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FOOD TECHNOLOGY

Baru (*Dipteryx alata* Vog.) agro-industrial by-products as a nutritive and healthy ingredient in brownie formulation

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ABSTRACT: The baru (*Dipteryx alata* Vog.) fruit stands out among the fruits native to the Cerrado for its high agri-food potential, and it consists of a thin peel covering the pulp and a woody endocarp coating the nut. During the extraction process of baru nut or its oil, the peel, pulp, and partially defatted nut are usually discarded or used as animal feed. However, these by-products are rich in proteins, dietary fibers, and bioactive compounds. Food preparations like brownies are attractive and popular despite having a high energy density and a low phytochemical content. Thus, this study developed nutritious brownie formulations using baru food ingredients [BFI: a mixture of partially defatted nut flour (DBF) with baru peel and pulp flour (BPF)]. Three formulations were tested: SBF - standard brownie made with wheat flour; BBF_1 - brownie made by replacing wheat flour with BFI_1 (50% DBF + 50% BPF); and BBF_2 - brownie made by replacing wheat flour with BFI_2 (75% DBF + 25% BPF). The chemical composition and functional properties of the brownies were evaluated. The addition of baru by-products in the formulations resulted in products with higher contents of protein, dietary fiber, phenolic compounds, and greater antioxidant capacity than the standard brownie. Therefore, the use of baru food ingredients in food formulations is indicated to design new food products with improved nutritional quality and nutraceutical properties.
Key words: baru fruit, by-product, functional ingredients, phenolic compounds, nutritional value.

Subprodutos agroindustriais do baru (*Dipteryx alata* Vog.) como ingrediente nutritivo e saudável na formulação de brownies

RESUMO: O fruto de baru (*Dipteryx alata* Vog.) se destaca dentre os frutos nativos do Cerrado por seu elevado potencial agroalimentar, sendo composto por uma casca fina que recobre a polpa e por um endocarpo lenhoso que envolve a castanha. Durante a extração da castanha de baru ou do óleo, a casca, a polpa e a castanha parcialmente desengordurada são em geral descartados ou destinados à alimentação animal. Entretanto, estes subprodutos são ricos em proteínas, fibras alimentares e compostos bioativos. Preparações alimentares como o brownie são atrativas e populares, embora possuam elevada densidade energética e baixo conteúdo de fitoquímicos. Assim, o objetivo deste estudo foi desenvolver formulações de brownie nutritivas, a partir de ingredientes alimentares de baru (IAB: mistura da farinha da castanha parcialmente desengordurada [FDB] com a farinha da casca e da polpa de baru [FPB]). Foram testadas três formulações: FBP - brownie padrão, elaborado com farinha de trigo; FBB_1 - brownie elaborado com substituição da farinha de trigo por IAB_1 (50% FDB + 50% FPB); and FBB_2 - brownie elaborado com substituição da farinha de trigo por IAB_2 (75% FDB + 25% FPB). Foram avaliadas a composição química e as propriedades funcionais dos brownies. A adição dos subprodutos de baru nas formulações resultou em produtos com maiores teores de proteína, fibra alimentar, e compostos fenólicos, e maior capacidade antioxidante, em relação ao brownie padrão. Assim, a utilização de ingredientes alimentícios de baru em formulações alimentícias é indicada para a elaboração de novos produtos alimentícios com melhor qualidade nutricional e propriedades nutracêuticas.
Palavras-chave: fruto de baru, subproduto, ingredientes funcionais, compostos fenólicos, valor nutritivo.

INTRODUCTION

Baru (*Dipteryx alata* Vog.) is a fruit native to the Brazilian Cerrado that stands out for its nutritional properties and economic potential. This fruit is composed of a thin peel (epicarp) that coats the pulp (mesocarp) and a woody endocarp that contains a seed called baru nut or baru almond (ALVES-SANTOS et al., 2021). The nut is the main commercialized product and stands out for its high contents of good-quality proteins, in addition to containing a remarkable concentration of dietary fiber, and a fatty acid profile that is beneficial to human health (FERNANDES et al., 2010; ALVES et al., 2016).

During the extraction of baru nuts, the peel and pulp (BPF) are usually discarded by the agro-industry. The process of pressing the nut to extract the oil generates another by-product known as baru cake – the partially defatted nut flour (DBF) (SIQUEIRA et al., 2015). BPF and DBF are not commonly

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used in the formulation of food products; although, some studies have explored the use of BPF in the development of cookies (FERREIRA et al., 2020), and cereal bars (LIMA et al., 2010). BPF has a high content of dietary fiber (32.90 g/100g), and phenolic compounds (507.01 mg GAE/100g) (ALVES-SANTOS et al., 2023a). DBF, in turn, stands out for its high concentrations of quality protein (35.28 g/100g), and dietary fiber (21.25 g/100g) (ALVES-SANTOS et al., 2023b). In addition, both baru by-products showed prebiotic activity *in vitro* (ALVES-SANTOS et al., 2023a; ALVES-SANTOS et al., 2023b), as fruit by-products rich in dietary fibers and polyphenols are potential modulators of beneficial gut microbiota (NAVES et al., 2023). These notable contents in nutrients and bioactive compounds suggested the use of baru by-products as food ingredients in healthier food formulations.

Brownie is a very popular product, although, it contains high energy density and low concentration of bioactive compounds (ISLAS-RUBIO et al., 2012). Conversely, there has been a significant increase in demand for 'clean-label' products with more natural ingredients used in traditionally consumed formulations, attracting the interest of both agro-industry and consumers (LUCARINI et al., 2021; LUSK, 2019). The use of baru by-products in brownie formulation could, therefore, enhance its nutritional quality, conferring beneficial properties to consumer health. In this regard, this study developed brownie formulations with baru food ingredients to add nutritional and functional value to the product and contribute to the full use and appreciation of the baruzeiro fruit.

MATERIALS AND METHODS

Baru ingredients and brownie formulations

Samples of partially defatted baru nut flour (DBF) and baru peel and pulp flour (BPF) were provided by a local agro-industry (Palmelo, Goiás, Brazil). The flours were crushed in a domestic blender (Oster, Brazil) and sieved (100-mesh). For the formulation of baru food ingredients (BFI), DBF and BPF were mixed in two proportions: BFI_1 - 50% DBF + 50% BPF, and BFI_2 – 75% DBF + 25% BPF. The food ingredients were vacuum packed and stored at 4 ºC until analysis and formulation preparation.

The *brownie* formulations were prepared based on preliminary tests to determine the best ones, considering the nutritional value and sensory attributes. The standard brownie formulation (SBF) was prepared with wheat flour, while the two BFI formulations (BBF) were developed by replacing wheat flour entirely with BFI_1 or BFI_2. Eggs (22.4 g/100 g) and sugar (SBF - 40 g/100 g; BBF - 30 g/100 g) were beaten in a domestic planetary mixer (Arno, Brazil), with subsequent addition of soybean oil (SBF - 18 g/100 g; BBF - 10 g/100 g). The oil concentration was adjusted according to the lipid content of the BFI. The cocoa powder (6.5 g/100 g), wheat flour, and BFI (14 g/100g) were added to the dough, and homogenized. Then, the mixture was transferred to greased baking pans and baked at 180 ºC for 20 min in a preheated electric oven (Layr, model Fast 1.75, São Paulo, Brazil).

Chemical and antioxidant capacity analyses

The centesimal composition of the brownie formulations was determined according to the methodology described by AOAC (2016) for moisture (method 934.06), ash (method 940.26), total nitrogen (method 920.152), and conversion to crude protein using a conversion factor of 6.25. Total lipid analysis was carried out according to BLIGH & DYER (1959). The total carbohydrate (CHO) content was estimated by the difference method, according to equation 1.

$$\% \text{ CHO} = 100 - (\% \text{ protein} + \% \text{ lipid} + \% \text{ ash} + \% \text{ fiber} + \% \text{ moisture}) \quad (1)$$

The analysis of total, insoluble, and soluble dietary fiber was performed by the enzymatic-gravimetric method (method 985.29) (AOAC, 2016). The enzymes used in the analysis were purchased from Sigma-Aldrich®. Finally, the energy value was calculated using the Atwater conversion factors of 4 kcal/g, for protein and carbohydrate; and 9 kcal/g, for lipid.

For the analysis of total phenolic compounds, the brownie formulations were homogenized with 50% methanol, placed in an ultrasonic bath (Unique, USC-2800A, Indaiatuba, Brasil) at 25 °C for 1 h, and subjected to centrifugation in a refrigerated centrifuge (MPW, 350-R, Warsaw, Poland), at 4000 rpm at 25 °C for 10 min to obtain the extracts. The total phenolic compounds were determined according to SINGLETON & ROSSI (1965) using a gallic acid standard curve (Concentration= [absorbance - 0.0265]/0.0067; r = 0.9995), and the results were expressed as mg of gallic acid equivalents per 100 g of sample (mg GAE/100 g).

Antioxidant capacity was determined using two methods: FRAP, according to PULIDO et al. (2000), and DPPH, according to BRAND-WILLIAMS et al. (1995). Trolox solution was used as a standard for FRAP calibration curves (Concentration = [absorbance – 0.0164]/0.0012, r = 0.9977) and DPPH (Concentration = [absorbance – 0.558]/-0.0005, r = - 0.9950). The results were expressed as Trolox equivalents per gram of sample (µmol TE/g).

Evaluation of technological properties of brownies

The texture profile included the analysis of hardness (N), springiness (mm), cohesiveness, chewiness and gumminess (N) using a TA.XT Plus Texture Analyzer (Stable Micro Systems, Surrey, UK). The samples were kept at room temperature, and each one underwent 12 double compression tests. The compression tests were performed with 50% strain, a 5-second interval between the two compression steps, and a compression speed of 1.7 mm/s using a 36 mm cylindrical probe. The initial force applied was 5 g, and the displacement was 7.5 mm.

For color analysis, three readings were recorded on the surface and internal of each sample using the CR-400 colorimeter (Konica Minolta, Tokyo, Japan) supported by SpectraMagic NX software (Konica Minolta, Tokyo, Japan). Color data were obtained by the CIELab system - brightness [L^*], redness [+a] or greenness [-a] indexes, and yellowness [+b] or blueness [-b] indexes and used to calculate perceptual parameters, such as h_{ab} (tonality) and chroma, C^* (intensity), according to equations 2 and 3.

$$h_{ab} = arctan\left(\frac{b *}{a *}\right) \quad (2)$$

$$C *= (a *^2 + b *^2)^{\frac{1}{2}} \quad (3)$$

Brownie formulations were weighed before and after heat treatment for yield analysis. The cooking factor (PARISOTO et al., 2013) and energy density (ROLLS et al., 2006) of the preparations were calculated using equations 4 and 5.

Cooking factor = weight of the final preparation/total net weight (4)

Energy density = total energy of preparation (kcal) /final weight of preparation (g) (5)

Statistical analysis

The analyses were performed in triplicate, and the results were expressed as mean ± standard deviation. Statistical analyses were conducted using R software (R Foundation for Statistical Computing, Vienna), version 4.1.3. The data were subjected to analysis of variance, followed by Tukey's test. All tests were performed at a significance level of 0.05.

RESULTS AND DISCUSSION

Formulations prepared with baru food ingredients (BBF_1 and BBF_2) had a higher protein content (approximately 1.5 times more) than the standard formulation (Table 1). The high protein content in baru food ingredients is due to the great concentration of protein in DBF (ALVES-SANTOS et al., 2023b).

The addition of BFI in brownie formulations significantly increased dietary fiber contents, contributing to values approximately 10 times higher than those observed in the standard

Table 1 - Chemical composition and functional properties of brownie formulations.

Parameter	SBF	BBF_1	BBF_2
Chemical composition (g/100 g)			
Moisture	11.04 ± 0.25^b	15.47 ± 0.81^a	14.83 ± 1.69^a
Ash	0.73 ± 0.03^b	1.37 ± 0.10^a	1.51 ± 0.03^a
Protein	6.56 ± 0.35^c	8.89 ± 0.18^b	9.93 ± 0.31^a
Lipid	19.95 ± 0.40^a	16.74 ± 0.15^c	17.62 ± 0.19^b
Carbohydrate	59.51 ± 0.57^a	29.57 ± 1.57^b	33.96 ± 2.25^b
Total dietary fiber*	2.35 ± 0.07^c	28.30 ± 0.42^a	23.00 ± 0.14^b
Insoluble dietary fiber	2.35 ± 0.07^c	28.30 ± 0.42^a	23.00 ± 0.14^b
Soluble dietary fiber	<0.1 ± 0.00	<0.1 ± 0.00	<0.1 ± 0.00
Energy value (kcal/100 g)	444.39 ± 1.05^a	303.54 ± 5.57^c	332.68 ± 7.48^b
Total phenolics (mg GAE/100 g)	51.27 ± 1.08^b	78.46 ± 1.58^a	106.77 ± 2.59^a
Antioxidant capacity (µmol TE/g)			
DPPH	5.73 ± 2.31^b	23.62 ± 0.64^a	21.67 ± 0.51^a
FRAP	9.15 ± 3.14^b	39.17 ± 3.84^a	43.33 ± 4.09^a

Values are expressed as mean ± standard deviation. Different letters in the same row denote significant differences ($P < 0.05$).
SBF: standard brownie; BBF_1: brownie made with BFI_1 (50% partially defatted baru nut flour + 50% baru peel and pulp flour); BBF_2: brownie made with BFI_2 (75% partially defatted baru nut flour + 25% baru peel and pulp flour); GAE: gallic acid equivalents; TE: trolox equivalents; DPPH: 2,2-diphenyl-1-picrylhydrazyl; FRAP: ferric reducing antioxidant power.
*The dietary fiber content of the brownies made with BFI was estimated based on the analyzed fiber in baru food ingredients.

brownie (Table 1). This is due to the high dietary fiber content of baru by-products (ALVES-SANTOS et al., 2023b). According to the technical regulation (RDC nº 54) proposed by the Brazilian Health Surveillance Agency (BRASIL, 2012), brownies made with BFI can be classified as foods with high dietary fiber content, as they contain at least four times more fiber than the minimum required content – 6 g/100 g (Table 1).

Fiber-rich diets are known to improve intestinal function, increase satiety, decrease blood-glucose concentrations and blood cholesterol, and reduce the risk of developing some types of cancer and cardiovascular diseases (PATHIRANNEHELAGE & JOYE, 2020). In addition to these health benefits, some dietary fibers are substrates used in the metabolism of potentially beneficial gut microbiota and, thus, acting as prebiotics (REZENDE et al., 2021). A daily intake of 14 g of dietary fiber per 1000 kcal is recommended by the Dietary Fiber Consensus from the International Carbohydrate Quality Consortium (ICQC) (AUGUSTIN et al., 2020), and the European Food Safety Authority (EFSA) recommends a consumption of more than 25 g per day (EFSA, 2019). Thereby, a serving of 50 g of the brownies made with baru food ingredients can contribute with around 50% of the recommended daily intake of dietary fiber (EFSA, 2019): 46% - BBF_2, and 56.6% - BBF_1 (Table 1).

Regarding lipid content, BBF presented lower values compared to SBF content (Table 1). Additionally, the remaining oil in DBF (ALVES-SANTOS et al., 2023b) has a fatty acid profile beneficial to human health. It contains approximately 50% monounsaturated fatty acids, primarily oleic acid, which can enhance the lipid profile and have a hypocholesterolemic effect (ALVES-SANTOS et al., 2021). BBF showed another healthy attribute with lower lipid concentrations – the energy value was reduced by about 30% in comparison to the standard formulation (Table 1). The energy values of BBF are also lower than those found in brownies made with fruit by-products: brownie with 50% replacement of wheat flour with pequi peel flour (417.21 kcal/100 g) (REIS FILHO et al., 2018), and brownie with replacing 70.6% of wheat flour with the mixture of peel and mango almond flour – 436.88 kcal/100 g (RAMOS et al., 2021).

The total replacement of wheat flour with BFI significantly increased the total phenolic compound contents and the antioxidant capacity in the BBF formulations (Table 1). This replacement also improved the quality of the product for human health, as polyphenols have antioxidant properties and a potential prebiotic effect (ALVES-SANTOS et al., 2020). Therefore, the brownies made with BFI are potentially prebiotic foods, as suggested by recent studies that baru by-products have prebiotic potential (ALVES-SANTOS et al., 2023a; ALVES-SANTOS et al., 2023b), which may improve the human intestinal health.

No significant difference was observed in the technological properties of the brownie formulations concerning their cooking factors (yield indicator – SBF: 0.96; BBF_1 and BBF_2: 0.94). This indicated that the total replacement of wheat flour with BFI did not affect the yield of the product. Regarding the visual evaluation, the brownies prepared with BFI maintained a moist interior, with an elastic texture and a crispy surface, which is their most characteristic attribute (ISLAS-RUBIO et al., 2012). The standard brownie, in turn, showed greater formation of a crispy crust on its surface (Figure 1), which can be attributed to the larger amount of sugar present in the formulation.

As for the texture profile, BBF_1 showed higher hardness and chewiness values, while BBF_2 values were similar to those of the standard (Table 2). Hardness represents the force required to compress food in the mouth until it breaks. Thus, higher values indicated that the product is harder, which, in turn, requires more strength to be chewed and broken into smaller pieces. This fact may be related to the higher insoluble fiber content in $BBF_{1,}$ since these nutrients have hydration capacity and can absorb part of the moisture in the dough, resulting in a slightly stiffer texture for the brownie (ELLEUCH et al., 2011). However, a slightly firmer product may not affect consumer preference of those that prefers to consume a tasty but more nutritious and healthier product with added value (LUSK et al., 2019).

Regarding the color of the brownies, BBF_2 showed a decrease in the brightness of the surface (L^*) (Figure 1). BBF_2 contains a higher amount of partially defatted baru nut flour, and the reduction of fat in baru nut decreases liposoluble pigments, contributing to a less intense color, as observed by LING et al. (2016). BBF_1 was more reddish (a^*). Conversely, there were no differences regarding the parameters b^*, C^*, and h between the formulations, demonstrating that the addition of BFI maintained the characteristic and expected color for brownies. The internal color of the brownies did not showed differences in L^* (brightness) and a^* (redness) parameters, indicating that the addition of BFI did not change inside the product when compared to traditional brownie.

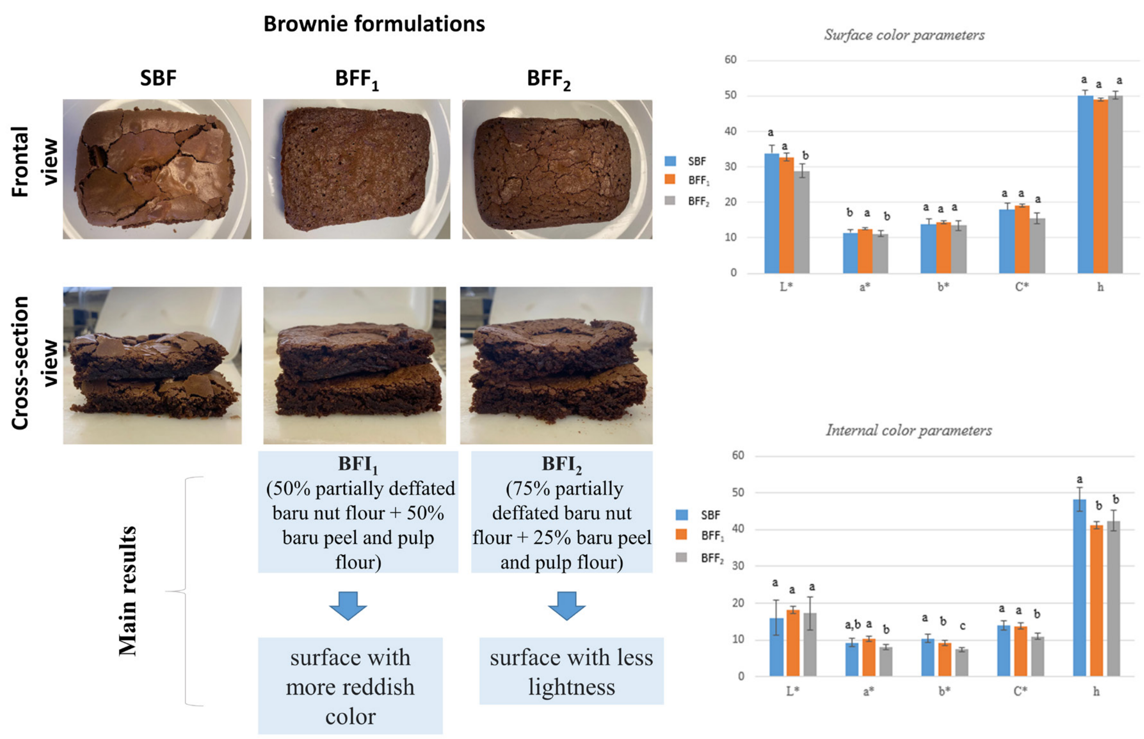

Figure 1 - Front and cross-section view and surface and internal color parameters of brownie formulations.

SBF: standard brownie; BBF_1: brownie made with BFI_1 (50% partially defatted baru nut flour + 50% baru peel and pulp flour); BBF_2: brownie made with BFI_2 (75% partially defatted baru nut flour + 25% baru peel and pulp flour). L^*: lightness; a^*: value represents redness (+a) to greenness (-a); b^*: value represents yellowness (+b) to blueness (-b); C^*: Chroma; h: hue.

CONCLUSION

Brownies made from baru processing by-products are food rich in compounds beneficial to health, including protein, dietary fiber, and polyphenols. The baru brownies also have a high antioxidant capacity and low caloric value, and they are potential prebiotic foods. In addition to the various health benefits, the utilization of baru by-products in new food products stimulates the use of the whole fruit, thus contributing to the increase of its added value and the development of local agro-industry.

Table 2 - Textural properties of brownie formulations.

Parameter	SBF	BBF_1	BBF_2
----------Textural properties----------			
Hardness (N)	770.54 ± 382.91^b	1343.51 ± 372.32^a	903.03 ± 191.98^b
Springiness (mm)	0.53 ± 0.18^b	0.66 ± 0.11^a	$0.61 \pm 0.07^{a,b}$
Cohesiveness	0.43 ± 0.03^a	0.43 ± 0.02^a	0.42 ± 0.02^a
Chewiness	$169.25 \pm 80{,}22^b$	373.69 ± 109.28^a	227.36 ± 43.60^b
Gumminess (N)	327.13 ± 154.86^b	570.47 ± 148.83^a	375.22 ± 72.97^b

Values are expressed as mean ± standard deviation. Different letters in the same row denote significant differences ($P < 0.05$).
SBF: standard brownie; BBF_1: brownie made with BFI_1 (50% partially defatted baru nut flour + 50% baru peel and pulp flour); BBF_2: brownie made with BFI_2 (75% partially defatted baru nut flour + 25% baru peel and pulp flour).

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHORS' CONTRIBUTIONS

MO Borges and GF Santos conducted the development of the formulations and the laboratory analyses, and wrote drown the original version of the manuscript. DC Fernandes carried out the development of the formulations, laboratory analyses, analyzed and discussed the results, and reviewed the manuscript. MMV Naves planned the study, supervised the research project, discussed the results and conducted a comprehensive and critical review of the manuscript. The final version of the manuscript received approval from all authors.

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