Food Chemistry Advances 10 (2026) 101240

Contents lists available at ScienceDirect

Food Chemistry Advances

journal homepage: www.elsevier.com/locate/focha

Innovative cookies for school meals: nutritional, technological, and sensory potential of crude palm olein (*Elaeis guineensis*) and cowpea flour [*Vigna unguiculata* (L.) Walp.]

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ARTICLE INFO

Keywords:
Crude palm fractions
Black-eyed pea
Vitamin A
Minerals
Food fortification

ABSTRACT

Micronutrient deficiencies, such as iron deficiency anemia and vitamin A deficiency, remain a concern among children in low- and middle-income countries. Despite the flour fortification policies in Brazil, nutrient bioavailability remains a challenge. Using local, nutrient-rich ingredients, such as crude palm olein (CPOL) and cowpea flour (CF), is a sustainable alternative for the nutritional improvement of school foods. This study aimed to develop and evaluate cookies enriched with CPOL and CF as vehicles for iron and provitamin A delivery during school meals. A 2^2 full factorial design was used, varying CF (60 or 120 g) and CPOL (25 or 50 g), while the control cookies (C0) contained only wheat flour and butter. Nutritional composition, color, texture, and sensory acceptance were also analyzed. High CF levels increased protein content (13.3–14.7 %) and mineral levels, including iron (31.6–41.2 μg/g), zinc, and magnesium. Carotenoid content ranged from 35.14 to 76.68 μg/g, and the reddish-brown color of the cookies likely resulted from both carotenoid pigments and Maillard reaction products formed during baking. The formulation containing 120 g of CF and 31.25 g of CPOL produced cookies with a crispy texture and high acceptance (score: 7.8). A 30-g serving may provide up to 15.5 % of daily iron and 13.9 % of retinol equivalents for children. These cookies have the potential to be accessible and acceptable fortification options for school feeding programs.

1. Introduction

Nutritional changes that in the last three decades indicate that the prevalence of anemia and hypovitaminosis A is at epidemic proportions and the main deficiency problems worldwide (WHO, 2024). In Brazil, food fortification policies have been implemented to combat micronutrient deficiencies, including the mandatory addition of iron and folic acid to wheat and maize flour (ANVISA, 2024). The latter presents difficulties related to bioavailability (Blanco-Rojo & Vaquero, 2019). Vitamin A deficiency not only impairs vision but also exacerbates anemia by affecting iron metabolism, underscoring the need for integrated interventions, for example: 1) high-dose vitamin A capsule supplementation, 2) food fortification, and 3) food diversification and nutritional education (Blanco-Rojo & Vaquero, 2019; Ng, et al., 2012; Rodrigues et al., 2011).

In Brazil, crude palm oil (CPO) is known as *azeite de dendê.* One liquid fraction (crude palm olein, CPOL) rich in unsaturated compounds and one solid fraction (palm stearin, rich in saturated compounds) can be obtained and used for various purposes in the food industry (de Almeida et al., 2013, 2019; Rodrigues et al., 2011). CPO contains a total of 422.10–940.20 ppm of carotenoids (provitamin A) (de Almeida et al., 2013). This term is applied to several carotenoids that can be biologically transformed into vitamin A. The most active of these is β-carotene. Fortification of foods with these molecules has the advantage of lower

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https://doi.org/10.1016/j.focha.2026.101240
Received 16 May 2025; Received in revised form 28 January 2026; Accepted 2 February 2026
Available online 3 February 2026

toxicity than that of vitamin A in its complete form (Ng et al., 2012).

Cowpea [*Vigna unguiculata* L. Walp.], also called macassar or green beans according to the location, is a staple food for low-income populations in Northeast, Brazil. Traditionally cultivated by small- and medium-sized family farmers, it represents an essential crop in regional agri-food systems, contributing to income generation and food security while preserving local culinary traditions and cultural identity. It provides proteins and carbohydrates, and contains considerable amounts of fiber, vitamins, and minerals (iron, magnesium, manganese, phosphorus, potassium, and zinc). Their flour is used to fortify foods and bakery products (Ayogu et al., 2016; Carvalho, 2012; de Almeida et al., 2008; Frota et al., 2010; Olapade et al., 2014; Shakpo and & Osundahunsi, 2016).

The growing consumer demand for clean labels and plant-based foods has stimulated the incorporation of legumes as functional and sustainable ingredients in novel food formulations (Affrifah et al., 2023). Moreover, their cultivation requires less water and fertilizer, making them key components of sustainable food systems and an emerging solution for future protein security (Yanni et al., 2023). Legume crops, such as beans, offer an environmentally friendly and economically viable alternative to animal-based proteins. Their low glycemic index and high nutrient density contribute to the prevention of chronic diseases, including cardiovascular disorders and type 2. Owing to their versatility and functional properties, legumes have been increasingly used in the development of plant-based and clean-label products, such as alternative milk, meat analogs, and gluten-free bakery goods, aligning with consumers' ethical, environmental, and health-driven preferences (Affrifah et al., 2023).

Cookie is an excellent fortification vehicle because of its low cost, long shelf life, good nutritional quality, and high consumption, especially by preschool and school-aged children in Brazil (Blanco-Rojo and Vaquero, 2019; Rodrigues, et al., 2011). This invention combines regional, low-cost, and readily available ingredients, reinforcing the valorisation of local production and alignment with clean labels and plant-based trends. A combination of cowpea (*Vigna unguiculata* L. *Walp.*), which is traditionally cultivated by family farmers in Northeast, Brazil, and CPOL enhances both the nutritional and functional qualities of the product. Collectively, these ingredients enrich cookies with provitamin A carotenoids, plant-derived proteins, iron, zinc, and other essential minerals, positioning them as sustainable and culturally relevant vehicles for micronutrient delivery to vulnerable populations.

Although several studies have investigated the use of legume flour and vegetable oils in bakery products for nutritional enrichment, limited research has systematically integrated cowpea flour and CPOL as a combined strategy to deliver minerals and provitamin A carotenoids while simultaneously evaluating technological performance and sensory acceptance. Furthermore, few studies have explored the potential of these regional ingredients as sustainable and culturally relevant vehicles for school feeding programs. In this context, the present study distinguishes itself by developing and optimizing cookie formulations enriched with cowpea flour and CPOL, providing an integrated assessment of nutritional composition, physicochemical properties, texture, color, and consumer acceptance, thus contributing to the advancement of natural and accessible fortified foods. To the best of our knowledge, this is the first study to comprehensively assess the combined use of cowpea flour and CPOL in cookie formulations aimed at school nutrition. To the best of our knowledge, this is the first study to comprehensively assess the combined use of cowpea flour and hybrid palm oil in cookie formulations.

2. Material and methods

2.1. Raw materials

Wheat flour (*Triticum aestivum*), brown sugar, fat, common salt, maize glucose, eggs, and other ingredients used in this study were purchased from supermarkets. Detailed information on the proximate composition of the ingredients (per 100 g) is provided in **Supplementary File 1**. Decorticated cowpea seeds (BRS Guariba variety) were locally sourced from a regional market in Salvador, Bahia, and CPOL was generously supplied by Oldesa Industrial (Nazaré, Bahia, Brazil). CPOL was heated at 45°C in the same vessel. Then, the samples were inerted with nitrogen gas and freezer-stored (¯20°C) for physicochemical analysis and cookie production.

2.2. Preparation of cowpea flour (CF)

The Brazilian cowpea seed variety (BRS), Guariba, was quartered (AISI 304, Jones Riffle) to collect 10 kg for use in this study. The cowpea seeds were processed according to the method by Silva et al. (2022) through cleaning and drying (PE 14 Junior Analógico, Pardal, Petrópolis, Brazil) at 60°C for 24 h, and milling using a standard protocol suitable for flour production (Pulverisette 15, Fritsch, Markt Einersheim, Germany) equipped with a 35-mesh (0.5 mm) sieve, ensuring uniform particle size and removal of seed coats. The resulting flour was vacuum-sealed in plastic bags and stored under freezing conditions until further analysis.

2.3. Experimental design

A complete 2^2 factorial design, including center point replications, was used to optimize the cookie formulations based on varying levels of CF and CPOL. The levels of the independent variables, as summarized in Table 1, were determined based on preliminary tests. The order of processing the experiments was randomized, and one formulation prepared with only wheat and butter (100 %) was designed to be the control cookie (C0) (Table 1).

2.4. Processing of cookies

Cookies were produced by Tok Gourmet (Salvador, Bahia, Brazil) following method 10-53.01, with slight modifications (AACC, 1995) (Supplementary File 2). Table 1 shows the ingredients of the standardized formulation of the cookies. To ensure proper mixing, the CPOL was preheated to 45°C, facilitating integration with the remaining ingredients. The brown sugar and eggs were blended for 5 min using an electronic mixer (KitchenAid, St. Joseph, Michigan, USA). Combined CF, wheat flour, baking powder, and CPOL were added to the creamed mixture and mixed thoroughly. The dough was cooled in an ice bath for 5 min to stabilize the CPOL. The dough was then formed into round shapes (3-cm diameter and 5-cm thickness) and baked at 150°C for 20 min. After cooling for 2 h, seven and three units of each cookie formulation were immediately analyzed for color, texture, diameter (cm), height (cm), thickness (cm), water activity (A_w), and moisture content (%).

All remaining cookies were stored for 24 h at −80°C before freeze-drying (Freeze-dryer LS 3000 D, Terroni Equipamentos Científicos Ltda., Brazil). They were then ground in a domestic stainless steel food processor (Cuisinart Coffee Grinder, Model DCG-20). The grounded material was stored in amber bottles at −20°C to have its minerals, total proximate composition, and α and β carotene analyzed.

2.5. Physicochemical characteristics of cookies

2.5.1. Proximate analysis of flour and cookies

Protein, lipid, ash, and moisture contents were determined ~~in triplicate~~ based on official methods 991.20, 920.39, 900.02, and 926.12, respectively (AOAC, 2016). Water activity and moisture were quantified using a decagon LabMaster (Novasina) and infrared radiation (Shimadzu), respectively. Carbohydrate content was estimated from the difference between 100 and the sum of proteins, lipids, ash, and moisture. Caloric value was calculated according to the Atwater factor (Watt

Table 1
Formulations used in the elaboration of cookies and ranges of the independent variables and their corresponding real and coded levels.

Cookies	Ingredients							Real variables		Codified levels	
	Wheat (g)	Butter	Eggs (g)	Maize glucose (g)	Brown sugar (g)	Baking powder (g)	Salt (g)	(CF) (g)	CPOL (g)	CF X_1	CPOL X_2
C0	120	50	50	10	30	1	1	0	0	Control	
C1	60	25	50	10	30	1	1	60	25	-1	-1
C2	60	0	50	10	30	1	1	60	50	-1	+1
C3	0	25	50	10	30	1	1	120	25	+1	-1
C4	0	0	50	10	30	1	1	120	50	+1	+1
C5*	30	12,5	50	10	30	1	1	90	37,5	0	0

*The center point (0.0) was replicated three times (n = 3); CF, cowpea flour; CPOL, crude palm olein.
C0 represents cookies with zero cowpea flour + zero crude palm olein (control); C1 represents cookies with 60 g of cowpea flour + 25 g of crude palm olein; C2 represents cookies with 60 g of cowpea flour + 50 g of crude palm olein; C3 represents cookies with 120 g of cowpea flour + 25 g of crude palm olein; C4 represents cookies with 120 g of cowpea flour + 50 g of crude palm olein; C5 represents cookies with 90 g of cowpea flour + 37.5 g of crude palm olein.

and Merrill, 1963). All measurements were performed in triplicate.

2.5.2. Cookie spread factor

The diameters of control and fortified cookies were measured using a pachymeter. The diameters of the seven cookies were measured after rotating each cookie to 90°C and the average cookie diameter was calculated. The thickness of each cookie was measured by using a digital micrometer. The spread factor (cm) of the cookies was measured as the ratio of the average diameter to the thickness of the cookies.

2.5.3. Color of cookies (CIELab)

Color parameters (L*, a*, and b*) were measured using a colorimeter (Konica Minolta, Chroma Meter, CR400, Japan) to evaluate the visual appearance of the baked cookies. The color of the cookies was measured at five points on the surface of seven cookies: L* (lightness), a* (red–green chromaticity), b* (yellow–blue chromaticity), c* (chroma), and hue (h_{ab}, angle). Then, the color difference (ΔE) between cookies was calculated as $\Delta E = \{(L_o - L)^2 + (a_o - a)^2 + (b_o - b)^2\}^{1/2}$, where L_o, a_o, and $b_o$are the color parameters of one cookie formulation, and L, a, and b correspond to those of another formulation used for comparison (Cardoso et al., 2021).

The ΔE values were determined to assess both the color difference between the control cookie and each fortified formulation, as well as the differences among the fortified samples themselves. Higher ΔE values indicate greater perceptible variation in color between cookies. The browning index (BI) was determined according to the Eq. 1 proposed by Maskan (2001):

$$BI = \left[100\, x \frac{(X - 0.31)}{0.172}\right. \qquad (1)$$

Where X = (a* + 1.75L*) / (5.645L* + a* − 3.012b*).

2.5.4. Instrumental texture

Texture profile analyses (TPA) were performed using a Brookfield CT_3 Texture Analyzer coupled with Texture Pro CT V1.4 software. Cookies (5 g; diameter of approximately 3.7 cm and thickness of approximately 5 cm) were used for a compression testing using a 2-mm diameter cylindrical probe, 5 g stainless steel, length of 20 mm, 10 g trigger load, and test speed of 1.0 mm/s. The textural variables evaluated in the first compression cycle were hardness, chewiness, gumminess, and cohesiveness (de Oliveira Pineli et al., 2015). All analyses were performed seven times.

2.5.5. Minerals in flour and cookies

The reagents and standard solutions were prepared as described by dos Santos et al. (2013). The samples were decomposed via acid digestion in a microwave oven with a cavity. The fresh sample decomposition of the three pretreated portions was performed in triplicate (dos Santos, et al., 2013).

An inductively coupled plasma-optical emission spectrometer (ICP-OES; OPTIMA 7300DV, PerkinElmer, USA) was used to determine the analytes. For the determination, a 40.00-mgL^{-1} multielement solution of the trace elements (Al, Ca, Cr, Cu, Fe, K, Mg, Mo, P, Se, and Zn) was prepared. The analytical curve was prepared in 2.0 mol L^{-1} HNO_3.

The ICP OES (OPTIMA 7300 DV, – PerkinElmer, USA) operating conditions were the following: measured power, 1300 W; signal integration time, 1 s; plasma gas flow, 15 L min^{-1}; auxiliary gas flow, 1.5 L•min^{-1}; nebulization gas flow, 0.70 L•min^{-1}; sample pump flow, 0.70 mL•min^{-1}. For sample introduction, a cyclonic chamber and GemCone nebulizer (Low Flow) were used. The chosen nuclear (I) and ionic (II) lines (nm) were the following: Al 396.153; Ca II 396.847; Cr II 267.716; Cu I 324.752; Fe II 238.204; K 766.490; Mg II 279.077; Mo II 204.597; P I 213.617; Se I 196.026; Zn II 213.857. The estimated limit of quantification (LOQ) was calculated as 3.3-fold of the limit of detection (LOD). The LOD and LOQ were calculated based on the measurement of the analytical signal of the blank digest assays ($n = 10$). The values of LOD and LOQ were (μgg^{-1}) as follows: Ca 0.59 and 1.69; Cu 0.00 and 0.00; Cr 0.07 and 0.01; Fe 0.018 and 0.061; K 0.085-0.283; Mg 1.59 and 5.31; Mo 0.003 and 0.018; P 0.016 and 0.054; Se 0.017 and 0.057; Zn 0.066 and 0.022.

2.5.6. Total carotenoids

Total carotenoids were extracted and quantified in triplicate according to the method described by de Almeida et al. (2013), with slight modifications. Freeze-dried samples (2 g) were extracted with 50 mL of cold acetone, and any particulate matter was removed by filtration. The solid residue was repeatedly washed with acetone until complete discoloration was achieved. The combined acetone extracts (approximately 65 mL) were then mixed with 50 mL of cold petroleum ether, and the acetone was removed by washing with ultrapure water (Milli-Q, Millipore). The absence of acetone was verified by using 2,4-dinitrophenylhydrazine. After saponification with methanolic KOH (10 %, w/v), the extract was washed with ultrapure water until reaching a pH close to 7. The organic phase was dried over anhydrous sodium sulfate and absorbance of the extract was measured at 450 nm. The total carotenoid content was calculated as follows Eq. 2:

$$Total\, carotenoid\, content(\mu g\, g-1) = A\, x\, V\, x\, 10^4 A^{1\%}_{1cm} x\, m \qquad (2)$$

where A= absorbance; V = total volume of extract in [mL]; $A^{1\,\%}_{1cm}$ = absorption coefficient of β-carotene in petroleum ether (2592); m = mass of the sample in [g].

2.5.7. α and β-carotene quantification

The obtained samples were placed in amber flasks, incubated, and immediately transported on dry ice in a thermal container. Chromatographic analysis was carried out using an HPLC (Shimadzu, Prominence) equipped with a quaternary pump system (LC-20AD), degasser, and UV-Vis DAD (SPD-M20A) detector. The chromatograms were obtained at

450 nm. The oven temperature was 40°C. Compound separation was performed by a C30 column (Develosil, 250 × 4.6 mm i.d.; 5 μm particle size) purchased from Nomura Chemical (Japan). Samples were resuspended in 1 mL of acetone, and the injection volume was 30 μL. The chromatographic analysis was performed according to the methodology proposed by Almeida et al. (2021). To determine the peaks of α- and β-carotene, a previous injection of the standard (Sigma-Aldrich) solutions was performed and the data was used to fit a calibration curve.

2.6. Sensory analysis

The study protocol was approved by the Ethics Research Committee of the School of Nutrition of the Federal University of Bahia, Bahia, Brazil (protocol no: 729930). For the attribute acceptance test, 158 untrained students from two public schools in Salvador, Bahia (89 female and 69 male students, age 10 to 14 years) evaluated the sensory attributes, such as visual appeal, aroma, taste, and texture were assessed using a standard nine-point hedonic scale, ranging from "extremely disliked" to "extremely liked". The tests were performed after 1 day of storage, and each panelist tested the samples in monadic order.

2.7. Statistical analysis

Statistica software version 7 was used to obtain the experimental design and data analysis, and construct graphics and equations. Therefore, a regression model with all variables of interest was obtained: $Y = \beta_0 + \beta_1.X_1 + \beta_2.X_2 + \beta_3.X_1.X_2 + \in$; where y is the response variable, β is the regression coefficient for each component of the model, X_1 is CF; X_2 is CPOL, and ∈ consists of errors for each component of the model. The coefficients of determination (R^2) were computed and the adequacy of the models was tested by separating the residual sum of squares into pure error, curvature test, and lack-of-fit. The F-statistic was used to test the hypothesis that the model was appropriate for the responses. The F ratio for lack-of-fit should not be significant for good fitting.

The correlation between CF content and protein concentration was determined using Spearman's correlation test. All analyses were performed in triplicate, except for the cookie spread factor, texture, and color, which were performed in seven replicates.

An estimate was made from the mathematical models obtained for hardness, hardness, h_{ab}, protein, moisture, α and β carotenoids, ashes, and iron of the cookies generated in the experimental design and using the Response Desirability Profiling function of Statistica software (Statsoft, Statistica 7.0 Tulsa, USA). This estimate determined the most desirable formulation for sensory analysis. Cookies with higher hardness, h_{ab} protein, ash, α- and β-carotene, and iron contents, together with lower moisture, were considered more desirable due to their improved texture, color (pigments; carotenoids), nutritional attributes, and longer shelf life.

3. Results and discussion

3.1. Proximate composition of CF and cookies

Table 2 shows the proximate composition, A_w, and caloric values of the CF and cookies. The A_w, moisture, ash, fat, protein, carbohydrate, and energy of CF were 0.403 ± 0.05; 8.6 ± 0.7 %; 3.7 ± 0.6 %; 0.5 ± 0.1 %; 20.01 ± 0.0 %; 67.3 ± 0.5 %; and 354.2± 1.1 kcal, respectively, within the values reported by Carvalho (2012, de Almeida et al. (2008), Onwuliri & Obu (2002)), and Ayogu et al. (2016) for various cowpea cultivars. As expected, the control cookie (C0) had higher carbohydrate and lower protein and ash contents than those of cookies made with CF (C1–C5) (Table 2).

The regression models for energy, proximate composition, and A_w showed R^2 values ranging from 55.79 to 98.30 % (Table 2). Models with $R^2 > 80$ %, including A_w, moisture, lipids, proteins, and kcal, were considered well fitted. The ash ($R^2 = 55.79$ %) and carbohydrate ($R^2 = 76.94$ %) models presented lower predictive power, although the latter was close to the acceptable threshold. No significant lack-of-fit ($p \geq 0.05$) was observed for most parameters, except for lipids ($p = 0.04$) and kcal ($p = 0.02$), suggesting that in these cases, the variation may be influenced by the restricted experimental range. Therefore, lipid and energy models should be interpreted as trend indicators, whereas other models can be considered predictive and representative of the experimental domain.

Fat is a basic component of cookie formulations and present at relatively high levels. It also prevents the excessive development of gluten in the mixture, imparts desirable eating qualities, and contributes to the texture and flavor of the product (Chávez-Santoscoy et al., 2016). The lowest fat contents (18.04 ± 0.20) were observed in samples C1 and C3, which contained more butter than that of the other cookies with CF. This result can be explained by the intrinsic composition of butter, which, according to *MAPA Ordinance No. 146* (Brasil, 1996), contains a minimum of 82 % fat, and the unsalted butter listed in the Brazilian Food Composition Table (TBCA, 2025) presents approximately 86 % lipids (**Supplementary File 1**). In contrast, palm oil is composed of 100 % lipids (TBCA, 2025) with no moisture or non-fat components. Therefore, formulations prepared with butter exhibited a lower total lipid content despite the higher amount of this ingredient used. These results reflect

Table 2
Predict models, significance level (p), Fisher test (F), and coefficient of determination (R^2 %) for proximate composition and A_w in cookies and cowpea flour.

Cookies	C0	C1	C2	C3	C4	C5*	CF	
A_w	0.469 ± 0.0	0.388 ± 0.0	0.397 ± 0.0	0.394 ± 0.0	0.353 ± 0.0	0.399 ± 0.0	0.403 ± 0.1	
Moisture	6.7 ± 0.2	4.9 ± 0.2	5.4 ± 0.1	5.0 ± 0,3	4.2 ± 0.4	5,0 ± 0.6	8.6 ± 0.0	
Ash	2.0 ± 0.1	2.5 ± 0.1	2.2 ± 0.3	3.2 ± 0.1	2.8 ± 0.6	2.5 ± 0.1	3.7 ± 0.6	
Lipids	18.7 ± 0.2	18.4 ± 0.1	20.2 ± 0.6	18.4 ± 0.2	18.9 ± 0.2	20.1 ± 0.2	0.5 ± 0.1	
Proteins	7.3± 0.6	9.9 ±0.0	9.6 ± 0.6	14.7 ± 0.5	13.3 ± 0.6	11.9 ± 0.9	20.1± 0.0	
Carbohydrates	65.2 ± 0.5	64.2 ± 0.2	62.5 ± 0.2	58.7 ± 0.6	60.8 ± 1.1	60.5 ± 1.1	67.3 ± 0.5	
Energy values (kcal/100 g)	458.7 ± 2.0	462.4 ± 1.4	470.3 ± 4.1	459.4 ± 2.2	466.1 ± 4.0	470.8 ± 1.1	354.2 ± 1.1	
	Predict models					Lack-of-fit (F value)	P	R^2 %
A_w	y = 0.31 + 0.00*CF + 0.00*CPOL - 0.00*CF*CPOL + 0.00					2.77	0.24	82.42
Moisture	y = 3.01 + 0.02*CF + 0.07*CPOL - 0.00*CF*CPOL + 0.01					0.64	0.51	96.03
Ashes	y= 2.04 + 0.01*CF – 0.01*CPOL+ 0.00*CF*CPOL + 0.03					0.27	0.65	55.79
Lipids	y = 15.33 + 0.02*CF + 0.12*CPOL - 0,00*CF*CPOL+ 1.32					23.15	0.04	95.63
Proteins	y = 4.49 + 0.09*CF + 0.02*CPOL - 0.00*CF*CPOL + 0,00					0.00	0.97	92.70
Carbohydrates	y =75.05 - 0.15 *CF - 0.21*CPOL + 0.00*CF*CPOL+1.04					0.64	0.51	76.94
Energy values (kcal/100 g)	y = 456.23 - 0.03*CF +0.37*CPOL -0.00*CF*CPOL + 38.71					57.68	0.02	98.30

*The center point (0.0) was replicated three times (n = 3). CF, cowpea flour; F, Fisher test; $p \geq 0.05$ not significant; R^2 % = coefficient of determination.
C0 represents cookies with zero cowpea flour + zero crude palm olein (control); C1 represents cookies with 60 g of cowpea flour + 25 g of crude palm olein; C2 represents cookies with 60 g of cowpea flour + 50 g of crude palm olein; C3 represents cookies with 120 g of cowpea flour + 25 g of crude palm olein; C4 represents cookies with 120 g of cowpea flour + 50 g of crude palm olein; C5 represents cookies with 90 g of cowpea flour + 37.5 g of crude palm olein.

the lower kcal values observed in C1 and C3 cookies (Table 2). Analysis of variance for ash did not show the significance of the CF and CPOL factors or interactions.

The significant positive effect of CF (+4.93) obtained from the experimental design model indicated that protein content increased with increasing CF levels. This result is consistent with the strong and positive correlation between CF and protein ($r = 0.930$, $p = 0.00$), as determined by Spearman's test. The incorporation of CF increased the protein content of the cookies from 7.3 % in the control formulation to values ranging from 9.6 to 14.7 %. This high protein content likely influenced some functional and sensory attributes. Proteins from cowpeas can enhance water absorption and dough cohesiveness, which affect texture parameters, such as spread ratio and hardness. In addition, the increased availability of amino acids may intensify non-enzymatic browning (Maillard reactions), contributing to the characteristic reddish-brown color and potentially influencing flavor development (de Oliveira Pineli et al., 2015). However, despite this improvement, the protein level per 30-g serving does not meet the regulatory requirements for a "high-protein" claim. According to Brazil (2020a; 2020b), food can be labeled as "source in protein" and "high in protein" only if at least 10 and 20 %, respectively, of its total energy value is provided by protein. In our formulations, the energy contributions of the proteins were below these thresholds.

According to Table 2, the model achieved an R^2 value of 92.7 %, demonstrating that the variation in protein concentration was largely explained by the independent variables, with only a small proportion (7.3 %) attributed to random or unexplained factors.

Moisture and A_W were high in control cookies (C0), at 6.8 % and 0.469 %, respectively. In Brazil, the maximum moisture content of wheat flour is 15 % higher than that of legumes (Brasil, 2005). The CF × CPOL interaction showed a significant negative effect (–5.21), indicating that moisture increased when CF was high and CPOL was low. Conversely, the main effect of CF (–4.37) indicated that moisture decreased as CF increased within the studied range. Shakpo and Osundahunsi (2016) demonstrated that cowpea substitution in flour blends with maize increased the water and oil capacities, foaming capacity, emulsion capacity, and stability.

3.2. Estimated retinol activity equivalent (RAE)

CPO is the world's richest natural plant source of carotenoids (de Almeida et al., 2013, 2019). Among the fitted models for total carotenoids, α-carotene, and β-carotene, only the total carotenoid model was predictive, showing a high R^2 value (89.73 %) and no significant lack-of-fit ($p \geq 0.05$). In contrast, α-carotene ($R^2 = 65.64$ %) and β-carotene ($R^2 = 61.14$ %) exhibited lower determination coefficients, indicating limited predictive capacity. The effects of CF and CPOL on α- and β-carotene levels were not statistically significant, indicating that the variations in these carotenoids were not significantly affected by the tested formulation variables.

Indeed, a higher CPOL content in the dough resulted in a higher carotenoid content in the cookies. C0 contained the minimum quantity of carotenoids (1.9 µg/g), whereas C2 and C4 contained the maximum quantities (Table 3). Damanik and Murkovic (2018) quantified β-carotene subjected to oxidation with rancimat at 120°C and concluded that these molecules decreased from 2.34 to 0.33 mg/g within 7.5 h of oxidation and after 7.5 h, no more β-carotene was detected. Furthermore, the incorporation of palm oil enhances the carotenoid profile and oxidative stability of bakery products, contributing to improved nutritional quality and shelf life (Almeida et al., 2021).

The Dietary Reference Intake (Institute of Medicine [IOM], 2006) established Recommended Dietary Allowance (RDA) values for vitamin A in both micrograms (µg) of preformed vitamin A (RAE). According to the DRIs for Vitamin A established by the IOM (2006), the conversion factors are: 1 RAE = 1 µg of retinol = 12 µg of β-carotene = 24 µg of other provitamin A carotenes.

Table 3
Total α and β carotenoids, retinol activity equivalents, and % RDA in children.

Cookies	Total Carotenoids (µg g^{-1})	Carotenoids (µg g^{-1}) β	α	RAE (µg g^{-1})	% RDA Children (4–8 years) (30 g of cookies)	% RDA Children (9–13 years) (30 g of cookies)
C0	1.90 ± 0.40	-	-	-	-	-
C1	40.39 ± 2.22	9.48	6.56	1.06	7.97	5.32
C2	76.68 ± 2.52	17.00	10.46	1.85	13.9	9.26
C3	35.14 ± 2.03	8.37	5.31	0.92	6.9	4.6
C4	54.77 ± 1.94	8.31	7.52	1.01	7.54	5.03
C5*	56.65 ± 0.86	11.59	7.75	1.29	9.67	6.44

Retinol Activity Equivalents (RAE) was calculated for a bioconversion factor of All-trans-β-carotene /12 + minor α carotene estimated/24; Recommended Dietary Allowance (RDA) per day per child (4–8 years) = 400 µg of RAE; RDA per day per child (9–13 years) = 600 µg RAE, DRI, 2001 (IOM, 2006).
C0 represents cookies with zero cowpea flour + zero crude palm olein (control); C1 represents cookies with 60 g of cowpea flour + 25 g of crude palm olein; C2 represents cookies with 60 g of cowpea flour + 50 g of crude palm olein; C3 represents cookies with 120 g of cowpea flour + 25 g of crude palm olein; C4 represents cookies with 120 g of cowpea flour + 50 g of crude palm olein; C5 represents cookies with 90 g of cowpea flour + 37.5 g of crude palm olein.

The vitamin A activity in cookies was estimated in the RAE using these conversion factors. The RAE values of the cookies ranged from 0.92 and 1.85 RAE µg/g. Institute of Medicine (2006) has a RDA of 400 µg of RAE for children aged 4 to 8 years and 600 µg of RAE for those aged 9 to 13 ~~14~~ years. Considering these Fig.s, we estimated that the consumption of 30 g of cookies may supply between 4.6 and 13.9 RAE in children and infants, respectively (Table 3). In Brazil, enriched or fortified food is defined as food to which one or more nutrients are added, containing a maximum of 15 and 30 % of the DRI in 100 g or 100 mL of liquid and solid food, respectively (Brasil, 2020b). In this study, formulation C2 provided approximately 47 µg of RAE per 30-g serving, corresponding to approximately 12–16 % of the DRI for vitamin A for infants and children. Although these values do not reach the minimum level required for a product to be considered fortified, the results are still nutritionally relevant, as they demonstrate the potential of CF and CPOL as natural sources of provitamin A carotenoids that can contribute to improving the micronutrient content of school meals.

3.3. Minerals

Among the analyzed elements, potassium (K) showed the strongest response to CF, with $R^2 = 98.30$ % and a positive linear effect (+10.60), indicating that higher CF levels (120 g) led to increased K content. This behavior reflects the compositional characteristics of cowpea flour, which naturally contains elevated levels of potassium. The proposed models for mineral contents were predictive, showing R^2 values between 80.63 and 98.30 % and no significant lack-of-fit ($p \geq 0.05$; Table 4). K was the most abundant element naturally present in CF (1402 ± 69 mg.100 g^{-1}), similar to raw cowpea (633 to 2.899 mg.100 g^{-1}) (Onwuliri & Obu, 2002), and the highest values were found in cookies with 120 g of CF (Table 4). K represented between 2.4 and 4.3 % of RDA in the cookies (C1–C5), according to the DRI values for minerals compiled in the IOM Summary (2006).

Similarly to K, phosphorus ($R^2 = 94.04$ %), magnesium ($R^2 = 89.66$ %), zinc ($R^2 = 96.18$ %), and copper ($R^2 = 97.53$ %) exhibited high predictive capacity, confirming the adequacy of the models. In contrast, iron ($R^2 = 80.63$ %) was at the lower predictive threshold, suggesting greater data variability for this element.

Calcium (Ca) levels were similar in CF (36.4 ± 3.1 mg.100 g^{-1}) compared with those that already reported BRS Guariba cowpea (35.0 mg.100 g^{-1}) (Carvalho, 2012). The linear model for Ca was adequate, with $R^2 = 88.54$ % and no significant lack-of-fit ($p \geq 0.05$), thus being

Table 4
Mineral contents in cookies and linear models, lack-of-fit, and coefficient of determination (R^2 %).

Cookies	C0	C1	C2	C3	C4	C5*			CF
Macroelements (mg 100 g^{-1})									
K	110 ± 7	360 ± 17	365 ± 29	605 ± 10	647 ± 29	504 ± 25			1402 ± 69
Ca	126 ± 4	166 ± 0.9	135 ± 4	173 ± 4	107 ± 5	126 ± 13			36 ± 3
P	47 ± 2	80 ± 3	74 ± 3	103 ± 3	91 ± 5	83 ± 4			137 ± 6
Mg	15 ± 1	43 ± 3	44 ± 4	71 ± 1	70 ± 5	59 ± 7			153 ± 7
Predict model					**F value**	**P**			**R^2 %**
K	Y = 144.74 + 3.50*CF - 1.21*CPOL + 0.02*CF*CPOL + 90.86				0.25	0.66			98.30
Ca	Y = 154.22 +0.71*CF + 0.17*CPOL - 0.34*CF*CPOL + 382.30				2.96	0.23			88.54
P	Y = 57.47 + 0.48*CF- 0.00*CPOL - 0.00*CF*CPOL + 15.93				1.69	0.32			94.04
Mg	Y = 13.85+ 0.48*CF + 0.07*CPOL - 0.00*CF*CPOL+ 6.00				0.23	0.67			89.66
Micro and trace elements (µg g^{-1})									
Fe	38.9 ± 1.5	38.9 ± 1.5	37.4 ± 2.8	41.2 ± 2.1	31.6 ± 4.8	39.5 ± 3.9		45.9 ± 1.3	
Zn	5.59 ± 0.4	10.1 ± 0.5	10.8 ± 1.2	14.5 ± 0.7	16.2 ± 1.3	13.2 ± 0.9		35.4 ± 1.7	
Cu	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.30 ± 0.1	0.37 ± 0.0	0.0 ± 0.0		1.75 ± 0.1	
	Predict model				**F value**	**P**		**R2 %**	
Fe	Y = 30.18 +0.17*CF+ 0.26*CPOL - 0.00*CF*CPOL + 4.93					1.19	0.39		80.63
Zn	Y = 6.25 + 0.06*CF - 0.02*CPOL + 0.00*CF*CPOL + 0.08					0.27	0.66		96.18
Cu	Y = -0.71 + 0.00*CF - 0.01*CPOL + 0.00*CF*CPOL + 0.00					2.00	0.29		97.53

The data are presented as means ± standard deviation c5* n = 9); *= $p \leq 0.05$. CF, cowpea flour; CPOL, crude palm olein.
C0 represents cookies with zero cowpea flour + zero crude palm olein (control); C1 represents cookies with 60 g of cowpea flour + 25 g of crude palm olein; C2 represents cookies with 60 g of cowpea flour + 50 g of crude palm olein; C3 represents cookies with 120 g of cowpea flour + 25 g of crude palm olein; C4 represents cookies with 120 g of cowpea flour + 50 g of crude palm olein; C5 represents cookies with 90 g of cowpea flour + 37,5 g of crude palm olein.

considered predictive (Table 4). However, within the experimental range none of the factors had significant effects on Ca content, indicating that the variable remained stable across treatments. The highest Ca levels present in cookies (107–173 mg•100 g^{-1}) were attributed to butter, eggs, and chocolate. There was a tendency to increase Ca values as a function of increased levels of butter content in the cookies (Table 4): C1 (166 mg.100 g^{-1}) and C3 (173 mg.100 g^{-1}).

Phosphorus (P) was detected at 137 mg/100 g^{-1} in CF. P concentration in raw cowpea was reported to vary between 300 to 442 mg.100 g^{-1} (Onwuliri and Obu, 2002) and 437 mg.100 g^{-1} (Frota et al., 2010). Olaleke et al. (2006) related the p-values in CFs to be lower than those in this study (8.3 to 13.0 and 13.35 to 18.26 mg.100 g^{-1}, respectively). Typically, the seed coat is rich in mineral nutrients, and a substantial proportion of mineral nutrients is lost when cowpea is decorticated and the seed coat is discarded, similar to this study (dos Santos et al., 2013). P represents between 1.8 and 2.5 % of the RDA of cookies (C1–C5) (IOM, 2006).

Fe was detected in concentrations between 45.9 ± 1.3 µg.g^{-1} and 31.6–41.2 µg.g^{-1} in CF and cookies, respectively. Carvalho et al. (2012) found Fe values in raw cowpea to be higher than those in this study (61–81 µg.g^{-1}).

These differences could be due to tegument removal, as already mentioned for P. Although the BRS Guariba cowpeas used in this experiment were biofortified with Fe, these values were lower than those of beans produced in Nigeria: 17.4–189 µg.g^{-1} (Onwuliri & Obu, 2002) and 86.2 µg.g^{-1} (Ayogu, 2016). The composition of legumes depends on the species or variety, as well as growing conditions, such as soil and rainfall (Frota et al., 2010).

The values recorded for Fe in cookies were higher than those determined by Frota (2010) in biscuits (5.8–15.6 µg.g^{-1}). These results demonstrate the importance of cowpea biofortification. The values of this mineral in control cookies (C0) were also elevated (38.9 ± 1.5 µg. g^{-1}; Table 4), reflecting the fortification of Fe in flour wheat required by the Brazilian legislation (Brasil, 2020). The portion of cookies (30 g) contained 11.8–15.5 % of the daily needs of Fe. Fe content in 100 g of cookies is between 39.6 and 51.5 % of the RDA, DRI, 2001 (IOM, 1997–2005).

Mg contents in CF and cookies were 152.9 ± 7.3 mg.100 g^{-1} and 43–71 mg.100 g^{-1}, respectively (Table 4). These values are consistent with those reported for Brazilian cowpeas (Carvalho, 2012). Zn content in CF obtained in this study (35.4 µg.g^{-1}) is comparable to those previously reported for BRS-Guariba cowpeas (33.0 and 36.0; 40.2 and 44.0 µg.g^{-1}) (Carvalho, 2012). The highest values of Mg and Zn were found in the formulation with 120 g of CF (70.0 to 71.0 µg.g^{-1} and 14.5 to 16.2 µg. g^{-1}, respectively) (Table 4). The levels of Mg and Zn in 30 g of cookies ranged between 5.4 and 8.9 µg.g^{-1}, and 3.8 and 6.1 µg.g^{-1} of RDA, respectively. Cu contents were low in CF (1.75 µg.g^{-1}), especially when compared with raw cowpea (20 µg.g^{-1}). Cu was only identified in C3 (0.30 µg.g^{-1}) and C4 (0.37 µg.g^{-1}) in cookies containing 120 g of CF.

Cr, Mo, and Se were not detected in the CF or sample cookies (C0–C5). The levels of these minerals in beans are generally low or undetectable (Olaleke, 2006). Cookies made with only wheat flour presented levels of Zn (5.59 µg.g^{-1}), K (110 mg.100 g^{-1}), P (47 mg.100 g^{-1}), and Mg (15 mg.100 g^{-1}), lower than those of the other samples (C1–C5); and their RDA percentage (DRI, 2001 and 2005; IOM, 1997–2005) of Zn, K, P, and Mg as 2.9, 0.73, 1.1, and 1.9, respectively.

3.4. Physical characteristics of cookies

Detailed texture profile data (hardness, fracturability, cohesiveness, springiness, gumminess, chewiness, and masticability) for all cookie formulations are provided in **Supplementary File 3**. The models for hardness, chewiness, gumminess, cohesiveness, and spread factor (cm) showed R^2 values above 76 %, which are close to the acceptable threshold (80 %), and no significant lack-of-fit ($p \geq 0.05$). These results indicate that the models adequately describe the experimental data and can be considered predictive of texture-related variables. In cookie production, the development of the gluten network is limited owing to the high levels of fat and sugar. However, proteins are not inert components in cookies, and higher levels of protein reduce the cookie spread factor owing to water retention, which competes for free water in the system (Chávez–Santoscoy et al., 2016) (Fig. 1). This explanation can be applied to cookies made with only wheat flour, which presented the lowest spread factor compared with that of other cookies (31.7 ± 2.5) **(Supplementary File 4)**. These results contradict those of Chavez-Santoscoy et al. (2016), who reported that the addition of bean flour reduced the spread factor. It is likely that CF absorb liquid olein, thereby producing more fluid and expandable dough.

In TPA, cohesiveness reflects the capacity of a material to resist breaking, whereas chewiness is derived from the product of hardness, elasticity, and cohesiveness parameters (Cardoso et al., 2021). These results showed cookies with the lowest cohesiveness (Fig. 1).

The higher addition of CF resulted in more value for these variables in cookies (Fig. 1). Bassinello et al. (2011) reported that more strength

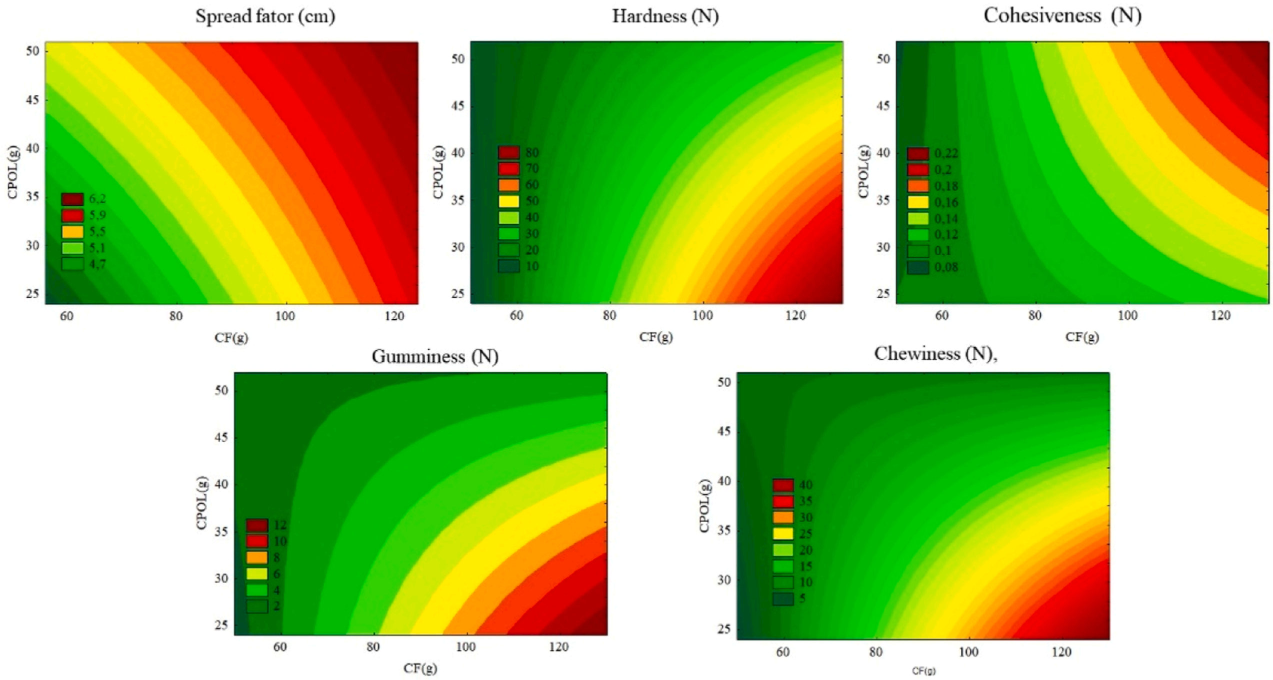

Fig. 1. Spread factor (cm), hardness (N), cohesiveness (N), chewiness (N), and gumminess (N) of cookies. Response contour surface generated by the experimental model. CPOL, crude palm olein; CF, cowpea flour.

was needed to break cookies incorporated with legumes flour.

Increasing the CPOL value resulted in a decrease in hardness, gumminess, and chewiness (Fig. 1). Cookies belong to a group of products that contain considerable amounts of fat and its overall quality is largely determined by the type of fat used. This result is similar to that in Mamat and Hill (2014). Biscuit dough containing palm olein was the softest and required the lowest compressive strength. These authors reported that when liquid oil is used in dough in the form of minute globules, it is far less effective in shortening and aerating than plastic fat films.

The regression models exhibited R^2 values below 80 % for most color parameters, except for b*. As the CF level increased to 120 g, L*, b*, and h_{ab} values decreased (Fig. 2), suggesting a darker and more reddish hue associated with higher flour incorporation. This result may be related to the original color of *macassar* cowpeas, which is darker than wheat flour (Bassinello, 2011; Rogério et al., 2014). Cookies formulated with more CF (120 g) had low chromium values (Fig. 2) **(Supplementary File 5)**. Presumably, the presence of cowpea protein in the mix facilitated non-enzymatic browning and Maillard reactions involving amino acids

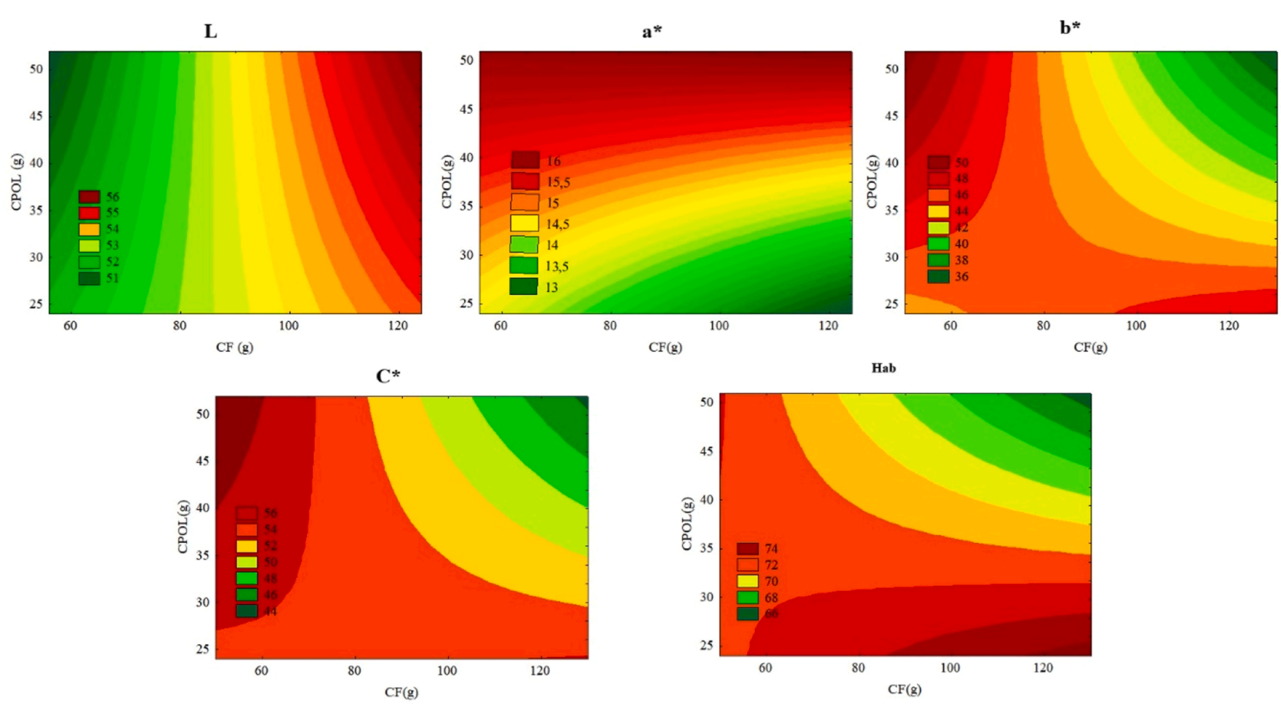

Fig. 2. Response contour surface generated by the experimental model for CIELab. L* (lightness); a* (negative values indicate green, and positive values indicate red, -a/+a); b* (negative values indicate blue, and positive values indicate yellow, +b/-b); C* (chrome) and h_{ab} (hue angle).

and reducing carbohydrates. During baking, these compounds undergo condensation and rearrangement reactions, leading to the formation of melanoidins, which are brown-colored high-molecular-weight polymers that contribute to their characteristic reddish-brown color. Therefore, the protein and sugar contents of CF likely enhanced non-enzymatic browning compared to the control formulation (de Oliveira Pineli et al., 2015).

The collective red-green profile (a* value) was the highest in cookies made with more CPOL (50 g) (Fig. 2) **(Supplementary File 5)**, which was obvious due to the higher amount of carotenoids in this ingredient. McWatters et al. (2004) reported that increased cowpea with either raw or extruded flour produced bread with crusts that were darker (lower L*), redder (higher a*), and less yellow (lower b*) than the other samples, which is similar to the results of this study.

These color measurements were confirmed using visual observations, where increased CF content and CPOL resulted in reddish-brown cookies compared with the control cookies (yellow-brown). There was a substantial difference (ΔE) between control cookies and fortified cookies (11.71–17.39): cookies with CF and CPOL presented ΔE of 2.46–9.44 and these differences were higher that that of C4 with C1, C2 and C5 **(Supplementary File 6).**

3.5. Desirability test and sensory analysis

The desirability test results indicated that the most desirable formulation for cookies was 120 g of CF and 31.25 g of CPOL. The optimum desirability test result is 0.60. For these cookies, the scores obtained for appearance, crispness, flavor, aroma, and overall acceptability were 7.3 ±1.5; 7.8 ± 1.5; 7.4 ± 2.0; 6.6 ± 2.0; 7.8 ± 1.5, respectively.

The acceptability of the cookies was evident because only one parameter, aroma, received a grade lower than 7 for both formulations. The scores in the sensory evaluation were higher than those in other studies using bean flour or CPO in the manufacture of cookies (Ayogu, et al., 2016). Legume flours, such as CFs, have been increasingly recognized for their functional and sensory contributions to bakery products, which enhance consumer acceptance when properly formulated (Munyaneza et al., 2025). Regarding aroma, the lowest score may have been influenced by the addition of CPOL and CF. Olapade and Adeyemo (2014) also reported a lower score for cookies with 80/20 cassava-CF blends than that for cookies produced with whole wheat flour. Jiang et al. (2016) reported that peroxidase and lipoxygenase are responsible for the undesirable "beany flavor" in legumes. Palm oil flavors are usually derived from a combination of volatile components, especially unsaturated fatty acids, such as oleic, linoleic, and linolenic acid, together with terpenes (Kuntom & Ariffin, 2010). Furthermore, the incorporation of CF significantly affects the physicochemical and sensory properties of cookies, improving their nutritional profile, and maintaining acceptable texture and flavor characteristics (Singh et al., 2024).

4. Conclusion

The findings of this study confirm the potential for the production of cookies with CF and CPOL. We concluded that supplementation with up to 120 g of CF and 31.25 g of CPOL yielded the best conditions for the formulation of cookies. Cookies containing high CF levels contained high levels of protein, Cu, K, Mg, Mn, Fe, and Zn. The cookies had a reddish-brown color due to the presence of carotenoids in the CPOL used. The consumption of 30 g of cookies might supply 11.8 to 15.5 % of the daily needs of Fe in children, and 4.6 and 13.9 of RAE for children 4–8 and 9–13 years, respectively. Textural and sensory analyses of the cookies revealed their crispy and hard nature. The cookies selected in the desirability test were deemed acceptable by the students. Therefore, the addition of CF (120g) and CPOL (31.25g) to cookies is an excellent alternative for fortification with its minerals, which is similar to C3 formulation (cookies with 120 g of cowpea flour + 25 g of crude palm olein).

Sensory ethical statement

The study protocol was reviewed and approved by the participants. Federal University of Bahia, Ethics Research Committee of the School of Nutrition (protocol no: 729930). Before participation, informed consent was obtained from all participants.

CRediT authorship contribution statement

Deusdélia Teixeira de Almeida: Writing – original draft, Visualization, Supervision, Methodology, Conceptualization. **Euzélia Lima Souza:** Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization. **Erislene Silva de Almeida:** Methodology, Formal analysis. **Simone Monteiro:** Methodology, Formal analysis. **Wagna Piler Carvalho dos Santos:** Methodology, Formal analysis. **Agnes Sophia Braga Alves:** Methodology. **Camila Duarte Ferreira Ribeiro:** Writing – review & editing, Validation. **Lafaiete Almeida Cardoso:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors express their gratitude to the members of the Coordination for the Training and Improvement of Higher Education Personnel (CAPES/Brazil, Finance Code 001). We would like to thank Professor Heloisa de Jesus Encarnação and Geruza de Araújo the directors of the Public Schools for providing all the infrastructure and support for the application of sensory analysis, as well as the students who participated in the research. C. D. F. R. thanks CNPq/Brazil for their Productivity Grants in Technological Development and Innovative Extension (Process No. 303587/2021–0).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.focha.2026.101240.

Data availability

No data was used for the research described in the article.

References

AACC. (1995). *Approved Methods of the American Association of Cereal Chemists* (10th ed.). St. Paul, MN: AACC International.

Agência Nacional de Vigilância Sanitária (ANVISA). (2024). Considerations on the food fortification policy in Brazil. https://www.researchgate.net/publication/234040507_Considerations_on_the_food_fortification_policy_in_Brazil.

Affrifah, N. S., Uebersax, M. A., & Amin, S. (2023). Nutritional significance, value-added applications, and consumer perceptions of food legumes: A review. *Legume Science, 5* (4), e192. https://doi.org/10.1002/leg3.192

Almeida, E. S., Silva Damaceno, D., Carvalho, L., Victor, P. A., Passos, R. M., de Almeida Pontes, P. V., Cunha-Filho, M., Sampaio, K. A., & Monteiro, S. (2021). Thermal and physical properties of crude palm oil with higher oleic content. *Applied Sciences, 11*, 7094. https://doi.org/10.3390/app11157094

AOAC. (2016). *Official Methods of Analysis of AOAC International* (20th ed.). Gaithersburg, MD: AOAC International.

Ayogu, R. N. B., Nnam, N. M., & Mbah, M. (2016). *Evaluation of two local cowpea species for nutrient, antinutrient, and phytochemical compositions and organoleptic attributes of their wheat-based cookies* (p. 60). Food and Nutrition Research. https://doi.org/10.3402/fnr.v60.29600

Bassinello, P. Z., de, G. C., Freitas, D., Ascheri, J. L. R., Takeiti, C. Y., Carvalho, R. N., Koakuzu, S. N., & Carvalho, A. V. (2011). Characterization of cookies formulated with rice and black bean extruded flours. *Procedia Food Science, 1*, 1645–1652. https://doi.org/10.1016/j.profoo.2011.09.243

Blanco-Rojo, R., & Vaquero, M. P. (2019). Iron bioavailability from food fortification to precision nutrition: A review. *Innovative Food Science & Emerging Technologies, 51*, 126–138. https://doi.org/10.1016/j.ifset.2018.04.015

Brasil. Agência Nacional de Vigilância Sanitária (ANVISA). (2020a). *Resolução RDC n° 429, de 8 de outubro de 2020. Dispõe sobre a rotulagem nutricional dos alimentos embalados*. Brasília, DF: Diário Oficial da União, 9 out. 2020. Retrieved from https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2020/RDC_429_2020_.pdf.

Brasil. Agência Nacional de Vigilância Sanitária (ANVISA). (2020b). *Instrução Normativa n° 75, de 8 de outubro de 2020. Estabelece os requisitos técnicos para declaração da rotulagem nutricional dos alimentos embalados*. Brasília, DF: Diário Oficial da União, 9 out. 2020. Retrieved from https://anvisalegis.datalegis.net/action/ActionDatalegis.php?acao=abrirTextoAto&numeroAto=00000075&valorAno=2020.

Brasil. (2005). *Instrução Normativa n° 8, de 2 de junho de 2005 – Regulamento Técnico de Identidade e Qualidade da Farinha de Trigo*. Brasília, DF: Ministério da Agricultura, Pecuária e Abastecimento, 3 jun. 2005. Retrieved from https://www.normasbrasil.com.br/norma/instrucao-normativa-8-2005_75598.html.

Brasil. (1996). *Portaria MAPA n° 146, de 07 de março de 1996 – Regulamentos Técnicos de Identidade e Qualidade dos Produtos Lácteos. Ministério da Agricultura*. Brasília, DF: Pecuária e Abastecimento. Diário Oficial da União, 11 mar. 1996.

Cardoso, L. A., Greiner, R., Silva, C.de S., Maciel, L. F., Santos, L. F. P., & Almeida, D. T.de (2021). Small scale market survey on the preparation and physico-chemical characteristics of moin-moin: A traditional ready-to-eat cowpea food from Brazil. *Food Science and Technology, 2061*, 1–8. https://doi.org/10.1590/fst.59920

Carvalho, A. F. U., de Sousa, N. M., Farias, D. F., da Rocha-Bezerra, L. C. B., da Silva, R. M. P., Viana, M. P., Gouveia, S. T., Sampaio, S. S., de Sousa, M. B., de Lima, G. P. G., de Morais, S. M., Barros, C. C., & Filho, F. R. F. (2012). Nutritional ranking of 30 Brazilian genotypes of cowpeas including determination of antioxidant capacity and vitamins. *Journal of Food Composition and Analysis, 26*, 81–88. https://doi.org/10.1016/j.jfca.2012.01.005

Chávez-Santoscoy y, R. A., Gutiérrez-Uribe, J. A., Serna-Saldivar, S. O., & Perez-Carrillo, E. (2016). Production of maize tortillas and cookies from nixtamalized flour enriched with anthocyanins, flavonoids, and saponins extracted from black bean (Phaseolus vulgaris) seed coats. *Food Chemistry, 192*, 90–97. https://doi.org/10.1016/j.foodchem.2015.06.113

de Almeida, D. T., Greiner, R., Furtunado, D., Trigueiro, I. N., & Araújo, M. D. P. N. (2008). Content of some antinutritional factors in bean cultivars frequently consumed in Brazil. *International Journal of Food Science & Technology, 43*(2), 243–249. https://doi.org/10.1111/j.1365-2621.2006.01426.x

de Almeida, D. T., Nunes, I. L., Conde, P. L., Rosa, R. P. S., Rogério, W. F., & Machado, E. R. (2013). A quality assessment of crude palm oil marketed in Bahia. *Brazil. Grasas & Aceites, 64*(4), 387–394. https://doi.org/10.3989/gya.118412

de Almeida, D. T., Viana, T. V., Costa, M. M., Silva, C., de, S., & Feitosa, S. (2019). Effects of different storage conditions on the oxidative stability of crude and refined palm oil, olein and stearin (Elaeis guineensis). *Food Science & Technology, 39*, 211–217. https://doi.org/10.1590/fst.43317

de Oliveira Pineli, L. D. L., de Carvalho, M. V., de Aguiar, L. A., de Oliveira, G. T., Celestino, S. M. C., Botelho, R. B. A., & Chiarello, M. D. (2015). Use of baru (Brazilian almond) waste from physical extraction of oil to produce flour and cookies. *LWT - Food Science and Technology, 60*(1), 50–55. https://doi.org/10.1016/j.lwt.2014.09.035

Damanik, M., & Murkovic, M. (2018). The stability of palm oils during heating in a rancimat. *European Food Research and Technology, 244*, 1293–1299. https://doi.org/10.1007/s00217-018-3044-1

dos Santos, W. P. C., Santos, D. C. M. B., Fernandes, A. P., Castro, J. T., & Korn, M. G. A. (2013). Geographical characterization of beans based on trace elements after microwave-assisted digestion using diluted nitric acid. *Food Analytical Methods, 6*(4), 1133–1143. http://repositorio.ufba.br/ri/handle/ri/17174.

Frota, K. D. M. G., Morgano, M. A., da Silva, M. G., da Mota Araújo, M. A., & dos Reis Moreira-Araújo, R. S. (2010). Utilização da farinha de feijão-caupi (Vigna unguiculata L. Walp) na elaboração de produtos de panificação. *Ciência e Tecnologia de Alimentos, 30*, 44–50. https://doi.org/10.1590/S0101-20612009005000003

Institute of Medicine. (2006). *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*. Washington, DC: National Academies Press. https://doi.org/10.17226/11537

Jiang, Z. Q., Pulkkinen, M., Wang, Y. J., Lampi, A. M., Stoddard, F. L., Salovaara, H., Piironen, V., & Sontag-Strohm, T. (2016). Faba bean flavour and technological property improvement by thermal pre-treatments. *LWT - Food Science and Technology, 68*, 295–305. https://doi.org/10.1016/j.lwt.2015.12.015

Kuntom, A., & Ariffin, A. A. (2010). Flavors of palm oil. *Handbook of Fruit and Vegetable Flavors* (pp. 1051–1069). John Wiley & Sons.

Mamat, H., & Hill, S. E. (2014). Effect of fat types on the structural and textural properties of dough and semi-sweet biscuits. *Journal of Food Science and Technology, 51*(9), 1998–2005. https://doi.org/10.1007/s13197-012-0708-x

Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of food engineering, 48*(2), 169–175. https://doi.org/10.1016/S0260-8774(00)00154-0

McWatters, K., Phillips, R., Walker, S., McCullough, S., Mensa-Wilmot, Y., Saalia, F., Hung, Y.-C., & Patterson, S. (2004). Baking performance and consumer acceptability of raw and extruded cowpea flour breads. *Journal of Food Quality, 27*, 337–351. https://doi.org/10.1111/j.1745-4557.2004.00660.x

Munyaneza, R., Oliveira, D. L., & Costa, N. M. B. (2025). Consumer perception and functional attributes of cookies developed with legume flours: A sensory-guided formulation approach. *Food Research International, 174*, Article 113145. https://doi.org/10.1016/j.foodres.2025.113145

Ng, T. K. W., Low, C. X., Kong, J. P., & Cho, Y. L. (2012). Use of red palm oil in local snacks can increase intake of provitamin A carotenoids in young aboriginal children: A Malaysian experience. *Malaysian Journal of Nutrition, 18*(3), 393–397. PMID: 24568080.

Olaleke, A. M., Olorunfemi, O., & Akintayo, T. E. (2006). Compositional evaluation of cowpea (Vigna unguiculata) and scarlet runner bean (Phaseolus coccineus) varieties grown in Nigeria. *Journal of Agriculture, Food and Environment, 4*(2), 39–43.

Olapade, A. A., & Adeyemo, M. A. (2014). Evaluation of cookies produced from blends of wheat, cassava and cowpea flours. *International Journal of Food Studies, 3*(2), 175–185. https://doi.org/10.7455/ijfs/3.2.2014.a4

Onwuliri, V. A., & Obu, J. A. (2002). Lipids and other constituents of Vigna unguiculata and Phaseolus vulgaris grown in northern Nigeria. *Food Chemistry, 78*(1), 1–7. https://doi.org/10.1016/S0308-8146(00)00293-4

Rodrigues, P. H. C., Pinto, M. E. M., & Szarfarc, S. C. (2011). O uso de azeite de dendê na fortificação de alimentos. *Segurança Alimentar e Nutricional, 18*(2), 53–59.

Rogério, W. F., Greiner, R., Nunes, I. L., Feitosa, S., Maria da Nóbrega, D., & Teixeira de Almeida, D. (2014). Effect of preparation practices and the cowpea cultivar (Vigna unguiculata L. Walp) on the quality and content of myo-inositol phosphate in akara (fried bean paste). *Food Science and Technology, 34*, 243–248. https://doi.org/10.1590/fst.2014.0040

Silva, C. S., Greiner, R., Marinho, L. Q. M., Alves, A. S. B., Cardoso, L. A., Maciel, L. F., & de Almeida, D. T. (2022). Development of a gluten-free ice cream basket alternative using cowpea flour (Vigna unguiculata L. Walp), rice flour (Oryza sativa), and crude palm oil (Elaeis guineensis Jacq.). *International Journal of Gastronomy and Food Science, 28*, Article 100431. https://doi.org/10.1016/j.ijgfs.2021.100431

Singh, A., Kumar, A., Kumari, S., & Kaur, M. (2024). Physicochemical, textural, and sensory characteristics of cookies incorporated with germinated cowpea flour. *Food Chemistry, 430*, Article 137237. https://doi.org/10.1016/j.foodchem.2023.137237

Shakpo, I. O., & Osundahunsi, O. F. (2016). Effect of cowpea enrichment on the physico-chemical, mineral and microbiological properties of maize: cowpea flour blends. *Research Journal of Food Science and Nutrition, 1*, 35–41. https://doi.org/10.31248/RJFSN2016.007

TBCA. Tabela Brasileira de Composição de Alimentos. (2025). *Versão 7.3. Universidade de São Paulo (USP)*. Centro de Pesquisa em Alimentos (FoRC). Recuperado de. http://www.fcf.usp.br/tbca.

Watt, B. K., & Merrill, A. L. (1963). *Composition of Foods: Raw, Processed, Prepared (Agriculture Handbook No. 8)*. Washington, DC: U.S. Department of Agriculture.

World Health Organization. (2024). *WHO Guideline on Use of Ferritin Concentrations to Assess Iron Status in Individuals and Populations*. Geneva: World Health Organization. Recuperate from https://www.who.int/health-topics/anaemia.

Yanni, A. E., Iakovidi, S., Vasilikopoulou, E., & Karathanos, V. T. (2023). Legumes: A vehicle for transition to sustainability. *Nutrients, 16*(1), 98. https://doi.org/10.3390/nu16010098