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Effect of thickening agent and temperature on rheological properties of thickened pandan juice

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ABSTRACT

Hydrocolloids are extensively used for dietary modification by individuals suffering from dysphagia. The effect of xanthan gum (Xan) or guar gum (GG) on the rheological properties of pasteurized pandan juices at different temperatures determined. Thickened pandan juices containing Xan or GG revealed shear-thinning behavior at all concentrations. Results showed that viscosity of thickened pandan juices increased at higher Xan or GG concentrations but decreased with increasing temperature. Significant changes in color values were found in all thickened pandan juices. As concentrations of Xan or GG increased L* and -a* values of thickened pandan juices decreased, whereas b* values increased. Findings suggested that the appropriate selection of a commercial food thickening agent for use in pasteurized pandan juices was necessary for individuals with dysphagia.

Keywords: thickening agent; temperature; rheological property; thickened pandan juice

1. INTRODUCTION

Difficulty in swallowing (or dysphagia) can occur at any age but incidence increases with advancing years. Prevalence of swallowing problems is 4.0% among adults aged ≥18 years and 15.0-33.7% for those aged ≥65 years (Baijens et al., 2016; Bhattacharyya, 2014; Roden and Altman, 2013). Dysphagic patients experience higher mortality, with lengthy hospitalization periods increasing healthcare utilization and costs (Attrill et al., 2018). Dysphagia can result from several pathologies, such as Parkinson's disease and strokes, and is expressed as difficulties in coordination of mastication, breathing and swallowing to allow the bolus to enter the esophagus rather than the trachea (Cichero, 2013; Takizawa et al., 2016). Dysphagia can also lead to serious consequences including malnutrition, dehydration, aspiration, pneumonia and even mortality (Sura et al., 2012; Roden and Altman, 2013). Thus, a well-established management approach for dysphagia involves modifying fluid viscosity by adding a thickening agent to reduce the chance of entrance to the airway (Newman et al., 2016).

Thickening agents used to treat dysphagia include modified starch and gums (Seo and Yoo, 2013). Drinks thickened with gums have recently gained popularity over modified starch, which provided a powdery taste with unstable viscosity (Vilardell et al., 2016). Previous studies found that low acceptability of excessive use of modified liquids increased the risk of dehydration and nutritional deficiencies in individuals with dysphagia (Cichero, 2013; Sura et al., 2012). Hence, the viscosity of liquids is very important when modifying drinks for individuals with dysphagia.

Thickened liquids are divided into four categories by the National Dysphagia Diet (NDD) guideline, including thin, nectar or syrup, honey or custard and pudding or spoon-thick with 1-50, 51-350, 351-1,750 and >1,751 mPa.s, respectively). These values are based on viscosity at a shear rate of 50 s^{-1}, which represents the shear rate operating in the oral cavity (Payne et al., 2011). Most available information on the rheological properties of thickened drinks focused on viscosity (Zargaraan et al., 2013), few studies have been done on the rheological properties of thickened juice added with thickening agents (Cho and Yoo, 2015; Ruihuan et al., 2017).

Pandan (*Pandanus amaryllifolius* Roxb.) leaves are used as a coloring agent for various recipes in Asian countries (Faras et al., 2014), thereby improving flavor, appearance and value of the final product. The combination of characteristic flavors and suitable physical properties of thickened drinks results in increased motivation and physiological drive to consume thickened drinks by individuals with dysphagia. Previous studies investigated the effect of commercially available mixtures of various gum-based food thickeners on many products (Cho and Yoo, 2015; Seo and Yoo, 2013; Koedcharoenporn and Siriwongwilaichat, 2019). However, a few research have addressed the rheological properties of specific thickeners used in juice. Furthermore, the effect of serving temperature (15°C), room temperature (25°C) and temperature during swallowing (35°C) on the viscosity of thickened juice has received less attention. Therefore, this research aimed to study the effect of type (xanthan gum or guar gum) and concentration of thickener (0.25%, 0.50% and 0.75% w/w) on the rheological properties of thickened pandan juice. The effect of temperature on the viscosity of the thickened juice was also recorded.

2. MATERIALS AND METHODS

2.1 Materials

Pandan leaves and sucrose (white sugar) were obtained from a supermarket in Bangkok, Thailand. Two commercial food thickeners, xanthan gum 402 (Xan) and guar gum DHV 150 (GG), were obtained from C.E. Roeper GmbH (Hamburg, Germany) and Dabur India Limited (Rajasthan, India), respectively. All ingredients were of food-grade purity.

2.2 Pasteurized pandan juice preparation

Selected fresh dark green pandan leaves, length 35-40 cm, were washed and drained to remove excess water. The pandan leaves were cut into small pieces of around 10 cm length and boiled in water at 100°C for 15 min to provide flavor and color. The ratio of pandan leaves to water was 1:4 by weight. Thickener dispersions (0.25%, 0.50% and 0.75% w/w) of Xan or GG were prepared by dispersing the thickeners in pasteurized pandan juice, with continuous stirring at room temperature for 30 min using a magnetic stirrer. Sugar was added to adjust the total soluble solid of pasteurized pandan juice to 10°Brix (Kobus et al., 2015) and heated at 85±1°C for 5 min. The juices were filled into plastic bottles (polypropylene; PP) at 82±1°C. Packaging was sealed and rapidly cooled in an ice-water bath to ambient temperature, followed by cold storage at 8°C. The quality and rheological properties of thickened pandan juice were determined.

2.3 Rheological measurement

The steady shear viscosity of the thickened pandan juices with Xan or GG at 0.25%, 0.50% and 0.75% were determined as a function of shear rate for a range of 1.12 to 100 s^{-1} at 15°C, 25°C and 35°C using a rheometer (Gemini 200 HR Nano, Malvern, UK) with a parallel-plate (40-mm diameter) at a gap of 500 μm. All samples were maintained at constant temperature for at least 5 min before viscosity determination. Shear stress and shear rates of thickened pandan juices with different Xan or GG concentrations were plotted to show the behavior of fluid and evaluated by the power law model as shown in Equation (1):

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

where τ = shear stress (Pa), $\dot{\gamma}$ = shear rate (s^{-1}), K = consistency index ($Pa.s^n$) and n = flow behavior index (Steffe, 1996; Tunnarut and Pongsawatmanit, 2018).

The effect of temperature on fluid viscosity at a specified shear rate of 50 s^{-1} was also described by the Arrhenius-type equation as shown in Equation (2):

$$\ln \eta_a = \ln \eta_\alpha + [E_a/RT] \quad (2)$$

where η_a = viscosity at the specific shear rate, η_α = frequency factor, E_a = activation energy (J/mol), R = the gas constant (8.314 J/mol K) and T = absolute temperature (K).

2.4 Color measurement

Color of the thickened pandan juices with Xan or GG was measured using a colorimeter (Hunter Lab, Colorflex-45-2, USA) with standard illuminant D65, observer 10° and measuring area. Each sample was carefully poured into a special glass sample cup with a cover at 1.2 cm depth of sample (30 mL). The CIE system was reported as L^* (varying from 0 = black to 100 = white), indicating the brightness value of color, a^* (red (+) to green (-)) and b^* (blue (-) to yellow (+)).

2.5 Total soluble solid measurement

Total soluble solid (TSS) content of pasteurized pandan juice with Xan or GG was determined using a refractometer (N1, °Brix range of 0-32; Atago, Tokyo, Japan). The TSS was measured by placing a drop of pasteurized pandan juice on the prism of the refractometer and expressed as °Brix.

2.6 Statistical analysis

The experimental design used a completely randomized design (CRD) and all analyses were performed in triplicate. Data collected were subjected to analysis of variance (ANOVA) using SPSS software (V.18, SPSS Co., Ltd., Bangkok, Thailand) and Duncan's multiple range test for measuring significant differences ($p \leq 0.05$). Pearson's correlation matrix between the hydrocolloids (Xan or GG) and temperature on consistency index, flow behavior index and viscosity of the thickened pandan juice was evaluated.

3. RESULTS AND DISCUSSION

3.1 Viscosity of thickened pandan juice

Viscosity was examined as a function of shear rate of thickened pandan juice (Xan or GG) for concentrations 0.25%, 0.50% and 0.75% at 15°C, 25°C and 35°C. Viscosity of all thickened pandan juices increased with an increase in Xan or GG concentrations. Decrease in viscosity with increasing shear rate for all thickened pandan juices revealed shear-thinning behavior (Figure 1). This observation was consistent with thickened fluids or beverages of various types of materials to treat dysphagia (Germain et al., 2006; Sopade et al., 2007). Viscosity of thickened pandan juice containing 0.25% and 0.50% Xan was higher than samples containing 0.25% and 0.50% GG at the same shear rates for 15°C, 25°C and 35°C. However, viscosity of thickened pandan juice containing 0.75% GG was higher than samples containing 0.75% Xan for shear rate over 15.57, 31.22 and 39.37 s^{-1} at 15°C, 25°C and 35°C, respectively. The viscosity at shear rate over 39.37 s^{-1} for thickened pandan juice containing 0.75% GG was greater than those of 0.75% Xan at 15°C, 25°C and 35°C. This indicated that viscosity of thickened pandan juice depended on type and concentration of thickener, temperature and shear rate. Our results concurred with Seo and Yoo (2013) who reported that rheological properties were related to the type of hydrocolloid (Xan and Xan-GG mixture) and gum concentration. Park et al. (2014) evaluated various levels of gum-based thickeners (Xan and GG) and found that the viscosity of GG thickened liquids changed more rapidly than Xan as the concentration increased, while Sopade et al. (2008) reported that GG-based thickeners gave the most viscous fluids.

Rheograms (shear stress as a function of shear rate) of thickened pandan juice samples prepared from different hydrocolloids (Xan or GG) and concentrations (0.25%, 0.50% and 0.75%) were plotted (data not shown). The power law model, as Eq. (1), was utilized to demonstrate flow behaviors of thickened pandan juices with different Xan or GG concentrations at different temperatures because of the high coefficient of determination (R^2 = 0.91-1.00), as shown in Table 1. The consistency index (K) of all thickened pandan juices increased with increasing Xan or GG concentrations (p≤0.05) but decreased with increasing temperature. Moreover, K values of thickened pandan juice containing Xan were higher than those containing GG at the same concentration and determined temperatures. Addition of Xan or GG in pasteurized pandan juice also altered the flow behavior index (n) to non-Newtonian behavior, with n values as low as 0.11-0.26 and 0.49-0.93 for thickened pandan juice containing Xan and GG, respectively (p≤0.05). Results exhibited that n values of all thickened pandan juices decreased with increasing Xan or GG concentration (p≤0.05), whereas increased with increasing temperature. The shear-thinning behavior of thickened pandan juice containing Xan was higher than samples containing GG at 15°C, 25°C and 35°C. Results displayed that Xan or GG improved the viscosity of thickened pandan juice and the flow behavior became more pseudoplastic (shear-thinning). Seo and Yoo (2013) reported that shear-thinning behavior of Xan at low concentrations was more pronounced, compared to other gums. The GG solution gave higher n value, compared to Xan. Therefore, the sliminess of thickened pandan juice containing GG was due to its higher n value.

Pearson's correlation coefficients (r) were applied to quantify the relationship between hydrocolloid (Xan or GG) concentration, K and n parameters from the power law model and viscosity at 50 s^{-1}. Results indicated that Xan concentration had strong positive correlation for K (0.992) and viscosity (0.970) and negative correlation for n (-0.881, Table 2, p≤0.01). GG concentration showed strong positive correlation for K (0.869) and viscosity (0.957) and negative correlation for n (-0.953, Table 2, p≤0.01). Thus, an increase in Xan or GG concentration of thickened pandan juices resulted in increasing K and viscosity, while decreasing n value. This indicated that the results were consistent with findings from Table 1.

3.2 Temperature dependence of thickened pandan juice rheological behavior

As discussed above, the viscosity of all thickened pandan juices decreased with increasing temperature (15-35°C) (Figure 1). Viscosity at shear rate 50 s^{-1} was selected to plot against temperature, representing the shear rate operating in the oral cavity, although in reality there was a wide range of shear rates from 1 to 1,000 s^{-1} (Payne et al., 2011). Viscosity distinctly decreased with an increase in temperature for thickened pandan juices containing 0.25%, 0.50% and 0.75% Xan or GG (Figure 2A). Influence of temperature on the viscosity of thickened pandan juice was calculated using the Arrhenius-type equation in Equation (2) by plotting $\ln \eta_a$ with $1/T$ (Figure 2B). Viscosity changes of all thickened pandan juices with different Xan or GG concentrations according to the Arrhenius-type equation showed high coefficient of determination (R^2>0.85). The plotting slopes were used to calculate the activation energy (E_a), indicating the sensitivity of viscosity to temperature. The E_a values of thickened pandan juice containing Xan (0.25%-0.75%) and GG (0.25%-0.75%) were 5, 4, 2 kJ/mol and 19, 12, 6 kJ/mol, respectively. Results indicated that addition of Xan or GG increased the viscosity and also the thermal stability of thickened pandan juices. Thermal stability of thickened pandan juices containing Xan was higher than those containing GG at the same concentration. Temperature was an important factor affecting the rheological properties of liquid and semiliquid materials, especially thickened liquids. Our results suggested that the viscosity of thickened pandan juice at serving temperature (15°C) was not the same as the viscosity at room temperature (25°C) and at temperature during swallowing (35°C) provided to individuals with dysphagia. Results were consistent with Adeleye and Rachal (2007) who reported that viscosities of ready-to-serve commercially packaged thickened beverages were significantly lower at elevated temperatures of 20°C compared to temperatures below 10°C. Most gum solutions showed decreasing viscosity with increasing temperature, with the exception of xanthan gum that had a slight change in viscosity for temperature ranging from 0°C to 100°C (Garcia et al., 2008). Results indicated that viscosity values of thickened pandan juice ranged from 31 to 598 mPa.s, based on the viscosity at a shear rate of 50 s^{-1}. Therefore, the viscosity of all thickened pandan juices could be divided into three categories as thin (1-50 mPa.s), nectar or syrup (51-350 mPa.s) and honey or custard (351-1,750 mPa.s). Viscosity ranges used to classify thickened pandan juices with different concentrations of Xan and GG at different temperatures are shown in Table 3. Three, nine and six samples were within the range of thin, nectar or syrup and honey or custard class, respectively. These distinctions could be used to meet specific needs of individuals with dysphagia, depending on swallowing ability.

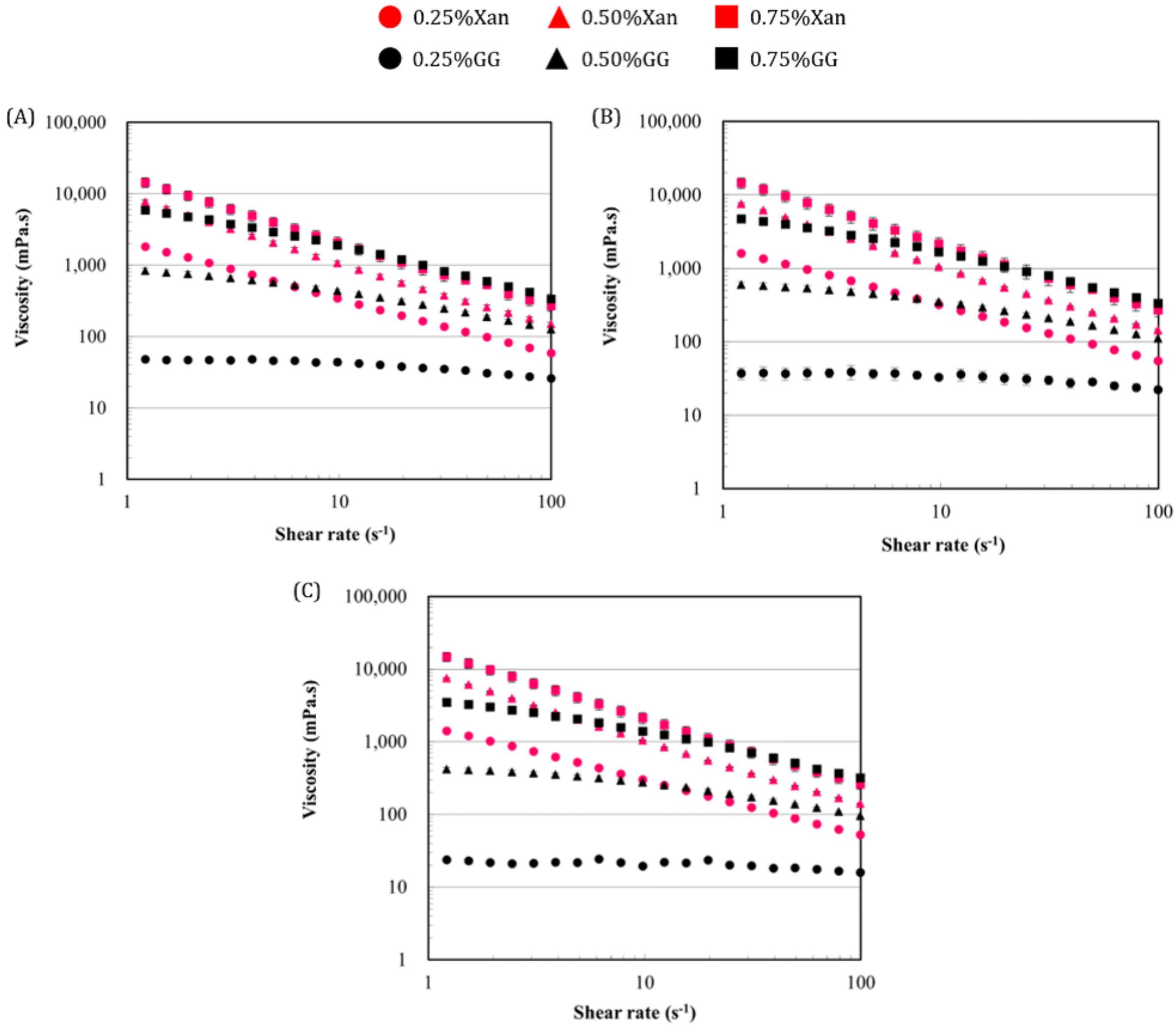

Figure 1. Viscosity of thickened pandan juice containing Xan or GG determined at: (A) 15°C; (B) 25°C and (C) 35°C

Table 1. Consistency coefficient (*K*), flow behavior index (*n*) and R^2 of thickened pandan juice containing Xan or GG determined at 15°C, 25°C and 35°C, shear rates = 1.12 to 100 s^{-1}

Sample	***K* (Pa.s^n)**			***n* (-)**			**R^2**		
	15°C	**25°C**	**35°C**	**15°C**	**25°C**	**35°C**	**15°C**	**25°C**	**35°C**
0.25%Xan	2.06± 0.04^{d,A}	1.84± 0.05^{d,B}	1.63± 0.04^{d,C}	0.22± 0.00^{d,C}	0.24± 0.00^{d,B}	0.26± 0.00^{b,A}	1.00	1.00	1.00
0.50%Xan	8.12± 0.57^{b,ns}	7.79± 0.34^{b,ns}	7.63± 0.14^{b,ns}	0.13± 0.00^{e,ns}	0.13± 0.01^{e,ns}	0.13± 0.00^{e,ns}	0.92	0.91	0.92
0.75%Xan	16.43± 0.26^{a,A}	16.29± 0.67^{a,A}	14.63± 0.51^{a,B}	0.11± 0.02^{e,ns}	0.12± 0.02^{e,ns}	0.12± 0.02^{e,ns}	0.95	0.93	0.92
0.25%GG	0.06± 0.01^{e,A}	0.05± 0.00^{e,A}	0.02± 0.00^{e,B}	0.85± 0.08^{a,ns}	0.86± 0.01^{a,ns}	0.93± 0.00^{a,ns}	0.98	0.97	0.99
0.50%GG	0.78± 0.07^{e,A}	0.55± 0.05^{e,B}	0.38± 0.02^{e,C}	0.68± 0.01^{b,C}	0.73± 0.02^{b,B}	0.78± 0.01^{b,A}	0.99	0.99	0.99
0.75%GG	5.92± 0.81^{c,A}	4.86± 0.86^{c,AB}	3.52± 0.60^{c,B}	0.49± 0.01^{c,C}	0.53± 0.01^{c,B}	0.57± 0.01^{c,A}	0.96	0.96	0.97

Note: ^{a,b,} Values in the same column followed by different letters are significantly different ($p \leq 0.05$).
^{A,B,} Values in the same row followed by different letters are significantly different ($p \leq 0.05$).
ns = not significant ($p > 0.05$)
R^2 = Coefficient of determination

Table 2. Correlation matrix between hydrocolloid (Xan or GG) concentration, consistency coefficient (*K*), flow behavior index (*n*) and viscosity at 50 s^{-1} selected shear rate of thickened pandan juice

	Xan				**GG**			
	Concentration	***K***	***n***	**Viscosity**	**Concentration**	***K***	***n***	**Viscosity**
Concentration	1.000				1.000			
K	0.992**	1.000			0.869**	1.000		
n	-0.881**	-0.846**	1.000		-0.953**	-0.901**	1.000	
Viscosity	0.970**	0.987**	-0.788**	1.000	0.957**	0.954**	-0.958**	1.000

Note: **Correlation is significant at the 0.01 level (2-tailed), $p \leq 0.01$

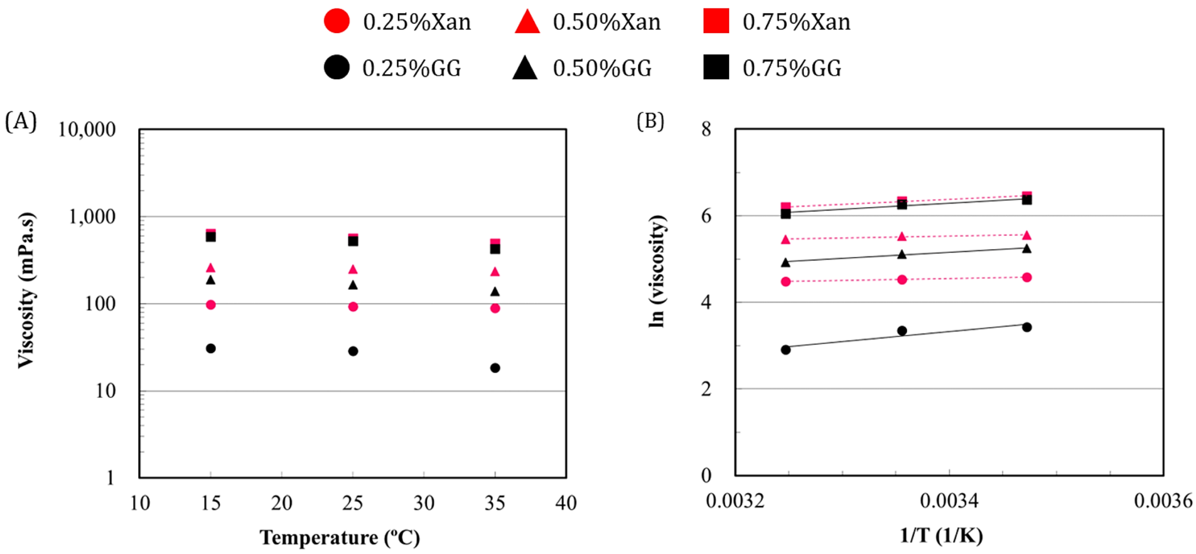

Figure 2. Temperature dependence at 50 s^{-1} shear rate of (A) viscosity and (B) Arrhenius plots of thickened pandan juice containing Xan or GG

Table 3. Categories of thickened pandan juice based on viscosity at shear rate of 50 s^{-1}

Category	**Sample**
Thin (1-50 mPa.s)	0.25% GG at 15°C, 25°C and 35°C
Nectar or syrup (51-350 mPa.s)	0.25% Xan at 15°C, 25°C and 35°C 0.50% Xan at 15°C, 25°C and 35°C 0.50% GG at 15°C, 25°C and 35°C
Honey or custard (351-1,750 mPa.s)	0.75% Xan at 15°C, 25°C and 35°C C 0.75% GG at 15°C, 25°C and 35°C

Note: National Dysphagia Diet Task Force, (2002) (NDDTF) category based on viscosity at shear rate of 50 s^{-1} and standard temperature 25°C.

3.3 Color values of thickened pandan juice

Significant changes were recorded ($p \leq 0.05$) for color values of thickened pandan juices with different concentrations of Xan or GG (Table 4). As concentration of thickener increased, L^* values of thickened pandan juices containing Xan were darker than samples containing GG. Change of a^* value for thickened pandan juices containing GG varied in a very broad range with increasing concentration. However, there was no significant ($p > 0.05$) difference in greenness ($-a^*$) of thickened pandan juices containing Xan or GG at the same concentration. Moreover, our findings showed that b^* values of thickened pandan juices containing Xan were yellower than samples containing GG as concentration of thickener increased. Addition of Xan provided a cream-colored powder greater than GG, which was white to cream-colored. Therefore, the visual color of thickened pandan juices was affected by type and concentration of thickener and dispersing media. Pandan leaves were used to naturally improve color and flavor in juices for individuals with dysphagia. Moreover, pandan leaves were used in cooking and also as a traditional herbal medicine for several diseases in Southeast Asian countries (Wongpornchai, 2006).

4. CONCLUSION

The viscosity of all thickened pandan juices increased with increasing Xan or GG concentrations but decreased with increasing temperature. Rheological parameters (K and n) obtained from the power law model in hydrocolloids were greatly influenced by the type and concentration of hydrocolloids used in thickened pandan juices. Our results revealed that Xan or GG addition increased the thermal stability of thickened pandan juices. Information gained from this study will help to improve understanding of the rheological properties of thickened pandan juices using Xan or GG at different temperatures to modify diets for individuals with dysphagia and promote their safe fluid intake. Further research is needed to reveal the effect of viscoelastic properties and other rheological parameters on the swallowability of thickened pandan juice, and also assess the clinical implications of differences among various thickened fluids.

Table 4. Values of *L*, a** and *b** of thickened pandan juices with different concentrations of Xan or GG

Sample	*L**	*a**	*b**
0.25%Xan	66.34±0.14[c]	-2.38±0.10[cd]	14.16±0.03[c]
0.50%Xan	64.29±0.46[d]	-2.13±0.07[abc]	15.58±0.12[b]
0.75%Xan	61.38±0.41[e]	-2.05±0.04[ab]	16.28±0.23[a]
0.25%GG	68.82±0.28[a]	-2.49±0.04[d]	11.68±0.18[e]
0.50%GG	68.32±0.35[a]	-2.30±0.13[bcd]	12.31±0.37[d]
0.75%GG	67.73±0.05[b]	-1.88±0.36[a]	14.16±0.39[c]

Note: [a,b]Values in the same column followed by different letters are significantly different ($p \leq 0.05$).

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