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PROTEIN, ENERGY, AND ANTIOXIDANT-DENSE FLAKED BREAKFAST CEREAL BY RESPONSE SURFACE OPTIMISATION OF COMPOSITE FLOUR COMPONENTS (YELLOW MAIZE, SOYBEAN, AND MANGO PEEL)

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ABSTRACT

Breakfast flakes are a popular choice among consumers for a quick and nutritious meal. However, to enhance their nutritional value, supplementation with nutrient-dense ingredients is essential. In this study, soybean and mango peel were utilized to develop protein, energy, and antioxidant-rich flakes through an optimized formulation process. A three-component constrained optimal mixture experimental design was employed, utilizing yellow maize (0-100%), soybean (0-50%), and mango peel flour (0-50 %) blends. Standard procedures were employed to analyze the proximate composition, antioxidant properties, and colour of the flake samples. Sensory analysis using a 9-point hedonic scale was performed by thirty panellists to evaluate the flakes. Statistical significance was determined at $\alpha \leq 0.05$, and optimization was achieved by maximizing protein, energy, and antioxidant properties. The moisture content of the flake samples ranged from (7.03-9.78 %), protein (8.05-35.37 %), fat (3.13-13.74 %), ash (2.72-5.88 %), crude fibre (1.75-5.55 %), and carbohydrate (39.41-70.94 %). The energy value ranged from 341.95 to 422.71 kCal. Mango peel flour increment significantly influenced the antioxidant properties of the flakes, while changes in protein, fat, and energy were dependent on the quantity of soybean flour. The inclusion of up to 33.33% mango peel flour did not significantly alter the sensory ratings compared to the control sample (100% maize flour). The optimized composite formulation for nutrient-dense flakes consisted of 50 % yellow maize, 28.45 % soybean, and 21.45 % mango peel. Enriching flakes with soybean and mango peel flour significantly improved their protein, energy, and antioxidant properties, making them a healthier choice for consumers of all ages.

1.Introduction

Ready-to-eat cereals have become a significant commodity in the global market, catering to the fast-paced lifestyles of consumers worldwide. Researchers have delved into the trend of ready-to-eat cereals by diversifying cereal products, including breakfast cereal flakes (Kince *et al.*, 2017; Tay *et al.*, 2021). Traditional flakes are predominantly derived from cereals, rich in carbohydrate content. This emphasis on carbohydrates may underlie the assertion that cereal-based foods are often labelled as unhealthy or "junk" foods (Bolanho *et al.*, 2015). Research, such as that by Jones & Poutanen (2020), suggests that the protein content in breakfast cereal flakes plays a pivotal role in conferring health benefits. Evidently, high-protein and antioxidant-rich breakfast meals are superior to low-protein and low-antioxidant breakfast meals in terms of maintaining normal blood sugar and resolving oxidative stress (Osunrinade et al., 2022; Ademosun et al., 2023).

The nutritional benefit obtainable from the consumption of a cereal flake is dependent on the characteristics of the flour samples (Okache et al., 2020). Researchers have explored the use of cereals, legumes, and tubers to determine their influence on the flakes produced (Adebanjo et al., 2020; Juniour et al., 2022; Olorunsogo & Adejumo, 2023; Sumczynski et al., 2015). Maize holds a prominent position as a primary cereal utilized in flake production, boasting a myriad of applications. It stands as the second most widely cultivated cereal globally, trailing only wheat in terms of production volume (Mir et al., 2019; Oladapo et al., 2017). In developing countries, maize plays a vital role, meeting more than half of the total caloric and protein requirements (Serna-Saldivar, 2015). Whole grain flour and maize-based products are sought after for their flavour profile and nutritional advantages (Žilić et al., 2010). Nevertheless, maize is deficient in lysine and tryptophan, and its protein content typically falls below 10% (Chaudhary et al., 2013). This deficiency underscores the necessity for enrichment and supplementation strategies when incorporating maize into nutrient-dense food products.

Enrichment and supplementation of cereal products have emerged as common practices aimed at addressing nutritional deficiencies and producing functional food items tailored to meet the populace's dietary requirements. Research indicates that combining cereals with legumes results in products with enhanced nutritional profiles and calorific values compared to those made solely from cereals or legumes (Tanyitiku & Petcheu, 2022). Soybeans, a commonly utilized legume for supplementation in cereal products, offer significant nutritional benefits. The formulation of food products with inherent nutritional properties has become increasingly vital as a strategy to mitigate various common diseases associated with oxidative stress in humans. By incorporating ingredients rich in antioxidants and other essential nutrients, food items can contribute to maintaining overall health and well-being.

Due to its nutritional value and cost-effectiveness, mango peel has gained attention as a possible nutritional source for dietary supplementation and enrichment. According to Jahurul et al. (2015), by-products from the mango business, such as the peel, make up between 35% and 60% of the entire fruit weight. Mango peels are frequently thrown away, although they contain a wealth of nutrients like phenolic compounds, carotenoids, vitamin C, and dietary fiber. According to Dorta et al. (2014), the extractable and non-extractable polyphenol (NEP) contents of mango peel are notably high at 7.22% and 5.54%, respectively. These polyphenols exhibit potent antioxidant activity, making mango peel a valuable dietary addition for combating oxidative stress and promoting overall health.

Given the growing urban population's preference for convenient breakfast options and the prevalent low protein and antioxidant content in ready-to-eat cereal-based meals, it is imperative to investigate optimization strategies for producing protein, energy, and antioxidant-rich breakfast cereal flakes. Therefore, this study utilized the D-optimal response surface methodology to determine the composite mixture of yellow maize, soybean, and mango peel flours that would produce protein, energy, and antioxidant-rich breakfast cereal flakes.

2.Materials and Methods

2.1. Materials

For this research, yellow maize grain (*Zea mays*) and soybeans (*Glycine max*) were sourced from the Sango market in Saki. Mangoes were hand-plucked from The Oke-Ogun Polytechnic, also located in Saki, Oyo State. Additional ingredients such as instant-filled milk (Dano™), granulated sugar, salt, and transparent plastic containers were procured from a local market.

2.2. Sample Preparation

2.2.1. Preparation of maize flour

The methodology outlined by Odimegwu et al. (2019) was followed with minor adjustments for this study. Initially, about 4 kg of yellow maize grain was carefully sorted, cleaned, and subsequently milled using an attrition milling machine. The resulting yellow maize flour was then carefully packaged into well-labelled, airtight polyethylene bags to maintain its freshness and integrity for subsequent usage and analysis.

2.2.2. Preparation of Soybean flour

The methodology outlined by Tanyitiku & Petcheu (2022) was employed with minor adjustments in this study. Briefly, about 4 kg of soybeans were sorted and wet cleaned. Subsequently, the soybeans were boiled in a pot of water for 20 min. Following the boiling process, the soybeans were manually dehulled, thoroughly washed, and then subjected to oven drying. Once dried, the soybeans were milled into flour using laboratory attrition mill. Finally, the resulting soybean flour was carefully packaged in a well-labelled, airtight, high-density polyethylene bag for further usage and subsequent analysis.

2.2.3. Preparation of Mango peel flour

The freshly harvested mango fruits underwent initial physical sorting to identify and remove any peel defects and spots. Following this, the mangoes were thoroughly washed with clean water and peeled using a knife. The resulting fruit peels were then cut into small pieces and subjected to drying at 50°C in a force-draught oven. Once adequately dried, the peel pieces were milled into fine flour using an attrition mill. Finally, the dried mango peel flour was carefully packaged in a well-labelled, airtight polyethylene bag for subsequent use and analysis.

2.2.4. Sample Formulation for the production of composite flour

Composite flour for preparing flakes made from maize, soybean, and mango peel flours was interacted using design expert 6.0.2 software, which lays out a strategy for mixture design of experiments that provides maximum efficiency and effectiveness. A three-component constrained 0-100 % (yellow maize), 0-50 % (soybean), and 0-50 % (mango peel flour) using D-optimal mixture response surface methodology was employed, and 14 randomized experimental runs were generated, which consisted of 10 factorial runs and four replicates.

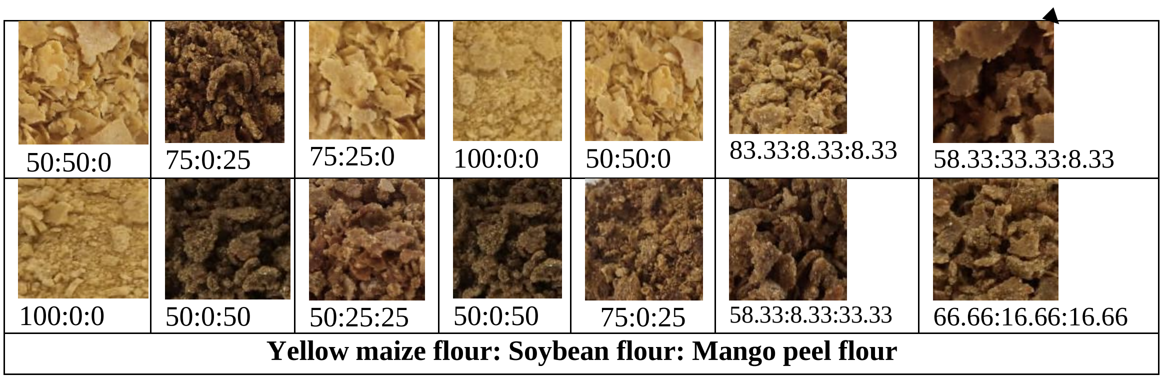

Figure 1. Flakes samples from composite of yellow maize, soybean and mango peel

2.2.5. Breakfast Cereal Flakes Production

A minor variation of the Tay et al. (2021) and Odimegwu et al. (2019) methods was used to prepare the breakfast cereal (flakes). The prepared composite flour (250 g) was combined with 750 ml of water, 10 g of sugar, 2 g of salt, and 6 g of milk. To get a semi-dried product, the batter was thinly put onto a cleaned, flat, and greased steel tray and baked at 125°C for 20 minutes. After being partially dried, the items were broken up into flakes and put back in the oven to toast and dry further at 130 °C for 15 minutes. After being cooled, the flake samples (Figure 1) were placed in an airtight container for subsequent laboratory analysis and sensory assessment.

2.3. Determination of Proximate Composition of Flakes and Flours

The proximate compositions of both flour and flake samples were assessed following the guidelines outlined by the Association of Official Analytical Chemists (AOAC, 2012). Protein content was quantified using the Kjeldahl method as specified by AOAC (2012). Flake samples ash content was quantified by subjecting the samples to a muffle furnace at 600 °C for 3 hours, while moisture content was determined through a forced air draft oven set at 105°C to operate for 4 h. Crude fiber and fat contents were also determined following the procedures outlined in AOAC (2012). Carbohydrate content was calculated through the difference method, while the Atwater factor that gives the energy value per unit mass for protein (4), carbohydrate (4), and fat (9) was used to estimate the energy content of flake samples in Kilo-calories per gram.

2.4. Determination of Antioxidant Properties

2.4.1. Extraction method for antioxidant analysis

The extraction of antioxidant components from flour and flake samples followed the method outlined by Osunrinade et al. (2022). In summary, samples were initially ground using a hand-operated attrition mill. Subsequently, 1g of the sample was subjected to extraction with 20 mL of 80 % ethanol for 48 hours with intermittent agitation. Following extraction, the mixture underwent filtration using Whatman No 1 filter paper. The filtrate was kept at 4 °C in a refrigerator prior to subsequent analysis of antioxidant properties.

2.4.2. Determination of the total phenolic content (TPC)

Total phenolic content (TPC) in flake samples was measured using the procedure described by Osunrinade et al. (2022). In short, 0.8 mL of 7.5% Na_2CO_3 and 0.2 mL of the extract were mixed with 1 mL of five-fold diluted Folin-Ciocalteu's reagent. After 20 minutes of reaction time at room temperature in the dark, the absorbance at 765 nm was measured in comparison to a blank sample. The findings were measured and reported as milligrams of gallic acid equivalent (GAE) per gram of dry weight.

2.4.3. Determination of Total Flavonoid Content (TFC)

The total flavonoid content (TFC) of flake samples was calculated using the approach described by Saikia et al. (2012). First, 1.25 mL of distilled water was used to dilute 0.25 mL of the flake sample extract and standard catechin solution, each in triplicate. After adding 75 µL of a 5% $NaNO_3$ solution, the mixture was allowed to sit at room temperature for six minutes. 150 µL of a 10% $AlCl_3$ solution was added after the first incubation, and the mixture was then incubated for an additional five minutes. After that, 0.5 mL of a 1 M NaOH solution was added, and then distilled water was added to bring the volume up to 3 mL. The absorbance was determined with a spectrophotometer (JENWAY, Model 7305) set at 510 nm. The concentration of TFC in the flake samples was calculated using a calibration curve and the resulting equation, which was represented in milligrams per gram (mg/g).

2.4.4. Determination of Total Antioxidant Capacity (TAC)

Flake extracts' total antioxidant capacity was evaluated using the methodology proposed by Osunrinade et al. (2022). The phosphomolybdenum reagent was made by mixing 3.3 mL of sulfuric acid, 335 mg of sodium phosphate, and 78.4 milligrams of ammonium molybdate with 100 mL of distilled water. After that, the phosphomolybdenum reagent and 0.1 mL of the flake extract were combined, and the combination was put in a water bath that was heated to 95 °C. After 90 minutes of boiling the combination, the absorbance of the resultant solution was measured at 695 nm. Instead of using the sample, different amounts of gallic acid were used to create a standard curve. The total antioxidant capacity of the flake extract was determined using the equation derived from the standard curve, and the findings were represented in milligrams of gallic acid equivalent per gram of sample.

2.4.5. 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging assay for flake samples

The DPPH radical scavenging assay, described by Osunrinade et al. (2022), was used to evaluate the flake extract's capacity to scavenge radicals. A 0.004% DPPH solution was first made. After that, 0.3 mL of the DPPH reagent and 0.1 mL of the flake extract were mixed, and the mixture was exposed to darkness for 30 minutes. At 516 nm, the absorbance of the resultant combination was measured. Without the sample extract, a control was made with the DPPH reagent. Equation 1 was used to calculate the extract's percentage inhibition.

$$Percentage\ inhibition = \frac{Ac - Ae}{Ac} x100\% \times 100 \quad (1)$$

Where:
Ac = Absorbance of control
Ae = Absorbance of extract

2.4.6. Determination of Ferric Reducing Antioxidant Power (FRAP)

In order to calculate the ferric-reducing antioxidant power (FRAP) for flake samples, the procedure outlined by Sukrasno et al. (2017) was used. First, 0.3 mL of the flake extract was diluted with 0.7 mL of distilled water, and then 2.85 mL of the FRAP reagent (acetate buffer, TPTZ, and $FeCl_3 \cdot 6H_2O$ at a ratio of 10:1:1, respectively) was added. The reaction mixture was then incubated at 50°C for 20 minutes, and its absorbance at 700 nm was measured. A standard curve was constructed using ascorbic acid to estimate the antioxidant power of both flour and flake samples.

2.5. Sensory Evaluation of Flakes

The sensory evaluation of flake samples from the composite of yellow maize, soybean, and mango peel flour was carried out by a panel of 30 semi-trained panellists who are familiar with the sensory attributes of flakes. The panellist used a nine-point hedonic scale—where 1 denotes "extremely dislike" and 9 denotes "extremely like"—to evaluate the sensory qualities based on appearance, taste, texture, aroma, and overall acceptability.

2.6. Statistical Analysis

Version 20.0 of the Statistical Package for Social Science (SPSS) (SPSS Inc. Chicago, IL, USA) was used to analyze the data. The Duncan multiple range test was used to determine the mean differences. The Design Expert 6.0.2 software determined composite mixture and optimisation that produced highly nutrient-dense flakes.

3. Results and discussion

3.1. Proximate, antioxidant and colour properties of composite flour components

The results of the proximate composition, antioxidants, and colour properties of yellow maize, soybean, and mango peel flour are presented in Table 1. The proximate composition of the flour samples (yellow maize, soybean, and mango peel) used for the production of flakes ranged as moisture (3.62 to 9.38%), Protein (3.13 to 47.80%), fat (2.5 to 21%), ash (2.22-4.79), crude fibre (1.41-10.27%), and carbohydrate (21% to 70.73%) while the energy value is between 317.94 and 464.20 kCal.

As presented, there is a significant ($p<0.05$) wide variation in the proximate compositions of yellow maize, soybean, and peel flours. Therefore, this variation is a major consideration for their choice to produce nutrient-dense flakes.

As expected, soybean flour had the highest Protein (47.80%), fat (21%), and Energy value (464.20 kCal). The high values of Protein, fat, and energy for soybean flour obtained in this work are in the range of those reported by Tanyitiku & Petcheu (2022) for soaked soybean flour [Protein (38.69 – 48.61%), Fat (21.93- 27.93%) and Energy (485.97-519.81 kCal)].

Table 1. Nutritional, antioxidant, and colour properties of maize, soybean, and mango peel flour

SAMPLE	FGP	MFF	WPS
Moisture (%)	9.38 [b]	10.18 [a]	3.62 [c]
Protein (%)	3.13 [c]	12.90 [b]	47.80 [a]
Fat (%)	2.50 [c]	9.89 [b]	21.00 [a]
Ash (%)	3.99 [b]	2.22 [c]	4.79 [a]
Crude fiber (%)	10.27 [a]	1.41 [c]	1.79 [b]
Carbohydrate (%)	70.73 [a]	63.40 [b]	21.00 [c]
Energy (kCal)	317.94[c]	394.21[b]	464.20[a]
Ferric Reducing Antioxidant Power (mg/g)	4.44 [a]	2.40 [b]	1.72 [c]
Total Flavonoid Content (mgQuarcetin/g)	6.45 [a]	2.32 [b]	1.59 [c]
Total Phenolic Content (mgGAE/g)	29.14 [a]	12.56 [b]	7.67 [c]
Total Antioxidant Content (mgGAE/g)	2.66 [a]	0.93 [b]	0.55 [c]
DPPH (%)	80.65 [a]	19.86 [c]	39.41[b]
l	47.66[b]	67.88 [a]	68.47 [a]
a	2.86 [a]	0.78 [c]	1.58 [b]
b	12.50 [c]	25.18 [a]	15.24 [b]
ΔL	29.74 [c]	49.28 [b]	50.54 [a]
Δa	-0.71 [a]	-2.80 [c]	-1.99 [b]
Δb	10.82 [c]	23.83 [a]	13.55 [b]
ΔE	31.65 [c]	54.54 [a]	52.03 [b]

Values are in mean +SD of duplicate determination. Means differently superscripted along the horizontal columns are significantly different (P<0.05).
FGP - mango peel, MFF- yellow maize, WPS – soybean

Soybean is recognized for its high protein content in comparison to cereal crops, as reported by Qin et al. (2022). Its favourable agronomic traits and protein quality akin to that of animal sources have led to its extensive utilization in food formulation. The proximate composition reported for Mango peel is similar to that reported [Moisture (10.66%), Ash (2.38%), fat (3.43%), protein (1.04%), Crude fibre (10.36%) and Carbohydrate (71.63%)] by Nur Azura et al. (2019) who used mango peel flour to substitute wheat in the production of alkaline noodles. The study of Bertha et al., (2019) on the in-vitro gastrointestinal digestion of mango by-product snacks, reported a very close percentage of carbohydrate (68.6%) and fat (3%) in mango peel which is comparable to the result obtained in this study.

Mango peel flour had significantly (p<0.05) higher antioxidant properties than soybean and maize flour. The antioxidant properties studied had their range for flour samples as TPC (7.67 - 25.14 mgGAE/g), TFC (1.59-6.45 mg quercetin/g), TAC (0.55-2.66 mgGAE/g), FRAP (1.72-4.44 mg/g) and DPPH (19.86-80.65%). The result of TPC (29.14 mgGAE/g) obtained for mango peel flour in this work is not significantly different from the value obtained for the palmer variety (30.53 mgGAE/g) but higher than the keith variety (26.20 mgGAE/g) of mango peel studied by Troiani et al. (2022).

The result of lightness (L), redness (a), and yellowness (b) showed that soybean had the highest lightness (68.47), which was higher but not significantly different (P<0.05) from that obtained for yellow maize flour (67.88). However, yellow maize had a significantly higher yellowness than soybean and mango peel flours. In addition, mango peel flour's redness (a) was significantly higher compared to yellow maize and soybean flour. The lower values of lightness (L) and yellowness observed in mango peel flour, as reported in this study, have previously been linked (Nur Azura et al., 2019) to the primary cause of the brown colouration observed in food products incorporating mango peel flour. This browning phenomenon in mango peel flour could be attributed to the oxidation of polyphenols present in the peel by enzymes such as polyphenol oxidase and peroxidase, resulting in a transition from yellow to brown colour (Priyadarshini et al., 2023; Sogi et al., 2013). The lightness of mango peel flour obtained in this work is within the range reported for the Palmer variety (43.47) mango peel flour but lower than that reported for the Keith variety of mango peel flour by Troiani et al. (2022)

3.2. Proximate Composition of Flake Samples

The result of the proximate composition of the flake sample is presented in Table 2. The moisture content range (7.03-9.78%) observed in flake samples suggests promising shelf life stability. This moisture content value aligns closely with the findings reported by Sumczynski et al. (2015) for commercial flake samples (9.2%). The ability to maintain the low moisture content in flake samples contributes significantly to their shelf life stability by inhibiting microbial activity and chemical reactions that may compromise food quality and stability (Okolie et al., 2022). An increase in the percentage inclusion of mango peel flour led to a significant ($p<0.05$) decrease in the percentages of flake’s protein and fat. Furthermore, an increase in the percentage inclusion of soybean flour caused a significant increment in the percentage of protein, fat, and energy value. The same significant increase in protein, fat, and energy by the inclusion of soybean has been severally reported to be due to the high protein and fat content in soybean (Akinjayeju et al., 2019; Okwunodulu et al., 2020). In addition, a gradual increase in protein and ash is attributable to the rise in the percentage of yellow maize used, with a significant ($p<0.05$) increase when the percentage of yellow maize used was increased from 50 to 100%.

The protein content of flake samples ranged from 8.05 to 35.37%, with the highest percentage of protein content obtained from using 50% soybean and 50% yellow maize flour. The lowest protein content was from a composite formulation containing 50% yellow maize and 50% mango peel flour. The highest protein content (35.37) obtained in this work is more than double of the highest (14.4%) reported for wheat-mango flakes by Juniour et al. (2022), while it is more than triple of the highest protein content (10.50%) reported by Adebanjo et al., (2020) for extruded flakes from pearl millet (*Pennisetum glaucum*)-carrot (*Daucus carota*) blended flours. However, the highest protein content (48%) reported for flakes by Olorunsogo & Adejumo (2023) was higher than that obtained in this work but within the range of the optimized sample protein content of 38% obtained from 30.5 % corn flour, 11.2 % millet flour, 18.3 % soybean meal

The fat content of flake samples ranged from 3.13% to 13.74%, with the highest fat content obtained from flake produced from 50% soybean and 50% yellow maize flour, while the lowest fat content was from 75% yellow maize and 25% mango peel flour. The work of Sumczynski et al. (2015) reported the lowest fat amount in commercial flakes (2.1%) and the highest amount was red wheat flakes (3.3%). The comparatively high fat content obtained in this study is due to the high percentage of soybean inclusion in flake production. Fats are nutritionally significant and possess physiological importance, serving as both an energy source and a crucial supplier of fatty acids (De Carvalho & Caramujo, 2018). However, they also impact food quality, as evidenced by their potential to induce off-flavors in stored flakes and flours (Yang et al., 2021).

Table 2. Result of proximate composition of flakes

Run	A:Yellow maize	B:Soybean	C:Mango peel	Moisture	Protein	Fat	Ash	Crude fibre	Carbohydrate	Energy
	%	%	%	%	%	%	%	%	%	kCal
1	50	50	0	7.06^{k}	35.37^{a}	13.74^{a}	2.72^{e}	1.71^{i}	39.41^{f}	422.71^{a}
2	75	0	25	7.12^{k}	8.84^{gh}	4.50^{g}	5.60^{ab}	3.79^{c}	70.15^{a}	356.49^{g}
3	50	50	0	7.35^{J}	35.02^{a}	13.64^{a}	3.16^{de}	1.75^{hi}	39.09^{f}	419.22^{b}
4	50	25	25	8.32^{f}	13.48^{d}	8.56^{e}	4.22^{c}	2.79^{e}	62.63^{c}	381.51^{e}
5	83.33	8.33	8.33	8.92^{e}	9.89^{f}	5.85^{f}	3.97^{cd}	2.08^{g}	69.28^{a}	369.38^{f}
6	58.33	33.33	8.33	9.49^{c}	22.15^{c}	11.83^{b}	4.77^{bc}	2.35^{f}	49.42^{d}	392.73^{c}
7	58.33	8.33	33.33	9.65^{b}	8.23^{h}	5.44^{f}	5.67^{ab}	4.42^{b}	66.59^{b}	348.21^{h}
8	100.00	0.00	0.00	7.70^{i}	10.86^{e}	3.21^{h}	5.72^{a}	1.83^{h}	70.69^{a}	355.03^{g}
9	66.67	16.67	16.67	8.15^{g}	9.63^{fg}	9.50^{d}	5.82^{a}	2.41^{f}	64.49^{bc}	381.98^{e}
10	75	25	0	8.93^{e}	29.68^{b}	10.50^{c}	5.56^{ab}	2.16^{g}	43.18^{e}	385.92^{d}
11	50	0	50	9.29^{d}	8.05^{h}	3.14^{h}	2.97^{e}	5.60^{a}	70.94^{a}	344.25^{i}
12	100	0	0	7.80^{h}	11.21^{e}	3.43^{h}	5.88^{a}	1.71^{i}	69.97^{a}	355.58^{g}
13	75	0	25	7.03^{k}	8.75^{gh}	4.00^{gh}	5.71^{a}	3.70^{d}	70.80^{a}	354.22^{g}
14	50	0	50	9.78^{a}	8.05^{h}	3.13^{h}	3.11^{de}	5.55^{a}	70.38^{a}	341.95^{i}

Values are in mean +SD of duplicate determination. Means differently superscripted along the vertical columns are significantly different (P<0.05).

Particularly vital in the diets of infants and young children, fat fulfils various essential functions, including the provision of necessary fatty acids, facilitation of fat-soluble vitamin absorption, augmentation of dietary energy density, and prevention of undesirable weight gain in infants (Ravisankar et al., 2015).

The carbohydrate content of the flake sample, which ranged from 39.41 to 70.94%, decreased significantly ($p<0.05$) with an increase in the percentage of soybean and gradually increased the percentage of yellow maize flour. However, the carbohydrate content of this study is higher than that reported (33.5 - 63.2%) for flakes from the combination of corn flour, millet flour, and soybean meal by Olorunsogo & Adejumo (2023). The relatively high percentage of carbohydrates in flake samples from the yellow maize, soybean, and mango peel flour composite indicates that the product will provide the energy required for optimum growth and development (Tanyitiku & Petcheu, 2022).

The ash content of flakes ranged from 2.72 to 5.88%. It was observed that an increase in the inclusion of mango peel flour and soybean flour in the flake samples increased the ash content. The interaction between maize and mango peel had a decreasing effect on the ash content, while the interaction between mango peel and soybean flour increased the ash content. The range of ash content obtained in this work is higher than that obtained for wheat-mango peel flakes Nur Azura et al. (2019) but similar to the flakes' ash content (0.99-5%) produced from corn flour, millet flour, and soybean meal by (Olorunsogo & Adejumo, 2023). This study's crude fibre of flake samples ranged from 1.75-5.55%. Mango peel flour had the highest contribution of crude fibre to flakes. The sample with the highest percentage of mango peel flour had the highest crude fibre. The crude fibre content of flakes obtained in this work is higher than the crude fibre content of the flakes (0.92-2.3) reported for wheat-mango flakes by Juniour et al. (2022).

The energy value of flakes ranged from 341.95-422.71 kCal, and the most energy value contributing mixture component was an equal volume of maize and soybean. The energy value of flakes significantly increases with increase in the inclusion of soybean flour. The highest energy value obtained for the flake sample (422.71 kCal) was obtained from the highest percentage (50%) inclusion of soybean flour. Concerning the energy value of flakes, the variation of yellow maize flour inclusion also significantly influenced the energy value of flake samples.

3.3. Antioxidant Composition of Flake Samples

Presented in Table 3 is the result of the antioxidant composition of the breakfast cereal flakes samples. The anti-oxidative parameters obtained were TPC (19.24-25.14 mgGAE/g), TFC (1.79-4.40 mgQuarcetin/g), FRAP (2.59-4.40 mg/g), TAC (0.89-2.61 mgGAE/g) and DPPH (30.91-80.52%). The result shows that flaked sample produced from 50% yellow maize and 50% soybean had the lowest total phenolic content (19.24 mgGAE/g) and the flaked sample from 58.33% yellow maize, 8.33% soybean and 33.33% mango peel flour had the highest total phenolic content (25.14 mgGAE/g) which is higher compared to the range of 3.96 – 8.86 mgGAE/g reported for commercial and non-traditional wheat flakes by Sumczynski et al., (2015). This finding indicates that mango peel possesses a significant concentration of antioxidant compounds, sparking considerable interest in the potential health benefits of consuming a diet abundant in antioxidants. Such dietary practices may potentially mitigate the risk of various prevalent chronic ailments, including cancer, cardiovascular disease, and chronic inflammatory conditions (Ademosun et al., 2023).

Generally, flakes' antioxidant properties, including FRAP, TPC, and DPPH, were significantly influenced by the increment in mango peel flour inclusion for flake production. More specifically, the highest percentage (50%) of inclusion of mango peel flour resulted in flakes with the highest values of FRAP (4.40 mg/g), TPC (25.12 mgGAE/g), and DPPH (80%). Except for the composite flour mixture of 58.33% (yellow maize), 8.33% (soybean), and 33.33% (mango peel) that gave the highest TFC (4.40) and TAC (2.61 mg/g), total flavonoids increased with an increase in the percentage of mango peel flour. Concerning TFC and TAC, there was no defined increase or decrease pattern in flakes regarding mango peel flour. This could be because the interaction of composite mixtures and processing had a combined greater influence on the TFC and TAC.

Table 3. Results showing the antioxidant properties of flake samples

S/N	Yellow maize	Soybean	Mango peel	FRAP	TFC	TPC	TAC	DPPH
				mg/g	mgQuarcetin/g	mgGAE/g	mgGAE/g	%
1	50	50	0	3.05^{c}	1.78^{c}	19.24^{f}	1.46^{e}	30.93^{j}
2	75	0	25	4.20^{d}	2.85^{b}	25.10^{a}	2.15^{b}	55.80^{f}
3	50	25	25	4.26^{a}	1.91^{bc}	25.12^{a}	2.26^{b}	78.94^{b}
4	83.33	8.33	8.33	3.44^{b}	1.91^{bc}	24.36^{b}	1.58^{de}	68.74^{d}
5	58.33	33.33	8.33	3.26^{bc}	2.35^{b}	23.94^{c}	1.78^{c}	37.17^{i}
6	50	50	0	3.07^{c}	1.79^{c}	19.21^{f}	1.44^{e}	30.91^{j}
7	58.33	8.33	33.33	4.39^{a}	4.40^{a}	25.14^{a}	2.61^{a}	69.90^{c}
8	100	0	0	3.43^{b}	1.86^{bc}	23.42^{d}	0.91^{f}	56.75^{e}
9	50	0	50	4.39^{a}	3.14^{a}	25.10^{a}	1.72^{cd}	80.51^{a}
10	66.67	16.67	16.67	3.40^{b}	2.52^{bc}	24.18^{bc}	1.54^{e}	47.13^{g}
11	75	25	0	2.59^{d}	1.89^{bc}	22.48^{e}	0.89^{f}	44.66^{h}
12	50	0	50	4.40^{a}	3.16^{a}	25.12^{a}	1.73^{cd}	80.52^{a}
13	75	0	25	4.23^{d}	2.83^{b}	25.13^{a}	2.14^{b}	55.81^{f}
14	100	0	0	3.40^{b}	1.87^{bc}	24.18^{bc}	0.92^{f}	57.13^{e}

Values are in mean +SD of duplicate determination. Means differently superscripted along the vertical columns are significantly different ($P<0.05$).

Yellow maize and soybean percentage variation in flake formulation did not significantly influence the antioxidant properties of the flake samples. Also, the DPPH of flake samples was the only antioxidant property that was significantly influenced by variation in composite flour formulation. However, there was no defined trend for both yellow maize and soybean flour. This could be linked to the comparatively low antioxidant properties of yellow maize and soybean flour when compared with mango peel flour

3.4. Colour Properties of flour and flakes

Colour is one of the fundamental criteria for the visual assessment of flakes. The result of lightness (L), redness (a), and yellowness (b) is presented in Table 4. Directly after the breakfast cereal flakes sample production, the L parameter that determined the colour brightness fluctuated between 22.34 and 48.21. In comparison, the redness (a) and yellowness varied from 3.71-8.72 and 6.76 to 20.62, respectively. The addition of mango peel flour causes a decrease in the yellow colouration of the sample. The highest yellow colouration was found in a flaked sample produced from 100%

yellow maize flour (20.62), which is a natural consequence of the colour of the maize.

Table 4. Results of the colour analysis of flakes

Sample	Yellow maize	Soybean	Mango peel	L	a	b	ΔL	Δa	Δb	ΔE
1	50	50	0	42.42^{b}	4.78^{b}	17.33^{b}	24.53^{b}	1.22^{b}	15.65^{b}	29.10^{b}
2	75	0	25	25.79^{h}	3.80^{cde}	8.62^{f}	7.84^{h}	0.22^{cde}	6.95^{f}	10.50^{h}
3	50	25	25	28.51^{g}	4.93^{b}	9.49^{e}	10.58^{g}	1.36^{b}	7.81^{e}	13.22^{g}
4	83.33	8.33	8.33	36.35^{c}	3.85^{cde}	13.77^{c}	18.42^{c}	0.29^{cd}	12.08^{c}	22.03^{c}
5	58.33	33.33	8.33	29.47^{f}	4.92^{b}	10.26^{d}	11.54^{f}	1.39^{b}	8.58^{d}	14.44^{f}
6	50	50	0	42.41^{b}	4.79^{b}	17.35^{b}	24.52^{b}	1.21^{b}	15.67^{b}	29.12^{b}
7	58.33	8.33	33.33	25.16^{h}	4.03^{cd}	8.15^{g}	7.23^{h}	0.46^{cd}	6.47^{g}	9.72^{i}
8	100	0	0	48.21^{a}	3.48^{e}	20.62^{a}	30.27^{a}	-0.08^{e}	18.94^{a}	35.72^{a}
9	50	0	50	22.33^{i}	3.71^{de}	6.74^{h}	4.4^{i}	0.12^{de}	5.07^{h}	6.71^{j}
10	75	0	25	25.78^{h}	3.81^{cde}	8.64^{f}	7.86^{h}	0.23^{cde}	6.94^{f}	10.51^{h}
11	66.67	16.67	16.67	30.42^{e}	4.09^{c}	10.44^{d}	12.49^{e}	0.51^{c}	8.76^{e}	15.26^{e}
12	75	25	0	33.34^{d}	8.72^{a}	13.66^{c}	15.42^{d}	5.15^{a}	11.98^{c}	20.20^{d}
13	50	0	50	22.34^{i}	3.70^{de}	6.76^{h}	4.41^{i}	0.13^{de}	5.08^{h}	6.72^{j}
14	100	0	0	48.2^{a}	3.47^{e}	20.61^{a}	30.28^{a}	-0.09^{e}	18.93^{a}	35.71^{a}

Values are mean +SD of duplicate determination. Means differently superscripted along the vertical columns are significantly different (P<0.05).

Including mango peel flour in flake formulation significantly reduced the lightness, redness, and yellowness of flake samples. However, the redness (a=3.48) for the control sample (100% maize flour) flakes was not significantly different from flakes produced with 0-50% inclusion of mango peel flour. Elevated redness (a) properties could be linked to brown colour caused by non–enzymatic browning during toasting and enzymatic browning due to oxidation of mango peel (Nur Azura et al., 2019). The colour difference (ΔE) between two samples determines colour perception by a human observer. In the examined flakes, the lowest colour difference was recorded in the flake sample from 50% yellow maize and 50% mango peel, while the highest colour difference was obtained from the flake sample from 100% yellow maize. The inclusion of mango peel flour caused a significant decrease in the colour intensity (ΔE) and other colour parameters determined in this study. A similar change was reported when mango peel flour was included in the production of noodles ((Nur Azura et al., 2019)

3.5. Sensory Evaluation of Flaked Sample

The sensory evaluation rating of breakfast cereals produced from the composite of yellow maize, soybean, and mango peel flour is presented in Table 5. The analysis showed that panellists' sensory ratings for all the samples were significantly different (p>0.05). The sensory appearance rating ranged from 6.04 to 7.69, with a high proportion inclusion of mango peel causing a reduction in the appearance rating by the panellist. Texturally, panellist rates ranged from 5.86 to 7.17, with the sample from 100% yellow maize having the highest rating. This result is similar to that of flakes from banana pulp and maize (Tay et al., 2021), which have the highest texture rating from yellow maize flakes (7.19).

Table 5. Results of the sensory analysis of flakes

Sample	Yellow maize	soybean	Mango peel	Appearance	Texture	Mouthfeel	Taste	Aroma	Overall acceptability
1	50	50	0	7.68[a]	6.48[abc]	6.40[ab]	6.51[abc]	6.57[ab]	7.64[a]
2	75	0	25	7.14[abcd]	6.71[abc]	6.49[ab]	6.38[bc]	6.69[ab]	7.37[ab]
3	50	25	25	6.35[de]	5.86 [c]	5.97[b]	6.10[bc]	6.21[ab]	7 [ab]
4	83.33	8.33	8.33	6.52[cde]	6.52[abc]	6.31[ab]	7[ab]	6.62[ab]	7 [ab]
5	58.33	33.33	8.33	6.62[bcde]	6.21[bc]	6.41[ab]	6.69[abc]	6.66[ab]	7 [ab]
6	50	50	0	7.69[a]	6.47[abc]	6.41[ab]	6.51[abc]	6.58[ab]	7.65[a]
7	58.33	8.33	33.33	6.76[bcde]	6.28[abc]	6.69[ab]	6.58[abc]	6.27[ab]	7 [ab]
8	50	0	50	6.04 [e]	5.86[c]	5.96[b]	5.71[c]	5.82[b]	6.71[b]
9	66.67	16.67	16.67	7.45[ab]	7.17[a]	7.21[a]	7[ab]	6.86[ab]	7.24[ab]
10	100	0	0	6.78[bcde]	6.54[abc]	5.97[b]	6.45[abc]	5.9 [b]	7.28[ab]
11	75	0	25	7.13[abcd]	6.72[abc]	6.48[ab]	6.37[bc]	6.67[ab]	7.36[ab]
12	75	25	0	7.35[abc]	7.07[ab]	6.86[ab]	7.41[a]	7.24[a]	7.59[ab]
13	50	0	50	6.03 [e]	5.85[c]	5.95[b]	5.71[c]	5.81[b]	6.71[b]
14	100	0	0	6.79[bcde]	6.55[abc]	5.96[b]	6.44[abc]	5.91 [b]	7.26[ab]

Values are in mean +SD of duplicate determination. Means differently superscripted along the vertical columns are significantly different (P<0.05).

In the inclusion of mango peel flour, up to 33.33% had sensory (appearance, texture, mouthfeel, aroma, and overall acceptability) ratings that were not significantly different from the control sample (100% maize flour) flake. Regarding overall acceptability, flakes produced from 50% yellow maize and 50 % soybean flours were the most acceptable by panellists. Whereas the least acceptable by panellists was made from 50% yellow maize and 50% mango peel flour. The inclusion of the combination of soybean and mango peel in yellow maize flour increased the sensory acceptability of the flakes produced.

3.6. Modeling and Optimization

3.6.1. Modeling of Proximate Composition of Flakes

The estimated coefficient of the model and analysis of variance showing the effect of raw materials on the flake's proximate composition is shown in Table 6 and the response surface plate is presented in Figure 2 a-g.

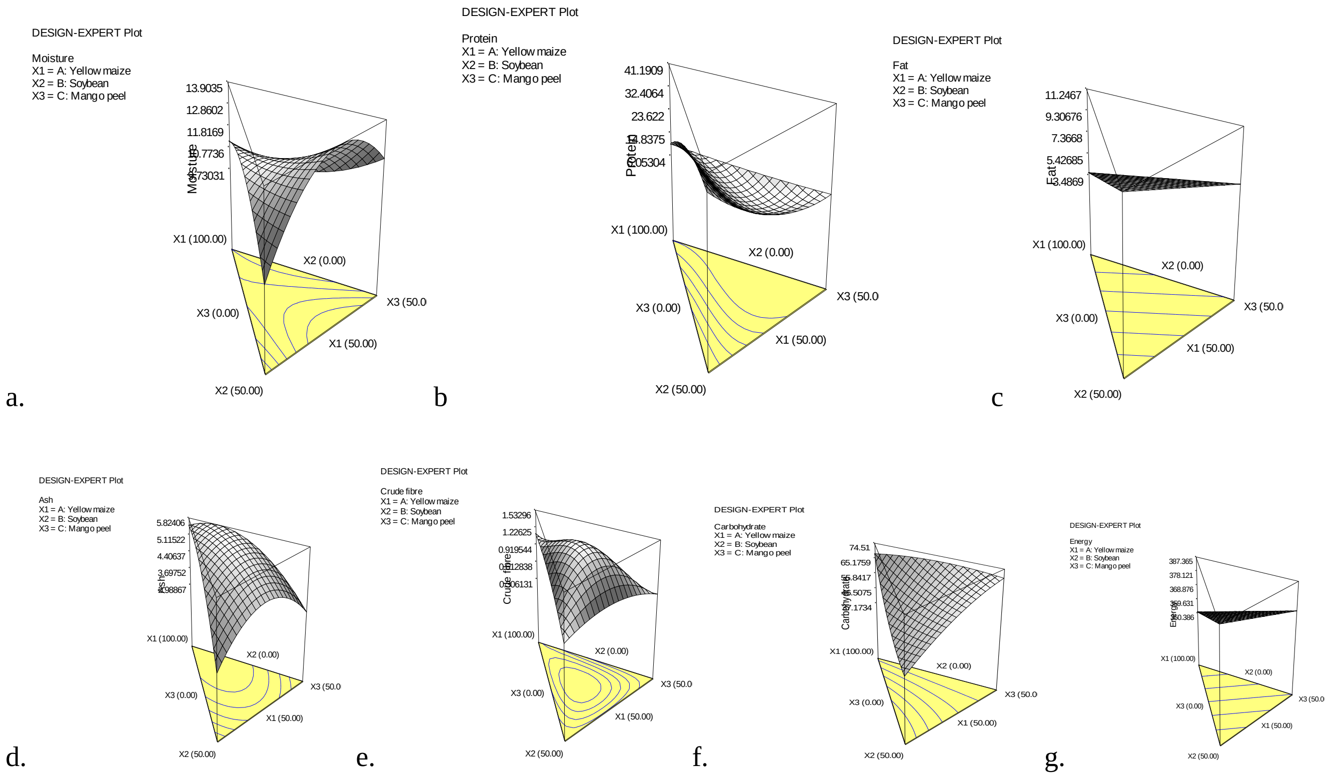

Figure 1. Response surface plot showing the effect of raw materials on flakes' proximate composition.

Table 6. Estimated coefficient of the model showing the effect of raw materials on flakes' proximate composition

Component	**Moisture**	**Protein**	**Fat**	**Ash**	**Crude fibre**	**Carbo-hydrate**	**Energy**
A-Yellow maize	7.75	10.67	3.19	5.53	1.72	70.94	358.19
B-Soybean	7.24	35.21	13.72	2.99	1.77	38.79	419.69
C-Mango peel	9.58	8.37	3.05	3.20	5.65	69.94	343.30
AB	7.77	24.22	9.21	3.28	0.96	-32.42	-
AC	-5.31	-3.07	4.58	4.65	0.04	6.24	-
BC	2.03	-30.56	2.07	6.09	-3.38	36.76	-
ABC	-	-204.07	-	-	-	70.94	-
R-Squared	0.76	0.99	0.99	0.76	0.98	0.97	0.97
Adj R-Squared	0.62	0.99	0.98	0.60	0.97	0.94	0.96
Pred R-Squared	0.08	0.89	0.97	0.37	0.95	0.87	0.96
Adeq Precision	5.73	34.45	30.85	5.46	23.34	17.00	32.43
p-value	0.0204	<0.0001	<0.0001	<0.0001	0.0233	<0.0001	<0.0001

The coefficient of determination (R^2) for fat (0.99), Protein (0.99), crude fibre (0.98), carbohydrate (0.97) and energy (0.97) are on the very high side for response surface and indicated that the fitted models accounted for over 95% of the variance in the experimental data, which were highly significant. Moreover, achieving a high precision greater than 4 for all proximate components indicates that the model can effectively navigate the design space (Osunrinade & Akinoso, 2020).

The model coefficient in Table 6 showed that an increase in soybean flour caused the highest increase in protein, fat, and energy level followed by yellow maize. Moisture content had the highest increment as mango peel flour inclusion increased. Also, the interaction of yellow maize, soybean, and mango peel caused a significant decrease in the protein content of flake samples, while the same interaction caused a significant increase in the carbohydrate content of the flake samples. However, the interaction of yellow maize and mango peel significantly reduced the moisture and protein content of flake samples.

The linear model proved significant ($p<0.05$) for the energy content of breakfast cereal flaked samples made from yellow maize, soybean, and mango peel flour. Conversely, the quadratic model was deemed suitable for modelling moisture, fat, ash, and crude fibre content. Meanwhile, the estimated coefficient of the special cubic model demonstrated adequacy in predicting the protein and carbohydrate content of flake samples. However, it's noteworthy that the quadratic model fitted for flake samples displayed no substantial agreement in the predicted values of R^2 and adjusted R^2. This suggests that apart from the raw materials used (such as yellow maize, soybean, and mango peel flours), processing temperatures could also play a crucial role in determining the moisture content of the final flake product.

3.6.2. Modeling of Antioxidant Properties of Flake

Response surface modelling was applied to examine the effect of raw material on flakes' antioxidant properties, and the result is shown in Table 7 while the response surface plots are shown in Figure 3 a-e. The result obtained confirmed the fitting of the model (R^2>0.50) for all antioxidant properties, which denoted that at least 50% of the predicted values could be matched with the actual values. The model coefficient indicated that an increase in mango peel led to a rise in total flavonoid content, total phenolic content, DPPH, FRAP, and TAC. The combination of soybean and mango peels increased the flake samples' antioxidant activities.

Table 7. Estimated coefficient of the model showing the effect of raw materials on flakes' antioxidant properties

Component	**TFC**	**TPC**	**DPPH**	**FRAP**	**TAC**
A-Yellow maize	2.36	23.72	59.21	3.45	1.56
B-Soybean	1.66	19.38	29.15	3.08	1.47
C-Mango peel	3.37	24.92	79.53	4.34	1.83
AB	-	4.73	-6.66	-3.02	-3.11
AC	-	1.27	-52.84	1.19	1.60
BC	-	12.21	69.37	1.97	2.44
R^2	0.528	0.962	0.854	0.977	0.652
Adj R^2	0.442	0.938	0.764	0.962	0.434
Pred R^2	0.357	0.904	0.591	0.934	0.343

Adeq Precision	6.603	18.569	9.255	24.394	6.430
p-value	0.016	0.000	0.003	0.000	0.082

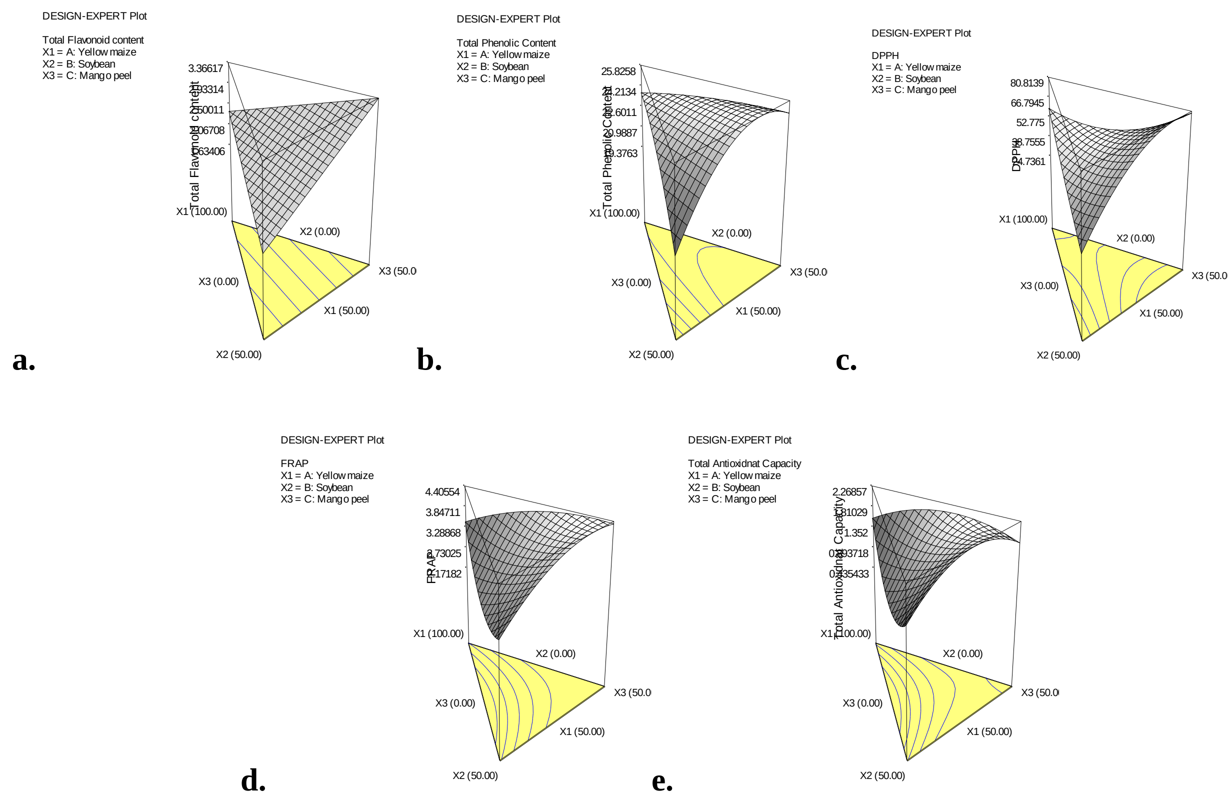

Figure 3. Response surface plot showing the effect of raw materials on flakes' antioxidant properties

The adequate precision values exceeding 4 for TFC, TPC, DPPH, FRAP, and TAC indicate the suitability of the design model. The estimated coefficients of the quadratic model were found to be adequate and significant ($p<0.05$) in depicting TPC, DPPH, and FRAP for flaked samples, while the linear component of the model significantly ($p<0.05$) sufficed to predict the TFC of flake samples. However, it's worth noting that the model fitted for TAC was not significant and this could be that there could be other factors such as the processing condition that determine the variation in the TAC of flake samples.

3.6.3. Modeling of Colour Attributes of Flakes

The estimated coefficient and analysis of variance of colour parameters presented in Table 8 indicated that the linear model was significant ($p<0.05$) for Lightness (L), yellowness (b), and colour intensity (ΔE). In contrast, the cubic model was significant for the redness (a) colour properties.

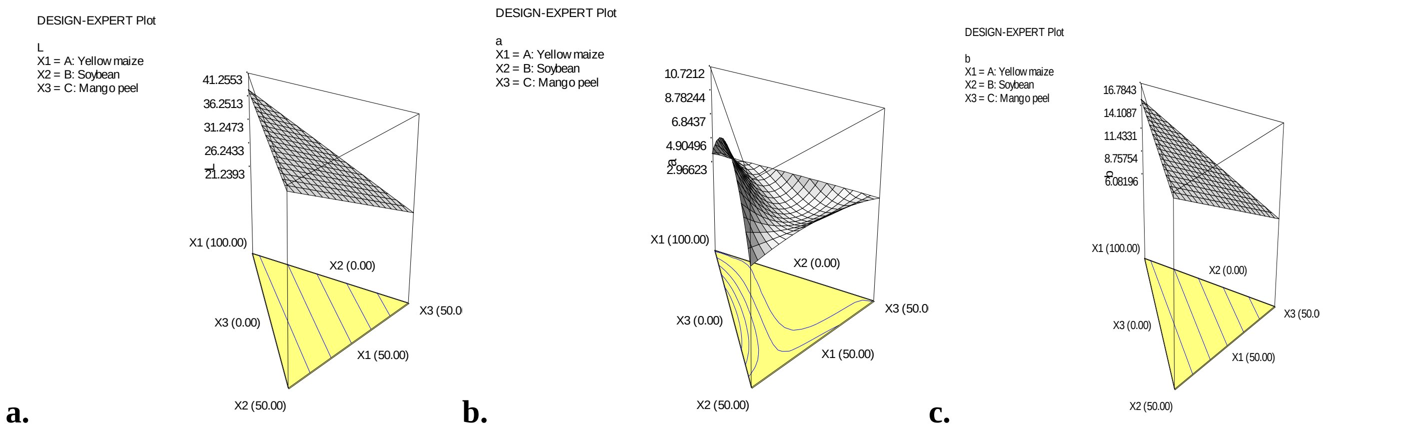

Figure 4. Response surface plot showing the effect of raw materials on flakes' colour properties

Table 8. Estimated coefficient of the model showing the effect of raw materials on flakes' colour properties

Component	**L**	**a**	**b**	**ΔL**	**Δa**	**Δb**	**ΔE**
A-Yellow maize	37.87	3.69	14.98	19.94	0.12	13.29	24.06
B-Soybean	40.18	4.71	16.21	22.27	1.14	14.53	26.70
C-Mango peel	21.24	3.84	6.08	3.31	0.27	4.40	5.36
AB	-	17.02	-	-	17.06	-	-
AC	-	0.32	-	-	0.31	-	-
BC	-	3.26	-	-	3.28	-	-
ABC	-	-79.99	-	-	-79.76	-	-
R^2	0.514	0.949	0.507	0.514	0.950	0.507	0.515
Adj R^2	0.426	0.905	0.417	0.426	0.907	0.418	0.427
Pred R^2	0.253	0.325	0.228	0.253	0.341	0.229	0.249
Adeq Precision	5.980	17.501	5.891	5.983	17.693	5.894	5.997
p-value	0.019	0.000	0.020	0.019	0.000	0.020	0.019

The response surface model presented in Table 8 indicated that a significantly increased yellow maize and soybean ($p<0.05$) increased the flakes' lightness. The decrease in the lightness is attributable to the inclusion of mango peel (Jahurul et al., 2015). The variation in the response surface plot shapes presented in Figure 4 a-e is an indication of the significant effect of the raw materials on the colour attributes of flake samples.

The regression model developed for the redness has the coefficient of determination R^2 of 0.949 and a p-value of 0.000, indicating that the special cubic model is adequate and significant to depict the effect of yellow maize, soybean, and mango peel on the redness of its flakes. The interactive effect of yellow maize and soybean caused the highest increase in the redness of flake samples. The response surface model shows that an increase in mango peel led to a decrease in the yellowness of the flakes, whereas yellow maize and soybean increased the flakes' samples' yellowness.

3.6.4 Optimisation for Protein, Energy, and Antioxidant rich flake

Considering the importance of protein content, energy value, sensory acceptability, and the antioxidant component of food, the optimization criteria for protein content, energy value, overall sensory acceptability, and all the antioxidant properties were set at maximum. In contrast, other flake parameters determined in this work were set to be in range to determine the optimum mixing ratio of yellow maize, soybean, and mango peel flours. The result presented in Table 9 indicated the highest desirability of 0.57 for the mixture of 50% yellow maize, 28.45% soybean, and 21.55% mango peel that gave the optimum property of protein (16.15%), energy (386.76kCal), overall acceptability (6.85), total phenolic content (24.76 mgGAE/g), total flavonoid Content (2.39 mg/g), total antioxidant capacity (2.22mgGAE/g), ferric reducing antioxidant power (4.11 mg/g) and DPPH (67.88%).

Table 9. Result of Optimisation for Flake Samples

Number	1	2	3	4
Yellow maize (%)	50	50	50	58.02
Soybean (%)	28.45	29.28	33.58	0
Mango peel (%)	21.55	20.72	16.42	41.98
Appearance	6.28	6.31	6.46	6.75
Texture	5.76	5.76	5.82	6.39
Mouthfeel	6.24	6.24	6.22	6.49
Taste	6.34	6.36	6.48	5.76
Aroma	6.34	6.34	6.37	6.18
Overall acceptability	6.85	6.87	7.00	7.29
Moisture (%)	8.75	8.70	8.46	8.57
Protein (%)	16.15	16.68	19.66	8.33
Fat (%)	9.63	9.80	10.67	3.69
Ash (%)	4.57	4.56	4.40	4.20
Crude fibre (%)	2.61	2.56	2.30	5.02
Carbohydrate (%)	61.24	60.62	57.13	70.94
Energy (kCal)	386.76	388.04	394.60	345.69
Total Flavonoid content (mgQuarcetin/g)	2.39	2.37	2.22	3.20
Total Phenolic Content (mgGAE/g)	24.76	24.64	23.89	24.90
DPPH (%)	67.88	66.85	61.00	69.15
FRAP (mg/g)	4.11	4.08	3.93	4.36
Total Antioxidant Capacity (mgGAE/g)	2.22	2.21	2.12	2.00
Desirability	0.546	0.545	0.533	0.306
	Selected			

4.Conclusion

This study utilized the composite of yellow maize, soybean, and mango peel flour to produce breakfast cereal flakes that are dense in protein, energy, and antioxidants. It was observed that an increase in the percentage inclusion of soybeans caused a significant increment in the percentage of protein, fat, and energy values. Further, the inclusion of mango peel increased the flake sample's carbohydrate and antioxidant properties. In contrast, yellow maize increased the flake samples' yellowness, lightness, and sensory acceptability. However, including the combination of soybean and mango peel with yellow maize flour increased the sensory acceptability of the flakes produced. The optimization result indicated that the mixture of 50% yellow maize, 28.45% soybean, and 21.45% mango peel gave the optimum protein, energy, and antioxidant properties.

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Conflicts of Interest

The authors declare no known conflict of interest.