International Journal of
Dairy Technology

SDT Society of Dairy Technology

doi: 10.1111/1471-0307.70088

RESEARCH ARTICLE

Flaxseed mucilage as a natural thickener in a chocolate whey beverage

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Background:
Growing consumer demand for healthier food products has intensified the search for natural additives. Due to its functional properties, flaxseed mucilage has significant commercial potential when it comes to enhancing desirable characteristics in food formulations.

Aim:
This study evaluated the potential of flaxseed mucilage as a natural thickening agent to replace conventional thickeners in chocolate whey beverages.

Methods:
Mucilage was extracted from flaxseeds using a water-based method, and its technological properties (solubility, water and oil absorption capacities) were characterised. Four chocolate whey beverage formulations were prepared: control beverage without thickener, beverage with carboxymethyl cellulose, beverage with flaxseed mucilage and beverage with carboxymethyl cellulose and flaxseed mucilage. Physicochemical parameters (pH, titratable acidity, moisture, ash, protein and fat) were analysed. Rheological behaviour was evaluated by rotational rheometry. Consistency, colour intensity and sensory acceptance (consumer testing using a 9-point hedonic scale) were also assessed. All experiments were conducted in triplicate. Data were analysed using the software R, with ANOVA, Friedman's test or Kruskal–Wallis test to identify significant differences between sample mean values ($P < 0.05$*), followed by post hoc Nemenyi's test for multiple comparisons.*

Major Findings:
The addition of flaxseed mucilage did not cause adverse changes to physicochemical parameters, but significantly improved beverage consistency and colour intensity ($P < 0.05$*). Rheological profiles were consistent with commercial standards, displaying pseudoplastic behaviour. Consumer tests demonstrated high sensory acceptance.*

Industrial Implications:
Flaxseed mucilage is a viable natural thickening agent for dairy beverages. Its industrial adoption could reduce reliance on synthetic additives while meeting clean-label consumer demands.

Keywords Sensory evaluation, Gums, Rheology, Beverages, Polysaccharides.

INTRODUCTION

Whey is a by-product of the chymosin coagulation in cheesemaking that is rich in proteins (β-lactoglobulin, α-lactalbumin and immunoglobulins), lactose, fats, vitamins and minerals. However, it is commonly underutilised and improperly disposed of in some countries, negatively affecting the environment (Detti *et al*. 2025).

Whey-based beverages must contain at least 51% of dairy base and may include nondairy ingredients, such as sugar, cereals, fruits, sweeteners, thickeners and flavourings (Brasil 2005). Chocolate whey beverages promote increased dairy consumption and nutrient intake by providing an excellent balance of minerals, vitamins, proteins and carbohydrates (Fayet-Moore *et al*. 2019). They are highly appreciated by children, teenagers and athletes due to their potential to aid muscle recovery (Li and Drake 2015; Lauricella and Koster 2016) and are particularly attractive for their convenience (Bogsan *et al*. 2017).

Thickeners are commonly added to whey beverages to improve physical properties, such as viscosity and mouthfeel (Gascoyne 2016). One of the most widely used thickeners in the market is carboxymethyl cellulose (CMC), obtained by reacting alkaline cellulose with chloroacetic acid and sodium hydroxide. CMC is valued in the food industry for its low cost, effectiveness and other technological attributes when present in beverage formulations (Biswal and Singh 2004; Dashipour *et al*. 2015). However, recent studies suggest that CMC may affect social anxiety behaviour and also induce obesity and metabolic abnormalities in mice (Holder *et al*. 2019).

Plant mucilage, a water-soluble polysaccharide extracted from seeds or certain stems, is used as a hydrocolloid due to its thickening, emulsifying and gelling properties (Liu *et al*. 2016). Moreover, this polysaccharide has attracted significant attention in the production of film and nanofiber due to its nontoxic nature, low irritability and cost-effectiveness (Beigomi *et al*. 2018; Raj *et al*. 2020).

According to Kučka *et al*. (2024), flaxseed mucilage has multiple applications in food, agriculture, medicine and other industries. Commercially, flaxseed mucilage has been used as a gelling agent, thickener, emulsion stabiliser and a material for food packaging, depending on certain of its functional characteristics, such as water-binding and foaming properties (Puligundla and Lim 2022).

Flaxseed contains approximately 8% mucilage, which presents excellent water absorption, solubility, swelling capacity and high viscosity, making it a promising thickening agent for food applications (Kaewmanee *et al*. 2014). Additionally, flaxseed mucilage consumption has been shown to increase faecal fat excretion, as well as reduce blood cholesterol and glucose levels in diabetic individuals (Basiri *et al*. 2018).

This study aimed to evaluate the potential of flaxseed mucilage as a substitute for conventional thickeners in chocolate whey beverages and to investigate the physicochemical, rheological and sensory characteristics of these formulations.

MATERIALS AND METHODS

Material

In this study, flaxseeds (*Linum usitatissimum* L.), pasteurised milk (3% fat), sugar and chocolate powder (Nestlé, Feira de Santana, Brazil), and CMC ($[C_6H_7O_2(OH)_2OCH_2COONa]_n$) (Changshu Wealthy Science and Technology Co., Changshu, China; DS: 0.65–0.85) were purchased by the authors at a local market in Fortaleza, State of Ceará, Northeast Brazil. The cheese whey was donated by a local dairy industry called Cooperativa Agrícola Mista de Maranguape.

Flaxseed mucilage extraction and composition

Flaxseed mucilage was extracted from whole seeds, which were first rinsed to remove surface particulate. Extractions were performed using a seed-to-water ratio of 1:13, at a temperature of $80 \pm 2°C$ (Ziolkovska 2012). The mixture was stirred for 1 h. The aqueous suspension was separated from the seeds by filtration through cheesecloth, followed by freeze-drying (Cui *et al*. 1994).

The dried flaxseed mucilage samples were stored at $25 \pm 2°C$ for subsequent analysis and use in whey beverages. Protein content of the freeze-dried mucilage was determined by the micro-Kjeldahl method, and fat content was analysed using the Soxhlet extraction method (AOAC 2012). Ash content and dry matter were evaluated gravimetrically (AOAC 2012).

Technological properties of flaxseed mucilage

Solubility

Solubility (S) was evaluated according to the method described by Kaewmanee *et al.* (2014). Flaxseed mucilage (25 mg) was weighed into microcentrifuge tubes, and 2 mL of distilled water was added. The mixture was gently shaken for 10 min at $25 \pm 2°C$. Tubes were then centrifuged at $3000 \times g$ for 15 min. The supernatant was collected and dried in an oven at 105°C, until constant weight was achieved. Solubility (g/100 g mucilage) was calculated using Equation 1:

$$S = \frac{M_s}{M_i} \times 100 \tag{1}$$

where M_s is the weight of dried supernatant and M_i is the sample weight.

Water and oil absorption capacities

Water absorption capacity (WAC) was determined using the method of Humbert (1974) with modifications. Flaxseed mucilage (1 g) was placed in a pre-weighed centrifuge tube, and 10 mL of distilled water was added. The dispersion was stirred for 1 min and then allowed to rest for 30 minutes. Samples were centrifuged at $3000 \times g$ for 30 min. The supernatant was decanted, and the centrifuge tube containing the sediment was weighed. WAC was expressed as the amount of water absorbed per gram of dry sample.

Oil absorption capacity (OAC) was measured using a similar method, also described by Humbert (1974), where 0.5 g of mucilage sample was mixed with 6 mL of corn oil. OAC was calculated as the amount of oil absorbed per gram of mucilage sample.

Elaboration and characterisation of whey beverages with added flaxseed mucilage

The dairy base for the beverages consisted of equal proportions of pasteurised milk and cheese whey, in accordance with Brazilian regulations (Brasil 2005). Sugar (5 g/100 mL) and chocolate powder (3 g/100 mL) were added. Four chocolate whey beverage (CWB) formulations were prepared: (1) Control beverage (CB)—CWB without thickener; (2) Beverage with CMC (BCMC)—CWB containing 0.1 g/100 mL of CMC; (3) Beverage with flaxseed mucilage (BFM)—CWB containing 0.6 g/100 mL of flaxseed mucilage; and (4) Beverage with CMC and flaxseed mucilage (BCMCFM)—CWB containing 0.1 g/100 mL of CMC and 0.6 g/100 mL of flaxseed mucilage (Basiri *et al*. 2018). The ingredients were mixed and pasteurised at 65°C for 30 min on a laboratory scale. Samples were stored at 5 ± 1°C for 24 h.

Physicochemical analysis

Samples were refrigerated until analysis and homogenised before testing. The pH was measured using a glass electrode pH meter (Ohaus, Greifensee, Switzerland) by direct insertion into the samples at room temperature. The electrode was calibrated before use with standard buffer solutions of pH 4.00 and 7.00. Titratable acidity was determined according to AOAC (2012) and expressed as the percentage of lactic acid per 100 g of whey beverage. Ash and moisture contents were determined by gravimetric methods, fat content by Gerber method (IAL 2008) and protein content by the micro-Kjeldahl method (AOAC 2012).

Colour coordinates (L, a, b^*) of the whey beverages were measured using a ColorQuest XE colorimeter (HunterLab, Virginia, USA). Total colour difference (ΔE) was calculated based on the measured colour coordinates, according to Equation 2:

$$\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \quad (2)$$

where $\Delta L^* = L^*_{(\mathrm{CB})} - L^*_{(\mathrm{sample})}$, $\Delta a^* = a^*_{(\mathrm{CB})} - a^*_{(\mathrm{sample})}$, $\Delta b^* = b^*_{(\mathrm{CB})} - b^*_{(\mathrm{sample})}$.

Higher ΔE values indicate greater colour difference, classified as imperceptible ($\Delta E^* < 1$), minimal ($1 \leq \Delta E^* < 2$), just perceptible ($2 \leq \Delta E^* < 3$), perceptible ($3 \leq \Delta E^* < 5$), strong difference ($5 \leq \Delta E^* < 12$) and different colour ($\Delta E^* \geq 12$) (Cecchini *et al*. 2011).

Rheological parameters

Rheological measurements were performed using a rotational rheometer (R/S Plus, Brookfield Engineering Laboratories, Middleboro, USA) equipped with concentric cylinder geometry (CC25) and a thermostatically controlled water bath to maintain the sample temperature at 7 ± 2°C. Flow curves were obtained by applying controlled shear rates ranging from 0 to 500 s^{-1} in both ascending and descending modes. Each ramp was recorded for 60 s, with a 2-min equilibration period between measurements to ensure sample stabilisation. All experiments were conducted in triplicate to guarantee reproducibility, and data fitting was performed using the software Origin 8.0 (OriginLab, Northampton, MA, USA). The flow curves were fitted to the power-law model (Equation 3):

$$\sigma = k \times \gamma^{\dot{n}} \quad (3)$$

where σ is the shear stress (mPa), $\dot{\gamma}$ is the shear rate (s^{-1}), k is the consistency index (mPa·s), and n is the flow behaviour index (dimensionless).

The area difference between ascending and descending flow curves was calculated to determine the thixotropic area (At).

Sensory analysis

The consumer acceptance test was conducted after the approval by the Brazilian Committee of Ethics (Approval No. 3.117.036). A total of 100 randomly selected consumers, aged 18–55, participated in the evaluation. Individuals with a known allergy to milk or lactose intolerance were excluded from the study.

The attributes of overall liking, colour, flavour and consistency were assessed using a structured 9-point hedonic scale (1 = ‘extremely disliked’ and 9 = ‘extremely liked’) (Hoffmann *et al*. 2020). In addition, a 9-cm unstructured linear hedonic scale was employed to evaluate the perceived intensity of brown colour and consistency. The samples of CWB were served in 15-mL plastic cups coded with random three-digit numbers, at a serving temperature of 5 ± 1°C. Water and bread were provided for palate cleansing between samples.

Purchase intention was assessed using a 5-point structured scale (1 = ‘certainly would not buy’ and 5 = ‘certainly would buy’) (Meilgaard *et al*. 2006). The overall acceptance score was calculated as the sum of the scores assigned to all evaluated attributes.

Statistical analysis

All experiments were conducted in triplicate. Data were analysed using the software R (R Core Team 2017). Analysis of variance (ANOVA) was applied for parametric data, whereas Friedman’s test or Kruskal–Wallis test was employed for nonparametric data. Significant differences were considered at $P < 0.05$. Post hoc comparisons were performed using Nemenyi’s test (Schaich and Hamerle 1984).

RESULTS AND DISCUSSION

Composition of flaxseed mucilage

The yield of flaxseed mucilage was 8.37% (w/w). In the study conducted by Saleh *et al*. (2026), flaxseed mucilage extracted by ultrasound yielded 8.73%, a value similar to that obtained in the present research. Its moisture and ash contents were 3.59 ± 0.23% and 11.36 ± 0.16%, respectively, while the freeze-dried material contained 4.35 ± 0.18% protein and 0.78 ± 0.19% fat. Similar yield, moisture and fat levels have been reported for flaxseed mucilage extracted at 90°C (Kaushik *et al*. 2017). Differences in flaxseed mucilage composition have been associated with cultivar and extraction temperature (Kaewmanee *et al*. 2014). Recent findings indicated that these parameters could vary markedly depending on the extraction method (temperature, time, pH, seed-to-water ratio) and the type of pre-treatment applied to the seeds (Puligundla and Lim 2022; Ren *et al*. 2023).

Technological properties of flaxseed mucilage

The technological properties of hydrocolloids, such as water absorption capacity (WAC), are essential for their applications in food systems, directly influencing product viscosity, stability and texture. WAC reflects the polymer's ability to retain water, thereby contributing to both viscosity and product stability. The flaxseed mucilage sample presented a WAC of 16.29 ± 0.25 g/g, consistent with previous studies (Kaur *et al*. 2018). This behaviour can be attributed to the abundance of hydrophilic carbohydrates within the mucilage matrix (Dev and Quensel 1988).

Other studies indicated that the WAC of flaxseed mucilage can vary considerably, depending on the extraction method, temperature, pH, seed-to-water ratio and seed pre-treatment. Kučka *et al*. (2024) reported that the WAC of flaxseed mucilage ranges from 1600 to 3000 g of water per 100 g of solids, depending on the genotype and extraction conditions. Hailu et al. (2024) showed that different extraction techniques can lead to significant variations in the water-holding capacity of the mucilage. These differences directly affect the technological properties of flaxseed mucilage, including viscosity, stability and the texture of food products.

Therefore, it is essential to carefully consider the extraction conditions and operational parameters when evaluating the technological properties of flaxseed mucilage in order to optimise its application in food systems.

The OAC of flaxseed mucilage (5.03 ± 0.45 g/g) was higher than values reported by Kaushik *et al*. (2017) and Kaur *et al*. (2018). This property is associated with the presence of nonpolar constituents that interact with oil droplets, enhancing lipid-binding ability (Rashid *et al*. 2018). More recent studies supported this association, indicating that the OAC can be influenced by the concentration of flaxseed gum (Li *et al*. 2025) and the extraction method employed (Liu *et al*. 2025).

A critical parameter for the use of hydrocolloids as thickeners, the solubility reflects the capacity of the polymer to disperse in water through hydrogen bonding (Doublier *et al*. 2000). The solubility of flaxseed mucilage in this study (71.60 ± 1.80 g/100 g) was consistent with values reported by Kaewmanee *et al*. (2014) and Kaur *et al*. (2018), although the latter authors observed lower values (69.15% and 40 g/100 g, respectively). This can be explained by the hot extraction process, which breaks the hydrogen bonds within the polysaccharide networks, thereby increasing solubility (Saleh *et al*. 2026).

Physicochemical analysis

The proximate composition and physicochemical parameters of CWB are presented in Table 1. Moisture, ash, protein, fat, pH and titratable acidity values were comparable to those reported for commercial CWB (Della Lucia *et al*. 2016). No statistically significant differences ($P > 0.05$) were observed in the overall composition of the beverages upon hydrocolloid incorporation.

Carboxymethyl cellulose (CMC) is widely recognised for its solubility (S) and WAC, properties directly related to its degree of substitution (DS) (Cai *et al*. 2018). The addition of flaxseed mucilage or CMC + flaxseed mucilage led to slight variations in ash, protein and titratable acidity values, although these changes remained within the expected range for CWB formulations.

The DS of the commercial CMC (0.65–0.85, as specified by the manufacturer) is within the range recommended for food applications (Murray 2000; Coffey *et al*. 2006). This DS range supports the observed functional properties and may account for the lower ash and moisture content in the CMC sample.

Table 1 Proximate composition and physicochemical parameters of CWB.

Sample	Moisture	Ash	Protein	Fat	pH	Titratable acidity
CB	82.66 ± 0.00^{a}	0.78 ± 0.05^{a}	1.84 ± 0.11^{a}	1.60 ± 0.08^{a}	6.55 ± 0.05^{a}	0.13 ± 0.01^{b}
BCMC	78.19 ± 0.01^{b}	0.63 ± 0.06^{b}	1.95 ± 0.06^{a}	1.63 ± 0.05^{a}	6.58 ± 0.02^{a}	0.14 ± 0.01^{b}
BFM	81.16 ± 0.04^{a}	0.87 ± 0.03^{a}	1.65 ± 0.06^{b}	1.57 ± 0.05^{a}	6.46 ± 0.04^{a}	0.15 ± 0.01^{a}
BCMCFM	80.56 ± 0.04^{a}	0.88 ± 0.08^{a}	1.99 ± 0.01^{a}	1.73 ± 0.05^{a}	6.49 ± 0.01^{a}	0.16 ± 0.00^{a}

Results are expressed as mean ± standard deviation. Different superscript letters in the same column indicate significant difference ($P < 0.05$). Moisture, ash, protein, fat and titratable acidity are expressed in [g/100 g].

BCMC, beverage with carboxymethyl cellulose (CMC); BCMCFM, beverage with CMC + flaxseed mucilage; BFM, beverage with flaxseed mucilage; CB, control beverage; CWB, chocolate whey beverages.

Table 2 Colour coordinates of CWB samples.

Sample	L^*	a^*	b^*	ΔE^*
CB	40.42 ± 1.02^a	10.02 ± 0.28^c	13.83 ± 0.65^b	–
BCMC	35.52 ± 0.15^b	10.98 ± 0.10^{bc}	15.37 ± 0.18^b	5.23
BFM	34.25 ± 1.36^b	11.26 ± 0.43^{ab}	13.99 ± 0.75^b	6.30
BCMCFM	29.76 ± 0.11^c	12.81 ± 0.13^a	17.68 ± 0.22^a	11.68

Results are expressed as mean ± standard deviation. Different superscript letters in the same column indicate significant difference ($P < 0.05$). Moisture, ash, protein, fat, and titratable acidity are expressed in [g/100 g].

BCMC, beverage with carboxymethyl cellulose (CMC); BCMCFM, beverage with CMC + flaxseed mucilage; BFM, beverage with flaxseed mucilage; CB, control beverage; CWB, chocolate whey beverages.

The incorporation of flaxseed mucilage into the whey beverage increased titratable acidity, likely due to the presence of acid polysaccharide constituents in the mucilage (Liu *et al*. 2016).

Colour analysis

The addition of hydrocolloids influenced the colour of CWB (Table 2). Significant differences ($P < 0.05$) were observed between the control and hydrocolloid-containing samples.

The BCMCFM sample intensifies the colour of CWB. This synergistic effect may be attributed to pigments (or tannins) from seed tegument, carried over during mucilage extraction, as suggested by Koocheki *et al*. (2009), or to higher extraction temperatures, enhancing pigment diffusion and resulting in darker colours.

Similarly, Arancibia *et al*. (2011) reported increased a^* and b^* values in dairy beverages with higher CMC concentrations. Gao *et al*. (2017) highlighted that hydrocolloids can modify the optical properties of beverages, affecting pigment stabilisation or destabilisation. As a result, formulation adjustments may be necessary for industrial standardisation and sensory acceptance.

Rheological parameters

The flow curves of the CWB samples were well fitted by the Power Law model, with coefficients of determination (R^2) ranging from 0.9972 to 0.9999 (Table 3).

The control beverage (CB) presented Newtonian fluid behaviour, indicated by a flow behaviour index (n) equal to 1.00. In contrast, all other samples showed pseudoplastic behaviour ($n < 1.00$), characterised by a lower apparent viscosity and higher shear rate (Amaral *et al*. 2018). Pseudoplastic behaviour has also been reported by Castro *et al*. (2013) in dairy-based systems, and by Jokar and Azizi (2022) in persimmon-enriched dairy beverages.

Table 3 Rheological characteristics of CWB samples.

Sample	Consistency index (k) (mPa s)	Flow behaviour index (n)	R^2	Thixotropic area (At) (Pa/s)
CB	2.06 ± 0.64^d	1.00 ± 0.04^a	0.9972	–
BCMC	20.02 ± 2.43^c	0.86 ± 0.02^b	0.9997	25.37 ± 3.88^a
BFM	73.55 ± 2.41^b	0.76 ± 0.03^c	0.9997	16.74 ± 2.74^b
BCMCFM	145.23 ± 10.07^a	0.73 ± 0.03^c	0.9999	12.49 ± 4.04^c

Results are expressed as mean ± standard deviation. Different superscript letters in the same column indicate significant difference ($P < 0.05$). Moisture, ash, protein, fat and titratable acidity are expressed in (g/100 g).

BCMC, beverage with carboxymethyl cellulose (CMC); BCMCFM, beverage with CMC + flaxseed mucilage; BFM, beverage with flaxseed mucilage; CB, control beverage; CWB, chocolate whey beverages.

The BFM beverage showed elevated consistency indices (k), as seen in Table 3. BCMCFM presented the highest k value, differing significantly from all other samples ($P < 0.05$), and suggesting a synergistic effect of the hydrocolloids on increasing beverage viscosity. This enhancement in sample viscosity may be attributed to the high solubility (S) and WAC of flaxseed mucilage observed in this study, together with the well-established technological properties of CMC.

Overall, flaxseed mucilage contributed to increased consistency and viscosity of whey beverages while reducing flow behaviour index, attributed to the mechanism by which hydrocolloids in dairy systems immobilise water within a three-dimensional polymer network, enhancing viscosity and justifying its use as a thickening agent (Saha and Bhattacharya 2010; Gao *et al*. 2017).

The BCMC, BFM and BCMCFM samples also displayed thixotropic behaviour (Table 3), indicative of time-dependent flow, likely arising from structural rearrangements within the material (Castro *et al*. 2013). This can be attributed to hydrocolloids, as both CMC and water-soluble polysaccharides are known to exhibit thixotropic properties (Benchabane and Bekkour 2008; Morell *et al*. 2014; Ghica *et al*. 2016).

Although n and k values indicate the expected thickening effect in samples containing CMC and flaxseed mucilage, minor variations in hydrocolloid type or concentration can induce complex synergistic effects on microstructure and rheological stability. Analyses based solely on these parameters may not capture viscoelastic or thixotropic changes occurring during long-term storage or under varying shear conditions (Martínez-Padilla 2024). Similar trends have been observed in reconstituted dairy beverages containing CMC and other thickeners, which exhibited increased consistency

Table 4 Sensory evaluation of CWB samples.

Sample	Overall liking	Color	Flavour	Consistency	Intensity of brown colour	Intensity of consistency	Purchase intention
CB	6.4 ± 1.7^{c}	5.8 ± 1.9^{c}	6.5 ± 1.9^{b}	5.5 ± 2.0^{c}	2.5 ± 1.8^{d}	2.3 ± 1.8^{d}	3.0 ± 1.1^{c}
BCMC	7.2 ± 1.4^{b}	7.3 ± 1.1^{b}	7.2 ± 1.6^{a}	6.9 ± 1.6^{b}	4.9 ± 1.6^{c}	4.1 ± 2.0^{c}	3.7 ± 1.1^{b}
BFM	7.6 ± 1.4^{a}	7.9 ± 1.0^{a}	7.4 ± 1.4^{a}	7.7 ± 1.3^{a}	5.8 ± 1.6^{b}	6.6 ± 1.8^{a}	4.1 ± 0.9^{a}
BCMCFM	7.8 ± 1.2^{a}	8.1 ± 1.2^{a}	7.3 ± 1.6^{a}	7.8 ± 1.2^{a}	7.3 ± 1.4^{a}	5.7 ± 1.9^{b}	4.1 ± 1.0^{a}

Results are expressed as mean ± standard deviation. Different superscript letters in the same column indicate significant difference ($P < 0.05$). Moisture, ash, protein, fat and titratable acidity are expressed in (g/100 g).

BCMC, beverage with carboxymethyl cellulose (CMC); BCMCFM, beverage with CMC + flaxseed mucilage; BFM, beverage with flaxseed mucilage; CB, control beverage; CWB, chocolate whey beverages.

and altered viscoelastic behaviour, without significant changes in proximate composition (Andrade *et al*. 2024).

BFM and BCMC had similar pseudoplastic behaviour, but BFM only achieved viscosities equivalent to BCMC when higher concentrations of flaxseed mucilage were used. However, the natural attributes and potential health appeal (related to soluble fibres) of flaxseed mucilage confer a ‘clean label’ to the product, highly valued by consumers.

Future investigations should evaluate rheological behaviour under prolonged storage conditions, as well as the interaction of mucilage with different cocoa sources and fat levels, in order to better understand its influence on colloidal stability and sensory perception.

Sensory analysis

In the sensory evaluation, a significant difference ($P < 0.05$) was observed among the samples (Table 4). The CB sample received the lowest scores for acceptance attributes and intensity parameters. Conversely, BFM and BCMCFM samples achieved higher scores, with no significant differences in overall liking, colour and consistency between them.

Overall liking, colour, flavour and consistency were assessed using a 9-point hedonic scale. Intensity of brown colour and intensity of consistency were assessed using a 9-cm linear hedonic scale. Purchase intention was evaluated using a 5-point structured scale.

The presence of hydrocolloid clearly improved the sensory acceptance of whey-based beverages. According to consumer testing, BFM enhanced brown colour intensity and consistency, supporting the findings of colour and rheological analyses. Similar results have been reported in cocoa-based beverages, where samples with more intense colour were preferred by consumers (Palma-Morales *et al*. 2024).

As a thickening agent—the primary focus of this study—flaxseed mucilage contributed to increasing the consistency of whey beverages, obtaining the highest scores for this attribute. Moreover, results indicated that flaxseed mucilage and CMC act synergistically as colour enhancers and viscosity modifiers. However, regarding purchase intention, consumers on average selected ‘maybe buy’ for BFM and BCMCFM formulations. This suggests satisfactory acceptance, but increasing chocolate intensity may be a potential strategy to further improve consumer preference.

The difference in consistency and brown colour intensity between BFM and BCMCFM samples was not decisive for assessed consumers. Thus, the addition of CMC is not strictly necessary unless maximising colour intensity is a key requirement. It should be noted that new methodologies for sensory analysis can be applied in future studies in order to further refine consumer preferences and also assess additional attributes (Freire *et al*. 2024; Nogueira *et al*. 2025).

CONCLUSION

This study demonstrated that flaxseed mucilage, alone or in combination with the commercial thickener CMC, improves the consistency and colour of chocolate whey beverages without negatively affecting their composition. Rheological and colorimetric analyses confirm the effectiveness of flaxseed mucilage as a thickening agent and colour enhancer in chocolate dairy beverages.

Sensory evaluation indicated high consumer acceptance, particularly for formulations containing flaxseed mucilage, consolidating it as a promising ingredient for technological and gastronomic innovations. The results obtained in this research also highlight flaxseed mucilage as a viable alternative to reduce the use of synthetic thickeners in dairy beverages, with a fairly competitive cost when compared to CMC, in line with market trends towards offering products with natural ingredients.

Therefore, flaxseed mucilage can be considered a new thickener with virtually no environmental impact, promoting a favourable cost–benefit ratio for the dairy industry in the formulation of whey-based beverages and for the development of other ‘high value added’ dairy products. However, its application on an industrial scale will require optimisation of extraction, drying, and incorporation to food, in order to ensure reproducibility and competitive costs.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the *Coordenação de Aperfeiçoamento de Pessoal de Ensino Superior* (Brazilian Federal Agency for Support and Evaluation of Postgraduate Education – CAPES) and *Embrapa Agroindústria Tropical* (*Embrapa Tropical Agroindustry*) for the financial and technical support for this research. We also appreciate the support from *Cooperativa Agrícola Mista de Maranguape* in providing and donating equipment and materials. The Article Processing Charge for the publication of this research was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) (ROR identifier: 00x0ma614).

AUTHOR CONTRIBUTIONS

Fernanda Batista Dantas: Conceptualisation, Formal analysis, Investigation, Methodology; Roles/Writing – original draft; **Antonia Samara Patricio Santos:** Formal analysis; **Gizele Almada Cruz:** Writing – review & editing; **Francisca Lívia de Oliveira Machado:** Writing – review & editing; **Israel Rodrigues da Costa:** Writing – review & editing; **Idila Maria da Silva Araújo:** Investigation; **Kaliana Sitonio Eça:** review & editing; **Rafael Audino Zambelli:** Supervision; **Juliane Döering Gasparin Carvalho:** Supervision, Writing – review & editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in at: https://repositorio.ufc.br/bitstream/riufc/47060/3/2019_dis_fbdantas.pdf.

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