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Rheological and Microstructural Properties of Acidified Milk Drink Stabilized with Butternut Squash Pulp Hydrocolloids (BSPHs)

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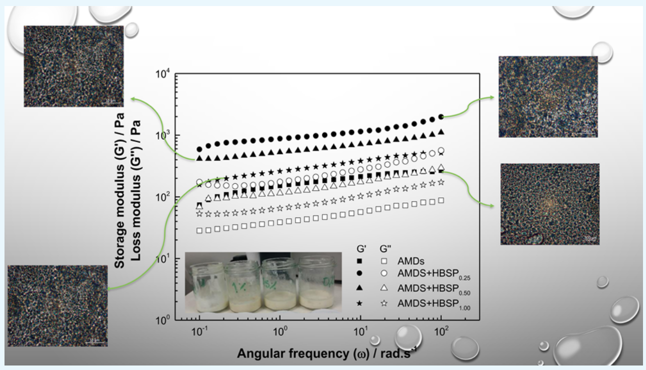

ABSTRACT: In this study, hydrocolloids from butternut squash pulp (BSPH) have been employed as stabilizers for the development of acidified milk drinks to evaluate their physicochemical, rheological, and microstructural properties. BSPH was obtained in the alkaline medium (yield of 630 mg of hydrocolloids/100 g of pulp), presenting 79.97 ± 0.240% carbohydrate and non-Newtonian-type shear thinning. Four acidified milk drinks (AMDs) were obtained with 0.25, 0.50, and 1.00% BSPHs and a control sample without BSPHs. The addition of BSPHs did not alter the proximal composition of AMDs with similar proximal values; also, the samples present typical behavior of non-Newtonian-fluid-type shear thinning adjusted to the Carreau−Yasuda model. Storage (G') and loss (G'') moduli values were slightly dependent on the frequency in most of the studied systems. Then, the addition of BSPHs retained their uniform internal structure and contributed to the stabilization of the products.

1. INTRODUCTION

Acidified milk drinks (AMDs) are a generic term for a group of popular beverages produced from fermented milk or by mixing fruit or fruit juice concentrates with milk.[1−5] AMDs are usually manufactured by direct fermentation or acidification of milk with lactic acid bacteria, followed by homogenization process and acidification with acids or juice of fruits;[6] the final pH of these products generally ranges from 3.6 to 4.6.[4]

One of the most common technological challenges faced in AMD preparation is "wheying" by forming a clear layer on top of the drink. This separation occurs due to a decrease in electrostatic repulsion between casein micelles, resulting in the aggregation of casein micelles, occurring when the milk is acidified at a pH lower than 4.6.[6,7] To prevent phase separation and aggregation, different products are used to stabilize AMDs; stabilizers are important for controlling the physical properties of the drink, such as texture and mouthfeel.[3] The addition of stabilizers is one of the key strategies to maintain the physical stability of food products. Protein−protein interactions and subsequent aggregation can be minimized by the addition of certain polysaccharides[8] for AMD products. The food additive must present high solubility and stabilization behavior of protein particles under acidic conditions without increasing the viscosity; some additives present limitations to prevent protein aggregation or precipitation under pH 4.0.[9] Currently, the commonly used stabilizers of acid dairy products are soybean-soluble polysaccharides[10] high-methoxy pectin,[2,3] carboxymethylcellulose,[11] carrageenan,[12,13] and gellan gum.[14,15]

The stability of AMDs has also been found to depend on the size of the protein particle; usually, homogenization is used in the dairy industry to reduce the creaming and sedimentation of milk. The exploration of natural stabilizers has attracted much attention from researchers. Formulation manufacturers especially value them for answering the increasing demand of consumers for "clean labels" and "natural ingredients" due to their perceived healthiness and sustainability.[16] In the case of butternut squash (*Cucurbita moschata*), the pulp is a source of carbohydrate[17] including xylose, arabinose, glucose, galactose, and gluconic acid. These are macromolecular compounds that are characterized by solubility in water and organic solvents and significant biological applications.[17,18] Different authors have studied the isolation of hydrocolloids from butternut squash. Yuan et al.[19] extracted starches from *Cucurbita maxima* Duch and *C. moschata* Duch. Ex Poir. Milosevic and Antov[20] and Fissore et al.[21] extracted pectin from the pulp and cell wall

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of *C. moschata*, respectively. Wang et al.[22] extracted polysaccharides from *C. moschata* seeds. Their application as a stabilizer in food products was studied by Rojas et al.,[23] who stablized natural yogurt with hydrocolloids from butternut squash seeds, and Orgulloso et al.[24] and Quintana et al.,[25] who employed hydrocolloids from butternut squash peel to stabilize mayonnaise-type sauce and jam, respectively.

However, there are few reports on squash pulp characterization and techno-functional properties and their use in developing food products. For example, Umavathi et al.[26] extracted polysaccharides from *C. moschata* Duch with biological activities (anti-inflammatory, antioxidant, and antimicrobial activities). Du et al.[27] studied the prebiotic potential of oligosaccharides from *C. moschata* with high solubility. Torkova et al.[28] obtained pectin from *C. maxima* D. var. Cabello de Ángel with antioxidant and antiproliferative properties. Baississe and Fahloul[29] extracted pectin from *C. maxima* with plastic properties. Nevertheless, the extraction from hydrocolloids from squash pulp has not been done. Therefore, this study aimed to stabilize acidified milk beverages with butternut squash pulp hydrocolloids (BSPHs) and evaluate their physicochemical, rheological, and microstructural properties.

2. RESULTS AND DISCUSSION

2.1. Butternut Squash Pulp Hydrocolloids (BSPHs).

Butternut squash pulp hydrocolloids (BSPHs) were obtained in an alkaline medium with 630 mg of hydrocolloids/100 g of pulp extraction yield. BSPHs present values of 4.80 ± 0.63% moisture, 3.01 ± 0.53% ash, 1.10 ± 0.35% fat, 12.21 ± 0.11% protein, and 79.97 ± 0.240% carbohydrate, associated with saccharide content including xylose, arabinose, glucose, galactose, and gluconic acids, the main components of *Cucurbita* sp. polysaccharides.[30] The results demonstrate that the pulp of butternut squash (*C. moschata*) is an excellent source of carbohydrates for the commercial production of hydrocolloids.

BSPHs show a decrease in apparent viscosity with increasing shear rate (Figure 1), indicating a non-Newtonian property-type shear-thinning behavior; this behavior is due to the alignment of biopolymer chains in the direction of probe rotation with the decrease in the macromolecule chain interactions and apparent viscosity[31] as well as breaking strong bonds at high shear rates.[32] The rheological properties of hydrocolloids influence their application in food products; they are an alternative to increase the viscosity or thickness of food products and improve the water-binding ability and texture of foods. The choice of hydrocolloid depends on the attributes desired in the final product and the conditions of processing.[23]

Then, shear-thinning behavior is reported for most hydrocolloids, such as hydrocolloids from *C. moschata* seed,[33] mulberry (*Morus alba* L.) leaves,[34] *Pereskia bleo*,[35] and *Prosopis flexuosa* seeds.[36]

The experimental data were fitted to the Carreau–Yasuda model, according to eq 1

$$\eta = \eta_\infty + \frac{(\eta_0 - \eta_\infty)}{[1 + (\lambda\dot{\gamma})^\alpha]^{n-1/\alpha}} \quad (1)$$

where η is the viscosity (Pa·s), $\dot{\gamma}$ is the shear rate (s^{-1}), η_0 is the viscosity at a low shear rate (Pa·s), η_∞ is the viscosity at a high shear rate (Pa·s), λ is the relaxation time constant (s) (the inverse of λ has an interpretation of the critical shear rate at the point where the viscosity begins to decrease), α is the power that determines the transition between low shear rate and high shear rate region (dimensionless), and n is the flow index (dimensionless).

The data adjust very well to the Carreau–Yasuda model, presenting a correlation coefficient (R^2) of 0.99. The BSPHs present η_0 of 22084.19 Pa·s, η_∞ of 0.15 Pa·s, $\lambda_{(c)}$ 425 s, a of 1.950, and n 0.01, corroborating the shear-thinning properties. Then, BSPHs are a potential ingredient in developing food products because their characteristics include desirable attributes in providing satisfaction to consumers.[20]

The viscoelastic properties of hydrocolloids were evaluated. The amplitude test performed over the studied stress range determines the linear viscoelastic region of BSPHs, indicating a linear viscoelastic region where G' and G'' were almost constant (between 0.1 and 10 Pa) and a nonlinear region where G' and G'' began to decrease; then, 1 Pa was chosen to perform a frequency sweep to obtain the mechanical spectra for BSPH at room temperature (Figure 2). The structure of polymers also influences the viscoelastic behavior of BSPHs.

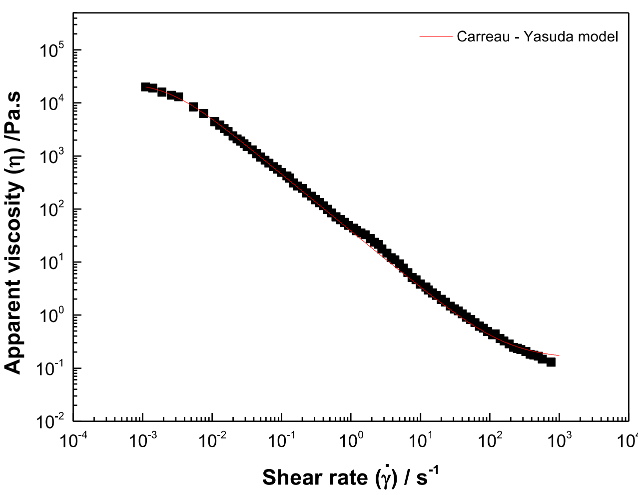

Figure 1. Viscous curve of hydrocolloids from butternut squash pulp (*C. moschata*).

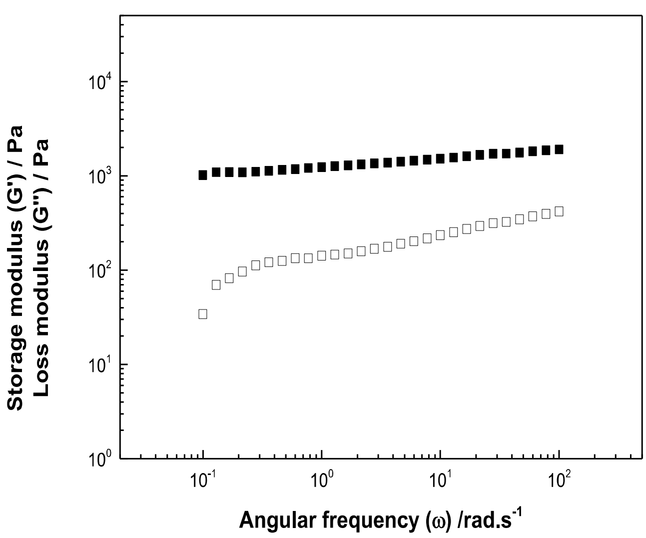

Figure 2. ■ Storage (G') and □ loss (G'') modulus of hydrocolloid from butternut (*C. moschata*) squash pulp.

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ACS Omega 2022, 7, 19235−19242

Storage modulus (G') was higher than the loss modulus (G'') in the entire angular frequency (ω), presenting more elastic properties than viscous ones, which corresponds closely to that of a gel increase with the increased frequency. Therefore, the gel structure and viscoelastic behavior of hydrocolloids were stable in the range of temperatures studied. Similar results have been reported for hydrocolloids with a high carbohydrate content, i.e., seed gum−xanthan blend[37] and amorphous *Gelditsia* depending on their concentration,[38] also according to the frequency sweep. BSPH presents a loss tangent value ($\tan\delta = G''/G'$) of 0.305, which suggests a concentrated amorphous polymer rather than a gel.[39]

The dynamic analysis can give information about the time or frequency dependence and the structural behavior of components. The results obtained are essential for predicting material behavior through the manipulation of processing.[40] The interactions of hydrocolloids with other components coexisting in food matrices allow increased flexibility for food research development. The stabilizers are indispensable in the design of food structure and functionality demanded by consumers in modern society.[41]

2.2. Acidified Milk Drinks. Four acidified milk drinks were obtained with 0.25% (AMDs + $BSPH_{0.25}$), 0.50% (AMDs + $BSPH_{0.50}$), and 1.00% BPSH (AMDs + $BSPH_{1.00}$); also, a control sample without BPSH (AMDs) was prepared. The physicochemical properties of AMDs are shown in Table 1.

Table 1. Acidified Milk Drink's Formation and Physicochemical Properties Stabilized with Butternut Squash Pulp Hydrocolloids (BSPHs)

code sample	BSPH (%)	pH[a]	SS[a] °brix	acidity (%) acid lactic
AMDs	0	3.81	10.70[b]	0.11 ± 0.05[b]
AMDs + $BSPH_{0.25}$	0.25	4.28	12.44[b]	0.19 ± 0.01
AMDs + $BSPH_{0.50}$	0.50	4.38	12.56[b]	0.17 ± 0.78
AMDs + $BSPH_{1.00}$	1.00	4.40	11.38[b]	0.17 ± 0.01

[a]Data with CV <0.5%. [b]Data are expressed as mean ± standard deviation. Different letters in the same columns express statistically significant differences ($p < 0.05$).

The control sample presents different pH, SS, and acidity value compared to the samples with BSPH; then, the employee of BPSH presents a slight increase in pH, soluble solids, and acidity.

The addition of BSPHs did not alter the proximal composition of AMDs ($p > 0.05$) with similar values of moisture (79.24−81.07%), ash (1.51−1.84%), carbohydrate (14.78−16.50%), and protein (0.38−0.47%) and an increase in fat (0.57−1.32%) (Table 2).

2.2.1. Rheological Properties. The AMDs viscous flow curves are shown in Figure 3a. The apparent viscosity of the samples decreases with the increasing shear rate, typical behavior of non-Newtonian fluid-type shear thinning; the same behavior is observed in acidified milk products. Aljewicz et al.[42] obtained shear-thinning behavior for yogurt-like products, Yuliarti et al.[43] for acidified milk drinks stabilized with carboxymethylcellulose and pectin, Janhøj et al.[44] for acidified milk drinks, and Martin et al.[45] for skim milk gels acidified with glucono-δ-lactone.

The samples present a critical shear rate at which the viscosity begins to decline,[46] which was due to the change in the structure of molecules upon the application of BSPHs. Then, to evaluate the shear stress behavior with the shear rate, a flow curve was plotted (Figure 3b) by adjusting the experimental data to the Herschel−Bulkley model (eq 2)

$$\tau = \tau_0 + m\dot{\gamma}^n \tag{2}$$

where τ is the shear stress (Pa), τ_0 is the apparent yield stress (Pa), m is the consistency coefficient (Pa·s^n), $\dot{\gamma}$ is the shear rate (s^{-1}), and n is the flow behavior index (dimensionless). This model can describe Newtonian and time-independent non-Newtonian fluids; then, there are six main classes to this model: shear thinning ($n < 1.0$), shear thickening ($n < 1.0$), and neither (1.0), with yield stress ($\tau_0 < 0$) or without yield stress ($\tau_0 > 0$);[47] when the yield stress is the minimum, the shear stress required to initiate product flow is related to the material's internal structure, which must be broken.[48,49]

Table 3 shows the rheological parameters obtained for acidified milk drink stabilized with BSPHs, which present higher correlation coefficients ($R^2 > 0.90$). A difference between the parameters with the formulation employee was observed. All samples have a flux index value (n) of less than 1 ($p < 0.05$), confirming the shear thinning behavior; also, the consistent coefficient (m) decreases with the increasing BSPHs ($p < 0.05$), preserving its pseudoplastic properties. The samples present an increase in yield stress ($\tau_0 > 1$) with the increase in BSPHs ($p < 0.05$), attributed to higher interaction as well as the presence of a thick three-dimensional structure. This behavior can be explained by the fact that the shear thinning in steady shear test, under large deformation, can occur when rodlike particles are aligned in the flow direction and have lost their junctions in polymer solutions, which, in turn, finally results in the breakdown of polymer agglomerate.[50]

The viscoelastic characteristics of AMDs depend on the concentration of BSPH (Figures 4 and 5). Storage (G') and loss (G'') moduli values were strongly dependent on the frequency in the majority of the system studied. For all samples, G' and G'' present a strong frequency dependence with the elastic component exceeding the elastic one for the whole frequency range examined, indicating an elastic-like behavior. All samples exhibited viscoelastic properties normally observed for weak-gel systems, which is typical in this type of product: the elastic response predominated over the viscous response, both dynamic moduli showed only slight variation

Table 2. Proximal Composition of Acidified Milk Drink Stabilized with Butternut Squash Pulp Hydrocolloids (BSPHs)

code sample	moisture (%)	ash (%)	fat (%)	carbohydrate (%)	protein (%)
AMDs	81.07 ± 0.41[a]	1.51 ± 0.43[a]	0.57 ± 0.25[a]	16.50 ± 1.13[a]	0.47 ± 0.008[a]
AMDs + $BSPH_{0.25}$	79.99 ± 0.08[a]	1.69 ± 0.57[a]	0.86 ± 0.15[a,b]	14.78 ± 0.30[a]	0.38 ± 0.005[a]
AMDs + $BSPH_{0.50}$	79.61 ± 0.25[a]	1.84 ± 0.66[a]	1.32 ± 0.10[b]	15.80 ± 0.60[a]	0.38 ± 0.004[a]
AMDs + $BSPH_{1.00}$	79.24 ±0.24[a]	1.71 ± 0.51[a]	1.10 ± 0.31[b]	16.22 ±1.55[a]	0.41 ± 0.009[a]

[a]Data are expressed as mean ± standard deviation. [b]Different letters in the same columns express statistically significant differences ($p < 0.05$).

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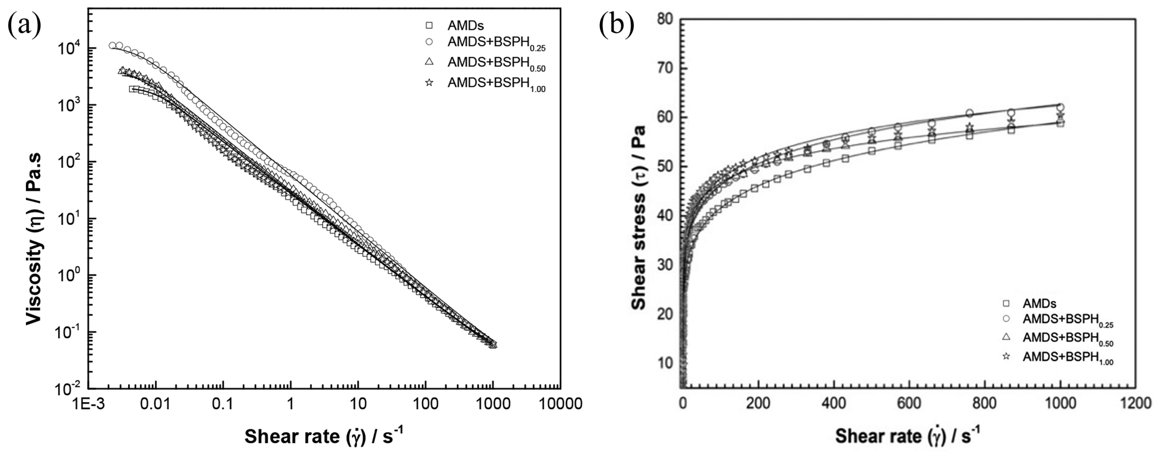

Figure 3. (a) Viscous flow behavior and (b) flow curve of acidified milk drink stabilized with BSPH.

Table 3. Parameters of Adjustment of Hershel−Bulkley Model of Acidified Milk Drink Stabilized with Butternut Squash Pulp Hydrocolloids (BSPHs)

sample code	τ_0 (Pa)	m (Pa·s^n)	n	R^2
AMDs	6.42 ± 0.98[a]	15.99 ± 1.05[a]	0.17 ± 0.001[b]	0.98
AMDs + $BSPH_{0.25}$	7.69 ± 2.43[a]	18.40 ± 2.61[b]	0.15 ± 0.01[b]	0.94
AMDs + $BSPH_{0.50}$	11.34 ± 3.80[b]	19.67 ± 4.04[b]	0.13 ± 0.02[a]	0.93
AMDs + $BSPH_{1.00}$	12.47 ± 0.56[b]	21.50 ± 1.31[c]	0.11 ± 0.09[a]	0.90

[a]Data are expressed as mean ± standard deviation. [b]Different letters in the same columns express statistically significant differences ($p < 0.05$).

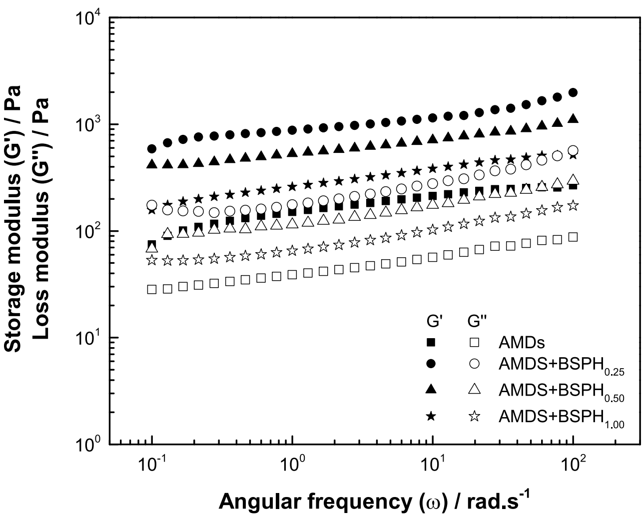

Figure 4. Storage (G') and loss (G'') moduli as the function of angular frequency (ω) of acidified milk drink stabilized with butternut squash pulp hydrocolloids (BSPHs).

with oscillation frequency, and the frequency dependencies of dynamic moduli become parallel.[51,52]

Then, the elastic contribution gradually prevailed over the viscous one; in AMD systems, the dynamic moduli (G' and G'') decrease with the increasing BSPH (Table 4). Then, the elastic contribution gradually prevailed over the viscous one; in AMD systems; the control samples (AMDs) present the lowest dynamic moduli (G' and G''); nevertheless, analyzing the addition of hydrocolloids, G' and G'' decrease with the increase in BSPH (Table 4) owing to the entanglement of gum. The intermolecular association of the chain of xanthan gum (1,4)-β-D-glucose with trisaccharide side chain[53] interacts with functional groups to form different structures.[54−58] Then,

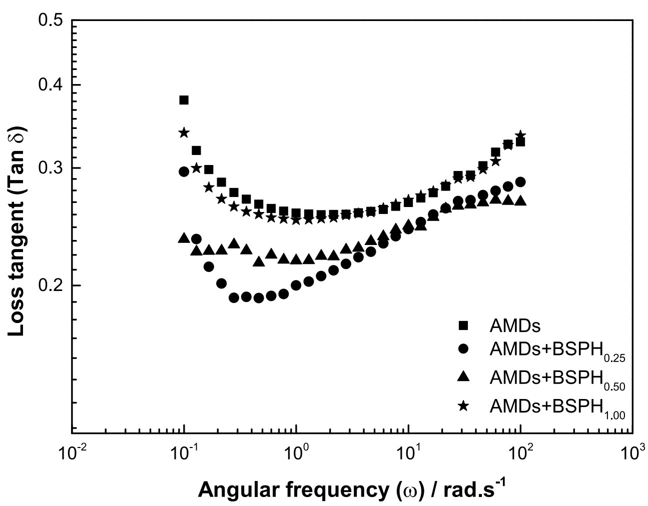

Figure 5. Loss tangent (tan δ) of acidified milk drink stabilized with butternut squash pulp hydrocolloids (BSPHs).

Table 4. Viscoelastic Parameters of Acidified Milk Drink Stabilized with BSPHs at the Frequency of 10.00 rad s^{-1}

sample code	G' (Pa)	G'' (Pa)	tan δ
AMDs	212.5	56.56	0.266
AMDs + $BSPH_{0.25}$	1142.0	263.3	0.237
AMDs + $BSPH_{0.50}$	712.3	175.1	0.245
AMDs + $BSPH_{1.00}$	381.8	102.6	0.269

similar results were obtained for acidified and fermented dairy products, e.g., acidified skim milk, yogurts, and fresh cheese, which can be considered as a viscoelastic soft matter.[59−63]

In this study, the loss tangent (tan δ) of samples (Figure 5) averaged between 0.237 and 0.269 (Table 4), demonstrating that the storage modulus is a primary characteristic to be

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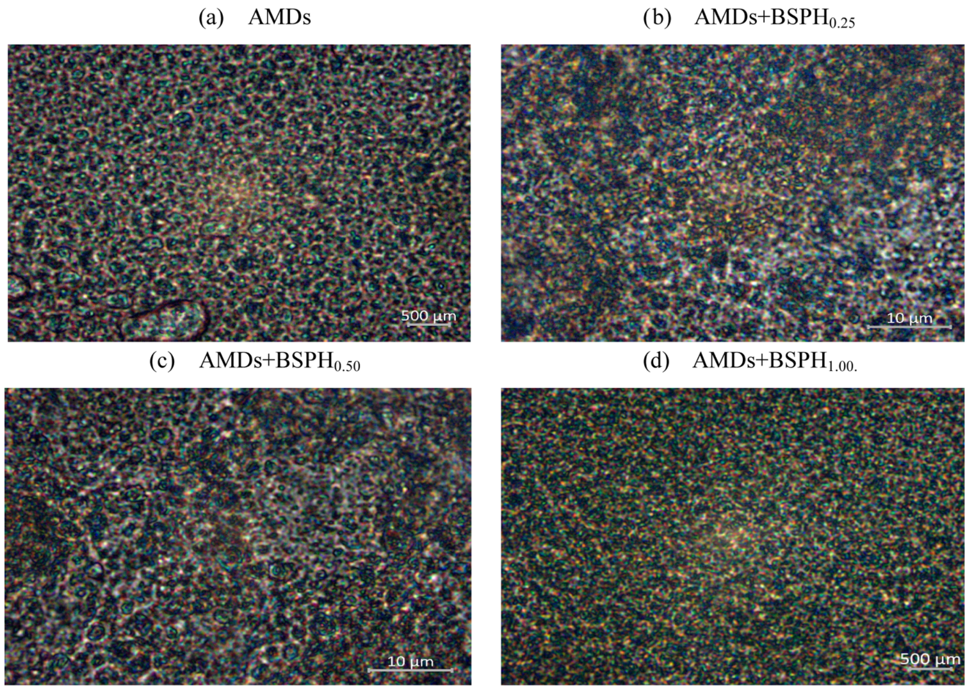

Figure 6. Microscopy (100×) of acidified milk drink stabilized with butternut squash pulp hydrocolloids (BSPHs). (a) AMDs, (b) AMDs + $BSPH_{0.25}$, (c) AMDs + $BSPH_{0.50}$, and (d) AMDs + $BSPH_{1.00}$.

considered in all AMDs stabilized with BSPHs and represents a small loss tangent as an elastic material.

2.2.2. Microstructural Properties. The microstructural properties of acidified milk drink stabilized with hydrocolloids from butternut squash (*C. moschata*) pulp are shown in Figure 6.

The stability of such a milk system might mainly be due to the increase in viscosity by added polysaccharides and the steric effect of electrostatic adsorption between negatively charged polysaccharides and positively charged casein particles.[64] The microstructure of protein−polysaccharide systems such as casein−BSPH mixtures is determined by the competition between the "phase separation" and the "electrostatic interaction" between the protein and polysaccharide.[65]

Many authors indicate a close relationship between structure and rheology.[66,67] Protein−polysaccharide aggregates, open cavities, and casein micelles were present in all of the AMD samples, suggesting that AMDs and AMDs + $BSPH_{1.00}$ have similar microstructures; the inclusion of BSPHs increased the openness of the sample, inhibiting the aggregation of casein particles, in agreement with previous studies.[68,69] From the previous research, it is reasonable to conclude that the polysaccharide−protein interaction can stabilize the emulsion system and yogurt gels.[70] Then, the BSPHs retained their uniform internal structure after the addition and contributed to the stabilization of the products. This behavior could be related to the increase in rheological parameters: yield stress (τ_0) and consistency index; where the dark areas, which could be related to a higher water retention capacity and a higher stability during storage.[71]

3. MATERIALS AND METHODS

3.1. Materials. Butternut squash with similar weight and commercial maturity was purchased from the local food market (Cartagena, Colombia). Hexane and ethanol (99.5% purity) were obtained from Panreac (Barcelona, Spain). Acetic acid, sodium hydroxide (NaOH, pellet for analysis), petroleum ether (grade for analysis), buffer solutions (boric acid/potassium chloride/sodium hydroxide), sodium azide, and phenolphthalein were purchased from Sigma-Aldrich (St. Louis, MO). Citric acid, sodium bicarbonate, and sucrose were purchased from Tecnas S.A. (Itagui, Colombia). Commercial pasteurized and homogenized milk and skim milk powder was purchased from a local Colombian market. All other reagents were of analytical grade.

3.2. Hydrocolloid Extraction. The extraction of hydrocolloids from squash pulp (BSPH) was done following the procedures described by Quintana et al.[25] and López-Barraza et al.[35] with some modifications. A ratio of 1:8 of pulp−water at pH 10 was continuously agitated at 80 °C for 4 h. The resulted mixture was separated by centrifugation for 15 min at 4000 rpm, and the supernatant was recollected. For isolating the polymeric hydrocolloids, the extract supernatant was added in a 1:1 ratio of 99.5% ethanol (analytical grade) to precipitate its biopolymer fraction, followed by centrifugation and freeze-drying at −50 °C and 0.02 Pa for 48 h by employing a freeze-dry equipment (Labconco Freezone 1.5 Liter Benchtop).

3.3. Formulation of Acidified Milk Drinks (AMDs). Skim milk powder was reconstituted with a nonfat milk drink of 16% (w/v) using deionized water with 0.02% (w/v) sodium azide to prevent microbial growth. The nonfat milk drink was stirred at 60 °C for 1 h to dissolve the milk powder completely. Subsequently, the sample was pasteurized at 121 °C for 5 min, cooled, and fermented with yogurt culture (3% w/v) at 43 °C until pH 4.1 was obtained. After that, the sample was cooled to 25 °C. Different amounts of BSPHs (0.25, 0.50, and 1.00%) were used as stabilizing products. Then, the mixture was homogenized using an ultraturrax (IKA T25 basic, Deutschland, Germany) with an S25 N−10ST dispersing tool at 16 800 rpm for 10 min at room temperature. Finally, the prepared AMDs were stored at 5 °C for future use. A control

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sample without BSPHs was performed. All experiments were carried out in duplicate.

3.4. Physicochemical and Proximal Composition. The physicochemical and proximal composition of the samples was performed following the procedures described by the Association of Official Analytical Chemistry 41. pH (AOAC 943.02), titratable acidity (AOAC 935.57), ash (AOAC 942.05), moisture (AOAC 934.01 and 930.15), fat (AOAC 926.08 and 945.16), protein (AOAC 984.13), and carbohydrate (AOAC 920.44/906.03) were analyzed.[72]

3.5. Rheological Properties. The rheological characterization of BSPHs and AMDs was carried out on a controlled-stress rheometer (Modular Advanced Rheometer System Haake Mars 60, Thermo-Scientific, Germany) based on the methods by Quintana et al. and Rojas et al.[23] using a parallel plate (diameter 35 mm and GAP 1 mm) for hydrocolloids and coaxial cylinder (inner radius 12.54 mm, outer radius 11.60 mm, cylinder length 37.6 mm). Each sample was equilibrated 600 s before the rheological test to ensure the same thermal and mechanical history for each sample.

3.5.1. Viscous Flow Properties. Viscous flow tests were carried out at a steady state by analyzing the variation in the apparent viscosity in a range of shear rates between 0.001 and 1000 s^{-1} at 25 °C.

3.5.2. Viscoelastic Properties. A small-amplitude oscillatory shear analysis was performed. Initially, stress sweeps were carried out by applying an ascending series of stress values from 0.001 to 1000 Pa at a frequency of 1 Hz at 25 °C to determine the linear viscoelasticity interval; after that, the frequency sweeps were performed in a frequency range between 10^{-2} and 10^{2} rad s^{-1} to obtain the mechanical spectrum using a stress value within the linear viscoelastic range.

The data recorded include the storage modulus (G'), which provides the elastic component, the loss modulus (G''), which is related to the viscous component of the material, and the loss tangent (Tan δ), which is the ratio G''/G' and provides the ratio of elastic to the viscous response of the material under consideration.

3.6. Microstructural Analysis. A primo Star optical microscope (Carl Zeiss Primo Star Microscopy GmbH, Jena, Germany) with a 100× magnification lens was used to observe the internal distribution and droplet size of the samples (ca. 50 μL). A DCMC310 digital camera with Scope Photo software (version 3.1.615) from Hangzhou Huaxin Digital Technology Co., Ltd., Zhejiang, China, attached to the optical microscope captured the image.

3.7. Statistical Analysis. Statistical analysis of the results was performed using the Statgraphics Centurion XVI (Statgraphics, Rockville, MD). An ANOVA (unidirectional) test was applied to determine statistically significant differences ($p < 0.05$) between the samples submitted to the characterizations. All tests were performed in triplicate.

4. CONCLUSIONS

Butternut squash pulp hydrocolloids (BSPHs) were obtained in an alkaline medium with a high percentage of carbohydrates (79.97 ± 0.240%), presenting a non-Newtonian-fluid-type shear thinning behavior adjusted to the Carreau−Yasuda model ($R^2 > 0.98$). The viscoelastic properties show that the storage modulus (G') was higher than the loss modulus (G'') in the entire angular frequency (ω), presenting more elastic properties than viscous ones and presents tan δ of 0.305, which suggests a concentrated amorphous polymer rather than a gel. The development of acidified milk drinks was carried out using hydrocolloids from butternut squash pulp as stabilizers, with percentages of 0, 0.25, 0.50, and 1.00%. The control samples (0% of hydrocolloids) have different pH, SS, and acidity values compared to the samples with BSPHs; then, the BPSHs added presented a slight increase in pH, soluble solids, and acidity; nevertheless, the addition of BSPHs did not alter the proximal composition of the drinks. Drinks present a typical behavior of non-Newtonian-fluid-type shear thinning and viscoelastic properties related to the percentage of hydrocolloids used: the storage (G') modulus is higher than the loss (G'') modulus presenting properties for weak-gel systems, typical of acidified or fermented milk products. The microstructure shows the interaction of milk protein with carbohydrate of hydrocolloids determined by the competition between the electrostatic interaction between protein and polysaccharide. Then, the addition of BSPHs retained its uniform internal structure and contributed to the stabilization of the products.

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Notes

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