

FORMULATION AND CHARACTERIZATION OF PLANT-BASED BEVERAGES PRODUCED FROM WATER-SOLUBLE COCONUT EXTRACT SUPPLEMENTED WITH CALCIUM AND PROTEIN

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ABSTRACT:

This study aimed to develop and characterize a plant-based beverage produced from a water-soluble coconut extract supplemented with protein and calcium as an alternative to animal-derived milk. Four formulations were prepared by varying the incorporation of chickpea extract, calcium carbonate, and xanthan gum. The beverages were evaluated over 28 days of refrigerated storage by analyzing proximate composition, calcium content, pH, titratable acidity, total soluble solids, instrumental color, and viscosity. Formulations containing chickpea extract showed a significant increase in protein content, rising from 0.60 – 0.63% to 0.85 – 0.87%, representing an increment of approximately 38 – 42% compared to formulations without this ingredient. Calcium supplementation with calcium carbonate resulted in an increase of nearly fourfold in calcium concentration, from 39 – 41 to 140 – 150 mg/100 mL, confirming the effectiveness of the fortification strategy. Xanthan gum markedly increased beverage viscosity. Among the evaluated treatments, formulation D, composed of coconut extract, chickpea extract, calcium carbonate, and xanthan gum, showed higher protein and calcium contents, although its high viscosity indicates the need to optimize the xanthan gum concentration. Overall, the results demonstrate that the combination of chickpea extract and calcium carbonate represents a promising strategy to improve the nutritional profile of coconut-based plant beverages.

Keywords: plant-based milk alternatives; chickpea extract; proximate composition; nutritional enhancement; viscosity.

FORMULAÇÃO E CARACTERIZAÇÃO DE BEBIDAS VEGETAIS À BASE DE EXTRATO HIDROSSOLÚVEL DE COCO SUPLEMENTADA COM CÁLCIO E PROTEÍNA

RESUMO:

Este estudo teve como objetivo desenvolver e caracterizar uma bebida vegetal produzida a partir de extrato hidrossolúvel de coco, suplementada com proteína e cálcio, como alternativa ao leite de origem animal. Quatro formulações foram elaboradas, variando-se a incorporação de extrato de grão-de-bico, carbonato de cálcio e goma xantana. As bebidas foram avaliadas ao longo de 28 dias de armazenamento sob refrigeração por meio de análises de composição proximal, teor de cálcio, pH, acidez titulável, sólidos solúveis totais, cor instrumental e viscosidade. As formulações contendo extrato de grão-de-bico apresentaram aumento significativo no teor de proteínas, elevando-se de 0,60 – 0,63% para 0,85 – 0,87%, o que representa um incremento aproximado de 38 – 42% em relação às formulações sem esse ingrediente. A suplementação com carbonato de cálcio resultou em um aumento de quase quatro vezes na concentração de cálcio, passando de 39 – 41 para 140 – 150 mg/100 mL, confirmando a eficácia da estratégia de fortificação. A goma xantana aumentou consideravelmente a viscosidade das bebidas. Entre os tratamentos avaliados, a formulação D, composta por extrato de coco, extrato de grão-de-bico, carbonato de cálcio e goma xantana, destacou-se pelos

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maiores teores de proteína e cálcio, embora a elevada viscosidade indique a necessidade de otimização da concentração de goma xantana. De modo geral, os resultados demonstram que a combinação de extrato de grão-de-bico e carbonato de cálcio constitui uma estratégia promissora para melhorar o perfil nutricional de bebidas vegetais à base de coco.

Palavras-chave: bebidas vegetais alternativas ao leite; extrato de grão-de-bico; composição centesimal; enriquecimento nutricional; viscosidade.

INTRODUCTION

Increasing consumer awareness of health and the environmental impacts of food production has led to greater demand for plant-based products. These products are derived from plant-based raw materials, contain no animal-derived ingredients, and are often designed to mimic the sensory characteristics of conventional products (Pacheco and Sadahira, 2022). In Brazil, a study by Lupetti and Casselli (2022) revealed that 65% of respondents replace animal-based foods with plant-based alternatives at least once a week. Plant-based beverages were among the main alternatives reported by respondents, indicating their potential in the Brazilian market.

Plant-based beverages have emerged as promising alternatives, meeting the needs of vegan and vegetarian consumers as well as individuals with food intolerances and allergies (Vashisht *et al.*, 2024; Escobar-Sáez *et al.*, 2022). Although there is no specific regulation for these products in Brazil, they fall under Decree No. 6,871/2009, classified as non-fermented beverages obtained by diluting plant extracts in potable water (Brasil, 2009).

Various raw materials are used in plant-based beverage formulations, such as soy, oats, almonds, nuts, and coconut (Brooker *et al.*, 2023; Aydar *et al.*, 2020). In the Brazilian context, coconut stands out due to its wide acceptance and rich composition of lipids, carbohydrates, proteins, medium-chain fatty acids, and essential amino acids (Aragão, 2022; Rocha *et al.*, 2021).

One of the main challenges in developing plant-based beverages is achieving adequate protein and calcium levels, essential nutrients that are often lacking in plant formulations. Strategies such as fortification with compounds like calcium carbonate and the use of ingredients like chickpeas, rich in protein, fiber, and minerals, have proven effective (Aydar *et al.*, 2020; Ribeiro *et al.*, 2020).

Thus, combining coconut extract, known for its high sensory acceptance, with chickpeas to enhance protein content, along with calcium supplementation, represents a strategic approach to developing more nutritionally balanced plant-based beverages. This type of innovation not only addresses nutritional demands but also contributes to the diversification

and growth of the plant-based market in Brazil (Ambiel *et al.*, 2021).

In this context, this study aimed to develop a plant-based beverage from coconut water-soluble extract, supplemented with chickpea extract and calcium, as an alternative to animal-based milk.

MATERIALS AND METHODS

Material

The preparation of the beverages and the analytical procedures were conducted in the Beverage Technology, Unit Operations, and Food Analysis Laboratories of the Food Engineering Department of the Instituto Federal Catarinense (IFC), Concórdia Campus. The main raw materials included were: dried grated coconut (Sococo, Brazil), chickpeas (Yoki, Brazil), calcium carbonate (Êxodo, Brazil), stevia (Linea, Brazil), sucralose (Linea, Brazil), xanthan gum (Sauce Foods, Brazil), potassium sorbate (Dinâmica, Brazil), and sodium benzoate (Dinâmica, Brazil).

Preparation of Plant-Based Beverages

The plant-based beverages were prepared using a procedure adapted from Rincon *et al.* (2020). Initially, the solid raw materials were ground in a blender (Philco® All In One Citrus 800W Multiprocessor) using water heated to 90 °C to facilitate the extraction of water-soluble compounds. The mixture was subsequently filtered to separate the water-soluble extract from the solid residue.

For the preparation of the chickpea water-soluble extract, the grains were soaked in potable water for 12 h and then pressure-cooked at 120 °C for 20 min. After cooking, the grains were ground using the cooking water as the dispersing medium, with additional water added until the desired volume was reached. The resulting mixture was filtered through a sieve to obtain the water-soluble extract.

Four experimental formulations were developed by varying the proportions of coconut and chickpea water-soluble extracts, as well as the addition of calcium carbonate and xanthan gum, as detailed in Table 1.

Table 1. Formulations used for the preparation of plant-based beverages.

Ingredients (%)	Formulations			
	A	B	C	D
Coconut	16.60	12.50	16.48	12.35
Chickpea	-	4.10	-	4.12
Water	83.20	83.20	82.40	82.42
Calcium carbonate	-	-	0.40	0.40
Stevia	-	-	0.01	0.01
Sucralose	-	-	0.01	0.01
Xanthan gum	-	-	0.49	0.49
Potassium sorbate	0.10	0.10	0.10	0.10
Sodium benzoate	0.10	0.10	0.10	0.10
Total (%)	100	100	100	100

Formulation A served as the control and contained coconut extract as the sole plant-based extract. The mixtures formulated according to Table 1 were subsequently homogenized, packaged in appropriate containers, and pasteurized in an autoclave at 65 °C for 20 min.

Characterization of Plant-Based Beverages

The formulations described in Table 1 were initially characterized on day 0 by proximate composition analysis, including moisture, protein content (determined by the Kjeldahl method), lipid content, ash, titratable acidity, and calcium content, according to the methodologies described by the Instituto Adolfo Lutz (IAL, 2008). Total carbohydrate content (%) was calculated by difference using Equation 1.

$$\text{Carbohydrate (\%)} = 100 - (\% \text{ moisture} + \% \text{ proteins} + \% \text{ lipids} + \% \text{ ash}) \quad (\text{Eq. 1})$$

Calcium content was determined by complexometric titration with EDTA, following the methodology described by IAL (2008). The method is based on the formation of a stable complex between calcium ions and EDTA, allowing the calcium concentration in the samples to be quantified from the volume of titrant consumed. The results were expressed as mg/100 mL.

For the storage stability study, the formulations were stored in a commercial refrigeration unit under controlled conditions (5.8 ± 0.5 °C and 88.3% relative humidity) for 28 days. Physicochemical parameters, including pH, titratable

acidity, total soluble solids (TSS), viscosity, and color coordinates (L*, a*, and b*), were evaluated at 7-day intervals (days 0, 7, 14, 21, and 28). All analyses were performed in triplicate.

The pH was measured by direct potentiometry using a pH meter (Hanna, HI8424). TSS were determined using an Abbé refractometer and expressed as °Brix. Viscosity was measured using a Ford Cup viscometer (Tech Vision Ltda.), with samples maintained at refrigeration temperature (5 ± 1 °C). Color measurements were performed 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 (–).

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

Proximate Composition and Calcium Content

The physicochemical composition of the plant-based beverages and the calcium content of the different formulations are presented in Table 2.

Table 2. Proximate composition and calcium content of plant-based beverages.

Analysis	Formulations			
	A	B	C	D
Moisture (%)	96.07 ± 0.18 ^c	94.86 ± 0.02 ^b	94.50 ± 0.08 ^b	93.88 ± 0.02 ^a
Ash (%)	0.14 ± 0.007 ^a	0.22 ± 0.02 ^b	0.34 ± 0.01 ^c	0.35 ± 0.01 ^c
Protein (%)	0.63 ± 0.03 ^a	0.87 ± 0.04 ^b	0.60 ± 0.02 ^a	0.85 ± 0.01 ^b
Lipids (%)	2.12 ± 0.10 ^b	1.99 ± 0.16 ^b	1.11 ± 0.04 ^a	1.32 ± 0.04 ^a
Carbohydrates (%)	1.04 ± 0.12 ^a	2.06 ± 0.20 ^b	3.45 ± 0.02 ^c	3.60 ± 0.05 ^c
Calcium (mg/100 mL)	39.00 ± 3.00 ^a	41.00 ± 1.00 ^a	150 ± 10.00 ^b	140 ± 2.00 ^b

* Means followed by the same letter in the same row do not differ by Tukey's test ($p > 0.05$).

The proximate composition of the plant-based beverage formulations showed variations directly related to the ingredients used (Table 1). Moisture content ranged from 93.88% to 96.07%. Formulation A showed the highest moisture content, followed by formulations B and C, which did not differ significantly from each other, while formulation D showed the lowest moisture content ($p < 0.05$). This result can be attributed to the greater proportion of added dry ingredients, particularly calcium carbonate and xanthan gum, which increased the non-aqueous fraction of formulation D.

Ash content was significantly higher in formulations C and D, which can be attributed to the addition of calcium carbonate. The same formulations contained approximately 140–150 mg calcium/100 mL, whereas formulations A and B contained approximately 39–41 mg/100 mL. Escobar-Sáez *et al.* (2022) reported that many non-fortified plant-based beverages contain substantially less calcium than cow's milk, whereas fortified products may reach calcium concentrations close to 120 mg/100 mL. Therefore, the values obtained for formulations C and D demonstrate that calcium carbonate effectively increased the mineral content of the beverages.

However, the effectiveness of calcium fortification depends not only on the total calcium concentration but also on the fortification strategy employed. In the present study, calcium carbonate was selected as the fortifying agent due to its high elemental calcium content, wide availability, and relatively low cost. Nevertheless, its limited solubility may favor sedimentation during storage, potentially leading to an uneven distribution of calcium throughout the product. Therefore, adequate shaking or mixing before consumption may be important to redisperse settled particles and ensure a more

consistent calcium intake (Palacios *et al.*, 2021; Smith *et al.*, 2022; Grau-Fuentes *et al.*, 2023; Rachtan-Janicka *et al.*, 2025).

Furthermore, Escobar-Sáez *et al.* (2022) emphasized that the nutritional effectiveness of calcium fortification is influenced by additional factors, particularly vitamin D status, since this vitamin plays an important role in intestinal calcium absorption. Therefore, the development of fortified plant-based beverages should consider not only the calcium concentration but also the selection of appropriate fortification strategies and clear consumer guidance regarding product homogenization before consumption.

The incorporation of chickpea extract increased the protein content from 0.60–0.63% to 0.85–0.87%, corresponding to an increase of approximately 38–42%. This result was expected because chickpea is a protein-rich legume and has been widely investigated as an ingredient to improve the nutritional quality of plant-based beverages. Rincon *et al.* (2020) developed coconut–chickpea beverages with different proportions of both extracts and demonstrated that increasing the chickpea fraction increased the protein content from 1.04 to 2.10 g/100 g, resulting in formulations with improved nutritional composition compared with many commercially available plant-based beverages.

Similarly, Aydar *et al.* (2020) highlighted legumes as important protein sources for plant-based milk alternatives. Beverages based on legumes, such as soy and peanut, generally contain higher protein levels than those derived from cereals or nuts, although protein content varies considerably according to the botanical source and formulation. Formulations B and D showed higher protein contents than the coconut-only formulations, confirming that

the chickpea extract contributed to protein enrichment.

The lipid content varied significantly among the formulations, reflecting differences in their overall composition. Formulations C and D exhibited lower lipid contents (1.11–1.32%) than formulations A and B (1.99–2.12%). This difference can be attributed to the combined effect of the ingredients used, including the proportions of coconut and chickpea extracts, as well as the incorporation of calcium carbonate and xanthan gum. These formulation changes modified the relative contribution of each ingredient to the final composition of the beverages. Similar variations have been reported for plant-based beverages, whose nutritional composition is strongly influenced by the botanical sources and formulation strategy employed (Fructuoso *et al.*, 2021).

The lipid fraction of plant-based beverages differs considerably from that of cow's milk, being generally cholesterol-free and containing a higher proportion of unsaturated fatty acids, depending on the plant source. Therefore, the objective of developing plant-based beverages should not be to reproduce the lipid composition of cow's milk, but rather to obtain products with suitable nutritional and technological characteristics according to their intended application (Fructuoso *et al.*, 2021).

Carbohydrate content, calculated by difference, was higher in formulations C and D (3.45–3.60%). Since this fraction was estimated indirectly, the observed values reflect the combined variation of moisture, protein, lipid, and ash contents (IAL, 2008; AOAC, 2019). In addition, formulation D contained

xanthan gum, a high-molecular-weight polysaccharide widely used as a stabilizer and thickening agent in food systems (Saha & Bhattacharya, 2010).

Overall, the results demonstrate that relatively small modifications to the formulations significantly influenced the physicochemical composition of the plant-based beverages. The incorporation of chickpea extract increased the protein content, whereas calcium carbonate effectively increased the calcium content. Coconut and chickpea have previously been combined in plant-based beverages, supporting the feasibility of using these ingredients in the same product matrix (Rincon *et al.*, 2020). Likewise, calcium carbonate is commonly used as a calcium fortificant in plant-based beverages (Grau-Fuentes *et al.*, 2023; Rachtan-Janicka *et al.*, 2025), while hydrocolloids such as xanthan gum are incorporated to increase viscosity and improve suspension stability (Asase and Glukhareva, 2024; Rastegarpour *et al.*, 2025). Therefore, these formulation strategies represent promising approaches for developing plant-based beverages with improved nutritional composition.

Determination of pH and Titratable Acidity

Regarding pH, formulations with similar compositions exhibited comparable trends during storage. Formulations C and D, supplemented with calcium carbonate, showed higher initial pH values (> 8.0), followed by a significant decrease during the first 7 days of storage and only minor variations thereafter (Table 3).

Table 3. pH values of plant-based beverages with different treatments during storage ($5.8 \text{ }^{\circ}\text{C} \pm 0.5 \text{ }^{\circ}\text{C}$, RH = $88.3\% \pm 0.5\%$ for 28 days).

Time (days)	Formulations			
	A	B	C	D
0	$6.76 \pm 0.16^{\text{bA}}$	$6.81 \pm 0.03^{\text{bA}}$	$8.30 \pm 0.25^{\text{aA}}$	$8.16 \pm 0.35^{\text{aA}}$
7	$6.61 \pm 0.13^{\text{bA}}$	$6.50 \pm 0.08^{\text{bB}}$	$7.39 \pm 0.35^{\text{aB}}$	$7.80 \pm 0.18^{\text{aAB}}$
14	$5.90 \pm 0.21^{\text{cB}}$	$6.38 \pm 0.10^{\text{bB}}$	$7.29 \pm 0.22^{\text{aB}}$	$7.34 \pm 0.17^{\text{aB}}$
21	$5.85 \pm 0.08^{\text{cB}}$	$6.22 \pm 0.05^{\text{bC}}$	$7.05 \pm 0.12^{\text{aB}}$	$7.03 \pm 0.05^{\text{aB}}$
28	$5.96 \pm 0.28^{\text{cB}}$	$6.38 \pm 0.05^{\text{bBC}}$	$6.96 \pm 0.09^{\text{aB}}$	$7.01 \pm 0.02^{\text{aB}}$

* Means followed by the same lowercase letter in the same row and by the same uppercase letter in the same column do not differ from each other according to Tukey's test at the 5% significance level.

In contrast, formulations A and B, which did not contain calcium carbonate, presented initial pH values around 6.7. Formulation A exhibited its greatest pH reduction after 14 days, whereas

formulation B showed a significant decrease by day 7, remaining relatively stable until the end of storage.

Rincon *et al.* (2020) reported a pH value of 6.45 for a plant-based beverage formulated with 50%

coconut and 50% chickpea, which is close to the values observed for formulations A and B in the present study. As expected, the addition of calcium carbonate resulted in higher pH values in formulations C and D throughout storage, reflecting the alkaline nature of this mineral ingredient.

As storage progressed, the reduction in pH was accompanied by an increase in titratable acidity (Table 4), consistent with the inverse relationship between these parameters.

Table 4. Total titratable acidity values (g/100 mL) of plant-based beverages with different treatments during storage (5.8 °C ± 0.5 °C, RH = 88.3% ± 0.5% for 28 days).

Time (days)	Formulations			
	A	B	C	D
0	0.16 ± 0.06 ^{bC}	0.33 ± 0.06 ^{aC}	0.10 ± 0.00 ^{bB}	0.10 ± 0.00 ^{bC}
7	0.20 ± 0.00 ^{bC}	0.29 ± 0.00 ^{aC}	0.10 ± 0.00 ^{cB}	0.10 ± 0.00 ^{cC}
14	0.20 ± 0.00 ^{bC}	0.36 ± 0.06 ^{aC}	0.10 ± 0.00 ^{bB}	0.13 ± 0.00 ^{bC}
21	0.36 ± 0.06 ^{bB}	0.52 ± 0.06 ^{aB}	0.16 ± 0.06 ^{cB}	0.33 ± 0.06 ^{bB}
28	0.59 ± 0.10 ^{abA}	0.69 ± 0.00 ^{aA}	0.29 ± 0.00 ^{cA}	0.49 ± 0.00 ^{ba}

* Means followed by the same lowercase letter in the same row and by the same uppercase letter in the same column do not differ from each other according to Tukey's test at the 5% significance level.

Initially, formulation B showed the highest acidity (0.33 g/100 mL), while formulations A, C, and D did not differ significantly from each other (0.10–0.16 g/100 mL). All formulations exhibited gradual increases in acidity over the 28-day storage period. The increase was more pronounced in formulations A and B, while formulations containing calcium carbonate maintained lower acidity values throughout storage, suggesting that the mineral influenced the acid-base balance of the beverages.

Total Soluble Solids (TSS)

Table 5 presents the total soluble solids (TSS, °Brix) of the plant-based beverages during refrigerated storage. From day 0 onward, significant differences were observed among the formulations, reflecting variations in the initial concentration of dissolved solids.

Table 5. Total soluble solids (°Brix) of plant-based beverages with different treatments during storage (5.8 °C ± 0.5 °C, RH = 88.3% ± 0.5% for 28 days).

Time (days)	Formulations			
	A	B	C	D
0	1.4 ± 0.00 ^{dA}	2.0 ± 0.00 ^{aA}	1.7 ± 0.00 ^{cA}	1.9 ± 0.00 ^{bA}
7	1.3 ± 0.06 ^{cB}	1.8 ± 0.06 ^{aB}	1.5 ± 0.00 ^{bC}	1.7 ± 0.06 ^{aB}
14	1.2 ± 0.00 ^{cB}	1.7 ± 0.06 ^{aB}	1.5 ± 0.06 ^{bC}	1.7 ± 0.00 ^{aB}
21	1.2 ± 0.06 ^{cB}	1.7 ± 0.06 ^{aB}	1.4 ± 0.06 ^{bBC}	1.7 ± 0.00 ^{aB}
28	1.1 ± 0.00 ^{cC}	1.7 ± 0.00 ^{aB}	1.6 ± 0.00 ^{bB}	1.7 ± 0.00 ^{aB}

* Means followed by the same lowercase letter in the same row and by the same uppercase letter in the same column do not differ from each other according to Tukey's test at the 5% significance level.

Formulation A showed the lowest initial value (1.4 °Brix), significantly lower than the other formulations ($p < 0.05$), whereas formulation B exhibited the highest value (2.0 °Brix). Overall, formulations B and D, which contained chickpea extract, maintained higher °Brix values throughout the storage period, indicating a greater contribution of this ingredient to the soluble solids content of the beverages.

All formulations exhibited a slight decrease in TSS during refrigerated storage, although with different magnitudes. For example, °Brix decreased from 1.4 to 1.1 in formulation A and from 2.0 to 1.7 in formulation B after 28 days of storage. Because °Brix reflects the refractive index of the soluble fraction (AOAC, 2019), changes in the physical stability of plant-based beverages, including particle aggregation and sedimentation, may affect the

measured °Brix values during storage (McClements, 2015).

Rincon *et al.* (2020) reported a TSS value of 2.88 °Brix for a plant-based beverage formulated with equal proportions of coconut and chickpea extracts. In the present study, the lower TSS values are likely related to differences in ingredient proportions and formulation composition.

Nevertheless, formulations containing chickpea extract (B and D) consistently exhibited higher °Brix values than those without this ingredient, confirming its contribution to the soluble solids content of the beverages.

Viscosity

Regarding viscosity (Table 6), formulations A and B showed similar values throughout storage and exhibited significantly lower viscosity than formulations C and D ($p < 0.05$), indicating a more fluid consistency. In contrast, formulations supplemented with xanthan gum (C and D) presented markedly higher viscosity during the entire storage period.

Table 6. Viscosity (cSt) of plant-based beverages with different treatments during storage ($5.8\text{ }^{\circ}\text{C} \pm 0.5\text{ }^{\circ}\text{C}$, RH = $88.3\% \pm 0.5\%$ for 28 days).

Time (days)	Formulations			
	A	B	C	D
0	$4.32 \pm 0.00^{\text{cAB}}$	$4.32 \pm 0.00^{\text{cA}}$	$229.69 \pm 12.41^{\text{aA}}$	$102.85 \pm 0.00^{\text{bB}}$
7	$1.90 \pm 0.83^{\text{cB}}$	$5.30 \pm 0.83^{\text{cA}}$	$217.80 \pm 12.10^{\text{aA}}$	$165.40 \pm 13.97^{\text{bA}}$
14	$3.40 \pm 2.20^{\text{bB}}$	$4.80 \pm 1.66^{\text{bA}}$	$105.90 \pm 6.67^{\text{aC}}$	$99.50 \pm 4.45^{\text{aBC}}$
21	$7.20 \pm 1.44^{\text{cA}}$	$5.80 \pm 0.00^{\text{cA}}$	$145.20 \pm 0.00^{\text{aB}}$	$91.80 \pm 2.25^{\text{bBC}}$
28	$2.40 \pm 0.83^{\text{cB}}$	$3.80 \pm 1.66^{\text{cA}}$	$133.10 \pm 0.00^{\text{aB}}$	$84.10 \pm 2.25^{\text{bC}}$

* Means followed by the same lowercase letter in the same row and by the same uppercase letter in the same column do not differ from each other according to Tukey's test at the 5% significance level.

The higher viscosity of formulations C and D can be associated with the addition of xanthan gum (0.49%), a high-molecular-weight hydrocolloid widely used as a thickening and stabilizing agent in beverage systems. Xanthan gum is capable of substantially increasing viscosity even at low concentrations by forming highly viscous aqueous dispersions with pseudoplastic behavior (Saha & Bhattacharya, 2010).

Similarly, Zhang *et al.* (2024) reported that the incorporation of xanthan gum into oat-based beverages significantly altered their rheological properties and contributed to improved physical stability. In the present study, the increase in viscosity from approximately 4 cSt in formulations A and B to 103–230 cSt in formulations C and D demonstrates the pronounced thickening effect of xanthan gum in the beverage matrix.

Formulation D showed lower viscosity than formulation C despite containing the same concentration of xanthan gum. As the main compositional difference between these formulations was the incorporation of chickpea extract, the results suggest that interactions between chickpea

components and xanthan gum may have influenced the rheological behavior of the beverage. However, the mechanisms involved were not investigated in the present study and remain to be elucidated through further rheological and microstructural analyses.

Color Parameters

The visual appearance of the beverages throughout storage is presented in Figure 1, while the instrumental color parameters are shown in Table 7. Visual evaluation indicated slight changes in beverage color over time, which were supported by the instrumental measurements. Regarding the color parameters (Table 7), no significant differences ($p > 0.05$) were observed in lightness (L^*) among the formulations during most of the storage period, except for formulation A on day 28, which showed a more pronounced reduction in L^* , indicating that the sample became darker. The most notable variations occurred in the chromatic coordinates a^* and b^* , suggesting differences in the beverage hue throughout storage.



Figure 1. Visual appearance of plant-based beverages with different treatments during storage ($5.8\text{ }^{\circ}\text{C} \pm 0.5\text{ }^{\circ}\text{C}$, $\text{RH} = 88.3\% \pm 0.5\%$ for 28 days). **Formulation A:** coconut extract; **Formulation B:** coconut and chickpea extracts; **Formulation C:** coconut extract supplemented with calcium carbonate, xanthan gum, stevia, and sucralose; **Formulation D:** coconut and chickpea extracts supplemented with calcium carbonate, xanthan gum, stevia, and sucralose. Potassium sorbate and sodium benzoate were included in all formulations as preservatives.

Table 7. Color analysis (L^* , a^* , and b^* parameters) of plant-based beverages with different treatments during storage ($5.8\text{ }^{\circ}\text{C} \pm 0.5\text{ }^{\circ}\text{C}$, $\text{RH} = 88.3\% \pm 0.5\%$ for 28 days).

Time (days)	Parameter	Formulations			
		A	B	C	D
0	L^*	77.34 ± 4.24^{aA}	79.61 ± 0.66^{aA}	79.10 ± 0.74^{aA}	76.30 ± 0.32^{aA}
	a^*	0.24 ± 1.33^{aA}	-1.59 ± 0.16^{bA}	-1.22 ± 0.04^{abAB}	-1.81 ± 0.07^{bA}
	b^*	0.33 ± 0.28^{cA}	3.16 ± 0.93^{bA}	1.50 ± 0.09^{cA}	5.24 ± 0.09^{aA}
7	L^*	71.03 ± 1.78^{aAB}	73.83 ± 3.02^{aA}	75.56 ± 1.52^{aAB}	73.96 ± 0.73^{aA}
	a^*	-1.01 ± 0.08^{aA}	-1.56 ± 0.05^{cA}	-1.17 ± 0.06^{bAB}	-1.89 ± 0.01^{dA}
	b^*	-2.02 ± 0.16^{cB}	0.49 ± 1.11^{bB}	-0.27 ± 0.33^{bAB}	3.31 ± 0.32^{aAB}
14	L^*	65.97 ± 4.16^{aABC}	74.07 ± 4.75^{aA}	69.73 ± 2.04^{aBC}	74.44 ± 1.80^{aA}
	a^*	-1.12 ± 0.17^{aA}	-1.50 ± 0.17^{bA}	-1.32 ± 0.06^{abB}	-2.18 ± 0.03^{cB}
	b^*	-2.16 ± 0.84^{bB}	0.79 ± 0.95^{abAB}	-0.43 ± 1.58^{bAB}	3.42 ± 0.94^{aAB}
21	L^*	64.82 ± 2.13^{aBC}	69.33 ± 10.65^{aA}	67.47 ± 3.64^{aC}	73.50 ± 2.69^{aA}
	a^*	-1.13 ± 0.13^{aA}	-1.42 ± 0.28^{aA}	-1.16 ± 0.08^{aA}	-2.10 ± 0.12^{bB}
	b^*	-2.20 ± 0.67^{bB}	0.94 ± 1.35^{abAB}	-1.17 ± 0.21^{bB}	3.00 ± 1.28^{aB}
28	L^*	59.41 ± 7.02^{bC}	73.96 ± 1.50^{aA}	73.27 ± 2.37^{aABC}	73.77 ± 0.94^{aA}
	a^*	-1.24 ± 0.18^{aA}	-1.76 ± 0.21^{bA}	-1.46 ± 0.03^{abB}	-2.54 ± 0.08^{cC}
	b^*	-2.19 ± 0.11^{dB}	0.66 ± 0.15^{bAB}	-0.50 ± 0.57^{cAB}	3.78 ± 0.59^{aAB}

* Means followed by the same lowercase letter in the same row and by the same uppercase letter in the same column do not differ from each other according to Tukey's test at the 5% significance level.

Rincon *et al.* (2020) reported lightness values close to those observed in this study for beverages prepared with 50% coconut and 50% chickpea, as well as for formulations containing only coconut,

indicating similar visual characteristics between the beverages. Formulations B and D maintained higher positive b^* values than formulations A and C throughout the storage period. These higher values correspond to a stronger yellow hue.

This behavior was expected because these formulations contained chickpea extract, which has a naturally cream-to-yellow color associated with pigments such as carotenoids (Queiroga *et al.*, 2021). Similar color characteristics have also been reported for coconut–chickpea beverages (Rincon *et al.*, 2020). However, b^* did not increase progressively during storage. Instead, the values fluctuated and were generally lower at the end of the storage period than on day 0. Therefore, the greater yellowness of formulations B and D appears to be primarily associated with the presence of chickpea rather than with storage time.

CONCLUSION

The incorporation of chickpea extract increased the protein content of the coconut-based beverages by approximately 38–42%, while the addition of calcium carbonate increased the calcium concentration from approximately 39–41 to 140–150 mg/100 mL. Xanthan gum markedly increased beverage viscosity; however, the high values observed indicate that its concentration should be optimized to achieve more suitable rheological properties. Among the evaluated formulations, formulation D combined higher protein and calcium contents with increased viscosity compared with the formulations without xanthan gum. These findings indicate that this formulation may serve as a basis for the development of nutritionally enhanced coconut-based beverages, provided that the xanthan gum concentration is optimized to achieve appropriate rheological properties.

This study provides a preliminary assessment of the formulation and physicochemical and nutritional characteristics of fortified coconut-based beverages. Further studies addressing formulation optimization, rheological properties, physical and microbiological stability, shelf life, sensory acceptance, and calcium bioavailability are needed to support the development of these formulations.

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