

Relationship between Apparent Viscosity and Line-Spread Test Measurement of Thickened Fruit Juices Prepared with a Xanthan Gum-based Thickener

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ABSTRACT: The flow behaviors of three thickened fruit juices (orange, apple, and grape juice) prepared with a commercial instant xanthan gum (XG)-based thickener that is marketed in Korea were investigated at different thickener concentrations (1.0%, 1.5%, 2.0%, 2.5%, 3.0%, and 3.5%) and setting times (5 and 30 min) using a rheometer and a line-spread measurement method. The flow distance values measured by the line-spread test (LST) were compared with the apparent viscosity ($\eta_{a,50}$) values measured with a sophisticated computer-controlled rheometer. The $\eta_{a,50}$ values of the juices increased as thickener concentration increased, whereas their flow distances decreased. The $\eta_{a,50}$ values at the 30-min setting time were much higher than those at the 5-min setting time, indicating that the setting time before serving or consuming thickened juices can affect viscosity values. Plots comparing $\eta_{a,50}$ values to LST flow distances revealed strong exponential relationships between the two measures ($R^2=0.989$ and $R^2=0.987$ for the 5- and 30-min setting times, respectively). These results indicate that the LST can be a suitable instrument for evaluating the viscosity of thickened fruit juices prepared with different XG-based thickener concentrations and setting times for the dysphagia diet.

Keywords: thickener, viscosity, thickened juice, dysphagia, line-spread test

INTRODUCTION

Dysphagia is generally defined as a difficulty or inability to swallow thin fluid foods such as water, juice, tea, and coffee, which may lead to aspiration pneumonia and other respiratory problems. Diet modification is a compensatory technique needed for the clinical management of dysphagic patients (1,2). Therefore, thin fluids are commonly thickened with commercial food thickeners to reduce the risk of aspiration and optimize the swallowing ability of patients with dysphagia. The effective treatment of dysphagia requires that fluid foods are consistently prepared with the correct viscosity. Inaccuracies in preparing fluid foods to target thickness levels can increase the risk of aspiration (3). Therefore, the use of sophisticated computer-controlled rheometers is necessary to provide a more accurate measurement of the viscosity of thickened fluids. However, these rheometers are costly and impractical for instructional purpose in most clinical settings.

In general, thickened fluids are classified into several

different “consistency” classes established by the National Dysphagia Diet Task Force: thin (1~50 mPa·s), nectar-thick (51~350 mPa·s), honey-thick (351~1,750 mPa·s) and pudding-thick (>1,750 mPa·s). These values are determined by the viscosity of a product at a shear rate of 50 s⁻¹, which is thought to represent the shear rate in oral cavity during swallowing (4-7). Recently, several researchers have studied the use of the line-spread test (LST) for estimating the viscosity of thickened fluids (2,4,8-10) because the LST is an inexpensive, simple and visual clinical tool (9). However, there is little information available regarding the ability of the LST to differentiate the flow distance of the consistency levels (nectar-, honey- and pudding-like) of thickened fruit juices prepared with a xanthan gum (XG)-based food thickener marketed in Korea. In particular, there are no studies exploring the relationship between the apparent viscosity (η_a) values obtained using a sophisticated rheometer and the flow distance (cm) values measured by the LST for thickened fruit juices at different setting times. In general, it is of considerable practical importance to in-

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investigate the effect of setting time on juice viscosity because some thickened fluids are prepared in bulk and served at a much later time (more than 30 min after preparation) rather than being served or consumed immediately after mixing with thickeners (11). Therefore, in order to manage dysphagia properly, it is vital to know the viscosity of thickened juices that have been prepared under different conditions before serving these juices to patients with dysphagia.

This study evaluated to ability of the LST to measure correct viscosity of thickened juices prepared with a commercial XG-based food thickener for the management of dysphagia. Thus, the objective of this study was to investigate the relationship between the apparent viscosity measured by a rheometer and the line-spread distance measured by the LST for XG-based thickened juices prepared with different setting times.

MATERIALS AND METHODS

Materials and sample preparation

A commercially available instant food thickener (Visco-up, Rheosfood Inc., Seoul, Korea) was used in this study. Visco-up is an XG-based thickener product that consists of XG, guar gum, and dextrin. Three commercial fruit juices were used as the dispersing medium [orange juice (Coca Cola Beverage Co., Yangsan, Korea), apple juice (Woongjin Foods Co., Ltd., Gongju, Korea), and grape juice (Coca Cola Beverage Co.)]. The thickened juices were prepared by mixing each of the fruit juices containing 1.0%, 1.5%, 2.0%, 2.5%, 3.0%, and 3.5% (w/w) Visco-up. Thickened juices were prepared at room temperature with moderate stirring for 1 min. Mild agitation was provided by a magnetic stirrer. The amount of thickener used was consistent with clinical practice guidelines (i.e., based on the manufacturer's recommendations for producing nectar-, honey- and pudding-like fluids).

Apparent viscosity measurement

The flow properties of the thickened juices were measured with a Carri-Med CSL² 100 rheometer (TA Instruments, New Castle, DE, USA), using a parallel plate system (4 cm diameter) at a gap of 500 μm . Steady flow data were obtained over a shear rate range of 0.1 ~ 100 s^{-1} . Temperature was controlled by a water bath connected to the Peltier system of the bottom plate. The apparent viscosity of the sample was calculated by entering the data collected with the rheometer (i.e., shear stress and shear rate) into the well-known power law model (Eq. 1).

$$\sigma = K\dot{\gamma}^n \quad (1)$$

where σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), K is the consistency index ($\text{Pa}\cdot\text{s}^n$), and n is the flow behavior index. The apparent viscosity ($\eta_{a,50}$) at 50 s^{-1} , the reference shear rate for swallowing, was calculated using the magnitudes of K and n . All samples were allowed to set at $22^\circ\text{C}\pm 0.1$ for 5 or 30 min. The viscosity measurements were performed in triplicate.

Line-spread test

The LST was used to measure the flow distance of the thickened fluid, in centimeters, across a flat surface. Briefly, a cylinder (3.5 cm high and 5.0 cm in diameter) that was resting on a clear plastic surface marked with concentric circles was filled with thickened samples that had been allowed to set at room temperature for 5 min or 30 min. Then, the cylinder was lifted and the thickened sample was allowed to flow on the flat plastic for 60 s. The flow distance value was considered to be the average of the readings at the four quadrants of the flow sheet. For each sample, the measurement was repeated five times in order to obtain an average line-spread reading.

Statistical analysis

Results were analyzed by an analysis of variance (ANOVA) using the Statistical Analysis System program version 9.2 (SAS Institute, Cary, NC, USA). Means were compared at the 0.05 significance level using Duncan's multiple comparison test. Regressions were performed to determine the relationships between the $\eta_{a,50}$ and LST measurements of the thickened fruit juices.

RESULTS AND DISCUSSION

Table 1 shows the apparent viscosity ($\eta_{a,50}$) measurements of thickened fruit juices prepared with different concentrations (1.0%, 1.5%, 2.0%, 2.5%, 3.0%, and 3.5%) of an XG-based thickener and different setting times (5 and 30 min). In general, significant differences in the $\eta_{a,50}$ values were found for the thickened fruit juices prepared with different thickener concentrations ($P < 0.05$), suggesting that thickener concentration played a large role in determining the viscosity of the thickened juices. The $\eta_{a,50}$ values of the thickened beverages significantly increased with increasing thickener concentration, indicating that small differences in the amount of food thickener produced significant changes in viscosity. The increase in $\eta_{a,50}$ values with thickener concentration may be due to the fact that XG has a high molecular weight, as noted by Seo and Yoo (3).

At the 30-min setting time, the $\eta_{a,50}$ values of the thickened juices were significantly higher than those at the 5-min setting time ($P < 0.05$), indicating that the vis-

Table 1. Apparent viscosity values of thickened fruit juices at different thickener concentrations (1.0~3.5%) and setting times (5 and 30 min)

Type of juice	Thickener concentration (%)	Apparent viscosity ($\eta_{a,50}$, mPa·s)	
		5-min setting time	30-min setting time
Orange	1.0	97.3±0.00 ^{aB}	201.1±0.01 ^{aA}
	1.5	188.2±0.02 ^{bB}	424.0±0.04 ^{bA}
	2.0	364.4±0.03 ^{cB}	842.9±0.07 ^{cA}
	2.5	704.4±0.02 ^{dB}	1,343±0.14 ^{dA}
	3.0	1,240±0.01 ^{eB}	2,075±0.06 ^{eA}
	3.5	1,769±0.02 ^{fB}	2,775±0.01 ^{fA}
Apple	1.0	109.4±0.01 ^{aB}	166.8±0.00 ^{aA}
	1.5	274.8±0.01 ^{bB}	497.1±0.04 ^{bA}
	2.0	544.6±0.06 ^{cB}	787.5±0.03 ^{cA}
	2.5	937.9±0.01 ^{dB}	146.2±0.08 ^{dA}
	3.0	1,443±0.05 ^{eB}	2,005±0.07 ^{eA}
	3.5	2,230±0.06 ^{fB}	2,431±0.05 ^{fA}
Grape	1.0	96.4±0.01 ^{aB}	154.3±0.01 ^{aA}
	1.5	236.3±0.01 ^{bB}	481.6±0.03 ^{bA}
	2.0	448.8±0.08 ^{cB}	844.8±0.03 ^{cA}
	2.5	766.3±0.05 ^{dB}	1,515±0.05 ^{dA}
	3.0	1,329±0.05 ^{eB}	2,105±0.05 ^{eA}
	3.5	2,071±0.01 ^{fB}	2,675±0.09 ^{fA}

Values are means±SD.

Means with different lowercase letters (a-f) within each column are significantly different ($P<0.05$).

Means with different capital letters (A,B) within each row are significantly different ($P<0.05$).

cosity of thickened juices is greatly influenced by the amount of time between the preparation and service of thickened juices (i.e., setting time). At the 5- and 30-min setting times, the $\eta_{a,50}$ values of all samples were in the range of 96.4~2,230 mPa·s and 154.3~2,775 mPa·s, respectively. At the 5-min setting time, the $\eta_{a,50}$ values of all of the thickened fruit juices were within the viscosity ranges for three of the “consistency” classes established by the National Dysphagia Diet Task Force (NDDTF) [i.e., nectar-like (51~350 mPa·s), honey-like (351~1,750 mPa·s) and pudding-like (>1,750 mPa·s)], whereas the $\eta_{a,50}$ values at the 30-min setting time were within two of NDDTF “consistency” classes (i.e., honey- and pudding-like). These observations indicate the viscosity values of the thickened fruit juices prepared with an XG based-food thickener are strongly influenced by small differences in thickener concentration and setting time. Therefore, the thickener concentration and setting time instructions for preparing thickened fruit juices from commercial food thickeners must be clearly specified, as suggested by Cho et al. (12).

The LST values at the 5- and 30-min setting times were in the range of 4.50~8.78 cm and 3.75~7.66 cm, respectively, and significantly decreased with increasing thickener concentration ($P<0.05$) (Table 2). In addition, the LST values at the 30-min setting time were significantly lower than those at the 5-min setting time ($P<0.05$), indicating that the viscosity of thickened juic-

Table 2. Line-spread distance values of thickened fruit juices at different thickener concentrations (1.0~3.5%) and setting times (5 and 30 min)

Type of juice	Thickener concentration (%)	Line-spread distance (cm)	
		5-min setting time	30-min setting time
Orange	1.0	8.71±0.14 ^{aA}	7.59±0.15 ^{aB}
	1.5	8.02±0.10 ^{bA}	6.33±0.19 ^{bB}
	2.0	7.00±0.01 ^{cA}	5.44±0.07 ^{cB}
	2.5	5.97±0.12 ^{dA}	4.88±0.14 ^{dB}
	3.0	5.21±0.19 ^{eA}	4.00±0.01 ^{eB}
	3.5	4.54±0.07 ^{fA}	3.75±0.12 ^{fB}
Apple	1.0	8.63±0.07 ^{aA}	7.08±0.14 ^{aB}
	1.5	7.58±0.07 ^{bA}	6.17±0.07 ^{bB}
	2.0	6.54±0.14 ^{cA}	5.38±0.12 ^{cB}
	2.5	5.67±0.19 ^{dA}	4.69±0.12 ^{dB}
	3.0	4.93±0.14 ^{eA}	4.19±0.07 ^{eB}
	3.5	4.50±0.12 ^{fA}	3.97±0.06 ^{fB}
Grape	1.0	8.78±0.13 ^{aA}	7.66±0.15 ^{aB}
	1.5	7.86±0.15 ^{bA}	6.38±0.14 ^{bB}
	2.0	6.73±0.13 ^{cA}	5.47±0.08 ^{cB}
	2.5	6.00±0.01 ^{dA}	4.84±0.01 ^{dB}
	3.0	5.21±0.19 ^{eA}	4.13±0.12 ^{eB}
	3.5	4.67±0.07 ^{fA}	3.88±0.10 ^{fB}

Values are means±SD.

Means with different lowercase letters (a-f) within each column are significantly different ($P<0.05$).

Means with different capital letters (A,B) within each row are significantly different ($P<0.05$).

ces increases over a 30-min period. Based on the $\eta_{a,50}$ values, the LST values for the nectar-like, honey-like and pudding-like consistencies were in the range of 7.01~8.78 cm, 4.54~7.00 cm, and less than 4.54 cm, respectively. These findings suggest that a flow distance measurement method can be used to differentiate between the nectar-like, honey-like and pudding-like consistencies of thickened juices that have been prepared with different concentrations of an XG-based thickener (1.0~3.5%) and with different setting times (5 and 30 min).

Fig. 1 shows the relationship between the $\eta_{a,50}$ values measured with a rheometer and the flow distance values measured by the LST. As the flow distance measured by the LST decreased, the $\eta_{a,50}$ value measured with the rheometer increased, indicating that flow distances are inversely related to $\eta_{a,50}$ values. Plots of the $\eta_{a,50}$ values (y-axis) versus the LST measurement (x-axis) at 5- and 30-min setting times revealed a good exponential relationship between the two measurements ($R^2=0.989$ for 5-min setting time; $R^2=0.987$ for 30-min setting time). This exponential relationship means that, at higher thickener concentrations, LST values decreased slowly with increasing thickener concentration. Therefore, the LST may be limited in its ability to determine the viscosity values of thickened juices prepared with higher thickener concentrations. The exponential relationships between the $\eta_{a,50}$ (y) and flow distance (x) values were well described by $y=52663e^{-0.712x}$ at the 5-min setting time

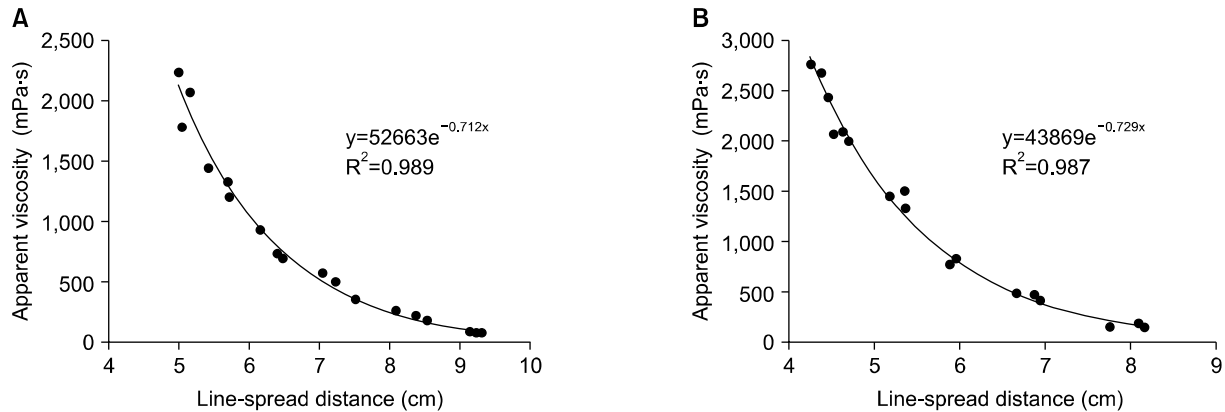


Fig. 1. Relationships of apparent viscosity ($\eta_{a,50}$) and line-spread distances of thickened fruit juices at different setting times (5 and 30 min). (A) 5 min, (B) 30 min.

and $y=43869e^{-0.729x}$ at the 30-min setting time. These relationships ($R^2=0.987\sim 0.989$) were much stronger than those ($R^2=0.86\sim 0.90$) reported in previous studies of other fluids thickened with starch-based thickeners (2,9). However, this study only investigated the relationship between the $\eta_{a,50}$ and flow distance values for one thickener brand (Visco-up); the relationship between the $\eta_{a,50}$ and flow distance values for other commercially available thickener products may be very different.

These results suggest that the LST provides a means to predict the rheometer-measured viscosity of fruit juices thickened with an XG-based thickener and is useful in the broad categorization of thickened fruit juices into therapeutically significant groupings, as suggested by Nicosia and Robbins (2). Therefore, it can be concluded that the LST is a reliable and simple method for evaluating the correct and desirable viscosity for the dysphagia diet, and that the LST may be a valuable clinical tool for caregivers and patients who need to prepare thickened fluids to a target level of consistency.

AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

REFERENCES

- Matta Z, Chambers E 4th, Mertz Garcia J, McGowan Helverson JM. 2006. Sensory characteristics of beverages prepared with commercial thickeners used for dysphagia diets. *J Am Diet Assoc* 106: 1049-1054.
- Nicosia MA, Robbins J. 2007. The usefulness of the line spread test as a measure of liquid consistency. *Dysphagia* 22: 306-311.
- Seo CW, Yoo BS. 2013. Steady and dynamic shear rheological properties of gum-based food thickeners used for diet modification of patients with dysphagia: effect of concentration. *Dysphagia* 28: 205-211.
- Adeleye B, Rachal C. 2007. 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.
- Sopade PA, Halley PJ, Cichero JAY, Ward LC. 2007. Rheological characterisation of food thickeners marketed in Australia in various media for the management of dysphagia. I: water and cordial. *J Food Eng* 79: 69-82.
- Payne C, Methven L, Fairfield C, Bell A. 2011. Consistently inconsistent: commercially available starch-based dysphagia products. *Dysphagia* 26: 27-33.
- Lotong V, Chun SS, Chambers E 4th, Garcia JM. 2003. Texture and flavor characteristics of beverages containing commercial thickening agents for dysphagia diets. *J Food Sci* 68: 1537-1541.
- Budke J, Garcia JM, Chambers E 4th. 2008. Comparisons of thickened beverages using line spread measurements. *J Am Diet Assoc* 108: 1532-1535.
- Mann LL, Wong K. 1996. Development of an objective method for assessing viscosity of formulated foods and beverages for the dysphagic diet. *J Am Diet Assoc* 96: 585-588.
- Paik NJ, Han TR, Park JW, Lee EK, Park MS, Hwang IK. 2004. Categorization of dysphagia diets with the line spread test. *Arch Phys Med Rehabil* 85: 857-861.
- Garcia JM, Chambers E 4th, Matta Z, Clark M. 2005. Viscosity measurements of nectar- and honey-thick liquids: product, liquid, and time comparisons. *Dysphagia* 20: 325-335.
- Cho HM, Yoo WC, Yoo BS. 2012. Steady and dynamic rheological properties of thickened beverages used for dysphagia diets. *Food Sci Biotechnol* 21: 1775-1779.