Kasetsart J. (Nat. Sci.) 45 : 346 - 352 (2011)

Extensional Flow Characteristics of Milk and Soy Set Yogurts with Polysaccharide Additives

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ABSTRACT

The extensional flow characteristics of milk and soy set yogurts were investigated using lubricated squeezing flow viscometry. The samples were compressed by a flat probe in a Lloyd Universal Testing Machine. Nine treatments were tested with different total solids (13, 18, 23%), different agar additions (0.1, 0.5, 1%) and different carrageenan additions (0.1, 0.2, 0.3%). Soy yogurt with agar addition elicited soft gel formation. Soy yogurt with carrageenan addition exhibited syneresis and viscous flow behavior. Compared to milk yogurt, yield stress values of soy yogurt were higher and reached a higher biaxial strain rate. With increasing solids content, yield viscosity values increased. The addition of increasing amounts of agar to both soy and milk yogurts also increased yield viscosity. However, unlike milk yogurt, soy yogurt with agar addition elicited lower yield viscosity values than plain soy yogurt. In contrast to soy yogurt, adding carrageenan resulted in higher yield viscosity values compared to plain milk yogurt. Yet, increasing amounts of carrageenan tended to reduce yield viscosity for both yogurts. The manipulation of the additives can be a useful determinant for the texture and sensory properties of soy yogurt as well as milk yogurt.

Keywords: soy yogurt, milk yogurt, extensional flow, texture, squeezing flow

INTRODUCTION

Yogurt is a product obtained from a process of milk fermentation. The fermentation proceeds symbiotically from thermophilic lactic acid bacteria *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus* (Walstra *et al.*, 1999). The bacteria form lactic acid after their ingestion of the natural sugar (lactose) in milk. The acid causes low pH in the milk and subsequently causes coagulation of milk protein (casein). From a physical chemistry point of view, yogurt curd can be characterized as a composite gel, in which milk fat globules are embedded in the protein matrix through fat globule membrane-casein cross links (Walstra and van Vliet, 1986).

There have been several studies regarding the rheological properties of both set and stirred yogurts. The absence of slip is generally assumed in most viscometry techniques. However, this assumption can be violated in the case of set yogurt because of the release of water due to the destruction during the test or syneresis (Suwansichon and Peleg, 1999; Raphaelides and

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Received date : 17/09/10 Accepted date : 22/12/10

Gioldasi, 2005). A squeezing flow technique could get round this problem, since slip is a prerequisite for this technique. This technique has been applied to many food products (Brandsma and Rizvi, 2001; Salazar-García *et al*., 2003; Osorio *et al*., 2003; Lee and Inglett, 2006; Song *et al*., 2007; Launay and Michon, 2008).

Nowadays, soy-based yogurt has become an attractive product in the marketplace, especially among vegetarians and consumers who prefer organic foods. The components of soy are reported to be beneficial to human health because of their potency for reducing the risk of cancer and heart disease as well as prevention of osteoporosis and high cholesterol levels in the blood (Kovalenko and Briggs, 2002). Yet, in Thailand, its production is mainly provided by a cottage industry. The increasing popularity of soy yogurt demands that comparisons be made with milk yogurt derived from cows and the possibility of developing the manufacture of soy yogurt on an industrial scale for the Thai market. Prior to large scale production, it is important to gain knowledge regarding the textural characteristics of soy yogurt. The objective of this study was to investigate the extensional flow characteristics of soy yogurt and milk yogurt obtained from lubricated squeezing flow viscometry tests.

MATERIALS AND METHODS

Yogurt samples preparation

Milk yogurt samples were prepared using pasteurized milk (CP-MEIJI Co., Ltd., Bangkok, Thailand) with the total solids in the samples being adjusted by adding whole milk powder (University Cooperative, Kamphaeng Saen, Nakorn Pathom, Thailand).

Three batches of milk were produced, each having a different amount of total solids (13, 18, 23%). To three further separate batches of milk with 13% solids content, agar (Patanasin Enterprise Ltd., Part, Bangkok, Thailand) was added at three concentrations (0.1, 0.5, 1%). To three more separate batches of milk with 13% solids content, kappa carrageenan (U&V Holding (Thailand) Co., Ltd., Thasai, Nonthaburi, Thailand) was added at three concentrations (0.1, 0.2, 0.3%). Plain yogurt (Dutch Mill Co., Ltd., Nakorn Chaisi, Nakorn Pathom, Thailand) was added as a starter culture, with a concentration of 15 g/500 mL of the milk mixture. The mixture was transferred to cylindrical plastic cups (3 cm height, 4 cm diameter) that had been carefully lined with aluminum foil to allow the yogurt to be removed easily. The cups were covered with lids and were incubated at 45 °C for 10 h. The final pH of all these samples was approximately 4.6. The samples were transferred to a refrigerator for storage at 5 °C for 24 h before testing.

Soy yogurt samples were prepared using soy milk. Unlike cow milk, soy powder is not usually available commercially. To make it easy to adjust the total solids in soy milk, the soybean (Thai Cereals World Co., Ltd., Bangkok, Thailand) was fine ground into soy powder. The soy milk was then prepared by dissolving soy powder in water at a pasteurized temperature. All treatments of soy yogurt were prepared using the same procedures as mentioned with milk yogurt.

Lubricated squeezing flow viscometry

The squeezing flow experiments were performed using a 50 N load cell. A flat probe was used with a crosshead speed of 0.6 mm/min. The yogurt samples (cylindrical with 3.8 cm diameter and 1.2 cm height) were carefully removed from the plastic cups. Both the top and bottom surfaces of each sample that were in contact with the probe were lubricated with vegetable oil.

The theory and computation for lubricated squeezing flow viscometry follow the theory of biaxial extension (Steffe, 1996). With a cylindrical sample, during squeezing flow, the biaxial extension strain rate $(\dot{\varepsilon}_B)$ is equal to onehalf the vertical Hencky strain rate (Equation 1):

$$\dot{\varepsilon}_B = \left(-\frac{1}{2h}\right)\frac{dh}{dt} = \frac{u_z}{2(h_o - u_z t)} \qquad (1)$$

where h is the instantaneous sample height at time t, h_o is the original sample height and u_z is the probe speed.

Biaxial extension stress (σ_B) when the gap is filled with an incompressible material and the sample volume is constant, is calculated as (Equation 2):

$$\sigma_B = \frac{Fh}{A_o h_o} \qquad (2)$$

where F is the driving force and A_o is the original cross section area of the sample. Then, the (apparent) biaxial extension viscosity or stress growth coefficient (η_B) is calculated from the net extensional stress and strain rate (Equation 3):

$$\eta_B = \frac{\sigma_B}{\dot{\varepsilon}_B} \qquad (3)$$

RESULTS AND DISCUSSION

Force-compression curve characteristics

Regardless of treatments, the force-compression curves for both milk yogurt and soy yogurt were similar. For example, Figure 1 shows the force-compression curve for milk yogurt having different amounts of added solids. Like other gels, the curve demonstrates viscoelastic behavior. The curve can be divided into two parts, elastic deformation and viscous flow. Elastic deformation is indicated in the first part of the curve; the linear increase in force with compression distance is a characteristic of an elastic solid. This deformation of the yogurt gel due to the compression force is resisted by the gel structure and its efforts at reformation (Raphaelides and Gioldasi, 2005). However, finally the resistance is overcome and the gel structure is destroyed, which can be noted from the force drop. After the dropping force transition period, the deformation continues leading to the second part of the curve. In this part, the squeezing flow becomes dominant. This part of the curve shows viscous deformation or viscous flow of gel particles and it can be seen from Figure 1 that the driving force increases as the compression distance increases.

Extensional flow characteristics

The extensional flow characteristics of yogurt in this experiment are expressed as changes of the apparent biaxial extension viscosity with the biaxial extension strain rate. As seen in Figures 2˘4, the apparent biaxial extension viscosity increased with the biaxial extension strain rate, during the elastic deformation phase, until reaching

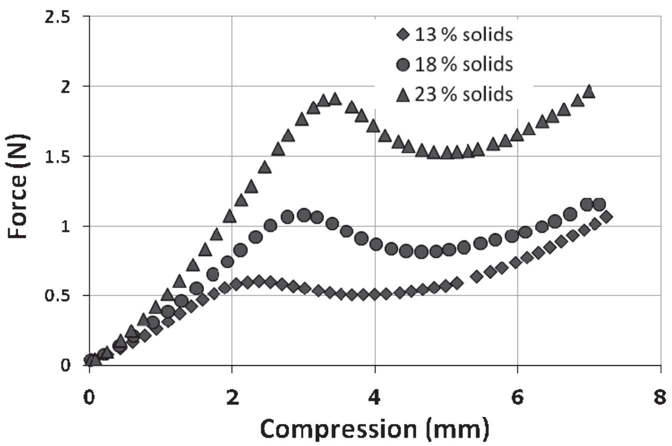

Figure 1 Force-compression curve for milk yogurt with different amounts of total solids.

the overshoot value at which point the yield viscosity is reached. After this yield point, the viscosity decreased continuously during the viscous flow phase. The non-linear tendency during this period resembles a power law fluid.

The yield viscosity values were used to compare the effect of the additives to the yogurt structures (Table 1). The significant differences can be determined between the yield viscosity values for both milk and yogurt. This extends the work of Raphaelides and Gioldasi (2005) who reported that the squeezing flow viscometry is sensitive enough to detect changes in the soy yogurt structure, as well as in the milk yogurt structure. It would be a simple method suitable for quality control.

Differences in total solids

In Table 1, an increase in total solids resulted in a significant increase in yield viscosity values, for both milk and soy yogurts. Inspecting the same level of solids content, soy yogurt provided higher yield values than milk yogurt. Yet, within each type of yogurt, inspecting the effect of solids increment showed stronger influence in milk yogurt than soy yogurt. Adding more solids from 13 to 23%, the yield viscosity value in milk yogurt was increased around threefold whereas it was around twofold in soy milk.

The added extra casein protein in milk yogurt produced more cross-links in the gel network. Thus, the gel structure became stronger and more cohesive and subsequently gained more resistance to compressive force (Raphaelides and Gioldasi, 2005). This was supported by the fact that the deformability , the biaxial strain rate value at the yield point, also increased with the total solids content (Figure 2). In the case of soy yogurt, it may be hypothesized that globulins in soy proteins such as β-conglycinin and glycinin might play an important role in gel formation properties. Considering gel formation, soy proteins at neutral pH will form a gel when heated at temperatures above 84 °C. This temperature range is just above the onset of denaturation of glycinin. During the cooling period, the soy proteins rearrange through non-covalent interactions with consequent stiffening of the gel structure (Renkema and van Vliet, 2002). Although the soy yogurt had the highest yield viscosity at 23% solids content, this occurred at the lowest biaxial extension strain rate; the biaxial extension strain rate was about 0.06 s^{-1}. The higher slope of its elastic region would suggest that the intermolecular bonding was

Table 1 Statistical analysis of mean yield viscosity.

Group	Treatment	Maximum viscosity of milk yogurt (Pa s)	Maximum viscosity of soy yogurt (Pa s)
Differences in total solids	13% solids	$8,321^{a} \pm 828$	$5,3296^{a} \pm 2,186$
	18% solids	$15,728^{b} \pm 1,861$	$8,7087^{b} \pm 2,617$
	23% solids	$27,606^{c} \pm 2,636$	$9,6159^{c} \pm 4,826$
Differences in agar additions	0.1% agar	$7,500^{a} \pm 1,389$	$11,217^{a} \pm 616$
	0.5% agar	$23,535^{b} \pm 2,152$	$34,334^{b} \pm 2,133$
	1% agar	$82,429^{c} \pm 8,031$	$41,509^{c} \pm 2,491$
Differences in carrageenan additions	0.1% carrageenan	$1,2698^{b} \pm 724$	$35,783^{c} \pm 1,781$
	0.2% carrageenan	$10,123^{a} \pm 1,025$	$30,485^{b} \pm 1,145$
	0.3% carrageenan	$11,204^{a} \pm 292$	$25,711^{a} \pm 1,677$

Yield viscosity values (mean ± SD) with different superscripts (in a column) within each of the three groups of yogurts are significantly different ($P < 0.05$).

making the yogurt behave in a way closer to a rigid solid. Accordingly, it would withstand high stress, but would not stay intact for a long time.

Differences in agar additions

The milk yogurt samples with agar addition were rigid and quite rubbery. Less syneresis occurred with higher agar content. The soy yogurt samples were softer and had a smoother texture than the plain soy yogurt samples. From Table 1, yield viscosity increased with agar addition, for both milk and soy yogurts. The deformability followed the same trend (Figure 3). The solids content of plain yogurt samples before adding agar was 13%. As seen in Table1, for soy yogurt, all levels of agar addition resulted in lower yield viscosity values than the plain yogurt. For milk yogurts, this trend was not apparent; most yield viscosity values of agar-added yogurt were higher than the plain yogurt. The lower value for 0.1% agar addition was within the limit of error. To understand this, it is worth noting that soy gels formed from globular proteins are not typical polymer gels and differ from casein gels. Considering the casein gels in milk yogurt, when agar is added, the ideas of Syrbe *et al.* (1998) might be relevant. They stated that some polymers may not only form the network of a gel with water

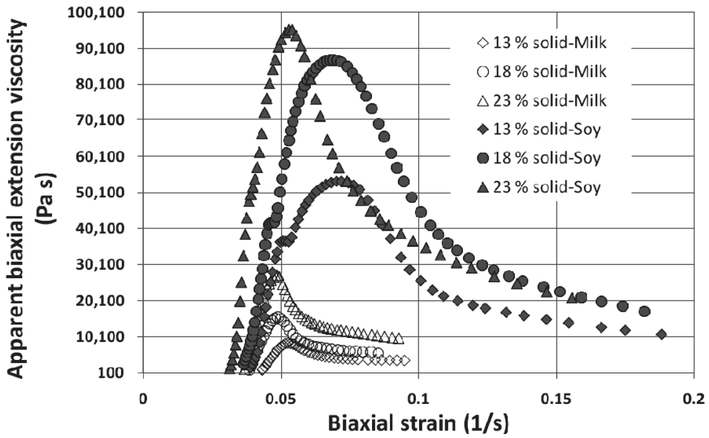

Figure 2 Apparent biaxial extension viscosity for yogurts with different amounts of total solids.

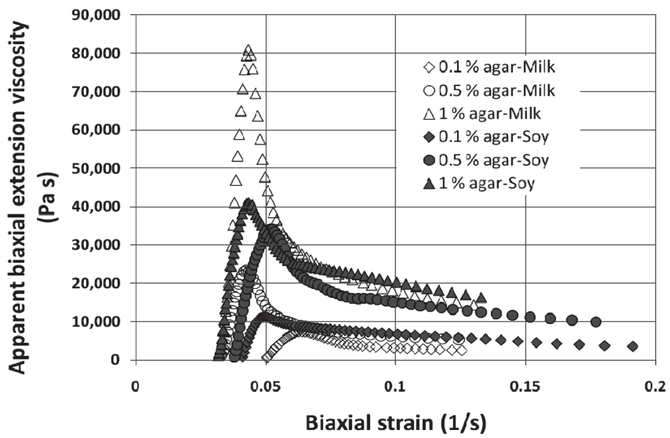

Figure 3 Apparent biaxial extension viscosity for yogurts with different amounts of agar additions.

trapped inside the casein cross-links, but also adsorb on the casein and other particles in the colloidal system. It may be hypothesized that with agar, this adsorption may integrate the particles into the gel structure with consequent strengthening.

Differences in carrageenan additions

From Table 1, the yield viscosity values of both milk yogurt and soy yogurt tended to decrease with carrageenan additions. This can also be seen from Figure 4. However, with higher yield viscosity values, the milk yogurt with carrageenan addition produced stronger yogurt gels than the yogurt without polysaccharide addition (13% total solids). This confirmed the results of Raphaelides and Gioldasi (2005). In the viscous flow phase of milk yogurt, adding more carrageenan tended to increase biaxial extension viscosity values especially at 0.3% carrageen content. It would seem that addition of carrageenan enhanced the viscoelastic behavior in milk yogurt. From sample observation, the milk yogurt gels with carrageenan addition were soft but elastic. On compression with a finger, the samples deformed and returned back to their original height after the pressing.

Soy yogurt gels, in the concentration range 0.1˜0.3% of carrageenan addition, yielded very soft gels with some syneresis. Preliminary tests had indicated that if the concentration of carrageenan was higher than 0.3%, the soy yogurt could not be formed as set yogurt. Unlike milk yogurt, it would seem that the addition of carrageenan detracts from the elastic property of soy yogurt. It can be hypothesized that carrageenan merely thickens the yogurt, but does not form intermolecular cross-links with soy proteins and particles. At higher carrageenan content, soy yogurt would become a viscous suspension.

CONCLUSION

Squeezing flow viscometry is sensitive enough to detect changes in the soy yogurt structure, as well as in the milk yogurt structure. It is a simple method that gives plenty of rheological information suitable for quality control. Due to different types of protein, milk and soy yogurt gels behaved differently with polysaccharide additions. Overall, the manipulation of the additives can be a useful determinant for the texture and sensory properties of soy yogurt as well as milk yogurt.

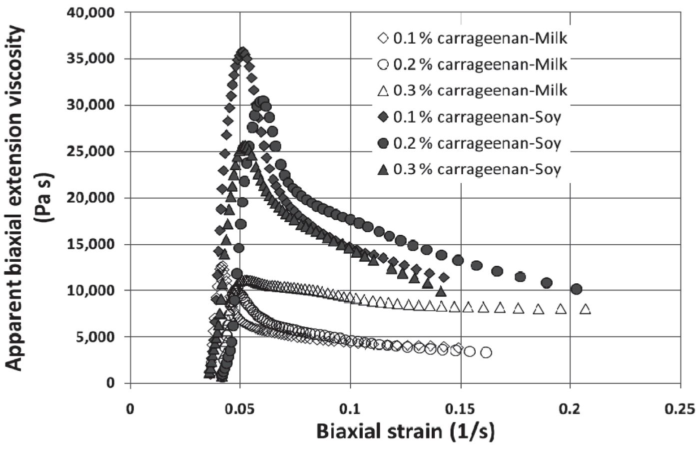

Figure 4 Apparent biaxial extension viscosity for yogurt with different amounts of carrageenan additions.

ACKNOWLEDGEMENTS

This research was funded by the Commission on Higher Education at the Ministry of Education and the Thailand Research Fund. The experimental comments and opinions are those of the authors and not necessarily those of the sponsors.

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