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Research Note

Effect of pH on Rheological Properties of Dysphagia-Oriented Thickened Water

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ABSTRACT: Flow and dynamic rheological properties of thickened waters prepared with commercial food thickeners were investigated at different pH levels (3, 4, 5, 6, and 7). The commercial xanthan gum (XG)-based thickener (thickener A) and starch-based thickener (thickener B), which have been commonly used in a domestic hospital and nursing home for patients with swallowing difficulty (dysphagia) in Korea, were selected in this study. Thickened samples with both thickeners at different pH levels showed high shear-thinning flow behaviors ($n=0.08\sim0.22$). Thickened samples at pH 3 showed higher n values and lower consistency index (K) values when compared to those at other pH levels. The K values of thickener A increased with an increase in pH level, while the n values decreased, showing that the flow properties greatly depended on pH. There were no noticeable changes in the K values of thickener B between pH 4 and 7. At pH 3, the thickened water with thickener A showed a higher storage modulus (G') value, while that with thickener B showed a lower G'. These rheological parameters exhibited differences in rheological behaviors between XG-based and starch-based thickeners, indicating that the rheological properties of thickened waters appear to be greatly influenced by the acidic condition and the type of food thickener. Appropriately selecting a commercial food thickener seems to be greatly important for the preparation of thickened acidic fluids with desirable rheological properties for safe swallowing.

Keywords: food thickener, pH, thickened water, swallowing difficulty, rheological property

INTRODUCTION

Texture modified foods and thickened fluids are commonly needed for clinical management of patients with dysphagia, which is defined as difficulty or inability to swallow solid and fluid foods, resulting in choking, aspiration, aspiration pneumonia, dehydration, weight loss, and malnutrition (1). A majority of patients with dysphagia are elderly people whose swallowing difficulties arise as a result of the loss of teeth by aging, neuromuscular disorders, cerebrovascular diseases, and others. It is known that swallowing difficulty also influences health and quality of life (2).

There are many ways to manage dysphagia, including feeding tubes and thickened fluids. For long-term management, thickened fluids play an important role for clinicians to address the effects of dysphagia (3). In particular, ensuring thickened fluids having suitable rheological properties is an essential part of dysphagia treatment to promote safe swallowing. It is known that suitable viscosity is vital to treat dysphagia because the fluid food with too low viscosity travels faster into the pharynx and is more likely to enter the airway before swallowing can be initiated (4). Therefore, various commercial food thickeners, which commonly consist of gums and starches as their base materials, have been widely used as additives in drinks to produce thickened fluids with desirable rheological properties for patients with dysphagia to elicit the optimal swallow response due to their simple preparation, convenience, and reasonable cost (5,6). Many researchers have also studied the rheological properties of various thickened fluids containing commercial food thickeners. According to several studies, thickened fluids prepared with food thickeners exhibit rheological properties depending on the thickener brand, type of medium for preparation, thickener concentration, temperature, compliance with recipe instruction, and time between preparation and service of thickened fluids (7-14). In practice, food thickeners may be applied to various drinks having a wide range of pH; in particular, several common beverages, such as fruits juices, carbonated drinks, and coffee, are acidic ($pH<7$). Therefore, it is necessary to determine the rheological properties of thickened waters as a function of pH because the thick-

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ened fluids prepared with food thickeners at acidic pH levels can produce different rheological properties. In the present study, commercial gum- and starch-based food thickeners were selected to prepare the thickened waters because they are widely known as favorable food thickeners used in a domestic hospital and nursing home in Korea. The main objective of this study was to investigate the effect of pH on steady and dynamic rheological properties of thickened waters prepared with commercial food thickeners marketed in Korea.

MATERIALS AND METHODS

Materials and sample preparation

Two commercially available food thickeners based on xanthan gum (XG) (thickener A) and starch (thickener B) marketed in Korea were selected; thickener A was a composite of xanthan gum, guar gum and dextrin, and thickener B was a composite of starch, xanthan gum, locust bean gum, and dextrin. To investigate the effect of pH on thickened waters under a controlled range of acidic pH levels (pH 3∼6), bottled water (JPDC, Jeju, Korea) was used as a dispersing medium to which powdered citric acid (Jungbunzlauer Austria AG, Wein, Austria) was added to achieve the desired pH levels. The thickened water samples were prepared by mixing the food thickeners at a 2% concentration with the waters having different pH levels. The amount of thickener used in this study was consistent with clinical practice guidelines based on the manufacturer's recommendations for producing honey-like fluids. Thickened waters were prepared at room temperature (22°C) with stirring for 1 min. Mild agitation was provided by a magnetic stirrer. The thickened water sample was immediately transferred to the rheometer plate at 22°C to measure the rheological properties.

Rheological measurements

Rheological properties were taken on a Carri-Med CSL^2 100 rheometer (TA Instruments, New Castle, DE, USA), using a parallel plate system (4 cm diameter) at a gap of 500 μm. Steady flow data of the thickened waters 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 on the bottom plate. Data (shear stress and shear rate) were fitted to the well-known power law (Eq. 1) and Casson (Eq. 2) models to describe the flow properties of the samples.

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

$$\sigma^{0.5}=K_{oc}+K_{c}\dot{\gamma}^{0.5} \quad \text{(Eq. 2)}$$

Where σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), 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 the linear regression of the square roots of shear rate-shear stress data.

Dynamic rheological data were obtained from frequency sweeps over the range of 0.63∼62.8 $rad{\cdot}s^{-1}$ at 2% strain using a small-amplitude oscillatory rheological measurement. Frequency sweep tests were also performed at 22°C. TA Rheometer Data Analysis software (version VI. 1.76, TA Instruments) was used to obtain the experimental data and to calculate the storage (or elastic) modulus (G') and loss (or viscous) modulus (G"). All samples were allowed to rest at 22°C for 5 min to relax the samples before the rheological measurements were taken. The rheological measurements were performed in triplicate.

Statistical analysis

The results are reported as the mean value with a standard deviation of triplicate analyses for each sample. Analysis of variance (ANOVA) and Duncan's test were used to establish the significance of differences among the mean values at the 0.05 significance level. Statistical analyses were performed using the Statistical Analysis System program (version 9.2) (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

Fig. 1 shows the flow behavior of thickened waters prepared with different food thickeners (thickener A and B) at different pH levels. It was found that there was a clear trend of pseudoplasticity (shear thinning behavior) and all of the samples had a non-Newtonian nature with yield stress. The experimental results of shear stress (σ) and shear rate ($\dot{\gamma}$) were well fitted to the simple power law model (Eq. 1) with high determination coefficients (R^2=0.96∼0.99) (Table 1). All thickened waters had high shear-thinning behaviors with low n values (0.08∼0.22). In particular, the n value of thickener A (0.08∼0.11) was much lower than that of thickener B (0.16) at higher pH levels (pH 5∼7). Such lower n values of thickener A could possibly be attributed to the shear-thinning character of XG due to its unique rigid rod-like conformation and high-molecular-weight aggregate (15). The n values of thickener A also increased with a decrease in pH, whereas no significant effect of pH was observed on n values of thickener B between pH 4 and 7. The thickened water samples with both thickeners at pH 3 showed much higher n values (0.21∼0.22) compared to those at other pH levels. The lower degree of shear

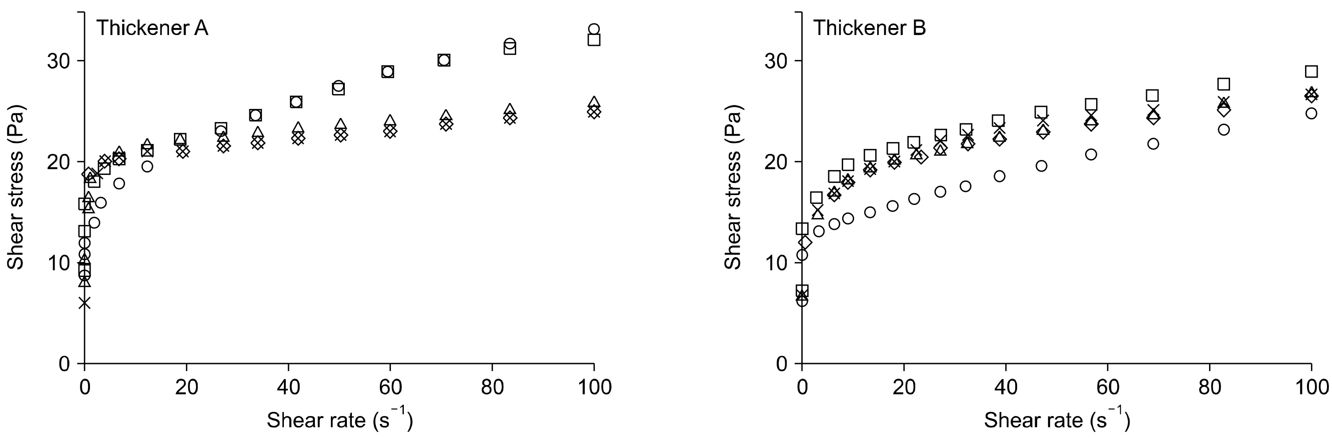

Fig. 1. Shear stress-shear rate plots for thickened water samples prepared with different thickeners at different pH levels: ○, pH 3; □, pH 4; △, pH 5; ◇, pH 6; X, pH 7. Thickener A, xanthan gum-based thickener; Thickener B, starch-based thickener.

Table 1. Rheological properties of thickened waters prepared with different thickeners at different pH levels

Thickener[1)]	pH	Power law			Casson yield stress (δ_{oc}, Pa)
		K (Pa·s^n)	n (−)	R^2	
A	3	11.2±0.08[c2)]	0.22±0.01[a]	0.97	14.1±0.25[e]
	4	12.3±0.45[c]	0.17±0.00[b]	0.97	15.1±0.14[d]
	5	15.3±0.08[b]	0.11±0.01[c]	0.97	16.5±0.35[c]
	6	16.0±0.01[ab]	0.09±0.00[cd]	0.96	18.1±0.50[b]
	7	16.6±0.22[a]	0.08±0.00[d]	0.96	19.8±0.66[a]
B	3	8.24±0.04[b]	0.21±0.01[a]	0.96	9.94±0.74[b]
	4	13.1±0.21[a]	0.16±0.00[b]	0.99	14.3±0.47[a]
	5	12.7±0.62[a]	0.16±0.00[b]	0.99	14.5±0.81[a]
	6	12.5±0.38[a]	0.16±0.00[b]	0.99	14.3±0.11[a]
	7	12.6±0.35[a]	0.16±0.01[b]	0.99	14.4±0.79[a]

Values are means±standard deviation.
[1)]Thickener A, xanthan gum-based thickener; Thickener B, starch-based thickener.
[2)]Values with different letters (a-e) in same thickener are significantly different ($P<0.05$).

thinning (high n value) behavior indicates that the thickened waters at higher acidic conditions can increase the organoleptic sliminess, as noted by Cho et al. (16). In general, it is known that the high degree of shear thinning (low n value) behavior means less sliminess in the mouth (17). In comparison to thickener B, thickener A exhibits a less slimy mouthfeel except for higher acidic conditions (pH 3 and 4).

In general, it is known that K and δ_{oc} values obtained from the power law and Casson models are flow rheological parameters for the flow velocity of a food bolus and the perceived ease of swallowing (16,18). In particular, the yield stress of thickened fluids means the stress required to break down the structure of fluid and initiate flow. It is also known that the yield stress is closely related to elastic behavior (19). Thus, thickened fluids having high yield stress require more pressure from the tongue to swallow (20). Significant differences were observed in the flow rheological parameters (K and σ_{co}) values of the thickened waters with thickener A at different pH levels ($P<0.05$) (Table 1). However, no significant change in K and δ_{oc} values with thickener B, except for samples at pH 3, was observed when the pH level was decreased from pH 7 to pH 4. In particular, there were greater reductions in K and δ_{oc} values at pH 3 compared to other pH levels, indicating that the reduced rheological parameters can be due to the greater conformation changes in XG (21) and a more damaged granule structure in starch in the higher acidic conditions (22,23). Such drastic decrease in K and δ_{oc} values in starch-based thickener (thickener B) at pH 3 can also be due to starch hydrolysis promoted by the severe acidic treatment, as noted by Mali et al. (23) and Rogols (24) who showed that severe acidic conditions decreased the viscosity of starches. In general, it is known that pH has little effect on the viscosity of XG solutions over the range encountered in food systems and also that their high viscosity values are maintained over a wide pH range, with some reductions at extreme pH levels (25). However, in case of thickened water samples with XG-based thickener (thickener A), a progressive decrease in K values was observed as the pH decreased from 6 to 3, and in particular, the drastic reduction in K value was found at higher acidic conditions (pH 3 and 4). Several researchers also reported similar response at extreme pH levels, indicating that XG molecules were degraded to some extents at lower pH levels (21,22,25,26). Sworn and Kerdavid (25) reported that the pH sensitivity of the viscosity can be expected because changes in the pH will result in changes to the charge density of XG which will in turn influence the molecular associations between XG molecules. They also explained that reducing pH progressively converts the carboxylate groups from the ionized to the un-ionized form ($COO^- + H^+ = COOH$), with consequent suppression of electrostatic repulsion between the XG side chains, resulting in a more compact molecular shape, which could explain the observed reduction in K values at lower pH levels. From these observations, it was found that the pH level in the thickened water samples with thickener A has an effect on the K and σ_{co} values and also that the difference in flow properties of thickened waters can be due to the different compositions of the food thickeners in acidic conditions.

In general, it has been noted that the dynamic rheological parameters, such as G' and G", are also relevant to the safe and easy swallowing of food bolus (1,14,19,27). Thickened water samples with thickener A at different pH levels showed much higher dynamic moduli (G' and G") values than those with thickener B (Table 2), indicating that the addition of XG-based thickener enhanced the viscoelastic properties of thickened waters having a wide pH range. In addition, dynamic moduli values of thickener A increased with a decrease in pH level, showing patterns opposite to those observed for K values (Table 1). In contrast, in the thickened water samples with thickener B, there were not much differences in G' values between pH 5 and pH 7, and in G" values among all pH levels, indicating that the pH had a very small effect on dynamic moduli values compared to those of thickener A. The thickened water with thickener B at pH 3 showed much lower G' than the other samples, indicating that starch granule structures were damaged to some extent in severe acidic conditions, as previously described. In general, changes in G' of thickener B followed patterns similar to those observed for K values. In contrast, the thickened water with thickener A at pH 3 showed much higher G' than the other samples. Such sharp increase in elastic properties may be attributed to an increase of intermolecular associations between XG molecules due to less negative charges ($-COO^-$) at higher acidic conditions, thereby promoting a network formation, as noted by Li and Hou (28). This network formation can cause an increase in the elastic properties of thickened water samples with thickener A, evidenced by the much higher G' compared to G". These results indicate that pH has different viscoelastic effects depending on the type of food thickeners. The findings of the present study demonstrates that detailed manufacturer's guidelines for preparing thickened acidic fluids from food thickeners are needed for the management of dysphagia. Furthermore, these results suggest that the dependence of rheological parameters on pH and thickener type can provide both clinicians and patients with valuable information to prepare the thickened acidic fluid products with desirable rheological properties for easy and safe swallowing. A limited number of commercial food thickeners and only bottled water without solids as a dispersing medium were used in this study. Therefore, additional studies are needed on various commercial food thickeners and acidic drinks with different compositions to extrapolate the results of this study.

Table 2. Storage modulus (G') and loss modulus (G") at 6.28 $rad \cdot s^{-1}$ of thickened waters prepared with different thickeners at different pH levels (unit: Pa)

Thickener[1)]	pH	G'	G"
A	3	73.9±0.05[a2)]	15.8±0.12[a]
	4	58.7±0.87[b]	14.3±0.40[b]
	5	56.1±0.23[c]	13.1±0.26[c]
	6	55.7±0.36[c]	12.9±0.08[c]
	7	52.7±0.40[d]	12.6±0.30[c]
B	3	31.6±0.08[c]	7.11±0.14[a]
	4	37.1±0.47[a]	7.23±0.25[a]
	5	34.3±0.83[b]	7.05±0.19[a]
	6	34.0±0.29[b]	7.02±0.23[a]
	7	34.8±0.80[b]	6.98±0.16[a]

Values are means±standard deviation.
[1)]Thickener A, xanthan gum-based thickener; Thickener B, starch-based thickener.
[2)]Values with different letters (a-d) in same thickener are significantly different ($P<0.05$).

AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

REFERENCES

1. Cho HM, Yoo B. 2015. Rheological characteristics of cold thickened beverages containing xanthan gum-based food thickeners used for dysphagia diets. *J Acad Nutr Diet* 115: 106-111.
2. Smith CH, Jebson EM, Hanson B. 2014. Thickened fluids: investigation of users' experiences and perceptions. *Clin Nutr* 33: 171-174.
3. Mills RH. 2008. Dysphagia management: using thickened liquids. *The ASHA Leader* 13: 12-13.
4. Glassburn DL, Deem JF. 1998. Thickener viscosity in dysphagia management: variability among speech-language pathologists. *Dysphagia* 13: 218-222.
5. Pelletier CA. 1997. A comparison of consistency and taste of five commercial thickeners. *Dysphagia* 12: 74-78.

6. Stanek K, Hensley C, Van Riper C. 1992. Factors affecting use of food and commercial agents to thicken liquids for individuals with swallowing disorders. *J Am Diet Assoc* 92: 488-490.
7. 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.
8. 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.
9. Garcia JM, Chambers E 4th, Matta Z, Clark M. 2008. Serving temperature viscosity measurements of nectar- and honey-thick liquids. *Dysphagia* 23: 65-75.
10. Sopade PA, Halley PJ, Cichero JAY, Ward LC, Hui LS, Teo KH. 2008. Rheological characterisation 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.
11. Sopade PA, Halley PJ, Cichero JAY, Ward LC, Liu J, Varliveli S. 2008. 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.
12. O'Leary M, Hanson B, Smith C. 2010. Viscosity and non-Newtonian features of thickened fluids used for dysphagia therapy. *J Food Sci* 75: E330-E338.
13. Payne C, Methven L, Fairfield C, Bell A. 2011. Consistently inconsistent: commercially available starch-based dysphagia products. *Dysphagia* 26: 27-33.
14. Kim SG, Yoo B. 2015. Viscosity of dysphagia-oriented cold-thickened beverages: effect of setting time at refrigeration. *Int J Lang Commun Disord* 50: 397-402.
15. Urlacher B, Noble O. 1997. Xanthan gum. In *Thickening and Gelling Agents for Food*. Imeson A, ed. Chapman & Hall, London, UK. p 284-311.
16. Cho HM, Yoo W, Yoo B. 2012. Steady and dynamic rheological properties of thickened beverages used for dysphagia diets. *Food Sci Biotechnol* 21: 1775-1779.
17. Szczesniak AS, Farkas E. 1962. Objective characterization of the mouthfeel of gum solutions. *J Food Sci* 27: 381-385.
18. Steele CM, Van Lieshout PH, Goff HD. 2003. The rheology of liquids: a comparison of clinicians' subjective impressions and objective measurement. *Dysphagia* 18: 182-195.
19. Seo CW, Yoo B. 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.
20. Reimers-Neils L, Logemann J, Larson C. 1994. Viscosity effects on EMG activity in normal swallow. *Dysphagia* 9: 101-106.
21. López MJ, Vargas-García MC, Suarez-Estrella F, Moreno J. 2004. Properties of xanthan obtained from agricultural wastes acid hydrolysates. *J Food Eng* 63: 111-115.
22. Miladinov VD, Hanna MA. 1996. Apparent viscosity of co-extruded starch and xanthan gum. *Ind Crops Prod* 5: 183-188.
23. Mali S, Ferreros C, Redigonda V, Beleia AP, Grossmann MVE, Zaritzky NE. 2003. Influence of pH and hydrocolloids addition on yam (*Dioscorea alata*) starch pastes stability. *LWT–Food Sci Technol* 28: 205-211.
24. Rogols S. 1986. Starch modifications: a view into the future. *Cereal Food World* 31: 869-873.
25. Sworn G. 2000. Xanthan gum. In *Handbook of Hydrocolloids*. Phillips GO, Williams PA, eds. CRC Press, New York, NY, USA. p 103-115.
26. Sea-kang V, Suphantharika M. 2006. Influence of pH and xanthan gum addition on freeze-thaw stability of tapioca starch pastes. *Carbohyd Polym* 65: 371-380.
27. Ishihara S, Nakauma M, Funami T, Odake S, Nishinari K. 2011. Swallowing profiles of food polysaccharide gels in relation to bolus rheology. *Food Hydrocolloid* 25: 1016-1024.
28. Li H, Hou W. 2011. Influences of pH and electrolyte on the rheological properties of aqueous solution of exopolysaccharide secreted by a deep-sea mesophilic bacterium. *Food Hydrocoll* 25: 1547-1553.