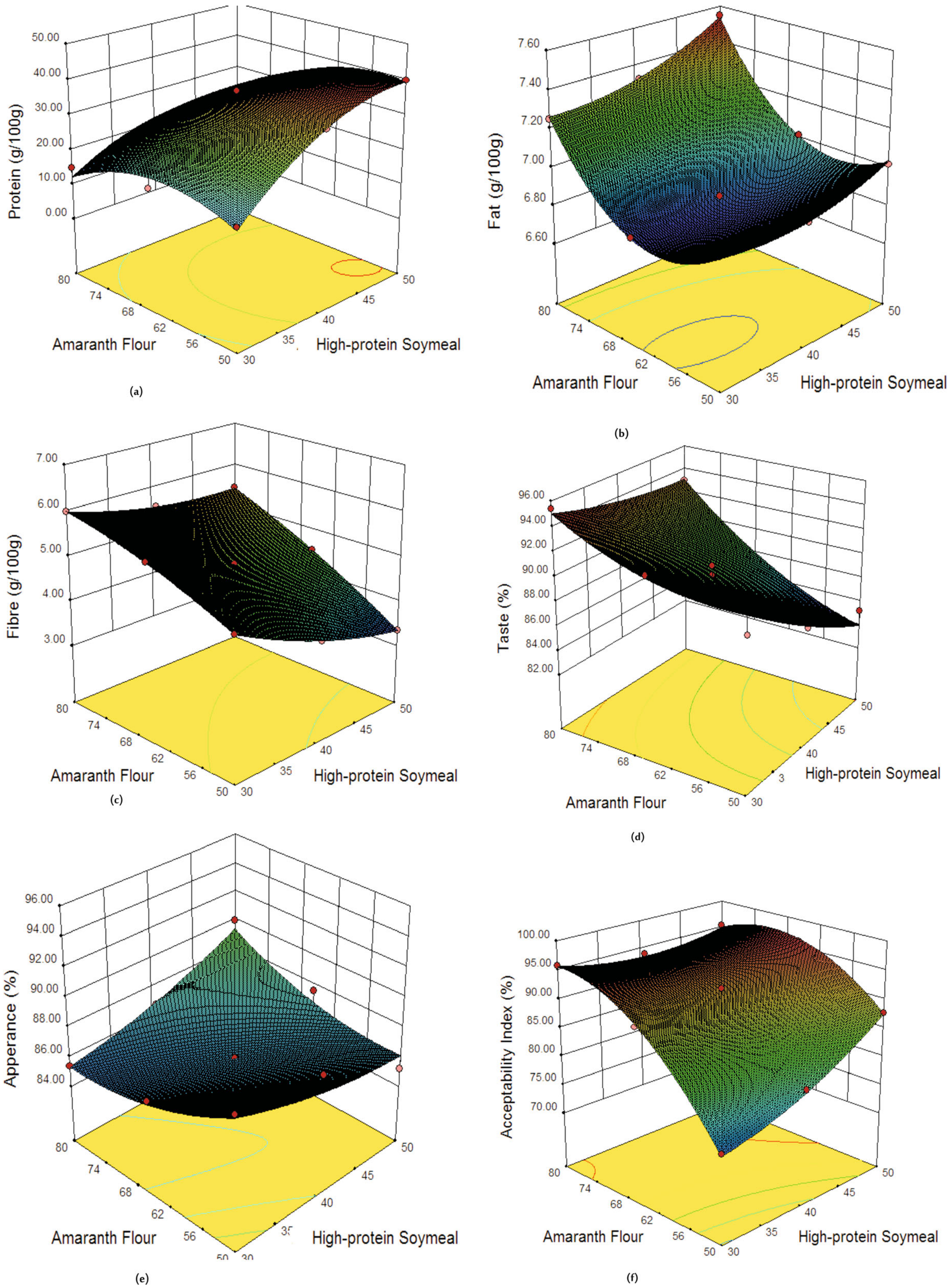

Fig. 2 Response surface plots for consumer-ready flake produced at optimal condition (**a**) protein (**b**) fat (**c**) fibre (**d**) taste (**e**) appearance (**f**) acceptability index

Table 4 Nutritional properties of consumer-ready flakes from high-protein soymeal, amaranth and modified corn starch produced under optimal condition

Parameter	Consumer-ready Flakes	Control (NASCO Cornflakes)[a]
Proximate (g/100 g)		
Protein	29.05 ± 0.91	7.50
Fat	6.00 ± 0.11	0.80
Fibre	4.10 ± 0.04	3.00
Ash	3.84 ± 0.19	
Moisture	8.96 ± 0.42	
Carbohydrate	48.05 ± 1.25	80.00
Mineral (mg/100 g)		
Sodium	40.36 ± 0.82	0.70
Calcium	249.74 ± 1.58	
Potassium	908.71 ± 2.83	
Magnesium	272.35 ± 1.76	
Iron	12.08 ± 0.98	14.00
Phosphorus	618.42 ± 1.94	
Zinc	38.63 ± 0.90	
Vitamin		
Thiamin (B_1) (mg/100 g)	0.19 ± 0.00	1.20
Riboflavin (B_2) (mg/100 g)	0.25 ± 0.01	1.30
Niacin (B_3) (mg/100 g)	6.41 ± 0.12	
Folic Acid (B_9) (μg/100 g)	123.50 ± 1.48	0.19
Pyridoxine (B_6) (mg/100 g)	4.85 ± 0.61	1.50
Pantothenic Acid (B_5) (mg/100 g)	1.98 ± 0.07	
Phytochemicals		
Tannin (g/100 g)	0.21 ± 0.01	
Phytate (mg/100 g)	1.85 ± 0.16	
Alkaloids (mg/100 g)	2.96 ± 0.13	
Total Phenolic (GAE/100 g)	908.24 ± 1.83	
Flavonoids (mg RE/100 g)	12.75 ± 0.25	
Antioxidant Activity		
DPPH (μmolTEAC/100 g)	1850.41 ± 2.31	
FRAP (mmol Fe^{2+} /100 g)	21.75 ± 0.83	
Colour		
L^* (Lightness)	55.42 ± 0.68	
a^* (Redness)	2.51 ± 0.09	
b^* (Yellowness)	4.05 ± 0.11	

Data are presented as mean ± standard deviation (n = 5). *TEAC* Trolox equivalent antioxidant capacity, *GAE* Gallic acid equivalent, *RE* Rutin equivalent, *DPPH* - 2,2-diphenyl-1-picryl-hydrazl, *FRAP* Ferric ion reducing antioxidant power
[a]Manufacturer's nutrition information

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 consumer-ready flakes from high protein soybean meal, amaranth flour, and modified corn starch.

Proximate, mineral, and vitamin compositions

The results of the proximate, mineral, and vitamin analyses conducted on the optimized consumer-ready flakes from high protein soybean meal, amaranth flour, and modified corn starch and the control are shown in Table 4. The results showed that the protein of the produced flake was 29.05 g/100 g whereas, that of the control was 7.50 g/100 g. That was higher than the 2 g reference standard protein value for ready-to-eat flakes according to USDA (2002). It was equally higher than the 13 g protein found in commercial corn flake (Golden morn). The higher amount of protein was due to the incorporation of high protein soymeal into the product. This is particularly good as protein plays a prominent role in bodybuilding. The fat content was found to be 6.00 g/100 g. That value was comparable to the value reported by Mbaeyi-Nwaoha and Uchendu (2016) 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 consumer-ready flakes was 4.10 g/100 g. The value was higher than what Mbaeyi (2005) reported for breakfast cereal from maize meal and coconut. Similarly, it was higher than the reference fibre content of 0.8 g according to USDA (2002). 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 consumer-ready flake makes it a healthy diet. The moisture content of the processed flakes was 8.96%. This value was found to be in the same range as the 4.71–9.88% range reported by Mbaeyi-Nwaoha and Uchendu (2016). It was also 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 48.05 g/100 g. 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 than the 24 g which is the reference value for carbohydrate according to USDA (2002). The ash content was 3.84 g/100 g. The high quantity could be an indication of the richness of the flakes in minerals. 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 40.36 mg/100 g 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 (2002). The not too high amount could be desirable because the excess of sodium in industrialized food could be dangerous to health (Santos et al. 2020). The calcium content was 249.74 mg/100 g. That was higher than the standard reference according to USDA which is 100 mg. The amount was comparable to the value reported by Okafor and Usman (2013) 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 (Sui et al., 2019). Potassium was found to be 908.71 mg/100 g. This figure is far more than the value reported by Mbaeyi (2005) for breakfast cereal from sorghum and pigeon pea, and potassium content of 107.0–238.0 mg/100 g. The potassium maintains a balance between acid and base content in the body (Soetan et al. 2010). The iron content was 12.08 mg/100 g. This was low compared to the figures quoted by Anne et al. (2019); they reported an iron content of 68.30–130.47 mg/100 g in their breakfast cereal samples. The quantity of phosphorus was high; the consumer-ready flakes yielded 618.42 mg/100 g. The zinc content was 38.63 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 0.19 mg/100 g, 0.25 mg/100 g, 6.41 mg/100 g, 123.50 mg/100 g, 4.85 mg/100 g and 1.98 mg/100 g, respectively. Thiamin is needed for energy metabolism and important in nerve function. Riboflavin supports growth, reproduction, and vision. Niacin is attributed to neurological functions whereas; folic acid is needed in making DNA and new cells. Pantothenic acid supports the skin, hair, healing of a wound, and blood lipid profile. Pyridoxine enhances nerve functioning and the formation of blood (FAO/WHO 2004).

Phytochemical compositions and antioxidant activities

Results of the tannin, phytates, alkaloids, total phenolic, and flavonoids as well as the antioxidant activities of DPPH and FRAP are presented in Table 4. Emerging research has shown that phytochemicals boast important health benefits such as reduced inflammation and hormone function (Liu 2013).

The quantity of tannin found in the consumer-ready flakes was 0.21 g/100 g. The low quantity of tannin in consumer-ready flakes is an indication that the flakes could readily be absorbed as little tannin is available to form an insoluble complex. The amount of flavonoids found in the consumer-ready flakes was 12.75 mg RE/100 g. Flavonoids are known to possess anticarcinogenic, anti-inflammatory, and anti-allergic properties (Brown 1980). The total phenolic component was found to be 908.24 GAE/100 g. Phenolics are the main source of antioxidants in cereal grains concentrated mainly in the bran/germ fraction and are considered powerful oxidants in vivo and in vitro. The phytate found in the flake was 1.85 mg/100 g. The low amount of this antinutrient shows that there will be little or no reduction in the absorption of minerals. Analysis of the flakes also revealed that it contained 2.96 mg/100 g of alkaloids. Alkaloids possess diverse and significant physiological effects on humans and have been used for thousands of years as medicines, stimulants, and aphrodisiacs.

The 2, 2-Diphenyl-1-picrylhydrazyl (DPPH) of the consumer-ready flake was obtained as 1850.41 μmol-TEAC/100 g. DPPH describes the potential of the consumer-ready flake as a free radical scavenger when consumed. The ferric reducing antioxidant power (FRAP) of the flakes was 21.75 mmolFe^{2+}/100 g. FRAP measures the reducing properties of flakes.

Physico-functional and sensory attributes

The results of the physico-functional and sensory attributes of the consumer-ready 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. The loose density of the consumer-ready flakes was 0.640 g/ml. This value is considered low and is a good attribute concerning its packaging and storage. The value of the packed bulk density (PBD) of the enriched flakes was 0.849 g/ml. The porosity of the enriched flake was 30.21%. Porosity is a measure of the voids between the solid particles of a material. Water absorption capacity represents the ability of a product to associate with water under conditions where water is limiting (Singh 2001). The water absorption capacity (WAC) of the flour analyzed at 30 °C, 50 °C and 70 °C were 22.41 g/g, 57.93 g/g, and 72.65 g/g, respectively. The result showed that as the temperature increased, the water absorption capacity of the flake increased.

In Table 5, the appearance of the enriched ready-to-eat flake was scored 87.10%. Considering the high score, it indicated that the flake had a very high eye appeal and was highly accepted by the panelists. The taste of the flake was equally scored high; it had 92.0%. The aroma of the flake got a score of 88.56% 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 92.75%. That was an indication that the flake had an overall sensory appeal and acceptability (Food Insight, 2011). In general, the optimized consumer-ready flake was significantly ($p < 0.05$) superior to the control in aroma, taste, and acceptability index.

The colour of the consumer-ready flakes as presented in Table 4 showed that the L*, a*, and b* values were 55.42, 2.51, and 4.05, respectively.

Amino acids profile

The amino acid profiles of the optimized enriched flake are presented in Table 6. With reference to hen's egg (g/100 g), most of the amino acids analyzed, especially the essential amino acids, in the consumer-ready flakes had a very high amino acid score. Methionine gave 110%, while histidine yielded 125.42%. Isoleucine gave 112.86%, leucine yielded 91.45%, lysine (85.81%), phenylalanine yielded 105.10%, threonine yielded 62.55%, while valine yielded 63.07% with reference to hen's egg. Methionine is essential to cartilage and liver health. 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

Table 5 Physico-functional and sensory characteristics of consumer-ready flakes from high-protein soymeal, amaranth and modified corn starch produced under optimal condition

Parameter	Consumer-ready Flakes	Control (NASCO Cornflakes)[a]
Physico-functional		
Loose bulk density (g/ml)	0.640 ± 0.011[a]	0.623 ± 0.015[a]
Packed bulk density (g/ml)	0.849 ± 0.023[a]	0.852 ± 0.012[a]
Porosity (%)	30.21 ± 0.34[a]	28.52 ± 0.89[a]
Water absorption capacity		
30 °C	22.41 ± 0.23[a]	17 ± 0.06[b]
50 °C	57.93 ± 0.25[a]	55.89 ± 1.03[a]
70 °C	72.65 ± 1.29[a]	68.35 ± 0.71[b]
Sensory attributes (%)		
Appearance	87.10 ± 1.24[b]	90.35 ± 0.49[a]
Aroma	88.56 ± 1.97[a]	82.17 ± 0.38[b]
Taste	92.00 ± 1.34[a]	87.25 ± 0.14[b]
Acceptability index	92.75 ± 1.72[a]	88.30 ± 0.52[b]

Physico-functional data are presented as mean ± standard deviation (n = 5). Sensory data are presented as mean ± standard deviation ($n = 50$)
[a, b]Values with the same superscript in the same row are not significantly different at 5% significant level using analysis of variance (ANOVA) and Duncan test

Table 6 Amino acids profile of consumer-ready flakes from high-protein soymeal, amaranth and modified corn starch produced under optimal condition

Amino Acid	Consumer-ready flakes	Hen's Egg[a] (g/100 g)	Amino Acid Score with Reference to Hen's (%)
Arginine	4.95 ± 0.24	6.10	81.15
Cysteine	2.01 ± 0.02	1.80	111.67
Methionine	3.52 ± 0.05	3.20	110.00
Histidine	3.01 ± 0.02	2.40	125.42
Isoleucine	6.32 ± 0.11	5.60	112.86
Leucine	7.59 ± 0.13	8.30	91.45
Lysine	5.34 ± 0.09	6.20	85.81
Tyrosine	2.91 ± 0.10	4.00	72.75
Phenylalanine	5.36 ± 0.02	5.10	105.10
Threonine	3.19 ± 0.08	5.10	62.55
Tryptophan	2.76 ± 0.01	–	–
Valine	4.73 ± 0.25	7.50	63.07
Glycine	3.90 ± 0.04	3.00	130.00
Glutamic Acid	16.28 ± 0.26	12.00	135.67
Aspartic Acid	11.32 ± 0.12	10.70	105.79
Serine	3.14 ± 0.10	7.90	39.75
Proline	4.80 ± 0.24	3.80	126.32
Alanine	4.21 ± 0.13	5.40	77.96
TAA	95.34	98.10	–
TNEAA	48.57	59.60	–
TEAA with histidine	46.77	40.4	–
TEAA without histidine	43.76	38	–
EAAI (%)	95.74	–	–
p-BV (%)	92.65	–	–
$p\text{-}PER_1$	2.05	–	–
$p\text{-}PER_2$	2.12	–	–

[a] Olaofe et al. (2013)

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)

kidney disease. Phenylalanine is required by the body for the synthesis of important signaling molecules (Olaofe et al. 2013). Isoleucine helps to increase the rate of protein synthesis and promote muscle tissue formation. The total amino acid in the optimized consumer-ready flake was 95.34% which competes favourably with hen's egg (98.10%). The results showed that some essential amino acids such as methionine, histidine, isoleucine, and phenylalanine of the produced flakes were superior to those of hen's egg.

The p-BV of the consumer-ready flake was 92.65%. The result indicated that the consumer-ready 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 (Bhilave and Nalawade 2011). The p-PER was 2.05 for the consumer-ready 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 95.74%. According to Shi et al. (2020), a good nutritional value is a representation of high EAAI and a protein-material is regarded as a good protein-source if it has EAAI greater than 90; conversely, a value below 70 is regarded as a low protein-source. This implies that the consumer-ready flake produced from blends of high protein soymeal, amaranth flour, and modified corn starch at optimized conditions was a good source of protein.

Table 7 Amino acids scores with reference to FAO provision amino acid scoring pattern (g/100 g)

Amino Acid	Consumer-ready flakes	Scoring value[a]	Amino acid score
Methionine + Cysteine	5.53	3.50	1.58
Isoleucine	6.32	4.00	1.58
Leucine	7.59	7.00	1.08
Lysine	5.34	5.50	0.97
Phenylalanine + Tyrosine	8.27	6.00	1.38
Threonine	3.19	4.00	0.80
Tryptophan	2.76	1.00	2.76
Valine	4.73	5.00	0.95

[a]Olaofe et al. (2013)

The amino acid scores with reference to the FAO amino acid scoring pattern are shown in Table 7. The high scores recorded by isoleucine, leucine, tryptophan, methionine, and cysteine indicated that the optimized flake is a good protein source.

Conclusion

Consumer-ready flakes were produced from *Amaranthus viridis*, high-protein soymeal, and modified corn starch. The established optimal flour mixtures were high-protein soymeal (34.78 g/100 g), amaranth (56.52 g/100 g), and modified corn starch (8.70 g/100 g). The flour mixtures resulted in flakes with 29.05 g/100 g protein, 6.0 g/100 g fat, 4.10 g/100 g fibre, appearance (87.10%), taste (92.0%), and acceptability index (92.75%). The formulated flakes showed good quality characteristics in mineral, vitamins, and amino acids. The EAAI> 90% in this study proved the product to be a good protein source. The study illustrated the feasibility of formulating quality consumer-ready flakes from flour blends of amaranth, high-protein soymeal, and modified corn starch. The production process is scalable and could be employed for both domestic and industrial purposes.

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Authors' contributions
TOF designed experiments, collected and analyzed data, manuscript preparation and supervision; KCA collected data and prepared manuscript; CCA designed experiments and collected data; LOO designed experiments and collected data; TMO collected data and analyzed data, prepared manuscript; JUC collected data and prepared manuscript; KOO collected data and prepared manuscript. All authors approved the manuscript.

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Author details
[1]Department of Food Technology, Akanu Ibiam Federal Polytechnic, Unwana, Ebonyi State, Nigeria. [2]Department of Science Laboratory Science, Akanu Ibiam Federal Polytechnic, Unwana, Ebonyi State, Nigeria. [3]Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

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