

PLANT-BASED AND COLLAGEN-ENRICHED INSTANT COFFEE BEVERAGES: DEVELOPMENT AND QUALITY ASSESSMENT

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ABSTRACT:

This study aimed to develop and evaluate powdered coffee-based beverages using as alternatives to cow's milk plant extracts enriched with hydrolyzed collagen (11.11%). Four plant-based formulations were prepared using almond (AM), oat (OA), coconut (CO), a blend of all three extracts (MIX), and compared with a dairy-based control formulation. The beverages were subjected to physicochemical, microbiological, and sensory analyses. Results indicated that the proportion of hydrolyzed collagen used (11.11%) was insufficient for the plant-based formulations (6.59%–7.82%) to reach protein levels comparable to those of cow's milk (10.93%). All formulations complied with Brazilian microbiological standards. The CO formulation presented the highest lipid content (11.28%), greatest lightness after reconstitution ($L^* = 43.97$), and showed the best sensory performance, achieving an acceptability index (AI) of 84.17% for aroma and a purchase intent of 45%. The remaining plant-based formulations showed AI values below 70% for flavor, texture, and overall appearance. Overall, the results indicate that coconut extract demonstrates potential as a dairy substitute in coffee-based beverages. For future studies, it is recommended to evaluate new strategies to increase the protein content and improve the sensory acceptance of the other formulations.

Keywords: food innovation; plant-based beverage; protein; sensory analysis.

BEBIDAS INSTANTÂNEAS DE CAFÉ COM EXTRATOS VEGETAIS E COLÁGENO: DESENVOLVIMENTO E AVALIAÇÃO DA QUALIDADE

RESUMO:

Este estudo objetivou desenvolver e avaliar bebidas em pó à base de café enriquecidas com colágeno hidrolisado (11,11%) e extratos vegetais de amêndoa (AM), aveia (OA), coco (CO) e mistura dos três (MIX), como alternativas ao leite de vaca, comparando-as com formulação de controle à base de leite bovino. As bebidas foram submetidas a análises físico-químicas, microbiológicas e sensoriais. Os resultados indicaram que a proporção de colágeno hidrolisado utilizada (11,11%) foi insuficiente para que as formulações vegetais (6,59%–7,82%) atingissem teor proteico equivalente ao do leite bovino (10,93%). Todas as formulações atenderam aos padrões microbiológicos brasileiros. A formulação CO exibiu o maior teor lipídico (11,28%), maior luminosidade após reconstituição ($L^* = 43,97$) e destacou-se sensorialmente, com índice de aceitabilidade (IA) de 84,17% para aroma e intenção de compra de 45%. As demais formulações vegetais apresentaram IA < 70% nos atributos sabor, textura e aparência global. Em geral, conclui-se que o extrato de coco demonstra potencial como substituto do leite em bebidas de café. Para estudos futuros, recomenda-se avaliar novas estratégias para elevar o aporte proteico e ampliar a aceitação sensorial das demais formulações.

Palavras-chave: Bebida vegetal; Proteína; Análise sensorial; Inovação alimentar.

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INTRODUCTION

Coffee is one of the most widely consumed and highly appreciated beverages in Brazil and worldwide for its distinctive sensory characteristics and stimulating effects due to its caffeine content. In Brazil alone, domestic coffee consumption reached 21.67 million 60-kg bags between November 2022 and October 2023 (Ferreira and Catavon, 2024), reaffirming the cultural and economic relevance of coffee in the country. Beyond traditional black coffee, milk-based preparations such as cappuccinos, lattes, and macchiatos are also widely consumed and represent important products within the specialty coffee beverage segment (Czarniecka-Skubina *et al.*, 2021).

Growing consumer interest in healthier lifestyles has increased the demand for dairy alternatives, particularly among individuals with lactose intolerance or cow's milk protein allergy, as well as those seeking to reduce their consumption of dairy products for dietary or environmental reasons. This trend has stimulated the development of plant-based beverages produced from cereals (e.g., oats and rice), legumes (e.g., soy), nuts (e.g., almonds), and seeds (e.g., sesame and flaxseed) (Vashisht *et al.*, 2024). Although these beverages are frequently fortified to improve their nutritional value, they still differ from cow's milk in terms of flavor, mouthfeel, and functional properties, often presenting undesirable sensory attributes such as grassy, earthy, or beany notes, in addition to limitations in emulsion stability and texture (Gorman *et al.*, 2021).

Driven by both market demand and scientific interest, the development of plant-based beverages has become a dynamic area of food research, with particular emphasis on improving sensory quality, nutritional value, and functional properties (Aydar *et al.*, 2020; Mauro *et al.*, 2022; Zakidou *et al.*, 2023; Thuraisingam *et al.*, 2023). Despite these advances, many plant-based beverages still present relatively low protein contents and an unbalanced essential

amino acid profile compared with dairy products, creating opportunities for nutritional enhancement.

In this sense, hydrolyzed collagen emerges as a promising functional ingredient due to its high protein content, excellent solubility, neutral flavor, and technological compatibility with beverage formulations (Al Hajj *et al.*, 2024). In addition to its favorable technological properties, collagen peptides have been widely investigated for their potential benefits to skin, joint, and connective tissue health, supporting their increasing use in functional foods and beverages (Hong *et al.*, 2019; Al Hajj *et al.*, 2024). In the present study, hydrolyzed collagen was used as a nutritional fortification strategy rather than as a substitute for plant proteins. Therefore, the proposed beverage is intended for consumers seeking dairy-free coffee beverages with enhanced nutritional value.

Thus, this study aimed to develop a soluble coffee beverage containing plant-based extracts enriched with hydrolyzed collagen, evaluating its physicochemical characteristics, nutritional composition, and sensory acceptance.

MATERIALS AND METHODS

Development of Plant-Based Beverages

The ingredients were obtained from specialty stores in Cuiabá, MT, Brazil, including soluble coffee powder (Iguaçu[®], Brazil), sugar (Itamarati[®], Brazil), hydrolyzed bovine collagen powder (Armazém Bezerra[®], Brazil), carboxymethylcellulose (Arcolor[®], Brazil), oat extract (Living Essence[®], Brazil), and both coconut and almond extracts (Natural do Norte[®], Brazil).

Four formulations of instant powdered beverages were developed in triplicate by mixing different plant-based extracts as substitutes for cow's milk, all enriched with hydrolyzed collagen, as shown in Table 1.

Table 1. Formulations of soluble coffee powder prototypes with plant extracts and hydrolyzed collagen.

Ingredients (%)	AM	OA	CO	MIX
Coffee powder	2.96	2.96	2.96	2.96
Oat extract	66.67	-	-	22.22
Almond extract	-	66.67	-	22.22
Coconut extract	-	-	66.67	22.22
Sugar	18.52	18.52	18.52	18.52
Carboxymethylcellulose	0.74	0.74	0.74	0.74
Hydrolyzed collagen	11.11	11.11	11.11	11.11
Total (%)	100	100	100	100

*AM = coffee with almond extract; OA = coffee with oat extract; CO = coffee with coconut extract; MIX = coffee with almond, oat, and coconut extracts.

The ingredients for each formulation were individually weighed using an analytical balance (BEL M – 214Ai, Brazil) according to the specific proportions of each treatment. The powdered mixtures were then homogenized in a low-speed blender with 1000 W power (BR 8L, Colombo, Brazil) for three minutes to obtain a fine lump-free blend. A commercial instant beverage made with whole cow's milk (Café 3 Corações®, Brazil) was purchased locally and used as a standard reference for comparison with the plant-based formulations (AM – almond; MIX – blend of plant extracts).

To prepare a serving, two tablespoons of the homogenized powder (~30 g) were added to 100 mL of water heated to 70°C. All samples were analyzed in their powdered form.

Proximate Composition Analysis

All parameters were evaluated following the methodologies established by the Instituto Adolfo Lutz (IAL, 2008). Moisture content was determined by oven drying at 150 °C until constant weight. Ash content was measured by incineration in a muffle furnace at 550 °C. Lipid content was assessed using the Soxhlet extraction method with petroleum ether as the solvent. Protein content was quantified using the Kjeldahl method, applying specific nitrogen-to-protein conversion factors: 6.38 for cow's milk, 5.83 for oats, 5.30 for coconut, and 5.18 for almonds. For mixtures of plant extracts, an average conversion factor of 5.43 was used.

Water Activity (Aw), pH and Total Titratable Acidity

Water activity was measured directly using a digital device (Aqualab 4TE, Meter Group), with internal temperature control set at 25 °C. The pH of the samples was measured at 25 °C using a digital pH meter (Mettler Toledo, Model MP220, Barueri – SP, Brazil). Titratable acidity was determined according to Instituto Adolfo Lutz (IAL, 2008). Samples were titrated with standardized 0.1 N NaOH using phenolphthalein as an indicator until a persistent pale-pink endpoint was reached. The results were expressed as milliequivalents of NaOH per 100 g of sample.

Color Parameters

The color of the powdered and reconstituted beverage samples was evaluated using a colorimeter (Konica Minolta, CR-400), following the manufacturer's instructions. The color parameters were expressed in the CIELAB color space (CIE, 2004), in which L* represents lightness (0 = black; 100 = white), while a* and b* represent chromaticity, with a* ranging from red (+) to green (–) and b* from yellow (+) to blue (–).

Microbiological Analysis

Microbiological assessments were performed according to the methods described by the American Public Health Association (APHA, 2001). Total and thermotolerant coliforms were determined using the Most Probable Number (MPN) technique. The presence of *Salmonella* spp. was evaluated in 25 g samples, following ISO 6579:2002, with pre-

enrichment in Buffered Peptone Water and selective enrichment in Selenite Cystine and Rappaport-Vassiliadis broths.

Sensory Analysis

Sensory evaluation was conducted in collaboration with the Union of Catholic Colleges of Mato Grosso (União das Faculdades Católicas de Mato Grosso), Cuiabá, after approval by the Ethics Committee of IFMT (CAAE 67556523.0.0000.8055). Individuals with allergies to any formulation components were excluded. All participants signed informed consent forms. A panel of 80 untrained consumers, both male and female, aged 18 and older, assessed attributes such as color, aroma, flavor, texture, and overall appearance using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Purchase intent was measured using a 5-point scale (1 = would certainly not buy, 5 = would certainly buy).

Overall product acceptability was calculated using the Acceptability Index (AI), which is the ratio of the mean score for a given attribute to the maximum possible score, multiplied by 100.

Statistical Analysis

Experimental data were statistically analyzed using analysis of variance (ANOVA), followed by Tukey's *post hoc* test at a 5% significance level. Analyses were performed using Statistica® software, version 7.0.

RESULTS AND DISCUSSION

Physicochemical Characterization

The results for proximate composition, water activity (A_w), titratable acidity, and pH of the beverage formulations are presented in Table 2.

The dairy-based control exhibited a significantly higher ash content (5.05%) compared to the plant-based formulations, which ranged from 0.99% to 1.50%. The almond (AM), oat (OA), and mixed extract (MIX) formulations did not differ significantly from each other ($p > 0.05$) in mineral content, while the coconut (CO) formulation showed a significantly lower ash content ($p < 0.05$). Since cow's milk is naturally rich in calcium, the lower mineral content in plant-based alternatives could be improved through mineral fortification. Furthermore,

the mineral content of plant-based beverages can vary depending on agronomic factors such as geographic location, soil composition, water source, irrigation practices, and fertilizer use (Silva *et al.*, 2016).

Similar findings were reported for coconut milk yogurts, which showed ash contents ranging from 0.60% to 0.90% (Guamán, 2021). Likewise, Lima *et al.* (2018) observed relatively low ash contents in coconut-based beverages and fermented coconut drinks with cajá, ranging from 0.39% to 0.41%.

All formulations showed significant differences ($p < 0.05$) in lipid content when compared to each other and to the control (Table 2). The control sample, containing only cow's milk, presented a significantly lower lipid content ($p < 0.05$) than the plant-based beverages. The CO formulation (with coconut extract) had the highest lipid content (11.28%), as expected due to the naturally high fat content of coconut. Fructuoso *et al.* (2021) similarly reported higher lipid levels in coconut-based drinks (up to 19%) compared to soy (3.68%) and oat-based beverages (2.69%). In general, plant-based beverages contain higher levels of unsaturated fatty acids, such as oleic and linoleic acids found in soy and oats, while cow's milk is richer in saturated fats, such as palmitic and stearic acids. Coconut fat, rich in medium-chain triglycerides (MCTs), has been associated with increased energy expenditure and appetite suppression, potentially contributing to reduced body fat (Thuraisingam *et al.*, 2023; Rincon *et al.*, 2020).

Regarding protein content, the control sample presented a significantly higher level (10.93%) than all plant-based formulations, which ranged from 6.59% to 7.82% ($p < 0.05$). These results indicate that the amount of hydrolyzed collagen added was insufficient to reach protein levels comparable to the cow's milk formulation. Zakidou *et al.* (2023) reported similar trends in plant-based cappuccino-style beverages, where mixtures containing coconut and soy had lower protein contents than their dairy counterparts, with oat-based drinks showing even lower values. Fructuoso *et al.* (2021) also reported low protein levels for coconut (0.1%–2.0%), oat (0.4%–1.86%), and soy-based drinks (0.99%–4.99%). Despite not matching dairy protein levels, plant-based beverages are rich in dietary fiber, unsaturated fats, and are naturally cholesterol-free (Aydar *et al.*, 2020).

Table 2. Physicochemical analysis of instant powdered coffee blends with plant extracts and hydrolyzed collagen.

Parameters	Control	AM	OA	CO	MIX
Moisture (%)	2.13 ± 0.11 ^a	5.23 ± 0.03 ^c	5.61 ± 0.14 ^d	3.87 ± 0.14 ^b	5.29 ± 0.03 ^c
Ash (% d.b.)	5.05 ± 0.07 ^c	1.45 ± 0.14 ^b	1.50 ± 0.11 ^b	0.99 ± 0.03 ^a	1.38 ± 0.02 ^b
Lipid (% d.b.)	0.87 ± 0.14 ^a	4.01 ± 0.47 ^b	5.35 ± 0.60 ^c	11.28 ± 0.95 ^e	7.84 ± 0.43 ^d
Protein (% d.b.)	10.93 ± 0.71 ^c	6.59 ± 0.50 ^a	7.82 ± 0.37 ^b	7.17 ± 0.17 ^{ab}	7.76 ± 0.69 ^b
Aw	0.34 ± 0.07 ^a	0.48 ± 0.00 ^b	0.48 ± 0.00 ^b	0.44 ± 0.01 ^b	0.47 ± 0.00 ^b
pH	6.91 ± 0.01 ^d	5.43 ± 0.02 ^a	5.46 ± 0.06 ^a	6.64 ± 0.00 ^c	5.87 ± 0.02 ^b
Titrateable acidity (mEq NaOH/100 g)	12.17 ± 0.53 ^a	10.31 ± 0.49 ^c	10.76 ± 0.12 ^{bc}	11.68 ± 0.39 ^{ab}	12.52 ± 0.76 ^a

*Means with different letters in the same row indicate significant differences in Tukey's test ($p < 0.05$). Control = coffee with cow's milk; AM = coffee with almond extract; OA = coffee with oat extract; CO = coffee with coconut extract; MIX = coffee with almond, oat, and coconut extracts.

According to Brazilian regulations, the moisture content of powdered soy products must not exceed 6.0% (Brasil, 1978), while Resolution RDC No. 272 (September 22, 2005) establishes a limit of 12% for dried or dehydrated vegetable products, including nuts (Brasil, 2005). In this study, the control sample had a significantly lower moisture content (2.13%) than the plant-based formulations (3.87%–5.61%) ($p < 0.05$), yet all samples remained within the established safety limits for powdered foods.

Water activity (Aw) is a critical parameter influencing the microbial stability and shelf life of powdered beverages. The control formulation had an Aw of 0.34, significantly lower than the values found in plant-based formulations (0.44–0.48) ($p < 0.05$), although no significant differences were observed among the plant-based samples ($p > 0.05$).

The pH of the control formulation was close to neutral (6.91), significantly higher ($p < 0.05$) than that of the plant-based beverages. The AM and OA formulations showed no significant difference ($p > 0.05$), with pH values of 5.43 and 5.46, respectively. The CO and MIX formulations had pH values of 6.64 and 5.87, respectively, differing significantly from each other and the other formulations ($p < 0.05$). These values are consistent with previous reports on similar beverages, where pH ranges from 5.0 to 7.0 are common (Okwunodulu *et al.*, 2021; Oluwadunsin *et al.*, 2021).

Due to the distinct nature of these matrices, titrateable acidity was not expressed in terms of a specific organic acid (e.g., lactic or citric acid), as this could hinder direct comparison among samples. Therefore,

the results were expressed as mEq NaOH/100 g, representing the overall titrateable acidity of the formulations. As shown in Table 2, titrateable acidity ranged from 10.31 to 12.52 mEq NaOH/100 g. The MIX formulation exhibited the highest value (12.52 mEq NaOH/100 g), although it did not differ significantly ($p > 0.05$) from the control (12.17 mEq NaOH/100 g) or CO (11.68 mEq NaOH/100 g). Similarly, no significant difference was observed between the control and CO ($p > 0.05$).

In contrast, AM showed the lowest titrateable acidity (10.31 mEq NaOH/100 g), differing significantly from the control, CO, and MIX formulations ($p < 0.05$), while OA (10.76 mEq NaOH/100 g) showed an intermediate behavior, with no significant difference from AM or CO. The relatively high titrateable acidity observed across the formulations may be partly attributed to soluble coffee, which contains several organic acids, including chlorogenic acids and their derivatives, that contribute to the overall acidity and buffering properties of coffee-containing products (Yeager *et al.*, 2023). Differences among formulations may also reflect the distinct composition and buffering capacity of milk and plant extracts.

Color Parameters of the Beverages

For the powdered samples (Table 3), the AM formulation (coffee with almond extract) showed the highest lightness ($L^* = 68.08$), significantly higher ($p < 0.05$) than the other samples, except MIX ($L^* = 66.64$). These two formulations were the lightest in color. All plant-based formulations exhibited

significantly higher lightness (L^*) compared to the control sample.

Additionally, the control had significantly higher a^* (3.11) and b^* (8.75) values ($p < 0.05$), indicating a more reddish and yellowish hue compared to the plant-based beverages, whose a^* values ranged from 1.12 to 1.49 and b^* values from 6.12 to 6.48.

For the reconstituted beverages, the CO formulation (coffee with coconut extract) exhibited the highest lightness ($L^* = 43.97$), likely due to its

higher fat content. Pietrasik (1999) observed that high-fat products tend to be lighter, with elevated L^* values, as fat reflects rather than absorbs light. The control formulation (cow's milk) had the second-highest L^* value (39.91), also significantly higher than the other plant-based formulations ($p < 0.05$). Besides fat content, casein micelles in cow's milk contribute to light scattering, enhancing the white appearance of milk (Yilmaz-Ersan and Topcuoglu, 2022).

Table 3. Color parameters of powdered and reconstituted coffee blends with plant extracts enriched with collagen.

Powder Blends			
Formulations	L^*	a^*	b^*
Control	50.19 ± 0.66^a	3.11 ± 0.03^d	8.76 ± 0.19^b
AM	68.08 ± 0.70^c	1.35 ± 0.07^{bc}	6.24 ± 0.23^a
OA	64.79 ± 0.91^b	1.12 ± 0.02^a	6.12 ± 0.16^a
CO	65.76 ± 0.76^b	1.49 ± 0.08^c	6.12 ± 0.06^a
MIX	66.64 ± 0.17^{bc}	1.26 ± 0.05^{ab}	6.48 ± 0.24^a
Reconstituted Beverages			
Control	39.91 ± 0.64^d	4.82 ± 0.52^{bc}	13.68 ± 0.36^a
AM	33.59 ± 0.59^a	5.26 ± 0.18^c	13.73 ± 0.77^a
OA	36.35 ± 0.19^b	5.21 ± 0.27^c	14.39 ± 0.94^a
CO	43.97 ± 0.50^e	3.67 ± 0.05^a	14.69 ± 0.13^a
MIX	38.10 ± 0.46^c	4.32 ± 0.15^{ab}	13.35 ± 0.22^a

*Means with different letters in the same column indicate significant differences in Tukey's test ($p < 0.05$). Control = coffee with cow's milk; AM = coffee with almond extract; OA = coffee with oat extract; CO = coffee with coconut extract; MIX = coffee with almond, oat, and coconut extracts.

The AM, OA, and MIX formulations had significantly lower lightness values, ranging from 33.59 to 38.10 ($p < 0.05$), and differed significantly from each other. After reconstitution, the chromatic coordinates a^* and b^* changed significantly ($p < 0.05$). The AM and OA formulations had similar a^* values (5.26 and 5.21, respectively), indicating a more reddish hue. In contrast, the CO and MIX formulations exhibited significantly lower a^* values.

No significant differences were observed in b^* values ($p > 0.05$), with all formulations showing positive values (13.35 to 14.69), corresponding to a yellowish hue.

Microbiological Evaluation

Table 4 presents the results of the microbiological analysis of the collagen-enriched

powdered coffee blends with plant extracts ready for consumption.

According to Brazilian regulations, Resolution RDC No. 724 of July 1, 2022, and Normative Instruction IN No. 161 of July 1, 2022, establish microbiological standards for different food categories. The powdered blends analyzed in this study are classified under category 17, which includes coffee, tea, mate, and infusion products, specifically subcategory “b”, referring to products subjected to heat treatment. For this category, the legislation requires the absence of *Salmonella* in 25 g of product and sets a maximum limit of 10^3 CFU/g for *E. coli* (Brasil, 2022a; 2022b).

As shown in Table 4, all blends based on almond, oat, coconut, and mixed plant extracts were free from *Salmonella* and *E. coli*. Therefore, all formulations comply with Brazilian legislation for their respective food category. Furthermore, the low counts of mesophilic bacteria (3.5×10^2 to 6.5×10^2 CFU/g), psychrotrophic bacteria (1.0×10^2 to 2.4×10^2 CFU/g), and coliforms (total: <3.0 to 7.4 MPN/g; thermotolerant: <3.0 MPN/g) confirm that these powdered blends are microbiologically safe for human consumption. These results also reflect the use of high-quality raw materials and adherence to good manufacturing practices.

Table 4. Microbiological characterization of powdered coffee blends with plant extracts enriched with collagen, ready for consumption.

Samples	Microorganisms Analyzed					
	Mesophilic (CFU/g)	Psychrotrophs (CFU/g)	Total coliforms (MPN/g)	Thermotolerant coliforms (MPN/g)	<i>E. coli</i> (CFU/g)	<i>Salmonella</i> spp. (CFU/25g)
AM	6.0×10^2	1.0×10^2	7.4	< 3.0	Abs.	Abs.
OA	3.5×10^2	2.4×10^2	< 3.0	< 3.0	Abs.	Abs.
CO	4.0×10^2	$< LD$	< 3.0	< 3.0	Abs.	Abs.
MIX	4.0×10^2	1.5×10^2	< 3.0	< 3.0	Abs.	Abs.
WHO	-	-	-	-	10^2	Abs.

*AM = coffee with almond extract; OA = coffee with oat extract; CO = coffee with coconut extract; MIX = coffee with almond, oat, and coconut extracts. CFU = Colony Forming Units; MPN = Most Probable Number; LD = Limit of Detection; Abs. = Absence (Microorganism not detected); WHO = World Health Organization (2007) recommended values for powdered botanical extracts.

Sensory Analysis

In beverage consumer research, sensory evaluations play a strategic role in assessing consumer acceptance and identifying attributes that may require product reformulation (Voss *et al.*, 2021). In this study, several sensory characteristics, including aroma, flavor, texture, and color, were evaluated, as these beverages were developed as alternatives to conventional coffee with milk. The control formulation (coffee with cow's milk) was not included in the sensory evaluation because the objective was to compare consumer acceptance among the formulations prepared with different plant

extracts. In addition, limiting the evaluation to four samples minimized sensory fatigue and helped improve the reliability of the panelists' responses. Table 5 presents the sensory analysis results for the reconstituted coffee beverages made with plant extracts enriched with collagen.

Although significant differences were observed in lightness (L^*) and red hues (a^*), these differences were not perceptible in the sensory evaluation, as no significant difference ($p > 0.05$) was detected in the color attribute of the beverages. On the hedonic scale, the formulations ranged from "indifferent" (MIX) to "slightly liked" (AM, OA, and CO).

Table 5. Sensory attributes and purchase intent evaluated for reconstituted coffee beverages with plant extracts enriched with collagen.

Sensory attributes	Formulations			
	AM	OA	CO	MIX
Color	6.40 ± 1.88 ^a	6.24 ± 1.92 ^a	6.06 ± 2.07 ^a	5.79 ± 1.84 ^a
Aroma	5.21 ± 2.14 ^a	5.54 ± 2.07 ^a	7.58 ± 1.51 ^b	5.78 ± 2.24 ^a
Flavor	4.45 ± 2.41 ^a	4.51 ± 2.32 ^a	6.68 ± 2.28 ^b	4.68 ± 2.60 ^a
Texture	5.10 ± 2.21 ^a	5.10 ± 2.23 ^a	6.38 ± 1.99 ^b	5.00 ± 2.37 ^a
Overall Appearance	5.05 ± 2.22 ^a	5.21 ± 2.16 ^a	6.89 ± 1.86 ^b	5.44 ± 2.08 ^a
Purchase Intent	2.55 ± 1.37 ^a	2.58 ± 1.34 ^a	3.60 ± 1.25 ^b	2.68 ± 1.43 ^a

*Means with different letters in the same row indicate significant differences in Tukey's test ($p < 0.05$). AM = coffee with almond extract; OA = coffee with oat extract; CO = coffee with coconut extract; MIX = coffee with almond, oat, and coconut extracts.

For the attributes of aroma, flavor, texture, and overall appearance, the CO (coconut extract) formulation stood out with significantly higher acceptance scores ($p < 0.05$), rated between "moderately liked" and "very much liked" for aroma, and between "slightly liked" and "moderately liked" for flavor, texture, and overall appearance. The AM, OA, and MIX formulations did not differ significantly ($p > 0.05$) from each other and received lower scores on the hedonic scale, ranging from "slightly disliked" to "indifferent" for flavor, and from "indifferent" to "slightly liked" for aroma, texture, and overall appearance.

The textural properties of beverages are primarily influenced by solids content, fat content, and the physical state of fats and proteins (Yilmaz-Ersan and Topcuoglu, 2022). The higher sensory score for texture in the CO formulation can be attributed to its greater lipid content. Studies have shown that beverages with higher coconut milk content are more acceptable sensorially due to appropriate viscosity and enhanced smoothness (Thuraisingam *et al.*, 2023).

Achieving satisfactory flavor and aroma in plant-based milk beverages remains a challenge. Coffee with dairy milk is generally more accepted than coffee with plant-based milks, largely due to the sweet taste of lactose. Flavors described as spicy, herbal, earthy, or sour tend to impair acceptability in these beverages, as demonstrated by Gorman *et al.* (2021), who investigated consumer acceptance and sensory perception of coffee with dairy milk versus oat, soy, and almond-based alternatives.

The CO formulation may have achieved greater acceptance due to its familiar aroma and flavor.

Previous studies have also observed that the coconut flavor in fermented products promotes greater familiarity and sensory acceptance (Mauro *et al.*, 2022). The addition of coconut extract to beverages can improve acceptability without the need for additional flavorings (Rincon *et al.*, 2020).

Acceptability Index and Purchase Intent

The Acceptability Index (AI) was expressed as the percentage of acceptance for each sensory attribute of coffee beverages formulated with plant extracts and enriched with collagen. For a product to be considered well accepted, it must achieve an AI of at least 70%.

Regarding color, the AM formulation (almond extract) achieved an acceptability of 71.11%, placing it in the "moderately liked" category. For aroma, the CO (coconut extract) was the highest-rated formulation, reaching an acceptability of 84.17% and falling between "liked very much" and "liked extremely". This greater acceptance may be associated with the familiar aroma of coconut. Similarly, for texture, flavor, and overall appearance, the CO formulation also received the highest scores, while the AM (almond), OA (oat), and MIX (blend) formulations showed lower acceptability, ranging from "neutral" to "slightly liked". This result may reflect the panelists' unfamiliarity with plant-based milk alternatives.

Figure 1 presents the sensory profile of the reconstituted beverages, highlighting the superior performance of the coconut extract formulation (CO) across all evaluated attributes, particularly aroma, flavor, texture, and overall appearance.

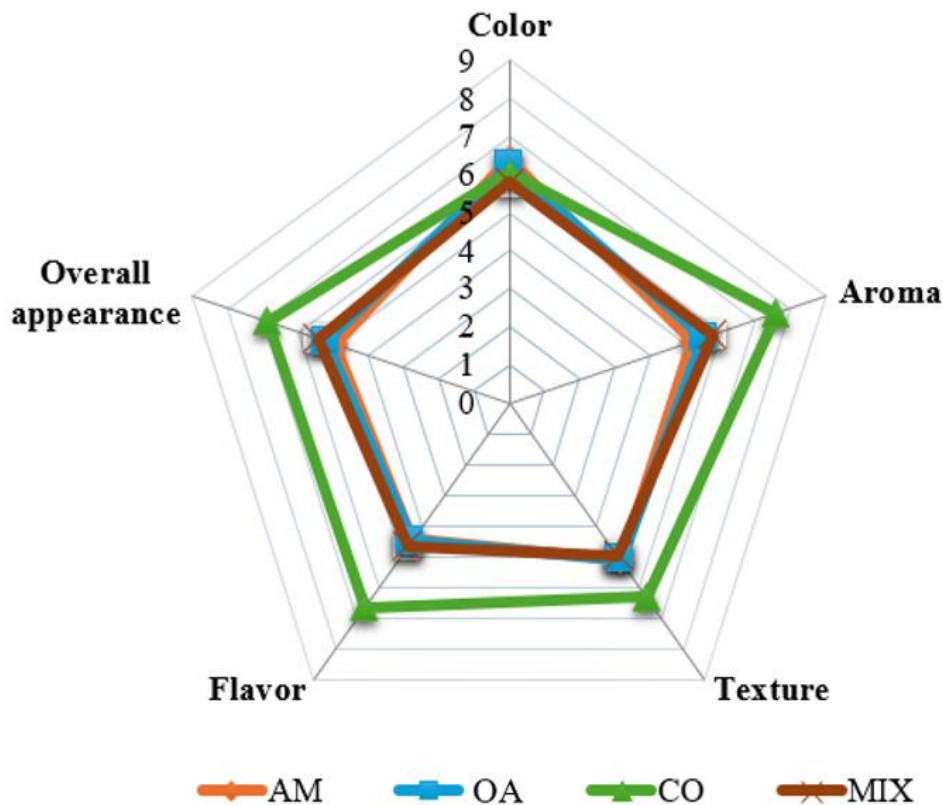


Figure 1. Radar chart presenting the average values attributed to the sensory aspects of reconstituted beverages made from coffee with plant extracts of almond (AM), oat (OA), coconut (CO), and a mixture of these extracts (MIX), enriched with hydrolyzed collagen.

Therefore, the results suggest that further studies should focus on improving the sensory attributes of the less accepted formulations and consider including panelists who are regular consumers of plant-based milks, particularly coconut-based beverages.

Figure 2 presents the purchase intent percentages for the coffee beverages developed with plant extracts. The CO formulation (coffee with

coconut extract) showed the highest purchase intent, with 36.25% of the panelists indicating they would "certainly buy" and 8.75% reporting they would "probably buy," resulting in a total positive purchase intent of 45%. Nevertheless, 41.25% of the participants remained undecided about purchasing this formulation.

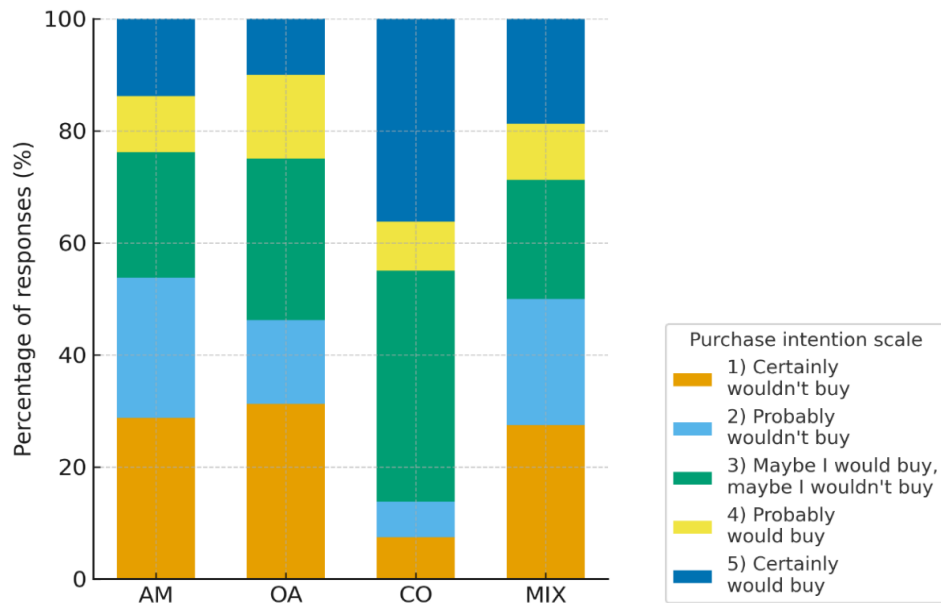


Figure 2. Purchase intent for coffee blends with almond (AM), oat (OA), coconut (CO), and mixed plant extracts (MIX) enriched with hydrolyzed collagen.

The remaining formulations showed lower purchase intent than CO, with positive purchase intent values of 23.75% for AM (almond), 25.00% for OA (oat), and 28.75% for MIX (blend). These results suggest that the coconut-based beverage was the most attractive formulation among consumers, although the high proportion of undecided responses indicates that further improvements in sensory characteristics may increase its market acceptance.

The average purchase intent scores revealed that the CO formulation had a significantly higher intent to purchase ($p < 0.05$) than the others, with a mean score of 3.60, which fell between "might or might not buy" and "probably would buy."

Overall, despite some uncertainty regarding the purchase of coffee beverages made with plant-based milks, 86.25% of panelists expressed some level of interest in buying the coconut-based beverage, and 50% expressed interest in the MIX formulation. Sensory evaluation results indicate that the coconut extract formulation stands out among the alternatives.

CONCLUSION

The physicochemical characterization revealed significant differences among the formulations in several key aspects. Despite the supplementation with hydrolyzed collagen, the plant-based extract formulations exhibited significantly lower protein content compared to the cow's milk formulation. Notably, the coconut extract formulation (CO) stood

out due to its higher lipid content. Color analysis indicated predominant red and yellow hues across samples, with beverages containing coconut extract showing greater lightness.

Microbiological analysis confirmed that all formulations met the required safety standards, with no detection of pathogens, ensuring the microbiological safety of the products. In sensory evaluations, the coconut extract beverage (CO) achieved the highest acceptance scores for texture, aroma, and flavor, as well as the greatest purchase intent among panelists.

Overall, these findings indicate that coconut extract is a promising alternative to dairy ingredients in coffee-based beverages. The addition of hydrolyzed collagen represents a strategy to improve the nutritional value of the product. Therefore, the proposed beverage is intended for consumers seeking dairy-free alternatives, such as individuals with lactose intolerance or cow's milk protein allergy, rather than those following vegan or vegetarian diets. Further studies are recommended to increase the protein content and improve consumer purchase intention while maintaining the desirable sensory characteristics of the beverage.

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