Food Sci. Biotechnol. 21(6): 1775-1779 (2012)
DOI 10.1007/s10068-012-0237-4

RESEARCH NOTE

Steady and Dynamic Rheological Properties of Thickened Beverages Used for Dysphagia Diets

Hyun-Moon Cho, Whachun Yoo, and Byoungseung Yoo

Received: 23 June 2012 / Revised: 1 August 2012 / Accepted: 8 August 2012 / Published Online: 31 December 2012

Abstract Thickened beverages prepared with commercial food thickeners are widely used to promote safer and more successful swallowing in patients with dysphagia. In this study, the rheological properties of cold thickened beverages (bottled water, orange juice, apple juice, and whole milk) prepared with a commercially available gum-based food thickener (xanthan-guar gum mixture) marketed in Korea were investigated at 3 different thickener concentrations (2, 3, and 4%, w/w). Thickened beverages showed high shear-thinning (n=0.12-0.21) behavior with Casson yield stress at all concentrations. Their apparent viscosity ($\eta_{a,50}$), consistency index (K), Casson yield stress (σ_{oc}), storage modulus (G'), and loss modulus (G'') increased with an increase in thickener concentration. Steady and dynamic rheological parameters also demonstrated greater differences in rheological behaviors between thickened beverages with different thickener concentrations. These results suggest that rheological properties of thickened beverages are strongly affected by thickener concentration and the type of beverage prepared.

Keywords: dysphagia, food thickener, thickened beverage, rheological property, viscosity

Introduction

Dysphagia affects approximately 20% of the adult primary-care population (1) and more than half of elderly individuals living in nursing homes (2). Dysphagia is defined as a difficulty or inability to swallow that could result from one of several pathologies such as neuromuscular disorders, brain injury, or stroke (3). There is a danger that watery fluid can flow quickly to the larynx before the entrance to the airway has closed, leading to aspiration in patients with dysphagia (4). This problem may discourage fluid intake, resulting in malnutrition and dehydration in patients with dysphagia. Therefore, food thickeners have been traditionally used as additives to fluid foods or beverages for patients with dysphagia to enhance viscosity, and many beverages containing food thickener have been developed (5). The effectiveness of a thickened beverage for safe drinking is dependent on its rheological properties which are affected by the thickener brand, type of medium for preparation, and thickener concentration. In addition, the correct rheological properties are important for treating dysphagia because patients with dysphagia could have different abilities to swallow.

Although extensive literature is available on the rheological properties of thickened beverages containing food thickeners marketed in different countries (4-10), no attempt has been made to study the effect of thickener concentration on the rheological properties of thickened beverages prepared with a commercial gum-based food thickener marketed in Korea. In particular, little information is available on dynamic rheological properties of thickened beverages by small-deformation oscillatory measurements. Thus, the objectives of this study were to investigate the steady and dynamic rheological properties of thickened beverages prepared with a commercial food thickener marketed in Korea as a function of thickener concentration, and to compare the rheological differences between the various thickened beverages.

Hyun-Moon Cho, Byoungseung Yoo (✉)
Department of Food Science and Biotechnology, Dongguk University-Seoul, Seoul 100-715, Korea
Tel: +82-2-2260-3368; Fax: +82-2-2264-3368
E-mail: bsyoo@dongguk.edu

Whachun Yoo
Rheosfood Inc., Seoul 100-715, Korea

Materials and Methods

Materials and sample preparation Visco-up, a composite of xanthan gum, guar gum, and dextrin (Rheosfood Inc., Seoul, Korea) as a powdered commercial gum-based food thickener manufactured and marketed in Korea, was used. Four beverages such as bottled water (Jeju Samdasoo, Jeju, Korea), orange juice (OJ) (Coca Cola Beverage Co., Yangsan, Korea), apple juice (AJ) (Woonjin Foods Co., Ltd., Gongju, Korea), and whole milk (Seoul Milk, Co., Ltd., Seoul, Korea) were prepared with the commercial thickener. The thickened beverages were prepared by mixing the food thickener at different concentrations (2, 3, and 4%, w/w) with the beverages at room temperature with moderate stirring for 1 min with mild agitation provided by a magnetic stirrer. The thickened samples were kept in a 5°C refrigerator for 1 h to thicken them completely.

Rheological measurements Rheological properties were obtained with a controlled stress Carri-Med CSL^2 100 rheometer (TA Instruments, New Castle, DE, USA), using a parallel plate system (4 cm dia.) at a gap of 500 μm. Steady shear (shear stress and shear rate) data were obtained over a shear rate range of 0.4-100/s at the serving temperature of 8°C. Data were fitted to the well-known power law model (Eq. 1) and Casson model (Eq. 2) to describe the steady and dynamic shear rheological properties of the samples.

$$\sigma = K\dot{\gamma}^{n} \tag{1}$$

$$\sigma^{0.5} = K_{oc} + K_c\dot{\gamma}^{0.5} \tag{2}$$

where, s is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (1/s), K is the consistency index ($Pa\cdot s^n$), and n is the flow behavior index (dimensionless). Casson yield stress (σ_{oc}) was determined as the square of the intercept (K_{oc}) obtained from linear regression of the square roots of the steady shear data. The apparent viscosity ($\eta_{a,50}$) at 50/s, a reference shear rate for swallowing, was calculated using the magnitudes of K and n.

Dynamic shear data were obtained from frequency sweeps over the range of 0.63-62.8 rad/s at 2% strain. A 2% strain value is in the linear viscoelastic region. Frequency sweeps tests were also performed at 8°C. TA Rheometer Data Analysis software (version VI. 1.76) was used to obtain the experimental data and to calculate the storage modulus (G'), loss modulus (G"), and loss tangent (tan δ=G"/G'). All samples were allowed to rest at 8°C for 5 min before the rheological measurements were taken. The rheological measurements were performed in triplicate.

Statistical analysis All results are expressed as the mean ±standard deviation (SD). An analysis of variance (ANOVA) was performed using the Statistical Analysis System software version 9.1 (SAS Institute, Cary, NC, USA). Differences in means were determined using Duncan's multiple range test.

Results and Discussion

Flow behavior The shear stress (σ) versus shear rate ($\dot{\gamma}$) data at 8°C were well fitted to the simple power law (Eq. 1) and Casson models (Eq. 2) with high determination coefficients (R^2=0.96-0.99), as shown in Table 1. All thickened beverage with different thickener concentrations had high shear-thinning behavior with flow behavior index (n) values as low as 0.12-0.21. Similar observations were reported by Sopade *et al.* (6,8,10), who studied the flow properties of thickened fluids prepared with food thickeners marketed in Australia as a function of thickener type. The higher shear-thinning behavior of thickened beverages could possibly be due to the presence of xanthan and guar gums in the food thickener, as suggested by Hong *et al.* (11). It is also known that the shear-thinning character of the xanthan gum at low concentrations is more pronounced in comparison to other gums due to its unique rigid rod-like conformation and high molecular weight (12). The observed shear-thinning behavior of thickened beverages prepared with a gum-based thickener can be explained by disruption of the entangled polysaccharide molecule network during shearing (13). Additionally, the n value of a food thickener is important because a high n value leads to a slimy feel in the mouth, as noted by Szczesniak and Farkas (14). They found that gums with a high degree of shear thinning (low n value) are not slimy in the mouth. However, the organoleptic sliminess of thickened beverages was not considered in this study. Therefore, more research is needed to determine the relationships between n value and sensory texture characteristics of thickened beverages for people with swallowing difficulty. No clear differences between n values (0.12-0.17) were observed for the thickened beverages except for milk at 2%, indicating that there was no effect of thickener concentration on n values of the thickened beverages.

It is important to recognize that viscosity is only one of several flow parameters that must be measured to define the rheological characteristics of a liquid. Recently, a yield stress parameter, which is defined as the minimum stress necessary to flow a fluid, has been proposed as potentially relevant for swallowing. Therefore, we obtained the yield stress from Casson model. In general, the consistency index (K), apparent viscosity ($\eta_{a,50}$), and Casson yield stress (σ_{oc}) values of the thickened beverages increased with an increase in thickener concentration. The order of effectiveness in increasing the $\eta_{a,50}$, K, and σ_{oc} values at higher thickener concentrations (3 and 4%) was as follows:

Table 1. Steady shear rheological properties of the thickened beverages at different thickener concentrations

Thickener concentration (%)	Beverage type	Apparent viscosity $\eta_{a,50}$ (Pa·s)	Power law			Yield stress σ_{oc} (Pa)
			n (-)	K (Pa·s^n)	R^2	
2	Water	0.55±0.01$^{d1)}$	0.13±0.00^c	16.4±0.30^d	0.98	16.7±0.31^d
	Orange juice	1.74±0.03^a	0.15±0.00^b	48.1±0.44^b	0.99	49.3±0.50^b
	Apple juice	1.68±0.03^b	0.12±0.01^c	51.9±0.26^a	0.98	58.9±1.01^a
	Milk	1.47±0.02^c	0.21±0.00^a	32.0±0.27^c	0.99	32.2±0.11^c
3	Water	1.10±0.01^d	0.13±0.01^b	32.4±0.25^d	0.99	33.3±0.11^d
	Orange juice	3.35±0.03^b	0.15±0.00^a	93.3±0.70^b	0.99	113±0.71^b
	Apple juice	2.65±0.09^c	0.13±0.01^b	80.8±1.60^c	0.97	95.6±1.19^c
	Milk	3.86±0.04^a	0.14±0.00^b	109±0.25^a	0.97	126±0.84^a
4	Water	1.74±0.08^d	0.15±0.00^c	48.4±1.47^d	0.98	50.4±1.70^d
	Orange juice	5.19±0.20^b	0.16±0.00^b	137±1.43^b	0.98	171±2.48^b
	Apple juice	4.04±0.05^c	0.15±0.00^c	113±4.08^c	0.96	145±10.5^c
	Milk	6.03±0.00^a	0.17±0.00^a	154±1.61^a	0.97	187±13.6^a

1)Mean values in the same column with different letters are significantly different (p<0.05).

milk>OJ>AJ>water. However, the $\eta_{a,50}$, K, and σ_{oc} values at a 2% thickener concentration increased in the following order: OJ>AJ>milk>water for $\eta_{a,50}$, and AJ>OJ>milk> water for K and σ_{oc}. These results showed that the water samples were all significantly thinner than other samples at all thickener concentrations. In particular, changes in the $\eta_{a,50}$, K, and σ_{oc} values of the thickened beverages with different thickener concentrations were more pronounced with milk in comparison to the other beverages. These differences in flow properties of thickened beverages can be attributed to the different constituents of the dispersing media that interact with the macromolecules (xanthan and guar gums) in the food thickener. In general, the composition of the dispersing medium can influence the flow behaviors of thickened fluids at low thickener concentrations, as described by Sopade *et al*. (6). There was also an essential change in σ_{oc} between concentrations of thickeners and between types of thickened beverages when compared to the K and $\eta_{a,50}$ values. This result indicates that the yield stress measurement is a better rheological parameter for estimating flow properties of various thickened beverages with different thickener concentrations. From these observations, the flow properties of the thickened beverages depended on the type of beverage and were strongly affected by adding the food thickener. Therefore, we propose that instructions for preparing thickened beverages from commercial food thickeners are better specified as to the type of beverage and thickener concentration.

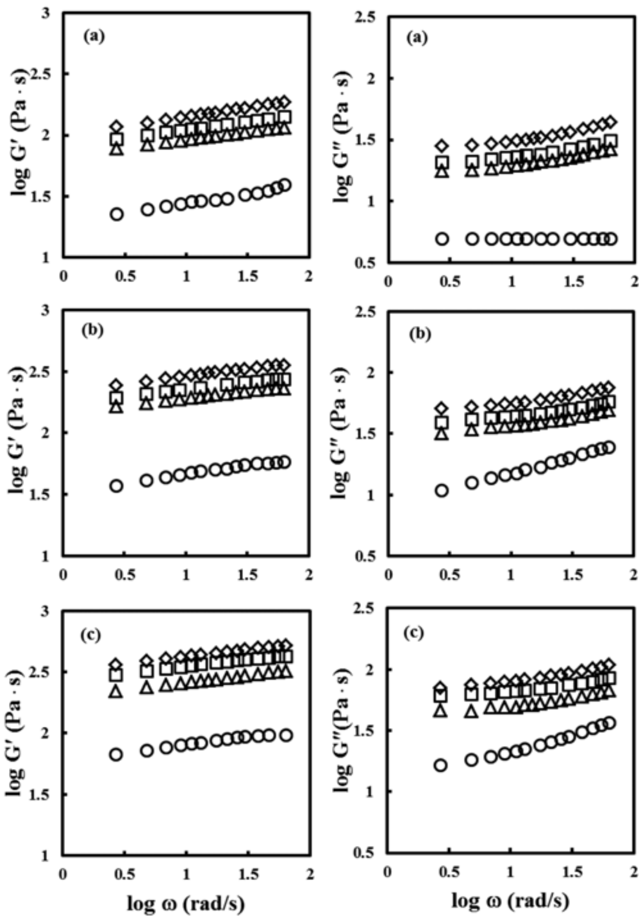

Fig. 1. Plots of storage modulus (G') and loss modulus (G") versus log frequency (ω) for thickened beverages at different thickener concentrations; (a) 2%, (b) 3%, (c) 4%. (○) water, (□) orange juice (OJ), (△) apple juice (AJ), and (◇) milk

Dynamic rheological properties Figure 1 shows changes in the G' and G" as a function of frequency (ω) for the various thickened beverages at different thickener concentrations. The thickened beverage samples exhibited a weak gel-like behavior, because their slopes were positive and the G' magnitudes were higher than those of

Table 2. Storage modulus (G'), loss modulus (G"), and tan δ at 6.28 rad/s for thickened beverages with different thickener concentrations

Thickener concentration (%)	Beverage type	G' (Pa)	G" (Pa)	tan δ
2	Water	25.5±0.76[d1)]	7.19±0.27[d]	0.28±0.02[a]
	Orange juice	103±1.51[b]	21.4±1,28[b]	0.21±0.02[b]
	Apple juice	85.6±1.70[c]	17.2±0.65[c]	0.20±0.01[b]
	Milk	130±3.24[a]	29.0±0.05[a]	0.22±0.01[b]
3	Water	43.1±0.55[d]	11.9±0.97[d]	0.27±0.02[a]
	Orange juice	210±7.62[b]	38.5±1.16[b]	0.18±0.01[b]
	Apple juice	180±2.75[c]	32.2±0.66[c]	0.18±0.01[b]
	Milk	267±9.61[a]	49.9±1.21[a]	0.19±0.01[b]
4	Water	76.2±1.05[d]	18.2±0.47[d]	0.18±0.01[a]
	Orange juice	334±3.43[b]	58.5±1.02[b]	0.17±0.01[b]
	Apple juice	244±1.16[c]	43.9±0.37[c]	0.18±0.00[b]
	Milk	403±1.80[a]	71.7±1.92[a]	0.18±0.00[b]

[1)]Mean values in the same column with different letters are significantly different ($p<0.05$).

G". The magnitudes of G' and G" increased with an increase in ω, showing a frequency dependent relationship. The dynamic moduli (G' and G") values of thickened beverages increased with an increase in thickener concentration from 2 to 4%, whereas tan δ values decreased (Table 2). The G' and G" values increased in the following order: milk>OJ>AJ>water, indicating that the increase in G' and G" was more pronounced with the milk samples. Such higher dynamic moduli values of the milk samples with different thickener concentrations may be due to the strong interactions between constituents in milk and gums in the food thickener. We also found significant differences between G' values for water and the other beverages (OJ, AJ, and milk). Specifically, the pronounced G' value for the 4% thickened milk sample can be explained by the formation of a greater elastic weak gel network at a high thickener concentration when compared to other samples. These results indicate that the elastic properties of thickened beverages can be influenced by the constituents in beverages which can interact with macromolecules (xanthan and guar gums) in the food thickener.

One characteristic value for evaluating the viscoelastic behavior is the loss factor (tan δ), which directly states the ratio of G"/G'. The tan δ values (0.17-0.28) of all samples were lower than one, indicating that the samples were more elastic than viscous. Their higher elastic properties may have been due to the presence of gums (xanthan and guar gums) in the food thickener. The tan δ values (0.18-0.22) of the OJ, AJ, and milk samples at 2 and 3% concentrations were much lower than those (0.27-0.28) of water, indicating that they was more structured and more elastic gel-like compared to those of the water sample. Such changes in the ratio of viscous to elastic properties (tan δ) suggest that a different structural product type is being presented to patients despite the fact that the thickened beverages have the same viscosity, as described by Payne *et al*. (9). These observations suggest that the viscoelastic properties of thickened beverages prepared with a food thickener are dependent on the type of beverage and the thickener concentration, and in particular, that their elastic properties are greatly influenced by the constituents in beverages which can interact with macromolecules in the food thickener. The results of this study contribute to our understanding of the rheological properties of various thickened beverages prepared with a commercial food thickener marketed in Korea to help patients with dysphagia safely swallow beverages.

Acknowledgments This study was supported by the Dongguk University research fund. We thank Rheosfood Inc. for providing the free food thickener (Visco-up) sample.

References

1. Wilkins T, Gillies RA, Thomas AM, Wagner PJ. The prevalence of dysphagia in primary care patients: a HamesNet Research Network study. J. Am. Board Fam. Med. 20: 144-150 (2007)
2. Layne KA, Losinski DS, Zenner PM, Ament JA. Using the Fleming Index of Dsyphagia to establish prevalence. Dysphagia 17: 298-307 (1989)
3. Matta Z, Chambers D, Garcia JM, Helverson JM. Sensory characteristics of beverages prepared with commercial thickeners used for dysphagia diets. J. Am. Diet Assoc. 106: 1049-1054 (2006)
4. O'Leary M, Hanson B, Smith C. Viscosity and non-newtonian features of thickened fluids used for dysphagia therapy. J. Food Sci. 75: E330-E338 (2010)
5. Tashiro A, Hasegawa A, Kohyama K, Kumagai H, Kumagai H: Relationship between the rheological properties of thickener solutions and their velocity through the pharynx as measured by the

ultrasonic pulse Doppler method. Biosci. Biotech. Bioch. 74: 1598-1605 (2010)
6. Sopade PA, Halley PJ, Cichero JAY, Ward LC, Hui LS, Teo KH. Rheological characterization of food thickeners marketed in Australia in various media for the management of dysphagia. II. Milk as a dispersing medium. J. Food Eng. 84: 553-562 (2008)
7. Adeleye B, Rachal C. Comparison of the rheological properties of ready-to-serve and powdered instant food-thickened beverages at different temperatures for dysphagic patients. J. Am. Diet Assoc. 107: 1176-1182 (2007)
8. Spade PA, Halley PJ, Cichero JAY, Ward LC. Rheological characterization of food thickeners marketed in Australia in various media for the management of dysphagia. I: Water and cordial. J. Food Eng. 79: 69-82 (2007)
9. Payne C, Methven L, Fairfield C. Consistently inconsistent: Commercially available starch-based dysphagia products. Dysphagia 26: 27-33 (2010)
10. Sopade PA, Halley PJ, Cichero JAY, Ward LC, Liu J, Varliveli S. Rheological characterization of food thickeners marketed in Australia in various media for the management of dysphagia. III. Fruit juice as a dispersing medium. J. Food Eng. 86: 604-615 (2008)
11. Hong SR, Sun DS, Yoo W, Yoo B. Flow behaviors of commercial food thickeners used for the management of dysphagia: Effect of temperature. Int. J. Food Eng. 8(2): Article 8 (2012)
12. Urlacher B, Noble O. Xanthan. pp. 284-311. In: Thickening and Gelling Agents for Food. Chapman & Hall, London, UK (1997)
13. Morris ER. Polysaccharide solution properties: Origin, rheological characterization, and implications for food system. pp. 132-163. In: Frontiers in Carbohydrate Research-1: Food Applications. Millane RP, BeMiller JN, Cahndrasekavan R (eds). Elsevier Applied Science Pub. New York, NY, USA (1989)
14. Szczesniak AS, Farkas E. Objective characterization of the mouthfeel of gum solutions. J. Food Sci. 27: 381-385 (1963)