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Baruburger, a plant-based choice produced with by-products: Nutritional value and technological characteristics

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Abstract

The population is increasingly seeking healthier products rich in nutrients such as high-quality proteins, dietary fibers, and polyphenols, which have the potential to be used as food ingredients aimed at promoting health, environmental sustainability, and circular economy practices. To develop a meat analog, this study uses raw materials from baru by-products, such as epicarp, mesocarp, and baru meal. The study evaluates its nutritional properties, creates a nutritional table for the vegetable burger based on the labeling information of the ingredients used in the formulation process, and assesses cooking yield, diameter, thickness reduction, and color to characterize the product. The results for the nutritional table indicated that formulation F6 (40% baru meal + 40% epicarp and mesocarp) contained protein (12.87 g/80 g), dietary fiber (13.79 g/80 g), and a low fat content (5.44 g/80 g). Formulation F4 showed the lowest cooking loss (7.36%), a diameter reduction of 0.78%, and a thickness reduction of 0.87%. Regarding the color analysis, formulations F3, F5, F6, F7, F8, and F10, which contained higher amounts of baru by-products, had a* values ranging from 9.11 to 9.33, indicating that these vegetable burgers tended to have a more reddish-brown color. Baru by-products represent an important vegetable raw material with the potential to benefit from its entire value chain, promoting sustainable products with high nutritional quality.

Keywords: sustainable food; alternative proteins; nutritional quality; nutritional table.

Practical Application: Burger can also be produced with vegetable by-products.

1 INTRODUCTION

The world population is increasing, as is the demand for food. One possible strategy to achieve this transition is the formulation of foods with alternative protein sources, such as edible insects, algae, or plant (Appiani et al., 2023).

Meat analog products, which can be defined as food products formulated to imitate meat in nutrients, texture, flavor, and appearance, appear to be the best solution for introducing alternative proteins into human dietary choices (Kumar et al., 2017; Nam et al., 2024; Zhang et al., 2023). Plant-based meat analogs are generally formulated with different ingredients and additives in addition to vegetable protein to achieve acceptable sensory properties (Ariz et al., 2024). A typical plant-based meat analog is generally composed of 50–80% water, 4–25% protein, 2–30% carbohydrates (CB), 0–15% lipids, and 0–15% additives, including binding agents, seasonings, flavorings, salt, and pigments (Chen et al., 2022, 2023).

Plant-based foods formulated as substitutes for animal products are one of the growing sectors among alternative food sources, covering a diverse range of products obtained from botanical sources, such as legumes, for example, chickpeas (CP), which are the third most cultivated legume in the world; seeds and nuts, for example, cottonseed, sesame seed, sunflower seed, pumpkin seed, grape seed, and hazelnut; and pseudocereals and cereals, for example, quinoa or oats, and mushrooms (Tachie et al., 2023).

In addition to these plant sources, agroindustry by-products can also be used in plant-based products, such as by-products of baru (*Dipteryx alata* Vog.), a fruit native to the Cerrado biome, which generate different fractions during almond production and oil extraction: epicarp, mesocarp, endocarp (EN), and baru meal (BM) (Egea et al., 2023). These fractions are rich in proteins, fibers, and fatty acids, have great technological potential, and can be used as a raw material in developing plant analogs (Sousa et al., 2024).

Burgers are one of the most popular meat products worldwide (Tabarestani et al., 2024). Several plant-based versions have been found on the market. The plant-based food market has expanded beyond traditional options such as veggie or plant-based burgers and tofu, now offering various products that mimic animal foods. Rapid expansion raises questions about nutritional value and health benefits (Locatelli et al., 2024). Thus, this work aims to develop a meat analog using CP and baru by-products to explore alternative and sustainable sources for producing plant-based products.

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1.1 Relevance of the work

More plant-based ingredient options are needed to meet consumers' new demand. Reusing by-products seems like an interesting option for producing plant-based ingredients. Combining the use of by-products with the full use of native fruits from Brazilian biomes can help promote the protection of these biomes by increasing interest in their biodiversity. Thus, the proposal of this research was to develop a product based on a by-product of the processing of baru, a native fruit of the Cerrado biome.

2 MATERIAL AND METHODS

2.1 Raw material acquisition

The baru fruit was collected from the Brazilian Cerrado region (Caiaponia, Goiás, Brazil). The fruits were manually separated into pericarp and baru almond. The pericarp was sanitized with sodium hypochlorite P.A (2 mg/L), submerged in autoclaved water for 24 h, and then separated into epicarp+mesocarp (EPME) and EN. After separation, the EPME was dried in an oven with forced air circulation (60 ± 2°C) for 24 h. BM, a by-product of almond oil extraction, was provided by Flora do Cerrado (Jussara, Goiás, Brazil). CP and other ingredients were purchased from a company in Rio Verde, Goiás, Brazil.

CP preparation was carried out according to Stantiall et al. (2018). Briefly, the grains were soaked in running water for 16 h, then drained and washed three times with running water to remove bitter compounds such as phytic acid and tannins (Alsalman et al., 2020). After washing, the grains were cooked in a pressure cooker at a 3:1 weight ratio (water: hydrated grain) for 20 min. Then, the water and cooked CP were transferred to a glass bowl and left in the refrigerator at 5°C for 24 h. Then, the aquafaba was separated from the cooked grains using a sieve, and the grains were homogenized using a blender for 20 min.

2.2 Baruburger preparation

Burgers were produced according to the formulations described in Table 1 on the same day. The simplex-centroid design for mixtures of three components with three interior points (Table 1) was used to study the effects of interactions between ingredients on the quality of the product. The studied variables were the concentration of CP, BM, and EPME. Each variable's maximum level (component proportion = 1) was 80% (related to the total burger base), with the remaining 20% composed of oat flour for all formulations. The response variables were the nutritional value and technological characteristics of the burger.

The other ingredients of the burger were calculated as a percentage of the mass: 5 mL of baru oil, 1% of salt, 0.33% of onion/garlic, 0.17% of paprika/dehydrated salt, 0.07% of smoke powder, and 0.03% of cumin.The first step was to add water to the BM and EPME flours. To prepare the samples, 100 g of each flour was mixed with 200 mL of distilled water. The samples were left to rest (overnight) for 12–24 h, allowing the flours to hydrate and fully absorb the water.

After weighing all the ingredients, they were manually homogenized and kept at rest for 30 min under refrigeration (6°C) to improve consistency. Subsequently, they were molded into 80-g portions according to the Normative Instruction of the National Health Surveillance Agency No. 75, of October 8, 2020 (Brasil, 2020), in a circular shape, 2 cm thick, using parchment paper. They were packaged in polyethylene bags and stored frozen at −14°C.

The samples were cooked on a previously heated electric griddle (approximately 160°C), with heat transferred through direct contact on both sides of the pieces. Using a spatula, the burgers were released after 30 s of cooking to prevent them from sticking to the griddle and were turned every 30 s to avoid excessive surface crust formation. Cooking was carried out until the samples' internal temperature (cold point) reached 72°C (temperature measured with a digital thermometer).

Table 1. Codified and decoded variables and response (nutritional value) of plant-based burger formulations containing chickpeas, baru meal, and epicarp + mesocarp.

Formulations	Coded variables			Decoded variables			100 g portion							
	CP	BM	EPME	CP	BM	EPME	CB (g)	TS (g)	PTN (g)	TF (g)	SF (g)	DF (g)	Sodium (mg)	EV (kcal)
F1	1.00	0.00	0.00	80	0	0	50.87	2.24	8.90	0.05	0.00	7.60	397.00	200.45
F2	0.00	1.00	0.00	0	80	0	47.93	0.80	28.25	13.26	10.50	15.60	391.40	424.68
F3	0.00	0.00	1.00	0	0	80	79.87	0.80	7.28	0.41	0.00	21.91	391.40	396.18
F4	0.50	0.50	0.00	40	40	0	46.08	1.52	18.58	6.75	5.25	11.60	394.20	312.56
F5	0.50	0.00	0.50	40	0	40	58.13	1.52	8.09	0.32	0.00	14.76	394.20	298.31
F6	0.00	0.50	0.50	0	40	40	60.58	0.80	17.77	6.83	5.25	18.76	391.40	410.43
F7	0.33	0.33	0.33	26.67	26.67	26.67	52.05	1.28	14.81	4.63	3.50	15.04	393.27	340.47
F8	0.67	0.17	0.17	40	20	20	49.81	1.52	13.33	3.53	3.00	13.18	394.00	305.44
F9	0.17	0.67	0.17	20	40	20	53.33	1.60	18.17	6.79	5.25	15.18	392.80	361.50
F10	0.17	0.17	0.67	20	20	40	57.06	1.60	12.93	3.58	2.62	16.76	392.80	354.37

BM: baru meal; CB: Carbohydrates; CP: containing chickpeas; DF: dietary fiber; EPME: epicarp + mesocarp; EV: energy value; PTN: proteins; SF: saturated fat; TF: total fats; TS: total sugars.

2.3 Nutritional value of burgers

The nutritional value of the products was calculated based on the Technical Regulation on Labeling of Packaged Foods (Brasil, 2002), the Technical Regulation on Portions of Packaged Foods for Nutritional Labeling Purposes (Brasil, 1998), and the Technical Regulation on Nutritional Labeling of Packaged Foods (Brasil, 2003).

The calculations were based on the values provided in the Nutritional Composition Table of the ingredients used in the production process. Data from the Brazilian Food Composition Table (Núcleo de Estudos e Pesquisas em Alimentação [NEPA] & Universidade Estadual de Campinas [UNICAMP], 2011) were used as a reference source for the foods' nutritional information.

2.4 Technological properties

The burgers' performance during cooking (yield, diameter reduction, and shrinkage) was evaluated. The yield during cooking was determined by measuring the weight of the vegetable analogs before and after cooking and calculating using Equation 1.

$$Yield\ (\%) = \frac{Weight\ of\ cooked\ sample}{Weight\ of\ raw\ sample} \times 100 \quad (1)$$

The percentages of reduction in diameter (RD) and thickness of the product were measured using a digital caliper, and the results were calculated using Equations 2 and 3, respectively. For the RD analysis, the burger was cooked on an electric griddle (150°C) until the internal temperature of the burger reached 75°C. The RD was determined by comparing the burger diameter before cooking (DB) and after cooking (DA), as shown in Equation 2 (Dreeling et al., 2000; Ramadhan et al., 2011).

$$Reduction\ in\ diameter\ (\%) = \frac{(DB-DA)}{DB} \times 100 \quad (2)$$

$$Reducton\ in\ thickness\ (\%) = \frac{Thickness\ (raw-cooked) + Diameter\ (raw-cooked))}{Raw\ sample\ diameter} \times 100 \quad (3)$$

Color analysis was performed on raw and grilled samples using a colorimeter (CR41, Konica Minolta, Tokyo, Japan). Results were obtained from the average of nine replicates outside the samples. Values were expressed as L*, C*, and h among the burgers.

2.5 Statistical analysis

All analyses were performed in triplicate. Data were expressed as mean and standard deviation and subjected to analysis of variance (ANOVA) for treatments (samples evaluated in this study), followed by the application of Tukey's test using Statistica 6.0 software (StatSoft Inc., USA). Differences were considered significant when $p < .05$.

The Scheffé canonical equation (Equation 1) was used to model the experimental data:

$$Y=\beta_1X_1+\beta_2X_2+\beta_2X_3+\beta_{12}X_1X_2+\beta_{13}X_1X_3+\beta_{23}X_2X_3+\beta_{123}X_1X_2X_3 \quad (4)$$

Where Y is the studied response, β1, β2, β3, β12, β13, β23, and β123 are the regression parameters, and X1, X2, and X3 are the levels of ingredients in the blends. Positive values for binary coefficients, βij, indicate synergistic effects, while negative values represent antagonism.

Triangular contour plots for each property were generated from polynomial equations using Statistica 6.0 for Windows (StatSoft Inc., Tulsa, OK, USA). The results obtained were evaluated using the response surface methodology and screened using the desirability tool with the highest levels of each response variable.

3 RESULTS AND DISCUSSION

3.1 Nutritional value of burgers

Table 1 presents the nutritional information for the plant-based analogs for a 100 g serving. Some formulations showed higher nutrient values than others. Table 2 shows the mathematical modeling performed with the response variables, R^2, R_{adj}, and the *p*-value. All dependent variables positively influenced the nutritional value of the formulations (positive effect).

The carbohydrate content ranged from 46.08 (F4) to 79.87 (F3) g/100 g, while the total sugar (TS) value ranged from 0.80 (F2, F3, and F6) to 2.2 (F1). As demonstrated by mathematical modeling, EPME was the variable that most influenced carbohydrate values (almost twice as much as CP and BM) (Table 2). This may have occurred because the total carbohydrate value (g/100 g) is 81.34 for EPME, 41.42 for BM (Sousa et al., 2024), and 57.00 for CP (NEPA & UNICAMP, 2011).

Table 2. Mathematical modeling of the response variables studied in the plant-based burger formulations containing chickpeas, baru meal, and epicarp+mesocarp.

Variables	R^2 (%)	R_{adj} (%)	*p*-value
Carbohydrates = 46.71CP + 46.72BM + 73.27EPME	83.47	78.75	< .00
Total sugars = 2.14CP + 0.98BM + 0.98EPME	71.89	63.86	.01
Protein = 9.39CP + 27.13BM + 7.91EPME	96.03	94.90	< .00
Total fat = 0.50CP + 12.56BM* + 0.78EPME	95.98	94.83	< .00
Satured fat = 0.41CP + 9.91BM* + 0.28EPME	95.33	94.00	< .00
Dietary fiber = 8.22CP + 15.55BM + 21.34EPME	96.01	94.86	< .00
Energy = 212.15CP + 417.62BM + 391.47EPME	96.00	94.86	< .00
Sodium = 396.62CP + 391.56BM + 391.56EPME	94.69	93.17	< .00

BM: baru meal; CP: containing chickpeas; EPME: epicarp + mesocarp.*Only significant effect.

The protein content of the formulations ranged from 7.28 (F3) to 28.25 (F2) g/100 g. According to Collegiate Board Resolution (RDC) No. 54, of November 12, 2012 (Brasil, 2012), which defines a "source of protein" as any food that contains a minimum composition of 6 g of protein, all formulations can be considered "rich in protein." F2 (80% of BM) presented the highest value of protein and total and saturated fats (SFs), resulting in the highest caloric value, and this was demonstrated by mathematical modeling, where the effect of BM was 2.9 times greater than CP and 3.4 times greater than EPME (Table 2 and Figure 1). As expected, BM is an ingredient that can contribute to increasing protein value (Egea et al., 2023) since it contains, on average, 33 g of protein/100 g (Sousa et al., 2024). In the study by Botella-Martínez et al. (2022), textured soy and peanut flour burgers demonstrated lower protein content (18.59 g/100 g).

The fat source used is also significant, both technologically and from a sensory, nutritional, and health perspective (Badar et al., 2021). The total fat (TF) content in the burger formulations developed ranged from 0.05 (F1) to 13.26 (F2) g/100 g, with a total SF content of 0.00 (F1) to 10.50 (F2) g/100 g. None of the developed formulations contained trans-fat. Low-fat food products should contain no more than 10% fat, and very-low-fat products should contain less than 5% fat (Choe et al., 2013). F1, F3, F5, F7, F8, and F10 can be classified as very-low-fat food products, while F4, F6, and F9 can be classified as low-fat.

Due to their composition, vegetable oils such as sunflower, canola, palm, and coconut have been appreciated in food products (Badar et al., 2021; Domínguez et al., 2024). In this formulation, baru oil was added to play an important role from a technological, sensory, nutritional, and health perspective (considering its fatty acid profile) (Sousa et al., 2024).

Although, in general, vegetable oil can be an ingredient that contributes to TF content, in the present study, the most significant contributor still appears to have been BM, which in previous studies reported 16.52 g/100 g of lipids (Sousa et al., 2024). Furthermore, the effect of BM on TF, indicated by mathematical modeling, was more than 15 times greater than that of the other ingredients (Table 2 and Figure 1). The same behavior was demonstrated for SF content. The results found for the TF content of F2 were close to what had been reported by Kothuri et al. (2024) for textured pea protein burgers (10.35 g/100 g).

The fat content of foods is the most significant contributor to their caloric value. As with TF and SF contents, the BM ingredient demonstrated a greater effect in mathematical modeling than the other ingredients (CP and EPME). In this study, the caloric value of burgers ranged from 200.35 (F1) to 424.68 kcal/100 g (F2). Notably, F1 had the lowest TF and SF contents, and F2 had the highest.

Plant-based protein meat analogs can be designed to be healthy; their enrichment with dietary fiber (DF) and plant-based amino acids can provide these plant-based burgers with enhanced sensory and nutritional profiles, not typically found in original meat burgers (Peñaranda et al., 2023). The DF content ranged from 7.6 (F1) to 21.91 g/100 g (F3), and all formulations can be considered "high in dietary fiber" by containing more than 6 g of fiber according to RDC No. 54, of November 12, 2012 (Brasil, 2012).

Normative Instruction No. 75/2020 establishes that for a food to be considered high in total DF, it must contain at least 20% of the recommended daily value (RDV) of this nutrient, per reference serving, being 25 g for adults aged 19 years or older and 38 g for adolescents aged 9–18 years (Brasil, 2020). The burger formulations in the present study contained 28.72–74.52% total DF, which can be considered high. DF levels can reduce formulation costs and improve the technological properties of meat products, such as cooking performance, emulsion stability, rheological parameters, palatability, and texture (Mehta et al., 2015).

Regarding fiber content, EPME appears to be the ingredient that contributes most to this content since the formulation containing 80% of this ingredient presented the highest value of this macronutrient. Through mathematical modeling, it was possible to observe that the effect of EPME was two and 1.4 times greater than CP and BM, respectively, corroborating the hypothesis that increasing this ingredient is much more positive for DF content than the other ingredients (Table 2 and Figure 1). This result corroborates the DF values reported for the epicarp (33.36 g/100 g) and mesocarp (29.32 g/100 g) by Sousa et al. (2024). The values found in the present study were higher than those reported for pea-based burgers (7.99 g/100 g) (Luz et al., 2024).

High sodium intake contributes to high blood pressure and a higher risk of cardiovascular disease, stroke, and coronary heart disease in adults. Therefore, the World Health Organization (WHO) recommends a sodium intake of less than 2 g/day, equivalent to 5 g/day of salt (WHO, 2012). The amount of sodium found in plant-based burgers ranged from 391.40 to 397.00 mg, indicating that by consuming 100 g of this product, an adult would be ingesting approximately 19.57–19.85% of the maximum recommended daily sodium intake.

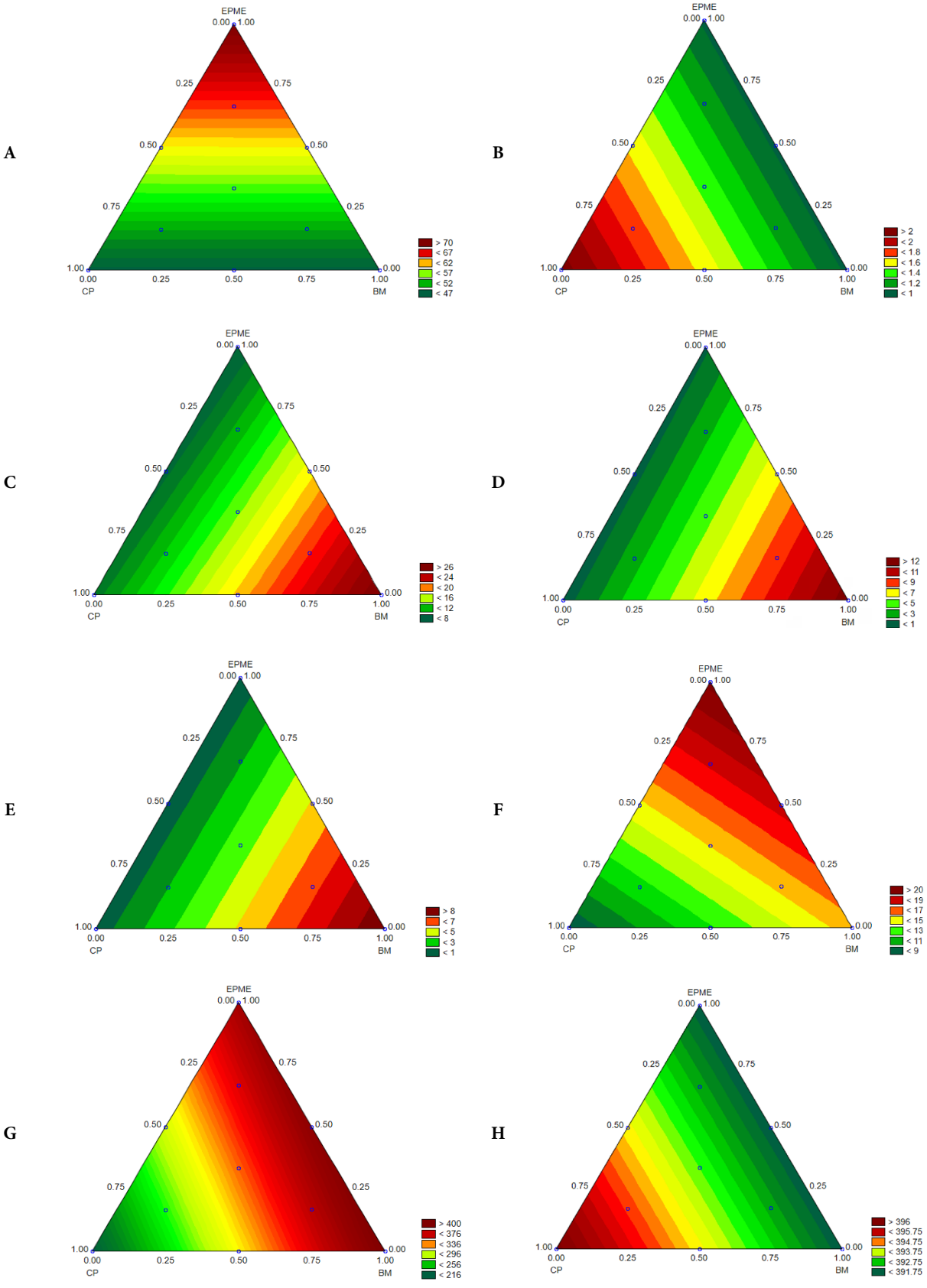
Of all the formulations, those containing some baru ingredient are the most likely to influence the variation in sodium levels, as indicated by the greater effect for BM and EPME in the mathematical modeling (Table 2 and Figure 1).

Commercial soy concentrate burgers from PlantPlus Foods contain 430 mg of sodium per 80 g, higher than those in the formulations developed in this study. Salt plays multiple roles, including enhancing flavor, intensifying flavor profiles, and contributing to savory notes typical of meat. It also helps modulate texture by increasing protein solubility and moisture retention, thus improving the juiciness and tenderness of meat analogs (Singh & Sit, 2025).

Iodine is essential for the development, growth, and normal functioning of the body and the central nervous system (Lage et al., 2015). According to the WHO, the recommended amount of iodine for adults is 150 µg per day (WHO, 2008). All burger analog formulations had an iodine content of 25 µg, which corresponds to approximately 16.67% of the recommended daily iodine intake.

3.2 Technological properties

As with meat products, macronutrient content in meat analogs also affects the system's ability to bind water and fat and, therefore, is responsible for cooking loss and dimensional changes (shrinkage and thickness) in the cooked product (Botella-Martínez et al., 2022).



BM: baru meal; CP: containing chickpeas; EPME: epicarp + mesocarp.

Figure 1. Contour plot of carbohydrate **(A)**, total sugar **(B)**, protein **(C)**, total fat **(D)** and saturated fat **(E)**, dietary fiber **(F)**, energy value **(G)**, and sodium **(H)** in the plant-based burger formulations containing chickpeas, baru meal, and epicarp + mesocarp.

Table 3 presents the cooking yield, cooking loss, and diameter and thickness reduction for plant-based analogs. None of these response variables presented a significant mathematical model.

Several factors, including pH, water-holding capacity, cooking method and type, and lipid content, can affect cooking loss (Vaskoska et al., 2020). Cooking yield values ranged from 81.27 (F10) to 92.64 (F4) %.

The lower volume loss in F4 may be related to combining ingredients with greater technological functionality and the higher protein content of 18.58 g/100 g (Table 1). On the other hand, F10, which had the lowest yield, had the lowest protein content of 12.93 g/100 g, which may have contributed to less structural network formation during cooking, favoring greater moisture loss. The low cooking loss observed in the formulated burgers may indicate their ability to retain fluids containing water, minerals, proteins, and fat (Vu et al., 2022).

The vegetable analogs presented an average cooking loss of 7.36 (F4) to 18.73 (F10) % (Table 3). Since this value is calculated from the yield, not surprisingly, the same behavior was observed for this property. Piñero et al. (2008) claimed that adding soluble oat fiber to low-fat beef burgers improved moisture retention. This behavior may indicate why F4 had the lowest cooking loss, likely due to its higher protein and fiber content (Table 2). Conversely, F10 demonstrated the highest cooking loss and the lowest fiber and protein content (Table 2). Even so, the cooking loss values found in the present study were lower than those highlighted by Trujillo-Mayol et al. (2021) for soy burgers (24.77%).

The values found for diameter reduction in the formulations ranged from 0.78 (F4) to 32.71 (F10) %, while for thickness reduction, they were from 0.56 (F4) to 32.68 (F10) %, in line with the values of the other parameters. This may be because greater losses during cooking lead to lower emulsion stability of meat analogs, with consequent loss of resilience, which decreases the speed and strength of recovery from emulsion deformation with the three-dimensional internal structure of the proteins, causing shrinkage of the products (Cornet, 2021).

Consumers consider color as the initial marker of food quality when purchasing (Wojtasik-Kalinowska et al., 2022). Table 4 shows the instrumental color results for each vegetable

Table 3. Technological properties of plant-based burger formulations containing chickpeas, baru meal, and epicarp + mesocarp.

Formulations	Cooking yield (%)	Cooking loss (%)	Diameter reduction (%)	Thickness reduction (%)
F1	83.94 ± 1.37^{d}	16.06 ± 1.37^{ab}	8.53 ± 1.19^{b}	10.05 ± 0.22^{c}
F2	88.31 ± 0.84^{b}	11.69 ± 0.84^{c}	32.71 ± 0.51^{a}	32.68 ± 0.29^{a}
F3	83.79 ± 0.35^{d}	16.21 ± 0.35^{ab}	2.14 ± 2.03^{c}	2.76 ± 0.16^{d}
F4	92.64 ± 0.44^{a}	7.36 ± 0.44^{d}	0.78 ± 0.40^{d}	0.87 ± 0.19^{ef}
F5	84.35 ± 0.78^{cd}	15.65 ± 0.78^{b}	1.67 ± 1.24^{cd}	2.96 ± 0.43^{d}
F6	86.47 ± 0.77^{c}	13.53 ± 0.77^{c}	1.87 ± 0.13^{cd}	3.09 ± 0.35^{d}
F7	82.04 ± 1.14^{de}	17.96 ± 1.14^{a}	2.28 ± 0.22^{c}	1.32 ± 0.20^{e}
F8	84.44 ± 1.30^{cd}	15.56 ± 1.30^{b}	2.99 ± 1.41^{c}	16.12 ± 0.12^{b}
F9	86.04 ± 0.26^{c}	13.96 ± 0.26^{c}	1.02 ± 0.20^{cd}	0.56 ± 0.17^{ef}
F10	81.27 ± 0.06^{e}	18.73 ± 0.06^{a}	1.40 ± 0.62^{cd}	1.11 ± 0.51^{e}

Means followed by the same letter in the row do not differ statistically from each other by Tukey's test ($p < .05$).

Table 4. Colorimetric parameters of plant-based burger formulations containing chickpeas, baru meal, and epicarp + mesocarp.

Formulation	Raw burger			Cooked burger		
	L*	C	h	L*	C	h
F1	64.95 ± 3.42^{a}	27.93 ± 0.49^{a}	79.69 ± 0.41^{a}	37.48 ± 3.29^{a}	23.75 ± 2.92^{a}	73.20 ± 0.43^{a}
F2	40.72 ± 1.16^{b}	13.84 ± 1.85^{b}	68.02 ± 1.78^{b}	38.10 ± 1.94^{a}	16.90 ± 1.24^{b}	68.74 ± 2.76^{a}
F3	34.12 ± 1.55^{c}	18.63 ± 2.77^{b}	56.50 ± 4.24^{c}	28.02 ± 1.67^{b}	20.93 ± 1.80^{b}	56.87 ± 1.68^{b}
F4	54.52 ± 2.27^{a}	17.69 ± 1.63^{b}	72.08 ± 0.99^{a}	30.08 ± 0.98^{b}	18.81 ± 0.97^{b}	70.96 ± 1.05^{a}
F5	43.88 ± 1.22^{b}	22.06 ± 0.85^{a}	62.04 ± 0.98^{b}	27.09 ± 1.02^{b}	23.00 ± 0.79^{a}	58.98 ± 1.18^{b}
F6	32.25 ± 2.43^{c}	17.79 ± 2.36^{b}	55.77 ± 2.84^{c}	26.71 ± 0.87^{b}	20.47 ± 0.45^{b}	60.79 ± 1.82^{b}
F7	41.98 ± 4.93^{b}	21.25 ± 1.65^{a}	62.67 ± 1.73^{b}	32.72 ± 1.57^{a}	20.34 ± 0.80^{b}	59.70 ± 2.02^{b}
F8	44.27 ± 1.49^{b}	20.86 ± 1.26^{a}	64.02 ± 2.10^{b}	26.88 ± 1.88^{b}	17.36 ± 0.91^{b}	58.76 ± 1.55^{b}
F9	41.13 ± 2.36^{b}	15.69 ± 0.99^{b}	61.65 ± 1.12^{b}	32.17 ± 1.68^{a}	20.47 ± 0.45^{b}	60.79 ± 1.82^{b}
F10	37.26 ± 3.32^{c}	19.64 ± 1.98^{b}	59.82 ± 1.91^{c}	30.31 ± 1.20^{b}	19.53 ± 1.00^{b}	56.25 ± 1.59^{b}

L*: luminosity; C: chroma; h: hue. Means followed by the same letter in the line do not differ statistically by the Tukey test ($p < .05$).

burger formulation, and significant differences were found between the formulations.

Regarding raw burgers, luminosity (L*) values closer to 100 indicate higher luminosity, while those closer to 0 indicate a surface with lower luminosity. In this study, F1 presented the highest L* value (64.95), significantly different from the other formulations, while F3 (34.12) and F6 (32.25) presented lower L* values. The other formulations presented intermediate values.

EPME and BM ingredients are darker, which may resemble the reddish color typical of traditional burgers. Furthermore, the adequate red color must be stable at the burgers' pH value and not degrade or become brown when heated (Botella-Martínez et al., 2022). This fact explains the behavior of formulations F3 and F6, with lower luminosity (L*) and color saturation (C), due to the combination of 40% FTB + 40% FPIME. After baking, all burgers became darker, as demonstrated by the decrease in the luminosity parameter. In general, color is highly dependent on the nature and moisture content of the raw materials and the reactions occurring during the baking process, such as protein denaturation, pigment degradation, Maillard reactions (Zhou et al., 2022), and surface water evaporation (Egea et al., 2012).

Chroma values remained virtually the same after baking, as did the hue angle of the burger formulations, which varied from red to yellow. This indicates stability in the saturation and hue of the burgers during heat treatment.

4 CONCLUSIONS

The results of this study indicate that baru by-products can be used in formulations as ingredients to improve nutritional value and technological properties. Of all the formulations evaluated, F6 (40% FTB + 40% FPIME) presented excellent protein and DF contents, as well as low fat content, demonstrating that the nutrients present add nutritional value to the developed plant-based analog.

Regarding the results presented for the cooking yield, diameter, and thickness analyses of formulations F2 (80% FTB) and F4 (40% GB + 40% FTB), this result may be related to the amount of protein present in the samples, as these two formulations presented higher levels. The color analyses performed on the samples showed that the formulations with a higher by-product content in their composition presented a more reddish-brown coloration, an essential characteristic for attracting consumers when purchasing the product, indicating that the raw materials analyzed have great nutritional, technological, and economic potential.

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