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Camel milk-sweet potato starch gel: steady shear and dynamic rheological properties

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Abstract

Camel milk is known to produce low quality gels. To address this drawback, sweet potato starch (SP), camel milk (CM), or cow milk (CWM) were blended and cooked in alkaline conditions. The rheological tests of the prepared gel were done using DHR- Hybrid Rheometer. Because the G' was, by far, larger than G", the prepared gel exhibited viscoelastic behaviour as well as shear thinning. The gel exhibited tan δ < 1.0 which indicates solid-like material, but obvious variances between the gels were detected. The gels prepared from CM were harder than CWM, but it was frequency-dependent at low frequencies from 0.1 to 1.0 (rad/sec). Samples containing camel milk presented stronger structure due to the low power law exponent (*n*), while CWM showed more shear thinning. The obvious high G' and the low (*n*) value is projected to have processing repercussions on CM gel.

Keywords: camel milk; rheology; gel; texture; dairy processing.

Practical Application: Improve camel milk gel properties.

1 Introduction

The population of Camels in the world is about 28 million while camel milk production is about 2.85 million tons (Food and Agriculture Organization, 2017). Despite its unique chemical composition, fermented camel produces weak gels (Kaskous, 2016; Khan & Alzohairy, 2011). Fermented camel milk products are characterized as watery, weak, and poor structure (Rahman et al., 2009). Probably, this distinguishing property is because of the extended structure and limited dispersion of casein and the lack of Beta-lactoglobulin (b-lg) in camel milk compared with CWM milk (Al Haj & Al Kanhal, 2010; El-Agamy et al., 2009; Kamal et al., 2017). The average molecular size of camel milk casein is 468 ± 1.00 nm, whereas CWM milk is 137 ± 1.50 nm. This difference explains the variation in the physicochemical properties between the CWM and camel milk (Bornaz et al., 2009; Kamal et al., 2017). The average camel milk composition is 2.2-6.1% fat, 3.2-5.6% lactose, 3.0-3.9 protein, 0.6-1.0 ash, and specific gravity of 1.026-1.036 (Getachew, 2003). Camel milk is rich in insulin, vitamins and minerals such as sodium, potassium, iron, copper, zinc and magnesium and low in cholesterol (Al-Hashem, 2009; Rao et al., 1970). Current findings indicate that the antidiabetic action of camel is not due to insulin action. Therefore, in an effort to determine the antidiabetic action of camel milk, researchers reported that insulin was not responsible for that this activity and suggested further research to determine the real cause (Abou-Soliman et al., 2020).

By virtue of its high vitamin C content (58.5 mg/kg) and low lactose content (for lactose intolerant consumers), it is possible to keep camel milk at ambient temperature for extended time (Singh et al., 2006). Therefore, camel milk is nutritious in addition to its medicinal value (Shabo et al., 2005; Shalash, 1980).

Camel milk has salty taste and opaque white color due to the small fat particles which consist mainly of long chain poly unsaturated fatty acid (Abu-Lehia, 1987). The average protein content of Camel milk is 2.65% but it lacks the allergic β-lacto globulin and different β-casein composition compared to other milks. Camel milk exhibits immunological and antioxidant activity, and contains various enzymes with antibacterial activity (Kappeler, 1998). A number of proteins known for their defensive and immunological action in camel milk are lysozymes, lactoferrin, lactoperoxidase, and peptydoglycon-recognition protein (Mal et al., 2006; Morin et al., 1995; Singh et al., 2006). Soft gel of camel milk can be attributed to the high ratio of whey protein to casein (Abu-Tarboush, 1996; Berhe et al., 2018; Shamsia, 2009).

Due to the soft gel of camel milk, researcher made efforts to improve the poor textural properties of camel milk products. Some of the approaches used were to fortify camel milk with powdered skim CWM milk (Salih & Ahmed Hamid, 2013) or by adding hydrocolloids or stabilizers (Al-Zoreky & Al-Otaibi, 2015). One of the most encouraging attempts to improve the gelling properties of camel milk was the use of microbial transglutaminase (MTGase) (Abdulqadr et al., 2014; Farnsworth et al., 2006; Ozer et al., 2007). Acceptable gel-firmness can be reached by incorporating $CaCl_2$ or sodium phosphate signified by higher G' and lower gelation time (Kamal et al., 2017).

Casein proteins are characterized as extended molecule with long coil-like or as subunits that can be considered as supermolecule (Farrell et al., 2006). Conversely, in alkaline environment such as urea, it disentangles, which is evident of hydrogen bonding between the supermolecule unites (Holt,

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1998). Although it is high in β-casein (65% versus 39%), camel milk is low in α (22% versus 38%) and kappa casein (3.5% versus 13%) (Yagil, 1982). This is also reflected by the different amino acid distribution. The lower k-CN content and the larger micelle size of camel milk result in the formation of a less firm gel and lower yield during cheese and yoghurt processing (Bornaz et al., 2009; Konuspayeva et al., 2014). Reports in the literature reveled major changes of proteins secondary structure or complete denaturation by urea especially at 8M solution, but protein molecules can open up at lower urea concentration due to the reduction in hydrogen bonding without reaching denaturation. Spray drying of camel and cow milk showed that camel exhibited significant higher loose bulk density than that of cow milk powder, whereas no statistical difference between the solubility of both types of milk powder. In addition, reports suggested that the differences between the two milk types can be ascribed to the physicochemical differences between camel and cow milk, especially the fat globule characteristics (Zouari et al., 2020). Because of the week gel of camel milk and the suggested approach to enrich camel milk with some type of hydrocolloids, it is important to develop ways by which to present the product to new consumers. Although dairy products are consumed by a vast majority of food consumers, new methods of advertising and presenting of new and existing products are needed. Diary method and Completion Task are the nuts and bolts tools of expanding dairy products to new consumers (Torres et al., 2020; Rodrigues et al., 2021)

The objective of this work was focused on determining the textural properties of precooked camel milk gel enriched with sweet potato starch in urea solution (pH 7.5). Because, when starch is heated in the presence of appreciable amount of water, it gelatinizes and form a vicious gel. This will increase the likelihoods of physical entanglement between camel milk protein and the gelatinized starch (amylose or amylopectin) to form the final gel-network. This gel is expected be firmer and more coherent than camel milk gel alone due to the starch.

2 Materials and methods

2.1 Milk samples

Pasteurized camel and CWM milk was donated by King Saud University farm (Riyadh, Saudi Arabia). Milk was pasteurized at 85 °C for 15 min then cooled to room temperature before freeze drying. Both milks were freeze-dried and stored at -20 °C. Sweet potato starch was prepared using the methods of Alamri et al. (2016).

2.2 Gel preparation

Blends of freeze-dried camel (CM) or Cow milk (CWM) and sweet potato starch (SP) were prepared as follows; high milk blends at 90:10 or 70:30 milk:SP (high milk blends) i.e., 90 g of milk and 10 g of sweet potato starch. The second set was milk:SP 50:50. The third was high starch blends SP:milk at 90:10, 70:30 (this is high starch blends) i.e., 90 g sweet potato starch and 10 g milk. Gels were prepared by cooking a suspension of dry blends in 2.0 M aqueous urea solution (pH 7.5) using Rapid Visco Analyzer (RVA). The prepared gel is then transferred to the dynamic rheometer for analysis. Slurry was prepared by mixing dry blends with urea solution, where 2.8 g (14% moisture content) and urea solution (2.0 M) was added to reach 28 g. The obtained slurry was loaded on RVA (Newport Scientific, Sydney, Australia). After 30 sec at 50 °C, it was then heated to 95 °C in 4.40 min and held for 4 min. The temperature of the gel was brought to 50 °C in 2 min and kept for 2 min. At the first 10sec, the paddle rotated at 960 rpm and reduced to 160 rpm for the remaining time of the experiment.

2.3 Dynamic rheological measurements

The gel prepared using RVA was transferred to the rheometer for dynamic rheological testing. DHR-1 Hybrid Rheometer was used to determine the dynamic rheological testing (TA instruments, DE, USA). The rheometer is equipped with 40 mm diameter parallel plates with 50 μm gaps and the temperature was set at 25 °C or 40 °C during the rheological testing. Before shear testing, a strain-sweep was done to establish the linear viscoelastic region of the precooked gels. Small amplitude oscillatory shear tests were conducted in the range of 0.1-100 (rad/sec) frequency at 5% shear strain. Shear storage modulus (G'), loss modulus (G") and complex viscosity (η* Pa.s) were the measured parameters. All calculations were made using the Rheology Advantage Data Analysis software (Version 5.7.0.) provided by the manufacturer of the rheometer.

To show that all data collection was in the range of the linear viscoelastic, a strain-sweep was performed. To establish that G', G", and η* were in the linear region, strain sweep was conducted to determine the linear viscoelastic region. The behavior of all measured materials in this study was in the linear range below 13% strain. Linear viscoelasticity proves that all measured parameters were shear strain independent. Testing was done at least in duplicates with fresh samples and the errors were at ±10%. The G' is the non-dissipative component, while the loss modulus indicates the dissipative element of the mechanical properties. Elastic materials are characterized by G´ independent of frequency and greater than G", however G" represents the viscous texture. The phase angle (δ) of solid materials is zero while δ=90 for the liquid with perfect viscosity. The $\tan^{-1}$ (G"/G') is the definition of the phase angle.

2.4 Steady shear measurements

Nonlinear experiment was done using the same instrument (DHR- Hybrid Rheometer). The steady shear test was conducted at 0.1-100 s^{-1} shear rate while the data was collected every 20 sec. Measurements were done in duplicate with fresh samples for each run. The relative errors between the runs were within the range of ± 10%.

2.5 Gel texture

Milk and SP blends were prepared at 10, 30, and 50% milk content. Blends were cooked using RVA and placed in 25 mL glass beakers (35 mm in height), stored at room temperature and tested after 12 hr. Gels texture measurement was accomplished by compressing the gels using Brookfield CT3 Texture Analyzer (Brookfield Engineering Laboratories, Inc. Middleboro, USA).

Two cycles penetration were performed at 0.5 mm/s to 10 mm into the gel using cylinder-shaped probe with 12.7 mm wide and 35 mm high.

3 Results and discussion

The data presented here was separated into two groups, high and low milk content. In dynamic rheological testing, storage modulus G', loss modulus G" and complex viscosity η* are the most measured parameters. The magnitude of changes to these parameters was quantified by creating perfect experimental conditions such as oscillation frequency, strain, temperature, and testing near the linear viscoelastic region (LVR) of the material. In this study, the LVR was represented by wide-ranging temperatures. Therefore, 5% strain at 25 to 50 °C was found to be within the LVR. Some researchers used up to 50% strain for the cooked starch-water systems between 10 and 47 (rad/sec) frequencies (Abd Karim et al., 2000; González-Reyes et al., 2003; Lagarrigue & Alvarez, 2001). Although the applied 5% strain was sufficiently low to keep the experiment within the LVR, it allows for gel characterization without causing major structural changes (Tattiyakul & Rao, 2000).

3.1 G' and G" of sweet potato and milk blends

High starch content blends

As suggested by other researchers, G' is the most suitable test to determine the experimental settings for starch gels because it has more processing application than G", particularly for starchy products (Addo et al., 2001; Hsu et al., 2000; Kasapis et al., 2000). The effect of oscillation on G' or G" was established by running frequency-dependence test. Although the G' of the blends with higher starch content was greater than G", which point to viscoelastic behavior, the G' and G" profile gap was not equal throughout the range of oscillation. Because at lower frequencies the gap between G' and G" profiles of CM gels were narrower and amplified after that. The data showed that both blends exhibited G' very dependent on starch content, since at 1.0 rad/sec the G' at 40 °C of the 90% SP was 3.85×10^2 Pa, 70% was 7.3×10 Pa, and the 50% was 5.1×10 Pa. However, at 25 °C the G' at 1.0 rad/sec was, 1.1×10^2 Pa, 1.5 ×10 Pa, and 3.2×10 Pa, for the 90%, 70, and 50%, respectively (Figure 1a, b, c, d). The viscoelastic solid-like behavior of the 90% SP is indicated by the one order magnitude reduction at lower SP content. Generally, the large G' in the presence of high SP content can be attributed to molecular entanglement, chain-chain interaction, or crosslinking, however, the shape of the G' curve presented in this study does not point to crosslinked material (Xu et al., 2006).

Therefore, only polymer chain interaction or molecular entanglement can describe the physical interaction between the SP and milk protein. Hence, more entanglement or chain to chain interaction occurred at 40^0C that lead to higher G' compared to 25 °C.

The G' of cow milk blends with SP at 40 °C exhibited, 3.7×10^2 Pa, 7.1×10 Pa and 2.3×10 Pa for the 90% SP, 70% and 50%, respectively, while at 25 °C it was 1.52×10^2 Pa, 2.6× 10 Pa, and 1.1×10 Pa, at 1.0 rad/sec, respectively (Figure 2a, b, c, and d). Generally, blends containing CWM maintained higher G' over G" like CM, but CWM revealed less solid-like behavior (lower G') compared to CA. The possible cause for the variation could be accredited to the large CM casein protein structure(Bornaz et al., 2009; Glantz et al., 2010).

Although the large casein structure was reported to be the main cause for the reduced firmness of CM coagulant, the data presented here seems to show firmer gel due to SPS and the action of urea. It is equally important to mention the contribution of gelatinized starch product (amylose and amylopectin) to the gel firmness by water immobilization. Since hydrogen bonding is the main force that holds CM casein molecules together, urea reduces these bonds thereby facilitates for casein molecules unfolding and become available for entanglement with starch molecules. Samples with more starch were more frequency-dependent at low oscillation frequencies because of the rapid increase in G' and G" as a function of frequency until around 1.0 rad/sec. After that, gradual increase was detected at 40 °C. This rapid increase at low frequencies was less evident for samples tested at 25 °C (Figure 1a, b, c, and d) (Mohamed et al., 2019). Unlike at 40 °C, the 50% CM blend at 25 °C was a lot less dependent on oscillation compared to other blends. In most cases, the profile of G' of the 50% CM blend plateau at 25 °C, but increased at 40 °C as a function of frequency (Figure 3a and b). This could identify additional points of contact between CM and starch components which facilitates for firmer structure and solid-like behavior as reflected by the G' plateau at 25 °C (Kamal et al., 2017). The 50% CWM blend was dependant on frequency at both temperatures (Figure 3c and d).

It is helpful to monitor the textural change of the gel at the beginning of oscillation as well as during oscillation, because it allows for following the coherency and the internal structure of the gel. The effect of temperatures on storage modulus (G') of the material was obvious at the beginning of the oscillation. Therefore, at the initial point of oscillation (0.1rad/sec), the G' value of the high starch samples started about 3 times higher at 25 °C than 40 °C for the same starch concentration, besides it was higher for the 90% SP compared to the 70% SP at the same temperature (Figure 1). This could be attributed to the formation of stronger amylose network at 25 °C, which gives the gel a solid like texture as opposed to 40 °C, where higher temperature gives rise to the viscous property. Conversely, G" did not exhibit significant changes due to temperature but to a certain degree, the 70% SP reduced G" at low oscillation (Figure 1). Despite the greater G' at 0.1 (rad/sec), the value of G' of the high starch samples over the frequency range (0.1-100 rad/sec) was lesser at 25 °C than at 40 °C (Figure 1) indicating softer gel at 25 °C. At lower frequencies, the gap between G' and G" of the high starch/CM blends was much narrower at 40 °C compared to 25 °C (Figure 1a and b), however, at higher frequencies the gap was even smaller. Greater frequencies and 25 °C appeared to reduce the G' and increase G" indicating the domination of viscosity over elasticity (Figure 1a and c). Consequently, higher frequencies have an adverse effect on the high starch gels.

High starch samples/CWM blends presented profiles with frequency-dependence at low frequencies because of the quick increase in both G' and G", particularly at 40 °C (Figure 2a and b). The profile gap between the G' and G" of CWM blends was larger

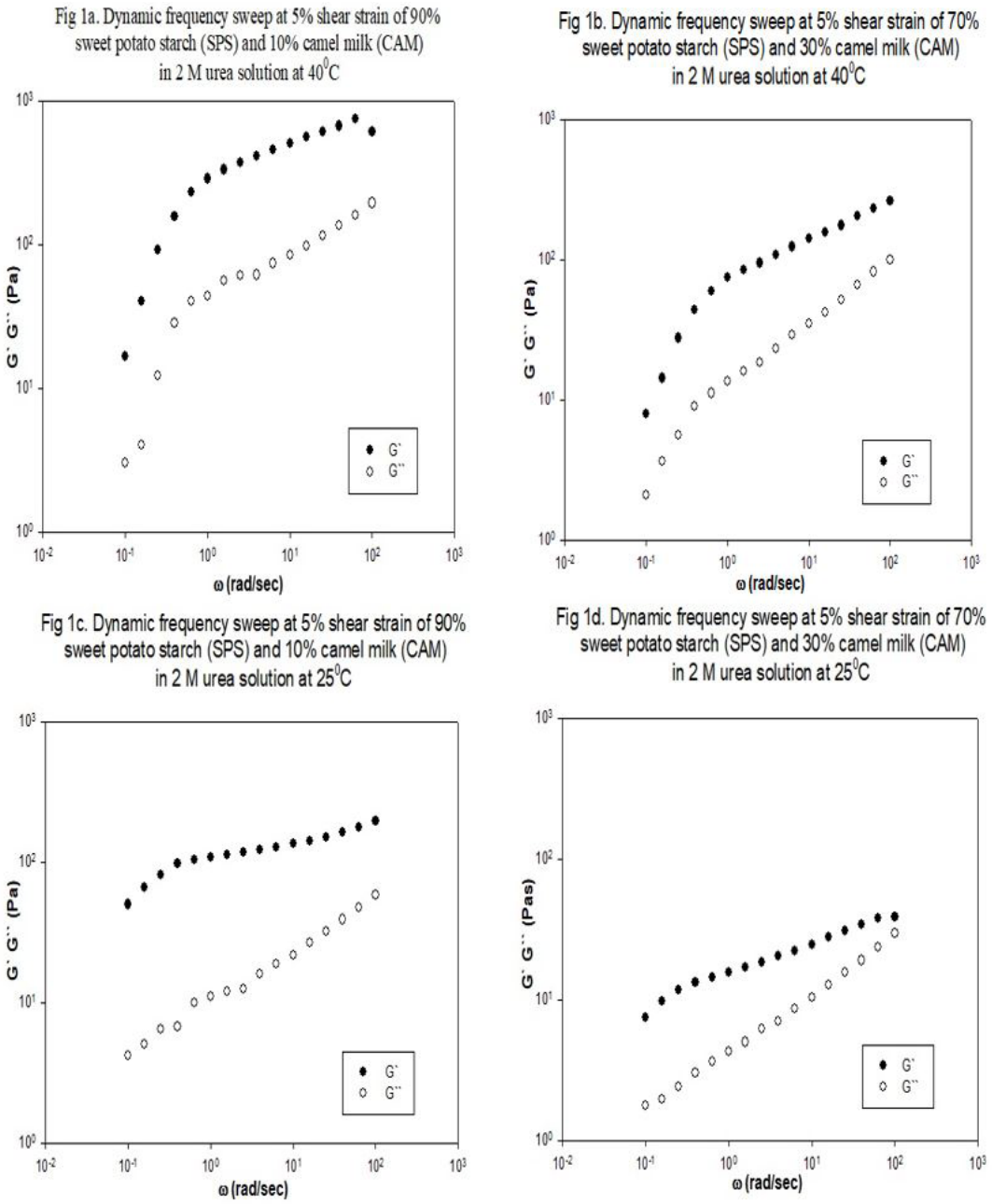

Figure 1. 1a - Dynamic frequency sweep at 5% shear strain of 90% sweet potato starch (SPS) and 10% camel milk (CAM) in 2 M urea solution at 40°C. 1b - Dynamic frequency sweep at 5% shear strain of 70% sweet potato starch (SPS) and 30% camel milk (CAM) in 2 M urea solution at 40°C. 1c - Dynamic frequency sweep at 5% shear strain of 90% sweet potato starch (SPS) and 10% camel milk (CAM) in 2 M urea solution at 25°C. 1d - Dynamic frequency sweep at 5% shear strain of 70% sweet potato starch (SPS) and 30% camel milk (CAM) in 2 M urea solution at 25°C.

at 25 °C at the start of oscillation compared to 40 °C, specifically for the 70% starch blend (Figure 2c and d). The domination of G' at 25 °C at lower frequencies indicates solid-like texture. Nevertheless, G' reached plateau as the frequency increased (Figure 2c). Since the material had more stable structure at elevated oscillation, this property can be used as processing tool. Therefore, both milk blends have stable texture at higher starch content and elevated frequencies at 40 °C by virtue of slower decrease in G' (Figure 1 and 2). In addition, milk blends with high starch content have typical solid-like texture, which is evident on the stability and the slope of G' as a function of oscillation intensity at 40 °C. The solid-like texture can be attributed to the amylose network and its ability to immobilize water. movement within the gel.

Equal amount of milk and SP

The G' of blends prepared with equal amounts of SP starch and camel milk (CM), between 0.1 and 1.0 frequencies (rad/esc)

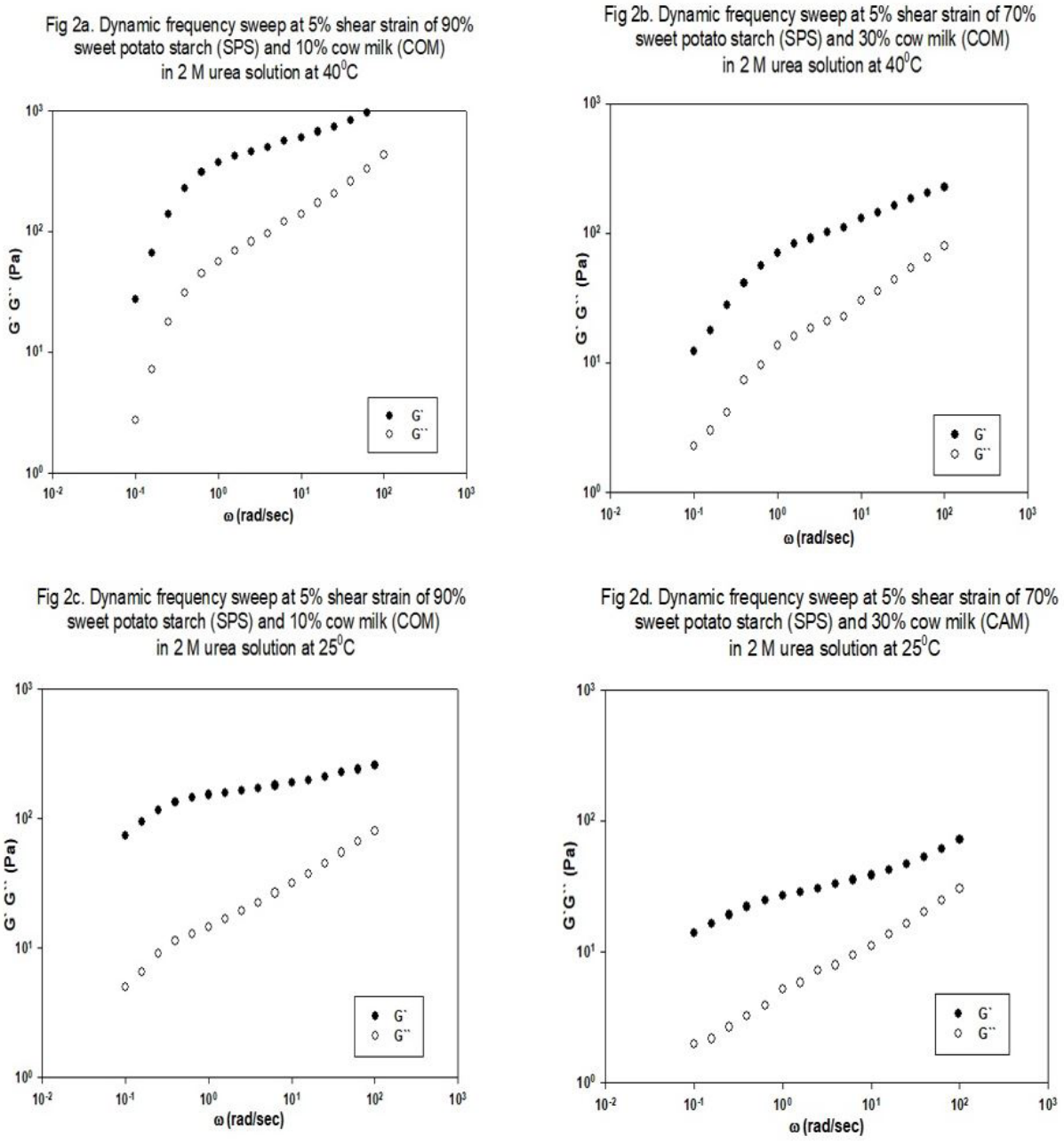

Figure 2. 2a - Dynamic frequency sweep at 5% shear strain of 90% sweet potato starch (SPS) and 10% cow milk (COM) in 2 M urea solution at 40°C. 2b - Dynamic frequency sweep at 5% shear strain of 70% sweet potato starch (SPS) and 30% cow milk (COM) in 2 M urea solution at 40°C. 2c - Dynamic frequency sweep at 5% shear strain of 90% sweet potato starch (SPS) and 10% cow milk (COM) in 2 M urea solution at 25°C. 2d - Dynamic frequency sweep at 5% shear strain of 70% sweet potato starch (SPS) and 30% cow milk (COM) in 2 M urea solution at 25°C.

was 8 times greater than G" and decreased at elevated frequencies due to surge in G" as a function of increased oscillation (Figure 3). After 1.0 (rad/sec), the influence of temperature on the difference between G' and G" was obvious. On the other hand, the G' of CM at 0.1 (rad/sec) was triple that of CWM, reflecting far more elasticity. Conversely, the G' of the 50% CWM was 4 times greater than G" for both 0.1 or 1.0 (rad/sec), but the profile gap between G' and G" was slimmer at higher frequencies. Consequently, the shape of G' and G" profiles of both milk blends was similar but the magnitude differs, because G' of CM was 3 times higher than CWM (more elastic). This difference was obvious in the parameters of other results discussed earlier.

High milk samples

The rheological profiles of these blends are shown in Figure 4. The G' of the 90% milk blends of each CM or CWM exhibited low G' particularly at low frequency. These blends were very oscillation-dependant and maintained constant increase in G'

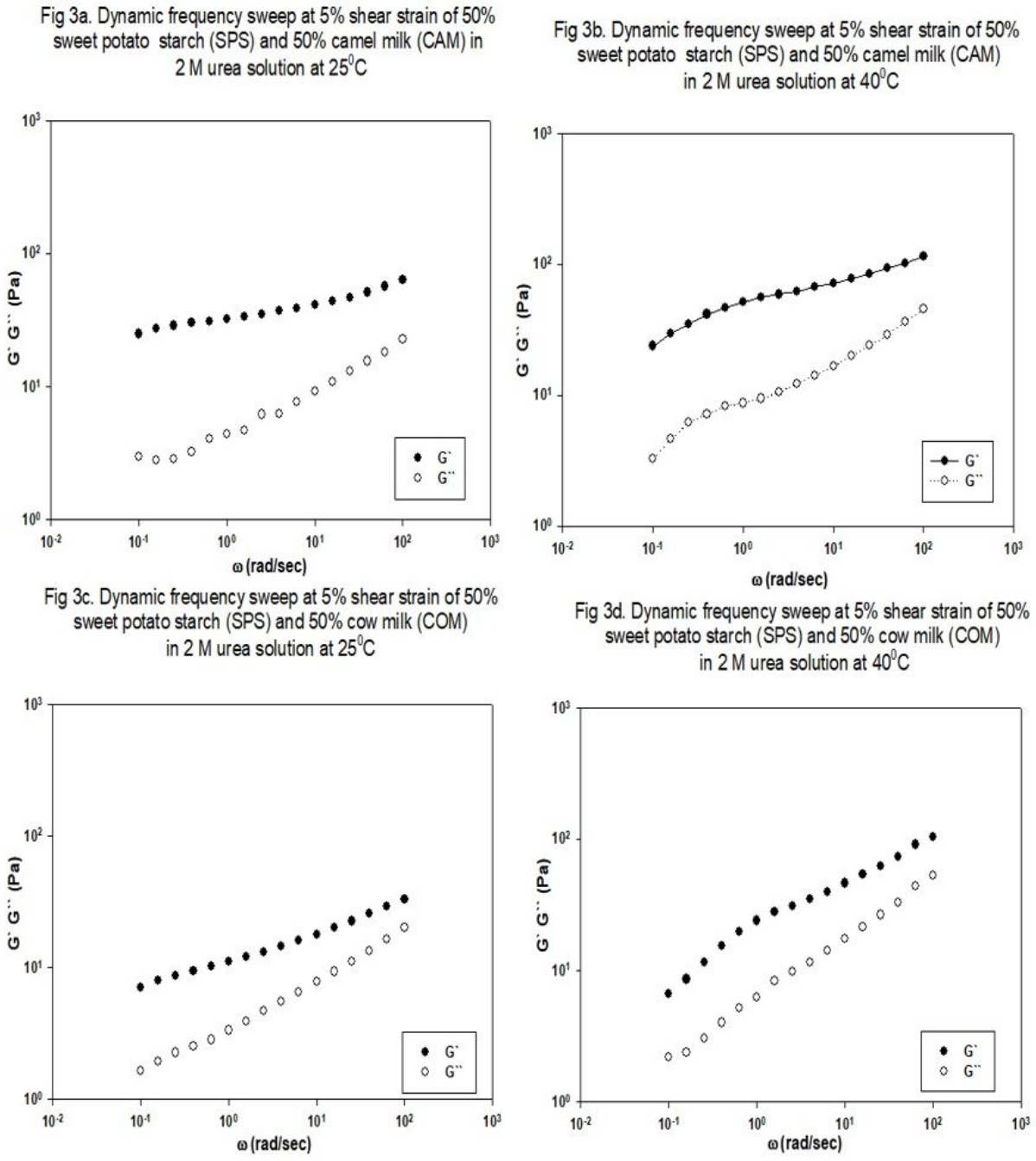

Figure 3. 3a - Dynamic frequency sweep at 5% shear strain of 50% sweet potato starch (SPS) and 50% camel milk (CAM) in 2 M urea solution at 25^{0}C. 3b - Dynamic frequency sweep at 5% shear strain of 50% sweet potato starch (SPS) and 50% camel milk (CAM) in 2 M urea solution at 400C. 3c - Dynamic frequency sweep at 5% shear strain of 50% sweet potato starch (SPS) and 50% cow milk (CAM) in 2 M urea solution at 25^{0}C. 3d - Dynamic frequency sweep at 5% shear strain of 50% sweet potato starch (SPS) and 50% cow milk (CAM) in 2 M urea solution at 40^{0}C.

and G" as a function of higher oscillation and showed no sign for plateau. At low oscillation, the material did not maintain one specific rheological behavior because it was shifting between elastic or viscous behavior (profile is not shown). However, for the same concentration, CM exhibited elastic behavior whereas CWM was more viscous. Unlike the 90% milk, the 70% milk blends sustained steady viscoelastic behavior as reflected on 2 to 4 times higher G' than G". The solid-like texture of the high CM content blends appeared to be oscillation and temperature-dependent as presented by the large difference between G' and G" including G' slope (Figure 4). This behavior was noticed for samples high in starch content as discussed previously and presumed to be due to amylose network. Once again, G' and G" differences at low oscillation frequency was more noticeable for the CM at 40 °C but the opposite was true at higher oscillation (Figure 4a and b). Regardless of temperature,

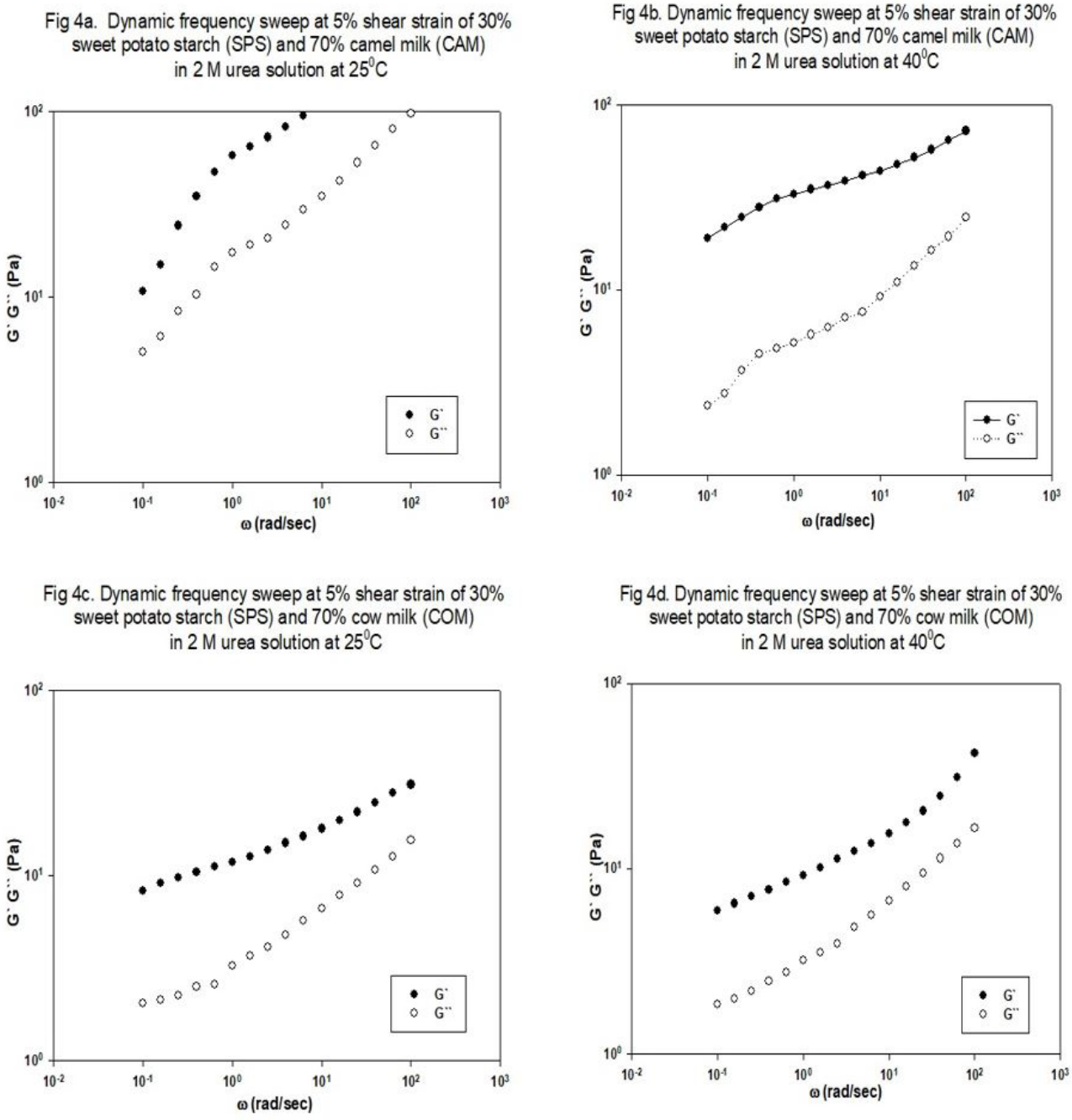

Figure 4. 4a - Dynamic frequency sweet at 5% shear strain of 30% sweet potato starch (SPS) and 70% camel milk (CAM) in 2 M urea solution at 25⁰C. 4b - Dynamic frequency sweet at 5% shear strain of 30% sweet potato starch (SPS) and 70% camel milk (CAM) in 2 M urea solution at 400C. 4c - Dynamic frequency sweet at 5% shear strain of 30% sweet potato starch (SPS) and 70% cow milk (CAM) in 2 M urea solution at 25⁰C. 4d - Dynamic frequency sweet at 5% shear strain of 30% sweet potato starch (SPS) and 70% cow milk (CAM) in 2 M urea solution at 40⁰C.

G' and G" of the high CWM blends did not change as much with increase in oscillation (Figure 4c and d). This may explain the basic molecular structural variation between CM and CWM with respect to the casein protein molecular size and its capacity to interact with the gelatinized starch, mainly at 40 °C (Glantz et al., 2010). At 1.0 rad/sec, the G' CM blends were 3 folds greater than G" at 25 °C and 6 times more at 40 °C, while the G' of CWM was triple G" for both temperatures (Figure 4). Therefore, higher CM blends exhibited elastic texture at higher temperatures which could be attributed to molecular mobility of casein which increased chances for interaction with starch components (amylose or amylopectin). At the same content, camel milk gel elasticity was superior compared with CWM by virtue of G' domination at the start of the oscillation (0.1 rad /sec). The opening up of casein protein of CM by reducing the intra hydrogen bonding (by urea)

allowed for molecular entanglement with starch components and the extended casein polypeptide of CA.

Storage modulus slope

In Table 1, the slopes of G' as a function of frequency were calculated to determine and compare the properties of CM and CWM gels at similar sweet potato starch content. The slope was calculated for blends prepared from 10, 30, 50, 70, and 90% milk content. Obviously, higher positive G' slope is a sign of structural changes at higher frequencies. The slopes of the high milk content blends increased at higher frequency indicating significant gel structural changes, whereas low slope is a sign of stability during oscillation, hence coherent gel structure. Samples with higher than 50% milk content didn't exhibit specific slope pattern (Table 1). The temperature appeared to be an important factor that causes significant change on the slope at higher SP content, because at 40 °C the slopes were closer in values regardless of milk type or content (Table 1). Temperature impact on other gel rheological properties was obvious as discussed earlier. This was reflected on the gel texture at higher milk content as it will be discussed later. As shown by other parameters presented above; camel milk slopes were lower than CWM milk, which indicates stable gel structure.

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

Milk type	Temperature (°C)	% Milk	G' slope	R^2
Camel milk	25	90	0.69	0.90
		70	0.39	0.94
		50	0.12	0.97
		30	0.22	0.92
		10	0.16	0.99
	40	90	0.43	0.93
		70	0.17	0.98
		50	0.20	0.99
		30	0.42	0.91
		10	0.43	0.77
Cow milk	25	90	0.89	0.91
		70	0.17	0.94
		50	0.22	0.97
		30	0.21	0.91
		10	0.14	0.98
	40	90	0.75	0.91
		70	0.26	0.86
		50	0.37	0.99
		30	0.38	0.92
		10	0.41	0.82

1 = R^2 = Coefficient of determination.

The tan δ

The tan δ (= G"/G') describes the relationship between the viscous and elastic portions of gels. Regardless of temperatures, composition or concentrations, the tan δ was < 1.0 for all blends which suggests solid-like texture with distinct differences between gels. The tan δ of high starch blends with CWM increased gradually as a function of frequency. Blends with 90% SP/10% CWM exhibited maximum tan δ as 0.31 and 0.42 at 25 °C, whereas 70% SP/30% CWM showed maximum tan δ as 0.39 and 0.35 at 40 °C. Greater tan δ is caused by a drop in G' at higher frequencies which represents gels with reduced elasticity. It is apparent how the temperature and SP level can affect tan δ values, since 90% SP at 25 °C showed more elastic material than viscous, by virtue of lower tan δ compared to higher temperature and low SP content. Conversely, CM milk gels presented drop in tan δ (at 40 °C) at lower frequencies between 0.1 and 1.0 (rad/sec) followed by steady increased, which means that these gels were more elastic at lower frequencies. However, the maximum tan δ of 90% and 70% SP blends with CA at 25 °C was 0.77 and 0.30, respectively, whereas 0.32 and 0.39 was recorded for the 40 °C for both SP levels. This indicates higher viscosity of CA blends at 25 °C compared to 40 °C and the 90% SP compared to 70% SP. The lower tan δ was expected because higher temperature increased the G' of CA gels as discussed earlier. The high milk content samples presented a weak gel with minimum elasticity and high tan δ, especially samples with 90% CWM, whereas the 70% and 50% CWM exhibited better elasticity (lower tan δ). A drop in tan δ at lower frequencies was observed which indicates more elastic gel, but it increased again signifying more viscous behavior. High CM blends at 40 °C showed elastic property at frequencies between 0.1 and 1.5 (rad/sec) followed by viscus behavior at higher frequencies. The variations between the two milks was evident in tan δ profiles where CM appeared to sustain elastic property at least at low oscillation (0.12-1.5 rad/sec) for all starch content regardless temperatures. In the most part, the G' of CA blends was more dominate than CWM. The data

Table 2. Power law model fitted parameters of camel milk and CWM milk at 25 °C and 40 °C.

%Milk	Camel milk						CWM 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	0.32	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	0.32	0.99	1.14	0.37	0.97	0.37	1.14	0.99

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

presented here indicated that CWM gels undergo major physical changes at 40 °C.

3.2 Nonlinear steady shear

Nonlinear steady shear testing was done to determine the response of SP/CM or CWM gels pertained to temperature and blend composition. Obviously, all blends exhibited shear-thinning profiles within the tested shear rate where at higher solid content the viscosities were higher (no precipitation). The viscosities profiles as a function of shear rate of the high milk samples showed that higher milk content caused significant drop in the viscosity especially at 90% milk content. The viscosity of CM was higher than CWM for the same temperature and solid content. This is in agreement with the behavior of CM revealed by other tests, as stated earlier. The viscosity profile of CM was more solid content-dependent than CWM, but higher sweet potato content (less milk content) instigated increase in viscosity. Conversely, the viscosity of CWM blends was less solid content-dependent at 25 °C. The level of viscosity at 25 °C and 40 °C was comparable for both milk blends, but at 40 °C the viscosities were dependent on the solid content. The effect of temperature on the slope of viscosity of the blends was more noticeable than the effect of shear rate. The power law has direct application on characterizing shear thinning behavior of the blends according to Equation 1.

$$\eta = k\gamma^{n-1} \quad (1)$$

where η is the shear viscosity, k is the constant, γ is shear rate, and n is power law exponent. The data of Equation 1 is listed in Table 2.

Blends with more milk content exhibited higher power law exponent with the exceptions of 30% CM at 25 °C and 40 °C (Table 2). Samples with 10% milk content exhibited lower exponents than those with the most milk content (90%) except for CWM at 40 °C (Table 2). The trend of power law exponent shift is in agreement with the effect of the solid content on the slope of the viscoelastic component mentioned above and listed in Table 1. Overall, samples with < 90% milk content appeared to have increasing exponent at lower milk content. This indicates changes in structure of the gel which may be due to chains interaction or molecular entanglement because the shape of G' curves (discussed earlier) did not indicate crosslinking profile. Similar behavior of legume protein-concentrate was reported (Xu et al., 2006). Therefore, the theory of chain-chain entanglement is the closest justification for the higher exponent of blends < 70% and >30% milk content. Usually, such materials flow easier under applied shear because the internal structure network is weakened or broken down. The difference between CM and CWM is evident when we consider the power law exponent value, where the n value was lower for CM. Consequently, CM-containing blends exhibited stronger structure (low n and high G') while CWM showed stronger shear thinning behavior by virtue of the higher n value. This behavior was observed for tapioca starch when combined with different polysaccharides and can be used to predict the behavior of the blend during processing (Fuongfuchat et al., 2012).

3.3 Gel texture

Gel hardness was another experiment used to show how milk and SP interact. Camel milk gels were harder than CWM gel after overnight storage at room temperature. The gel hardness of the 10%, 30%, and 50% CM was 133, 47, 9.7 g, respectively, whereas CWM exhibited 109, 28, and 13 g. This data is in agreement with the superior rheological properties of CM over CWM.

4 Conclusions

Dynamic rheological tests of precooked sweet potato-fortified camel milk and cow milk gels were performed and the results showed that camel milk exhibited more elastic behavior at 40 °C compared to CWM milk. CM gels had harder texture with major difference between G' and G" profiles and frequency-dependent at lower frequencies, in addition to lower tan δ. CWM exhibited grater G' slopes as a function of oscillation frequency compared to camel milk which indicates obvious looser structure. The lower power law exponent (*n)* value of CM blends indicates coherent gel while CWM exhibited more shear thinning due to the higher n value. This difference can be used to predict samples processing conditions. The outcome of this work showed that the use of urea caused casein to open up and interact with gelatinized starch and produce gels with more elastic properties. This data introduces a new approach to expand camel milk utilization.

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