Hindawi
Journal of Chemistry
Volume 2019, Article ID 4267829, 12 pages
https://doi.org/10.1155/2019/4267829

Research Article

Rheological and Structural Properties of Camel Milk/Sweet Potato Starch Gel

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Received 13 December 2018; Revised 15 May 2019; Accepted 23 May 2019; Published 4 July 2019

Academic Editor: Jean-Marie Nedelec

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The unique composition of camel milk limited its use for fermented products preparation. In this research, camel milk (CAM) or cow milk (COM) was blended with sweet potato starch (SPS). Blends were precooked and the rheological properties of the gel were determined. Since the elastic modulus (G') was much greater than the viscous modulus (G''), milk + SPS gels are considered viscoelastic. The tan δ of all blends was <1.0, signifying solid-like behavior; however, variations between CAM gels or COM were identified. Unlike COM, CAM was more frequency-dependent at low frequencies (0.1 to 1.0 rad/sec). Gels exhibited shear thinning according to the nonlinear rheological tests. Camel milk exhibited gel hardness much higher than cow milk. Because of the domination of G' and the low power law exponent, camel milk is expected to present processing complications such as in extrusion cooking.

1. Introduction

Conferring to recent statistical reports of FAO 2014, camel population in the world is about 28 millions [1]. Camel is considered the most important animal for Bedouins in the Arabian peninsula as a main source of food, primarily camel milk. About 30 million tons a year of camel milk is produced mostly in the Middle East according to the FAO. Presently, dairy products made from camel milk have spread to the European markets (EICMP 2017) in addition to fresh milk production [2].

Technically, camel milk does not form conventional gel through lactic acid fermentation because of its unique composition [3, 4]. Some obvious characteristics of fermented camel milk products include watery texture and weak and poor structure [5]. This characteristic is due to the large size and distribution of casein micelles and the absence of b-lg casein protein [2, 6, 7]. Camel milk casein has high beta-casein compared to cow milk (65% versus 39%), low alpha-casein (22% versus 38%), and low kappa-casein (3.5% versus 13%) [8]. Farrell et al. [9] predicted that caseins are natively unfolded proteins with an extended coil-like structure or in the form of subunits that can be characterized as supermolecules. However, when treated with excess urea, it disassociates, which indicates that the supermolecule is held together via hydrogen bonding [10].

The size distribution of casein micelles of camel milk is about 468 ± 1.00 nm, in relation to 137 ± 1.50 nm for cow milk. Nonetheless, other researchers reported 280–550 nm range for camel milk and 90–210 nm range for cow milk. This difference could be attributed to the variation in their physicochemical composition [6, 11]. Camel milk composed of 2.2–6.1% fat, 3.2–5.6% lactose, 3.0–3.9 protein, 0.6–1.0 ash, and specific weight between 1.026 and 1.036, whereas cow milk has higher specific gravity [12]. The lactose content of camel milk is 3 times lower than cow milk which can be helpful for consumers with lactose intolerance. Camel milk has unusual characteristics which are much different from other mammal's milk such as a high level of insulin, vitamins, and minerals, i.e., sodium, potassium, iron, copper, zinc, and magnesium, and very low cholesterol [13, 14]. Furthermore, camel milk does not spoil at room temperature for some time (Singh 2006). Consequently, camel milk has nutritional as well as medicinal values. For instance, vitamin C content is 4 to 11 times greater compared to cow milk ($58.5\,mg{\cdot}kg^{-1}$) [15, 16].

The small size fat particle dispersions and high mineral content give camel milk its opaque color and salty taste. Milk fat consists of long-chain polyunsaturated fatty acids [17]. Camel milk has noticeable antioxidant activity as a result of the appreciable amount of vitamin C. The low pH perhaps is due to the high concentration of vitamin C which is responsible for the relatively long shelf life under room temperature. Camel milk contains a number of enzymes with antibacterial and immunological activities whereby camel milk can exhibit natural healing properties as mentioned in [18]. Lysozymes, lactoferrin, lactoperoxidase, and peptidoglycan-recognition protein are known for protective proteins and immunological action [19–21].

Many attempts were made to address the textural property issues of camel milk products such as fermented milk and yoghurt. One of the adapted methods was to enrich camel milk with powdered skim cow milk [22] or by adding hydrocolloids or stabilizers [23]. Another approach was to use microbial transglutaminase (MTGase), which seemed to be the most promising application to improve the quality of fermented camel milk dairy products. Several studies showed textural properties improvement of yoghurt gel by using MTGase [24–26]. The storage modulus (G') and loss modulus (G'') of camel milk gels are significantly lower than those of cow milk gels. Gelation properties of camel milk can be improved by adding $CaCl_2$ or sodium phosphate as indicated by the higher gel firmness and gelation time [6].

The dairy industry has developed fermented dairy products starters for bovine, sheep, and goat milk. Conversely, no data are available on commercial starter cultures for camel milk. The acidification rate in camel milk was lower than that in bovine milk [27]. However, high acidification rates were obtained for camel milk mixed with cow milk or enhanced with casein hydrolysate. Berhea et al. [28] established that starter cultures were not inhibited by camel milk and concluded that the growth rates of these cultures in pure camel milk are limited by the low hydrolysis rate. In addition, the high ratio of whey protein to casein compared to cow milk is considered the cause of the softer gels [29]. In addition to the larger micelle size, lower k-CN content is the cause of the less firm coagulum and lower yield during cheese and yoghurt processing [11, 30]. The World Health Organization (WHO) estimates 19 million children worldwide suffer from acute malnutrition and recommends the use of high protein intake [31]. Meanwhile, camel milk has limitations when used in fermented dairy products, but it can be a good candidate for use in high-energy dry blends fortified with different micronutrients. It is a fact that camel milk protein is a supermolecule (micelle), low in alpha- or kappa-casein, and softer gel which limits its utilization in fermentable dairy products. The objectives of this study were focused on determining the rheological properties of gels prepared by cooking camel milk fortified with sweet potato starch. The presence of the starch will increase the possibility for physical entanglement of camel milk proteins with amylose or amylopectin during the formation of the gel network. The outcome of this work can be used to utilize camel milk in ready-to-use high-protein dry mixes in order to circumvent fermentation limitations.

2. Materials and Methods

2.1. Milk Samples. Fresh camel and cow milk were obtained from King Saud University farm (Riyadh, Saudi Arabia). Both milk types were freeze-dried and sealed in airtight glass bottles and stored at −20°C for further use. Sweet potato starch was isolated according to the method in [32].

2.2. Gel Preparation. Gels were prepared by blending powdered camel milk (CAM) or cow milk (COM) with sweet potato starch (SPS) in two sets of samples; one set of milk: SPS at 10 : 90, 30 : 70 (this set will be known as high-starch samples throughout the paper), and 50 : 50. The other set of milk: SPS at 90 : 10 and 70 : 30 (this will be the high-milk sample). Gels were prepared by suspending dry blends in distilled water and precooked in the Rapid Visco Analyzer (RVA) then transferred to the rheometer.

2.3. Rapid Visco Analyzer (RVA) Measurements. Milk and SPS blends (2.8 g at 14% moisture basis) were directly weighed in Rapid Visco Analyzer (RVA) canister (Newport Scientific, Sydney, Australia), and the total weight of 28 g was completed by adding distilled water and hand-mixed at first. The slurry was held at 50°C for 30s, heated to 95°C in 4.40 min (at 10.23°C/min), and held at 95°C for 4 min. It was cooled down to 50°C in 2 min (at 22.5°C/min) and held for 2 min. At first, the speed of the paddle was 960 rpm for 10s then reduced to 160 rpm through the remaining time of the experiment. At high camel milk concentrations, RVA is not sensitive enough to illustrate viscosity profiles, that is why RVA is used for cooking the samples. These gels will be used for dynamic rheological properties.

2.4. Dynamic Rheological Measurements. Dynamic rheological measurements were carried out using DHR-1 Hybrid Rheometer (TA instruments, DE, USA) with a parallel plates system (40 mm diameter) and with 50 μm gaps. Samples were tested at 25°C and 40°C. To ascertain that all measurements were done in the linear viscoelastic range of the experiment, a strain-sweep experiment was performed. This was done before the dynamic rheological measurements. Below 10% of strain, all measured materials in this study were in the linear range. Linear viscoelasticity signifies that the measured parameters are independent of shear strains. Below 13% of strain, all measured materials in this study were in the linear range. Fresh samples from the same material were used for each experiment where the applied shear strain in the linear range was implemented for the other viscoelastic property measurements. Thus, 5% strain used in this study is low enough to be within the LVR and permit for gel description without adjusting or destroying its structure. Small amplitude oscillatory shear tests were done over a frequency-sweep range of 0.1–100 (rad/s) at 5% shear strain yielding shear storage modulus (G'), loss modulus (G''), and complex viscosity (η^* Pa·s). The frequency range used here is typically used for frequency sweep to ascertain that G', G'', and η^* are within the linear region. The storage modulus represents the nondissipative element of mechanical properties, whereas the loss modulus signifies the dissipative component of the mechanical properties of the material. Elastic behavior indicates that G' is independent of frequency and greater than G'', where G'' is characteristic of viscous properties. Materials can be described as solid with faultless elasticity when the phase shift angle (δ) is zero, liquid with impeccable viscosity when $\delta = 90$, or somewhere in the middle. The phase angle is defined as $\delta = \tan^{-1}(G''/G')$.

2.5. Gel Texture. The gel texture test was done by preparing 10, 30, and 50% milk content blends. Gels prepared in RVA were transferred into 25 mL beakers (35 mm in height) with internal diameters of 30 mm and kept overnight at room temperature. Textural properties were obtained by compressing gels using Brookfield CT3 Texture Analyzer (Brookfield Engineering Laboratories, Inc. Middleboro, USA). The test was performed in two penetration cycles at a speed of 0.5 mm/s to a distance of 10 mm using 12.7 mm wide and 35 mm high cylindrical probe. Gel hardness was recorded directly from the instrument.

2.6. Nonlinear Steady Shear. Nonlinear rheological measurements were performed at a shear rate of 0.1 S^{-1}–500 S^{-1}, and data was recorded every 20 sec using DHR-1 Hybrid Rheometer (TA instruments, DE, USA). Linear viscoelasticity means of the measured parameters are independent of shear strains. Below 13% of strain, all measured materials in this study were in the linear range. Measurement was repeated at least twice with fresh samples. The relative errors were within the range of ±10%.

3. Results and Discussion

The results were discussed by separating the data into two groups based on milk concentration; one group was high in milk content and the other was high in starch content. Generally, the G', G'', and η^* are the most discussed parameters in dynamic rheological studies. The energy stored and recovered during oscillation movement and the estimates of the solid behavior of the material is represented by G', whereas G'' characterizes the loss of heat energy per oscillation cycle and represents the liquid or viscous property of the material. The measure of changes to these parameters can be assured by establishing optimum testing conditions (oscillation frequency, strain, and temperature) and instituting the linear viscoelastic region (LVE). In the work presented here, the LVR was determined in a wide range within the temperatures of the experiment, but 5% strain between 25 and 50°C was found to be within the LVR. For their precooked starch water systems, researchers used up to 50% strain at a range of 10 to 47 (rad/sec) frequencies [33–35]. Therefore, 5% strain used in this study is low enough to be within the LVR and allows for defining the gel properties without modifying or destroying its structure [36].

3.1. Frequency Dependence of G' and G''

3.1.1. High-Starch Samples. Some researchers recommended the use of G' as a guide to determine the experimental conditions because it is more of value than G'', especially for products with high starch content [37–39]. A linear dynamic frequency-sweep experiment was performed to determine the oscillation frequency dependence of G' and G''. Even though the G' of the high-starch samples with either CAM or COM was higher than G'', which indicates viscoelastic behavior, the gap between G' and G'' was not the same throughout the frequency range. For instance, the gaps between G' and G'' for camel milk gels at 40°C were narrower at low frequencies and widened after that, but at 25°C, the gap was narrower at higher frequencies. Both samples exhibited that G' was highly dependent on starch concentration, where at 1.0 rad/sec, the G' of the 90% SPS at 40°C was 3.80×10^3, the 70% was 1.24×10^3, and the 50% was 1.27×10^2. However, at 25°C, it was 4.20×10^2, 2.85×10^2, and 1.28×10 for 90% SPS, 70%, and 50%, respectively (Figures 1(a)–1(d)). The one-order magnitude increase in G' indicates viscoelastic solid-like behavior at 90% SPS, but it decreases at lower SPS content. It is reasonable to consider the increase in G' at higher SPS is attributable to chain-chain interaction or molecular entanglement because the shape of the G' curve in this study did not point toward cross linking [40]. Hence, only chain-chain interaction or molecular entanglement can explain the relationship between SPS and the milk. This interpretation could be used to explain why solid-like behavior was more obvious at 40°C compared to 25°C, i.e., we can assume that molecular entanglement and chain-chain interaction were prevalent at higher temperature.

With respect to SPS blend with cow milk at 40°C, the 90% SPS exhibited G' around 4.14×10^3, 3.57×10^2 for the 70%, and 1.77×10^2 for the 50%, while at 25°C, it was 5.31×10^2 for the 90% SPS, 3.22×10^2 for the 70%, and 7.4×10 for the 50% (Figures 2(a)–2(d)). In general, the G' of COM samples behaved in the same way as CAM, but the domination of the solid-like behavior was more dominant for CAM. The reason for the difference could be attributed to the large micelle size of CAM casein [11, 41]. However, large micelle size was reported to be the reason for the reduced firmness of camel milk coagulant, but it seems more effective in developing firmer gel in the presence of SPS. This could be accredited to the large molecular size of the gelatinized starch components (amylose and amylopectin) and its ability to network and immobilize water. At low frequencies, high-starch samples were more frequency-dependent by virtue of their rapid increase in G' and G'' as a function of frequency until around 1.0 rad/sec, but after that slower increase was observed at 40°C. Nonetheless, the rapid increase at low frequencies was

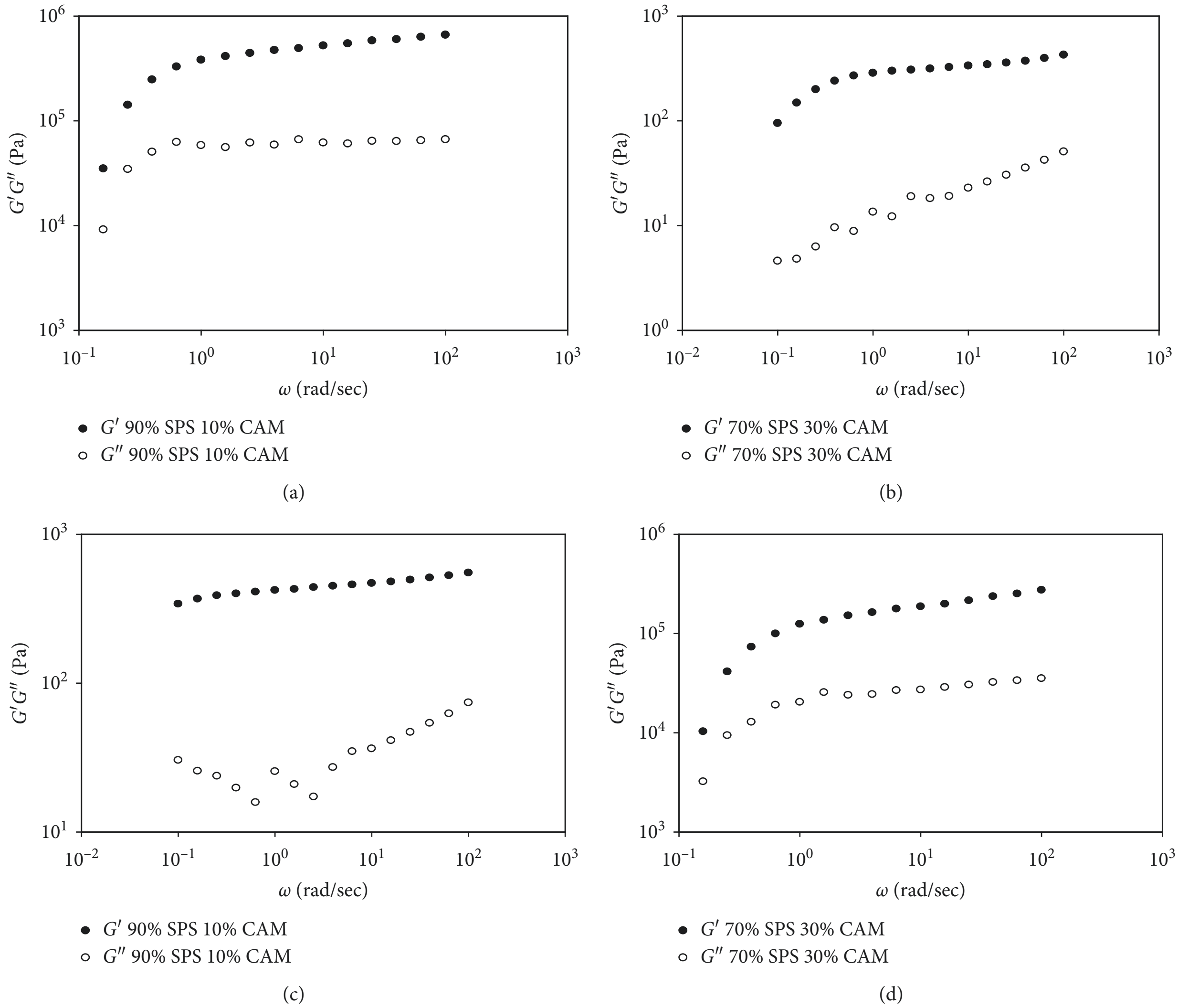

Figure 1: (a) Dynamic frequency sweep at 5% shear strain of 90% sweet potato starch (SPS) and 10% camel milk (CAM) at 40°C. (b) Dynamic frequency sweep at 5% shear strain of 70% sweet potato starch (SPS) and 30% camel milk (CAM) at 25°C. (c) Dynamic frequency sweep at 5% shear strain of 90% sweet potato starch (SPS) and 10% camel milk (CAM) at 25°C. (d) Dynamic frequency sweep at 5% shear strain of 70% sweet potato starch (SPS) and 30% camel milk (CAM) at 40°C.

less evident at 25°C (Figures 1(a)–1(d)). At the 50% COM concentration, the material was much less dependent on oscillation at 25°C compared to other concentrations, whereas at 40°C, it was extremely oscillation-dependent. For the most part, G' exhibited plateau profile after 1.0 (rad/sec) at 25°C (Figures 3(a) and 3(b)), but for the 50% CAM, the material was frequency-dependent at both temperatures. This could mean that the maximum points of contact between CAM or COM and starch was after 1.0 (rad/sec), which facilitates for stronger structure leading to a more solid-like behavior as reflected by the G' plateau (Kamal et al. 2017) (Figures 3(a) and 3(b)). However, at 40°C, the G' profile did not exhibit a plateau after 1.0 (rad/sec), which made both milk gels frequency-dependant after 1.0 (rad/sec) (Figures 3(c) and 3(d)).

It is valuable to know the status of the gel before and during oscillation because it provides information regarding the internal structure and coherency of the gel. The data presented here clearly revealed the effect of temperatures on the storage modulus (G') of the gel at the beginning of the oscillation. Therefore, the G' of the high-starch CAM samples started at different points at the beginning of oscillation (0.1 rad/sec). Both the temperature and the starch content have influenced the initial value of G' (Figure 1). At 25°C, the G' of the 90% SPS samples exceeded the G' of the 70% SPS by 9 times at the start of the oscillation, whereas at 40°C, it was 3 times. Conversely, when comparing the effect of temperature, the G' of the 90% SPS and 70% SPS was 100 and 110 times more at 40°C compared to 25°C, respectively (Figure 1). The reason for that could be amylose retrogradation at 25°C as opposed to 40°C.

On the other hand, the loss modulus (G'') exhibited significant changes due to starch concentration and not due to the temperature, but the gap between G' and G'' was temperature-dependent (Figure 1). The overall magnitude of G' of the high-starch samples over the frequency range

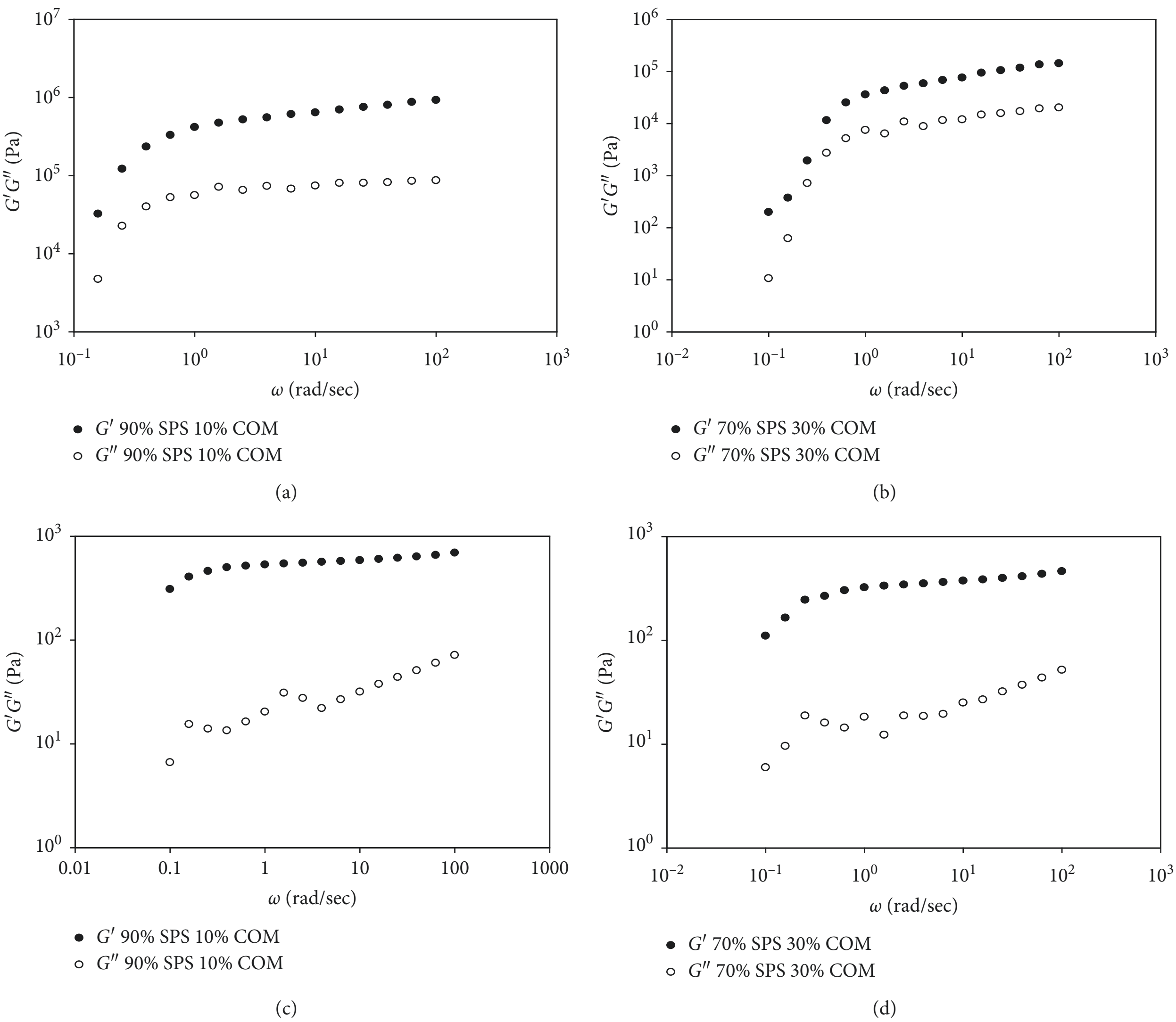

FIGURE 2: (a) Dynamic frequency sweep at 5% shear strain of 90% sweet potato starch (SPS) and 10% cow milk (COM) at 40°C. (b) Dynamic frequency sweep at 5% shear strain of 70% sweet potato starch (SPS) and 30% cow milk (COM) at 40°C. (c) Dynamic frequency sweep at 5% shear strain of 90% sweet potato starch (SPS) and 10% cow milk (CAM) at 25°C. (d) Dynamic frequency sweep at 5% shear strain of 70% sweet potato starch (SPS) and 30% cow milk (CAM) at 25°C.

0.1–100 rad/sec was lower at 25°C than that at 40°C (Figure 1), indicating less solid-like behavior (softer gel) at 25°C. The gap between G' and G'' at 40°C was much narrower than that at 25°C at low frequency (Figures 1(a) and 1(c)), but at higher frequencies, the gap became smaller. Higher frequencies and 25°C appeared to close the gap between G' and G'' by lowering the G' and increasing the G'', which indicates a more viscous material than an elastic material (Figures 1(a) and 1(c)).

High-starch COM samples exhibited frequency-dependence because of the rapid increase in G' and G'' at lower frequencies at 40°C (Figures 2(a) and 2(b)). COM at the beginning of oscillation showed larger gap between G' and G'' at 25°C compared to 40°C, especially at 90% starch (Figures 2(c) and 2(d)). The gap was caused by large increase in G' at lower frequency which points to a solid-like material at 40C°; however, G' started to plateau at higher frequency. This parameter is important in processing because the material has a stronger structure at room temperature and high frequency. Therefore, both milk samples high in starch can be considered more stable at higher frequencies at 40°C by virtue of limited change in G' (Figures 1 and 2). Generally, the behavior of high-starch/CAM or COM was dominated by solid-like behavior which is evident in the limited change in G' slope as a function of oscillation at 40°C.

3.1.2. High-Milk Samples. The profiles in Figures 4 and 5 showed that high milk gels of both CAM and COM exhibited low G' especially at 25°C and low oscillation, where the highest value for G' was 32.6 (Pa) and 281.2 for the 40°C which is much lower than that of the high-starch samples discussed above. Both types of milk were extremely oscillation-dependant by virtue of constant increase in G'

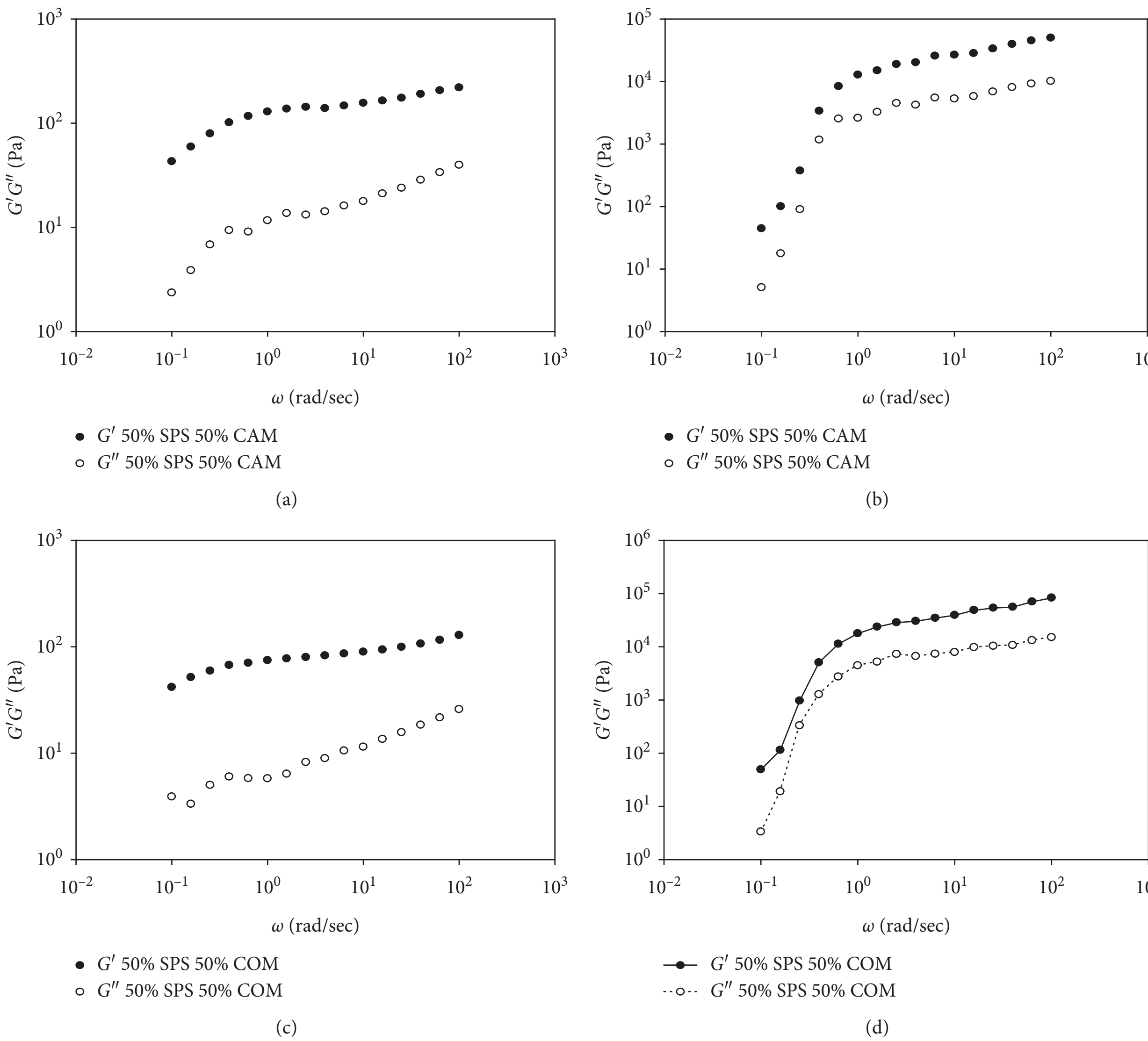

Figure 3: (a) Dynamic frequency sweep at 5% shear strain of 50% sweet potato starch (SPS) and 50% camel milk (CAM) at 25°C. (b) Dynamic frequency sweep at 5% shear strain of 50% sweet potato starch (SPS) and 50% camel milk (CAM) at 40°C. (c) Dynamic frequency sweep at 5% shear strain of 50% sweet potato starch (SPS) and 50% cow milk (COM) at 25°C. (d) Dynamic frequency sweep at 5% shear strain of 50% sweet potato starch (SPS) and 50% cow milk (COM) at 40°C.

and G'' as a function of increasing oscillation (Figures 4(a)–4(d)). Regardless of milk type, the flow properties of the material were dependent on temperature as well as milk content because samples higher in SPS exhibited higher G' at higher temperature (Figures 4(a) and 4(c)). Therefore, the G' exhibited 4.9 (Pa) and 32.7 (Pa) for the 90% CAM and 70% CAM, respectively, at 25°C and 1.0 (rad/sec), whereas at 40°C, the values were 4.6 and 281 (Pa). The gap between the G' and G'' was much higher than that at low oscillation at 25°C but became narrower at higher oscillation (Figure 4(a)). In addition, at 40°C and low oscillation, samples with higher SPS showed a sharp jump in G' and G'' (Figure 4(b)).

COM upheld similar rheological properties as CAM since it was oscillation- and temperature-dependent. As shown in Figure 5, COM did not maintain a specific rheological pattern because the G' was very low at 25°C, but it was less oscillation-dependent at 70% COM compared to the 90% COM (Figures 5(a) and 5(b)), indicating direct influence of starch. However, G' of the 70% COM sample at 40°C was much higher than the 90% COM at the same temperature when compared at 1.0 (rad/sec). Nevertheless, for the same concentration (70%) and temperature, COM was more elastic than CAM, but at 90%, the flow properties were comparable for both milk types. Unlike the 90%, the 70% CAM or COM maintained steady viscoelastic behavior where G' was 4 to 10 times higher than G''. This solid-like behavior was observed at high-starch samples discussed earlier. The solid-like behavior of the 70% COM appeared to be oscillation- and temperature-dependent as shown by the gap between G' and G'' and the slope of G' after 1.0 (rad/sec) (Figures 4(a) and 5(a))). At low oscillation, the gap between G' and G'' of COM and CAM was much higher at 25°C, but

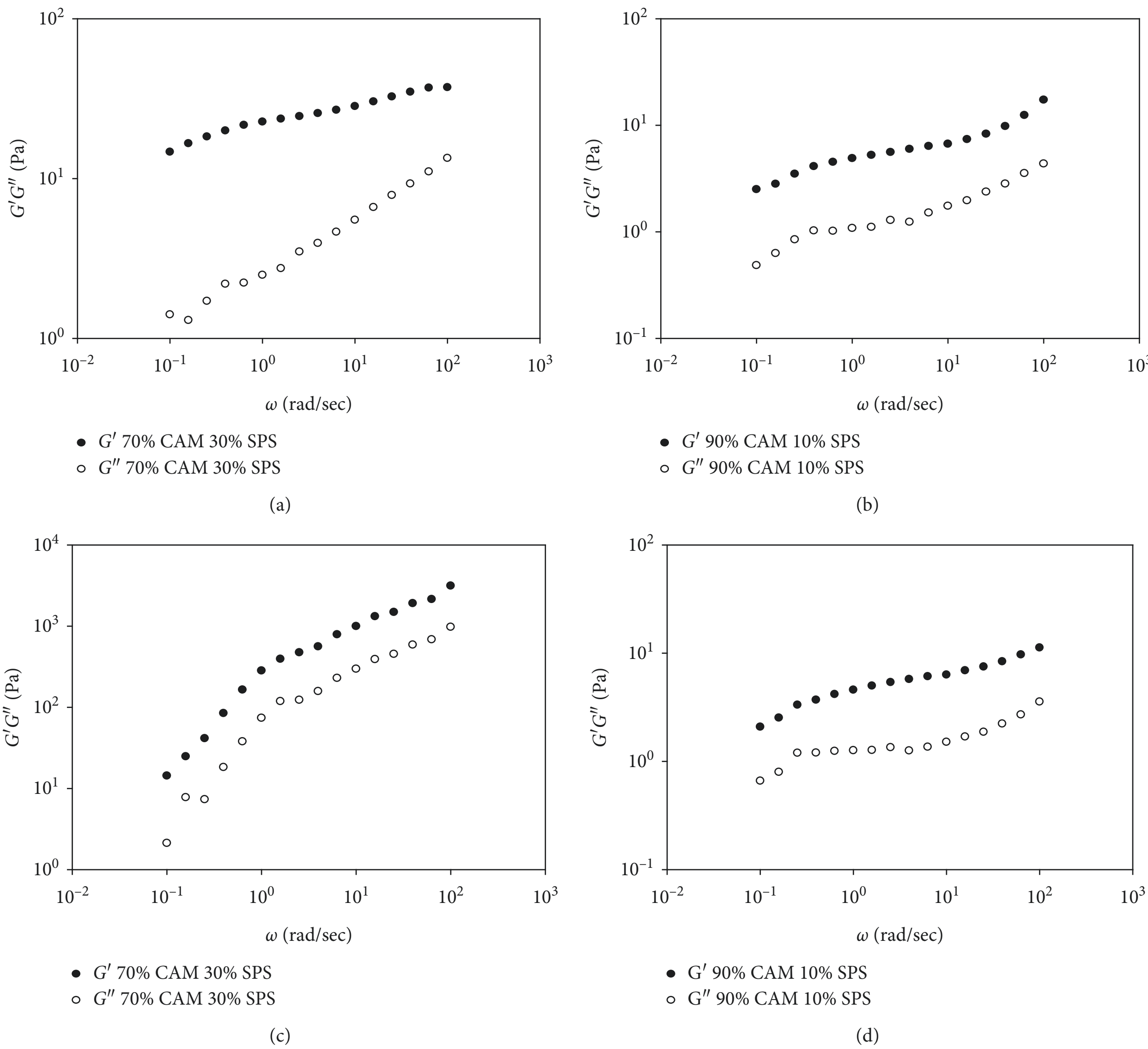

Figure 4: (a) Dynamic frequency sweep at 5% shear strain of 30% sweet potato starch (SPS) and 70% camel milk (CAM) at 25°C. (b) Dynamic frequency sweep at 5% shear strain of 10% sweet potato starch (SPS) and 90% camel milk (CAM) at 25°C. (c) Dynamic frequency sweep at 5% shear strain of 30% sweet potato starch (SPS) and 70% cow milk (CAM) at 40°C. (d) Dynamic frequency sweep at 5% shear strain of 10% sweet potato starch (SPS) and 90% cow milk (CAM) at 40°C.

the gap was narrower at higher oscillation, but at 40°C, COM showed smaller gap between G' and G'', which indicates that the material was less elastic (Figure 5(b)). Similar behavior was observed for the high-starch samples but at a lower scale. This could point to the basic structural differences between CAM and COM with respect to the casein micelles size and its ability to interact with starch components especially at 40°C [41]. This was evident when relating Figures 4(d) and 5(d). At 1.0 rad/sec, the G' for the high-COM material (70% COM) was 20 times greater than G'' at 25°C and 4 times higher at 40°C, while 90% COM exhibited 3 times more G' than G'' at 40°C (Figure 5). COM was more elastic at higher temperatures which could be due to the higher molecular mobility and chances for interaction with starch components. CAM gel seemed to be more elastic compared with COM at the same concentration by virtue of higher G' at the start of the oscillation (0.1 rad/sec), but at higher oscillation, COM prevailed. High-camel milk samples showed more consistent rheological behavior than cow milk samples by virtue of higher G' when compared at the same concentration and oscillation frequency.

3.1.3. Equal Amounts of Milk and SPS. The G' of materials with 50% CAM and 50% SPS was 18 times more than G'' at 0.1 (rad/sec) versus 10 times for COM up to 1.0 (rad/esc), but at higher frequencies, the gap was smaller due to rapid decrease in G'. The effect of temperature on the gap between G' and G'' was more evident before reaching 1.0 (rad/sec). In Figure 3, a sharp increase in G' and G'' of CAM and COM at

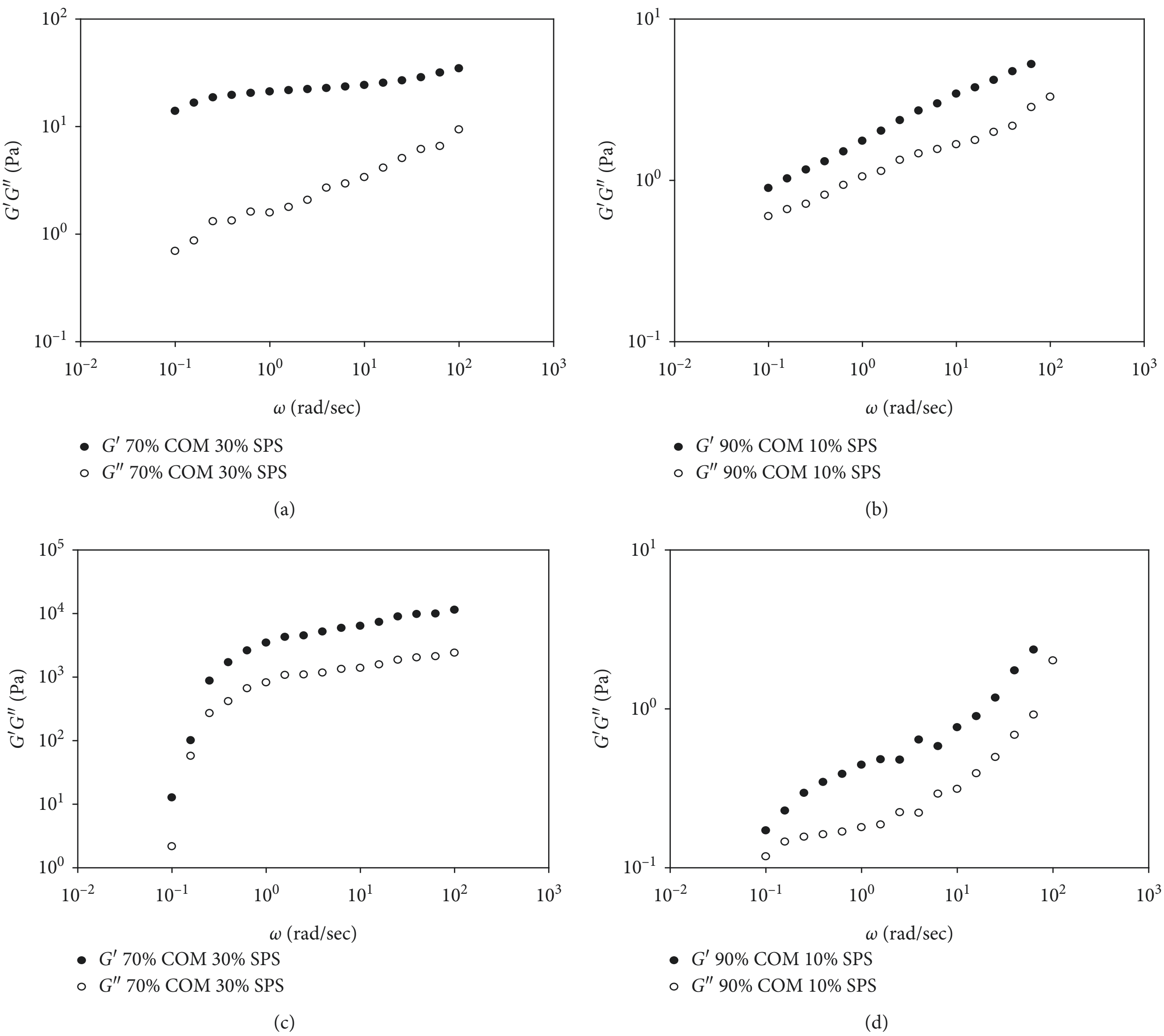

Figure 5: (a) Dynamic frequency sweep at 5% shear strain of 30% sweet potato starch (SPS) and 70% cow milk (COM) at 25°C. (b) Dynamic frequency sweep at 5% shear strain of 10% sweet potato starch (SPS) and 90% cow milk (COM) at 40°C. (c) Dynamic frequency sweep at 5% shear strain of 30% sweet potato starch (SPS) and 70% cow milk (COM) at 25°C. (d) Dynamic frequency sweep at 5% shear strain of 10% sweet potato starch (SPS) and 90% cow milk (COM) at 40°C.

40°C about 300 to 350 folds from 0.1 to 1.0 (rad/sec) followed by a moderate increase. In contrast, the G' of COM at 1.0 (rad/sec) was 1.4 times higher than CAM presenting much more elasticity (Figures 3(b) and 3(d)). Therefore, at 50% milk content, the pattern of G' and G'' of both types of milk was similar, but COM was more elastic. The difference between COM and CAM was obvious in the other parameters discussed previously.

3.1.4. Gel Texture. The gel texture data showed that CAM gels were harder than COM after 24 hr storage at room temperature. The hardness of 10, 30, and 50% CAM samples was 133, 47, 9.7 g, respectively, compared to 109, 28, and 13 g for COM samples. Therefore, amylose retrogradation was more prominent in the CAM samples versus COM because the outcome of amylose retrogradation is a formation of strong amylose network capable of controlling the water in the system. The gel containing >50% CAM or COM was less coherent.

3.1.5. Storage Modulus Slope. The slopes of the storage modulus (G') as a function of frequency were also used to show the difference between CAM and COM for the same SPS concentration (Tables 1 and 2). Obviously, higher positive G' slope indicates changing structure at higher frequencies. The G' slope of both milk types was temperature-dependent because at 25°C, the slope was lower at low milk content and increased at 40°C (Table 1). From the data in Tables 1 and 2, the slope of the high-starch samples was lower, indicating a more stable gel structure. In addition, COM samples slopes were higher than CAM. The slopes of both milk types were higher at 40°C compared to 25°C.

Table 1: Slopes of the storage modulus (G') as a function of oscillation (rad/sec) of camel milk or cow milk at 90, 70, and 50% milk (w/w) + 10, 30, and 50% sweet potato starch (SPS) at 25°C and 40°C.

Type of milk	Temperature (°C)	% Milk	G' slope	R^2
Camel milk	25	90	0.22	0.95
		70	0.11	0.98
		50	0.12	0.96
	40	90	0.21	0.96
		70	0.53	0.94
		50	0.32	0.94
Cow milk	25	90	0.27	0.98
		70	0.10	0.94
		50	0.13	0.96
	40	90	0.34	0.95
		70	0.27	0.98
		50	0.34	0.96

Table 2: Slopes of the storage modulus (G') as a function of oscillation (rad/sec) of camel milk or cow milk at 10, 30, and 50% milk (w/w) + 90, 70, and 50% sweet potato starch (SPS) at 25°C and 40°C.

Type of milk	Temperature (°C)	% Milk	G' slope	R^2
Camel milk	25	10	0.06	0.98
		30	0.09	0.76
		50	0.12	0.85
	40	10	0.12	0.63
		30	0.17	0.71
		50	0.29	0.73
Cow milk	25	10	0.06	0.80
		30	0.09	0.74
		50	0.11	0.94
	40	10	0.17	0.71
		30	0.31	0.74
		50	0.30	0.73

Overall, higher milk content increases the slope at higher frequency which indicates that the structure of the material is changing, whereas low slope points to oscillation-independency, thus stable structure. Although the G' of the higher SPS content was higher, the higher slope describes the rate of change in G' but not its magnitude. For that reason, samples containing 50% SPS exhibited higher slope at 40°C, indicating faster structural changes, but not lower G' value (Table 1). The opposite was true for the samples at 25°C where low slope does not mean higher G'.

High-milk samples content did not exhibit a specific pattern of slope at 40°C for both milk types (Table 1). The temperature seemed to have a significant effect on the slope as it was shown to impact other parameters as discussed earlier. This was reflected on the gel texture at higher milk content as discussed above. Generally, COM slopes were higher than CAM, which is in line with the solid-like behavior of CAM shown by other parameters presented above (Tables 1 and 2).

3.1.6. tan δ. The tan δ ($= G''/G'$) represents the measure of the relationship between the viscous portion and the elastic portion of the gels. All high-starch CAM or COM gels regardless of temperatures or concentrations exhibited tan $\delta < 1.0$, signifying solid-like behavior, but differences between gels containing CAM or COM were detected. The tan δ of high-starch gels (70, 50, and 90% SPS) blended with COM increased steadily through the tested frequency (0.1–100 rad/sec) at 25°C and decreased at 40°C. The increase in tan δ is caused by the drop on G' at higher frequencies and temperature which points to more viscous behavior than elastic. By virtue of lower tan δ, CAM at high SPS was more elastic at 40°C compared to COM, whereas at 25°C, only the 90% and 70% SPS exhibited lower tan δ. The lowest tan δ for the COM was observed at 90% SPS for both temperatures. The effect of temperature was obvious because the tan δ at 25°C is increased at higher frequency; however, it decreases at 40°C for the same frequency. This indicates elastic behavior at higher temperature. Therefore, the blends became more viscous at higher temperature and higher frequency and the opposite is true. Nonetheless, COM was more viscous than CAM at 25°C, but at 40°C, CAM was more elastic due to the lower tan δ.

The tan δ for the high-milk samples indicates less elasticity (high tan δ) at both temperatures especially for the 90% milk concentrations, while steady increase in tan δ was observed at higher frequencies and 25°C. At 40°C, both types of milk behaved as solid-like between 10.0 and 100.0 (rad/sec). High-milk samples (high-CAM) at 40°C behaved as elastic material between 1.5 and 100.0 rad/sec. The difference between COM and CAM was evident in tan δ profiles where CAM appeared to maintain elastic property at least at high frequencies (10.0 to 100.0 rad/sec) for all concentrations. For the most part, the domination of G' was observed for CAM milk. The effect of temperature on tan δ was more prominent on COM than CAM. The data showed that COM gels undergo major change at 40°C perhaps due to changes on the molecular mobility of starch components and COM casein micelles. The domination of G' has processing implications, for instance, in extrusion cooking as it relates to power requirements to transport melt material.

3.2. Nonlinear Steady Shear. A nonlinear steady shear experiment was conducted to better understand the behavior of the precooked SPS/CAM or COM with respect to temperature and milk concentration. As expected, all samples exhibited shear-thinning behavior over the measured shear rate, and the viscosities were higher at higher concentrations indicating no precipitation. The viscosity of the system significantly dropped at high milk content especially at the 90% milk. CAM exhibited viscosities higher than COM for the same concentration and temperature. This is in line with the behavior of CAM under the frequency-sweep test discussed above. Camel milk showed viscosities more concentration-dependent than COM, where reduced milk content (higher SPS) caused increase in the viscosity. On the other hand, the viscosity of COM was less concentration-dependent at 25°C. The magnitude of the viscosity at 25°C and 40°C was similar for both types of milk, but at 40°C, the viscosities were concentration-dependent. The temperature appeared to have more effect on the slope of the viscosity versus shear rate. The shear-thinning behavior can be characterized by the power law:

Table 3: Power law model fitted parameters of camel milk and cow milk at 25°C and 40°C.

% Milk	Camel milk						Cow milk					
	25°C			40°C			25°C			40°C		
	K^a	n^b	R^2	K	n	R^2	K	n	R^2	K	n	R^2
90	0.95	0.56	0.96	0.55	0.48	0.98	1.45	0.88	0.92	0.98	0.68	0.97
70	1.16	0.41	0.99	0.70	0.31	0.99	0.53	0.31	0.99	0.52	0.22	0.99
50	0.67	0.32	0.99	0.93	0.34	0.99	0.54	0.36	0.99	0.78	0.47	0.99
30	0.99	0.41	0.99	1.63	0.51	0.97	0.67	0.39	0.99	0.39	0.67	0.99
10	0.63	0.37	0.99	1.04	0.42	0.99	1.14	0.37	0.97	0.37	1.14	0.99

[a]K = constant; [b]n = power law exponent.

$$\eta = k\gamma^{n-1}, \tag{1}$$

where η is the shear viscosity (Ps), k is the constant (Pa), γ is the shear rate, and n is the power law exponent. The results of equation (1) are listed in Table 3.

The power law exponent was higher as a function of higher milk concentration, except for COM at 40°C, which indicates shear thickening attributable to amylose retrogradation (Table 3). This was not true for CAM perhaps because the large size casein of CAM interacted with amylose and prevented retrogradation. There was lower power law exponent for samples with low SPS at 40°C, while at high starch content, the exponent was higher at 40°C compared to 25°C (Table 3). The trend of power law exponent shift is consistent with the effect of concentration on the linear viscoelastic behavior discussed earlier and listed in Table 1. In the most part, for the 50% SPS, the exponent appeared to be the same regardless of temperature. These values indicate no changes in structure which may be due to chain-chain interaction or molecular entanglement and not due to cross linking because the shape of G' curves did not point to cross linking behavior. Comparable behavior of legume protein-concentrate was reported in [40]. Therefore, chain-chain entanglement is the most applicable explanation for the higher exponent of materials at 25°C compared to 40°C and low milk content. Typically, such materials flow more easily under shear because some internal structure of the material is weakened or broken down. The difference between CAM and COM is clear with respect to the exponent value, where CAM exhibited lower n value in the most part (Table 3). Therefore, CAM-containing samples exhibited a stronger structure while COM showed stronger shear-thinning behavior due to the higher n value. This difference can be related to the prediction of processing conditions. Tapioca starch in the presence of polysaccharides exhibited similar behavior [42].

4. Conclusions

Camel milk gel (milk + sweet potato starch) was more elastic at 40°C compared to cow milk and exhibited harder gels, larger gap between G' and G'', and frequency dependence at lower frequencies and had lower tan δ. Cow milk exhibited greater G' slopes as a function of oscillation frequency compared to camel milk, indicating less stable structure. Low power law exponent (n) value of CAM samples point to a stronger structure, whereas stronger shear-thinning behavior of COM was indicated by the higher n. This information can be valuable in predicting gel behavior during processing. The soft texture of pure camel milk gel limited its utilization in fermented products. This drawback can be limited by introducing thickeners like starch and other hydrocolloids. The outcome of this work can be used to develop high-protein nutritious dry mix fortified with micronutrients such as iron. This can help in developing ready-to-use therapeutic food (RUTF) which can contribute to solving severe acute malnutrition, especially in areas where camel milk is available.

Data Availability

The data used to support the findings of this study are included within the article.

Additional Points

Practical Application. Our work is original and focused on introducing camel milk as a source of protein. The idea of the paper was stimulated by the limitation of camel milk to produce fermented milk compared to cow or other milks. The limitation has been attributed to the chemical structure of camel milk protein. Therefore, preparing camel milk-sweet potato starch powdered dry mix for use as ready-to-use food can be helpful in utilizing camel milk and introducing a new product. The outcome of this work can potentially be used to produce high-energy nutritious mix. This can contribute to solving acute malnutrition which is a worldwide problem according to the World Health Organization.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding this work through research group no. RGP-114.

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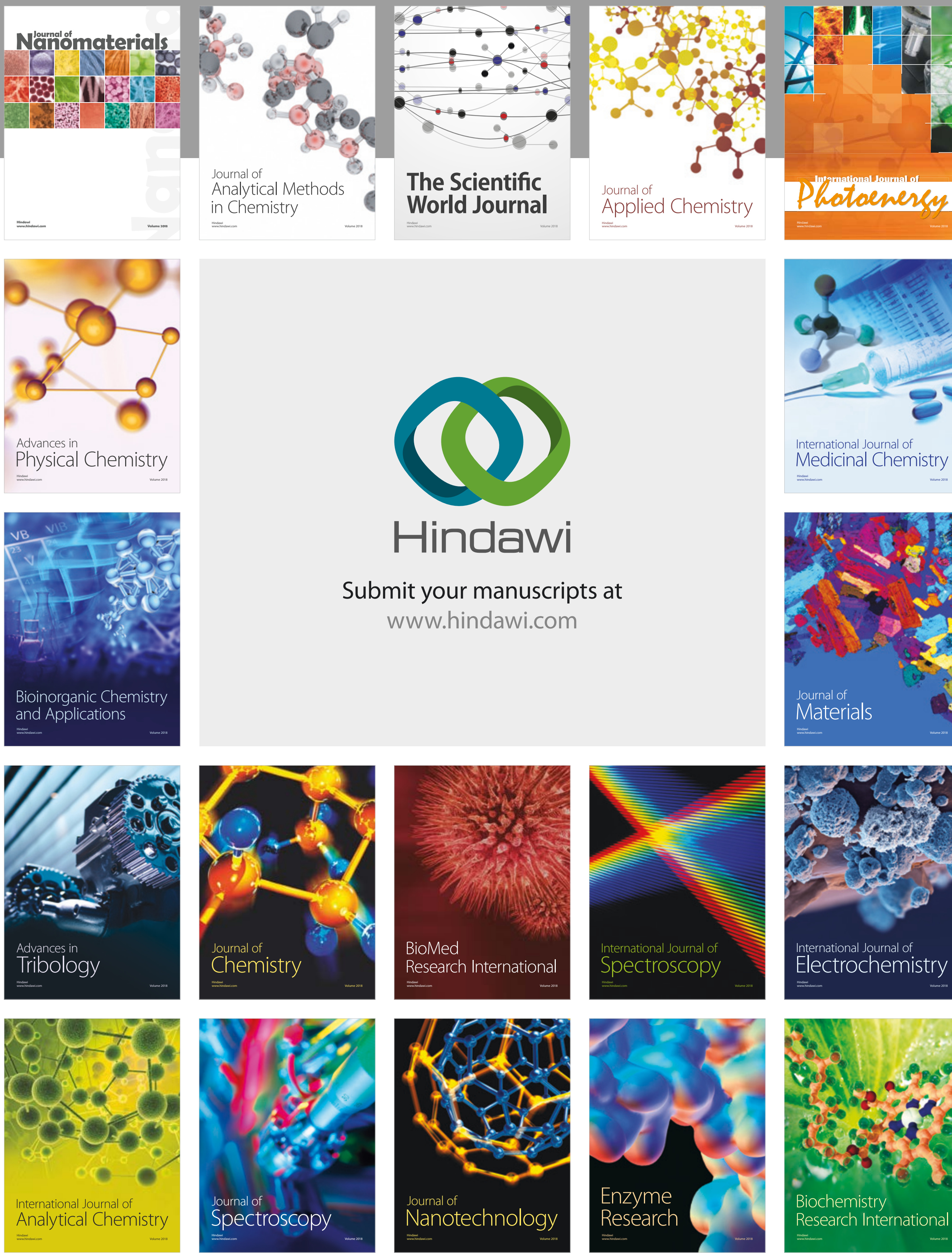
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