Journal of Food Technology Research
2023 Vol. 10, No. 1, pp. 11-24.
ISSN(e): 2312-3796
ISSN(p): 2312-6426
DOI: 10.18488/jftr.v10i1.3307

The effects of different starches and gums on instant pureed rice porridge for patients with dysphagia

Hui-Yin Yong[1]
Syahariza Zainul Abidin[2+]
Norrazatul Hanim Mohd Rozalli[3]
Norsila Abdul Wahab[4]

[1,2,3]*Food Technology Division, School of Industrial Technology, University of Science Malaysia, 11800 Penang, Malaysia.*
[1]*Email:* huiyin_yong@yahoo.com
[2]*Email:* syahariza@usm.my
[3]*Email:* norazatulhanim@usm.my
[4]*School of Dental Sciences, University of Science Malaysia Health Campus, 16150 Kota Bharu, Kelantan, Malaysia.*
[4]*Email:* norsila@usm.my

(+ Corresponding author)

Article History
Received: 25 November 2022
Revised: 18 January 2023
Accepted: 3 February 2023
Published: 1 March 2023

Keywords
Dysphagia
Instant rice porridge
Rheological
Sensory
Thickener.

ABSTRACT

Dysphagia is defined as the difficulty to swallow food and liquid. Pureed food is commonly used in dysphagia management. For patients with dysphagia, a commercially available thickener is usually added during the preparation of pureed food to impart desired consistency which aids in reducing the risk of choking. However, high costs and limited availability of commercial thickener are burdens for some patients. Besides, the foods prepared by the commercial thickener also have consistent viscosity problems. Therefore, the use of instant pureed food has been proposed as an alternative solution for these shortcomings. This study was designed to evaluate the suitability of starch and gum as a thickener in instant pureed rice porridge for patients with dysphagia using rheological and sensory parameters. The experiments were then divided into two main sections: (1) analyses on rice porridge powder and (2) analyses on reconstituted rice porridge. Instant pureed rice porridge was developed for patients with dysphagia according to the framework outlined by the International Dysphagia Diet Standardisation Initiative (IDDSI). Overall, this study has successfully developed instant rice porridge that was suitable for consumption among patients with dysphagia and was proven to be acceptable through sensory study. Xanthan gum was shown to have the greatest potential to be used as a thickener in instant rice porridge. The success of the incorporation of xanthan gum into instant rice porridge can be a cheaper and more convenient option to the existing commercial thickener for dysphagia management.

Contribution/Originality: The use of commercial thickener during food preparation for patients with dysphagia often associated with inconsistent thickness level, which may increase the risk of choking during swallowing. Based on rheological data, xanthan gum provides the greatest potential as an alternative thickener, to be use in dysphagia management.

1. INTRODUCTION

Dysphagia can be defined as the difficulty or inability to swallow food and liquid. It can result from several conditions such as cancer, stroke, neurological disorders, and brain injury (Cichero, 2013; Houjaij, Dufresne, Lachance, & Ramaswamy, 2009). People with dysphagia may also encounter difficulties in controlling saliva secretion, problems in chewing solid foods, and a feeling that food is stuck in throat (Adeleye & Rachal, 2007). Consequently, it leads to complications such as malnutrition and dehydration due to some food restrictions or losing eating pleasure (Andersen, Beck, Kjaersgaard, Hansen, & Poulsen, 2013).

Dysphagia is a symptom of an underlying disease. Often, the disease must be treated first before dysphagia can be managed successfully. However, as patients need to be fed to maintain their nutritional intake, texture modification of food is usually prescribed for patients as a compensatory method to manage dysphagia. Pureed food, a class of texture-modified food, is highly recommended for patients with dysphagia, who may benefit from this diet prescription because it requires minimal oral preparation and manipulation (Munialo, Kontogiorgos, Euston, & Nyambayo, 2020). Pureed food is usually prepared by blending, followed by straining to remove lumps. Thickener is often added during the preparation of pureed food to achieve the desired consistency. According to Hanson, O'Leary, and Smith (2012) food with increased viscosity can help to slow down the swallowing process, thus resulting in safer swallowing.

The commercial thickener often sold at high price and its limited availability can be a financial burden to the patients with dysphagia. Besides, the use of commercial thickener was reported to produce inconsistent thickness level during preparation of food (Payne, Methven, Fairfield, Gosney, & Bell, 2012) which may increase the risk of choking during swallowing. Accordingly, the use of pre-thickened pureed food has been proposed to overcome the shortcomings of commercial thickener in preparing dysphagia-oriented food. Furthermore, the effort of developing pre-thickened pureed food can help to reduce the preparation time and eliminate difficulties in preparing pureed food for patients with dysphagia. Nevertheless, the existing pre-thickened pureed food is very limited and only available in certain countries such as Japan and United States.

The characteristics of pureed food after addition of thickener mostly examined through rheological test to predict the effectiveness of a pureed food for swallowing among patients with dysphagia. However, from the literatures, only a few studies focused on the rheological properties of dysphagia-oriented pureed foods (Sharma, Kristo, Corredig, & Duizer, 2017). Therefore, the information relating to the objective measurement of dysphagia-oriented pureed foods has been relatively scanty (Steele et al., 2015). The lack of objective measurement regarding the food texture and consistency is a major barrier to the diet management of patients with dysphagia. In the existing guidelines, only subjective descriptions such as the smooth texture with no lump and the ability to form shape are used. Besides, sensory evaluation also plays an essential role in characterizing pureed food for patients with dysphagia because instrumental methods which often conducted under a controlled condition cannot completely explain the complex texture and sensory attributes of food (Janssen, Terpstra, De Wijk, & Prinz, 2007). Combination of rheological and sensory analyses would help to develop foods with suitable consistency and desired sensory properties for patients with dysphagia.

In general, this study was designed to evaluate the suitability of starch and gum as a thickener in instant pureed rice porridge for patients with dysphagia using rheological and sensory parameters with the aims to find a cost-effective and convenient alternative for current commercially available thickener. The experiments were divided into two main sections: (1) analyses on rice porridge powder and (2) analyses on reconstituted rice porridge. In the first section, the effect of different types of thickener on swelling power, solubility, and pasting properties of instant rice porridge was evaluated. In the second section, the reconstituted rice porridge samples were evaluated on their rheological properties and sensory test among patients with dysphagia. Rice porridge was selected as a food model in this study as porridge is considered as a comfort food that usually recommended by doctors for patients. The porridge's texture is soft and easily digestible, hence, it is very suitable for those who are just recovering from illnesses or having weak digestion. Rice porridge also can help to increase energy intake as the carbohydrates from the rice can serve as a good energy source.

2. MATERIALS AND METHODS

2.1. Drying Process

The fresh pureed rice porridge samples with 1% gum (xanthan and guar) and 2% starch (tapioca and sago) were prepared in accordance to Yong, Syahariza, Uthumporn, and Karim (2017). The concentration for each thickener was selected based on preliminary test using line spread test (LST) that carried out by Yong et al. (2017). LST is an empirical rheology test to quantify the consistency of a standard amount of thickened product by measuring the distance travelled across a flat surface after the sample being released from a confined chamber. The pureed rice porridge samples were then subjected to hot air drying in a cabinet dryer at 80°C for 3 h to reach the desired moisture content (approximately 8%) (Mandge, Sharma, & Dar, 2014). The control sample (pureed rice porridge without any addition of thickener) was also dried using the same method. After that, all the dried samples were ground into powder form and passed through a 1 mm sieve before they were kept in air-tight containers and stored in a desiccator.

2.2. Analyses on Instant Rice Porridge

2.2.1. Swelling Power and Solubility

The method outlined by Sun and Yoo (2015) was used to determine the swelling power and solubility of rice porridge powder in triplicate. The sample (0.5 g) was weighed into a beaker and mixed with 100 g distilled water. The dispersion was then moderately stirred for 1 h at room temperature, followed by heating at 95 °C in a water bath for 30 min. The hot mixture was cooled to room temperature using an ice water bath and centrifuged (Model 4000, Kubota Corporation, Japan) at 2100 × *g* for 20 min. The supernatant was collected in a pre-weighed aluminium dish. The swelling power was calculated using the weight of wet and dry sediment in the centrifuge tube based on Equation 1:

$$\text{Swelling power (g/g)} = \frac{\text{Weight of wet sediment (g)}}{\text{Weight of dry sample}} \quad (1)$$

The supernatant was then evaporated for 4 h in an oven at 120 °C. The solubility was calculated using the following Equation 2:

$$\text{Solubility (\%)} = \frac{\text{Weight of dried supernatant (g)}}{\text{Weight of dried sample (g)}} \times 100\% \quad (2)$$

2.2.2. Pasting Properties

The pasting properties of rice porridge powder were measured using the Rapid Visco™ Analyzer (Model RVA Series 4, Newport Scientific Pvt. Ltd., Warriewood, Australia) according to Marta and Tensiska (2017) with slight modification. The rice porridge powder (2.5 g, adjusted to 12% moisture basis) was weighed directly in the aluminium RVA sample canister, followed by the addition of distilled water to make the total constant sample weight of 27.5 g. A programmed heating and cooling cycle were used respectively where the samples were held at 30°C for 1 min, heated to 95°C for 3.7 min, held at 95°C for 2.5 min before cooling to 50°C in 3.8 min, and then held at 50°C for 2 min. The measurements were replicated three times for each sample. The parameters obtained from this analysis consisted of peak viscosity, breakdown viscosity, relative total setback, and pasting temperature. The relative total setback was calculated based on Arocas, Sanz, and Fiszman (2009) using Equation 3:

$$\text{Relative total setback} = \frac{\text{Final viscosity} - \text{Trough viscosity (Pa} \cdot \text{s)}}{\text{Final viscosity (Pa} \cdot \text{s)}} \quad (3)$$

2.3. Analyses on Reconstituted Instant Rice Porridge

2.3.1. Line Spread Test (LST)

A preliminary test was conducted to select the most suitable ratio of rice porridge powder to hot water for each sample with different thickener using LST. The final ratio for each rice porridge powder sample was selected based on its compliance with the characteristics of pureed form listed in International Dysphagia Diet Standardization Initiative (IDDSI) framework. The testing procedure of LST was conducted at room temperature by following the method described by Budke, Garcia, and Chambers IV (2008) with slight modification. The test was conducted using a clear glass plate (19.5 cm x 19.5 cm) laid on top of a sheet marked with concentric circles spaced 1.0 cm apart from 2.0 cm to 5.0 cm radius. The rice porridge (5 g) was poured into the hollow glass cylinder (2.0 cm in diameter and 2.9 cm in height) that positioned at the center of the circles. After 10 min, the cylinder was lifted to allow the sample to spread on the glass plate for 1 min. The average measurements of LST were made based on the sample spreading at the four quadrants of the circle. This procedure was repeated three times for each sample.

2.3.2. Rheological Measurements

The rheological properties of pureed rice porridge were evaluated through both stepped flow and oscillatory frequency sweep tests using controlled stress AR 1000 rheometer (TA Instruments, New Castle, DE, USA) equipped with a temperature controller. All the measurements were carried out at 37°C using parallel plate geometry (20 mm diameter) with a gap of 1.0 mm. All the rheological measurements were performed in triplicate.

Stepped flow test data were obtained over a shear rate range from 0.1 to 100/s. The data collected were then fitted to the well-known power law model Equation 4 and Casson model Equation 5 to describe the rheological behavior of the samples (Abu Zarim, Zainul Abidin, & Ariffin, 2018; Sun & Yoo, 2015).

$$\sigma = K\dot{\gamma}^{n} \quad (4)$$

$$\sigma^{0.5} = K_{oc} + K_{c}\dot{\gamma}^{0.5} \quad (5)$$

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 flow behavior index (dimensionless). Casson yield stress (σ_{oc}) was calculated as the square of the intercept (K_{oc}) which obtained from linear regression of the square roots of shear stress-shear rate data.

2.3.3. Sensory Evaluation

Twenty participants with oropharyngeal dysphagia (12 males and 8 females, 27-72 years, mean age 52.5 years, SD 13.8) were recruited from Hospital Universiti Sains Malaysia (USM), Kelantan. The participants were individuals who were diagnosed with oropharyngeal dysphagia based on their medical record or clinical dysphagia examination that was carried out by an experienced speech-language therapist. Before the start of the sensory test, a written consent was obtained from each participant before the evaluation.

Visual Analog Scale (VAS) was used to rate several sensory attributes, namely thickness, stickiness, swallowing effort, graininess, and overall acceptability. All participants were guided on how VAS is used prior to the presentation of the samples. They were required to rate the attributes on the 100 mm lines with descriptors labeled at both ends. The samples (about two teaspoons each) were placed in plastic cups (coded with random three-digit numbers) and presented to the participant one after another. The presentation order of the samples was randomized to minimize the effect of the order on responses. All participants were also reminded to rinse their mouth with provided water for cleansing purposes before testing each sample. Participants could have short rest periods in between if they feel fatigued during testing. The sensory test was also conducted under supervision by an experienced speech-language therapist to monitor choking.

2.4. Statistical Analyses

Statistical analyses were conducted using Statistical Package for Social Sciences (SPSS) Statistics Desktop 22.0 (IBM Corporation, United State (US)). The results obtained were represented as the mean values of three individual replicates ± standard deviation (SD). Comparison of the mean was performed by using one-way Analysis of Variance (ANOVA) using Tukey's test at 5% probability level. The correlation between sensory attributes was calculated using Pearson Correlation analysis.

3. RESULTS AND DISCUSSION

3.1. Analyses on Instant Rice Porridge

3.1.1. Swelling Power and Solubility

The swelling power and solubility values of the rice porridge powder samples were in the range of 9.94-17.58 g/g and 28.33-53.75% respectively, as summarized in Table 1. The results indicated that the swelling power of rice porridge increased with the presence of thickener.

Table 1. Swelling power and solubility of different rice porridge powders.

Samples	Swelling power (g/g)	Solubility (%)
Control	9.94 ± 0.34^{a}	28.33 ± 1.00^{a}
Xanthan	17.58 ± 1.17^{c}	48.05 ± 1.35^{b}
Guar	14.96 ± 0.81^{b}	53.75 ± 2.41^{c}
Sago	11.36 ± 0.14^{a}	30.12 ± 1.41^{a}
Tapioca	13.75 ± 0.54^{b}	30.25 ± 0.63^{a}

Note: Values were expressed as mean ± standard deviation of triplicate samples; values followed by the same letters in the same column were not significantly different at $p < 0.05$.

Based on the results, the greatest swelling power of rice porridge powder with xanthan gum could be due to the ability of xanthan gum to form interactions among the gelatinized granules (Mandala & Bayas, 2004). Xanthan gum could entrap and keep the gelatinized starch granules closely, thus increasing the forces on these granules to facilitate water absorption and enhance the swelling process. Besides, the presence of guar gum in rice porridge powder showed the second highest value in swelling power. The possible explanation for the high swelling power of guar gum sample obtained in this study can be associated with the high branching degree of guar gum as well as its great hydration capacity (Yoo, Kim, & Yoo, 2005).

The swelling power of a powder sample also can be influenced by the size of starch granules. The presence of tapioca starch in rice porridge powder exhibited higher swelling power compared to the control sample. The observed higher swelling power could be interpreted as the result of the larger granule size of tapioca starch (4-35 µm) which capable of holding more water than the rice starch (1-3 µm) (Sun & Yoo, 2015). In relation to the smaller granule size of rice starch, the control sample had the lowest swelling power due to strong associative force within the granular arrangement and hence required more energy to initiate the relaxation (Qazi, Rakshit, Tran, Ullah, & Khan, 2014). Also, the difference in swelling properties among starches could be attributed to variation in amylose content. According to Lii, Tsai, and Tseng (1996), the higher the amylose content, the lower the extent of granular swelling. This is because amylose acts as an inhibitor of swelling in starch (Singh, Singh, Kaur, Sodhi, & Gill, 2003). This can be proven by the rice porridge with sago starch that showed lower swelling power in this study with the reason of sago starch has higher amylose content than tapioca starch.

For the solubility test, no significant difference in solubility values was observed between the control sample and sample with starch. This is probably because starch is generally considered to be insoluble in water (Li & Nie, 2016). In contrast to its low swelling power, the high solubility of the control sample could be due to its small granule size. The small granule size of starch probably results in granule suspension and loss in supernatant during centrifugation (Lin, Kao, Tsai, & Chang, 2013). The results also revealed that the rice porridge with gum showed higher solubility values than starch. This is because gum is usually considered as a water-soluble hydrocolloid. Taking rice porridge with guar gum as an example, its highest solubility was mainly because of the presence of high percentage of water-soluble polysaccharides (33-40% galactose units) in guar gum. Consequently, the galactose units also prevent strong cohesion of the main backbone and allow water to penetrate easily to hydrate or dissolve the gum (Wielinga, 2000).

Both swelling power and solubility are the important contributor for good reconstitution quality of instant rice porridge powder. The present findings showed that the instant rice porridge powder with gum are higher in swelling power and solubility as compared to instant rice porridge powder with starch.

3.1.2. Pasting Properties

The pasting characteristics of rice porridge powder samples were depicted in Table 2. Overall, the pasting properties of control sample were notably different from the samples with a thickener.

Table 2. Pasting properties of different rice porridge powders determined using Rapid Visco™ Analyzer (RVA).

Samples	Viscosity (Pa·s)		Relative total setback	Pasting temperature (°C)
	Peak	Breakdown		
Control	0.43 ± 0.02[a]	0.05 ± 0.00[a]	0.50 ± 0.01[c]	94.82 ± 0.34[c]
Xanthan	4.41 ± 0.17[d]	2.56 ± 0.07[c]	0.26 ± 0.01[a]	48.47 ± 0.14[a]
Guar	4.43 ± 0.12[d]	2.97 ± 0.13[d]	0.38 ± 0.02[b]	48.40 ± 0.10[a]
Sago	0.99 ± 0.03[b]	0.13 ± 0.00[ab]	0.48 ± 0.02[c]	87.12 ± 2.48[b]
Tapioca	1.45 ± 0.06[c]	0.27 ± 0.02[b]	0.49 ± 0.03[c]	84.37 ± 1.24[b]

Note: Values were expressed as mean ± standard deviation of triplicate samples; values followed by the same letters in the same column wer not significantly different at $p < 0.05$.

Peak viscosity can be defined as the maximum viscosity of the swollen granule before rupture and often refers as the water binding capacity of the starch (or mixture) (Chantaro, Pongsawatmanit, & Nishinari, 2013). The presence of thickener showed significantly increased in peak viscosity of rice porridge powder, where gum had a more pronounced effect compared to starch. Most of the authors relate the greater swelling power with higher peak viscosity (Fadzlina, Karim, & Teng, 2005; Karim, Tie, Manan, & Zaidul, 2008; Weber, Clerici, Collares-Queiroz, & Chang, 2009). A positive correlation was found between swelling power and peak viscosity of rice porridge powder in this study ($r = 0.910$). Therefore, the higher peak viscosity achieved by the rice porridge with gum samples lends support to the fact that the presence of gum increased the capacity of starch granules to swell. Besides swelling power, the amount of amylose in starch also can affect the peak viscosity. As reported by Zaidul, Yamauchi, Kim, Hashimoto, and Noda (2007) high amylose content had been associated with lower peak viscosity. This is because amylose molecules tend to bind to each other very strongly (Lai, 2001) and in turn, reduce the swelling process. In the case of sago starch with high amylose content, the sample showed lower peak viscosity compared to tapioca starch.

Breakdown is the tendency of a sample towards shear force during the holding period at 95°C (Karim et al., 2008). Again, the presence of sago starch helped in reducing the breakdown of rice porridge. This can be explained by the presence of high amylose content in sago starch that strengthens forces within the granules and prevents breakdown. Nevertheless, the high breakdown of rice porridge with gum was connected to high swelling power. Weber et al. (2009) reported that high swelling indicates a low degree of binding forces within the swollen granules. This suggests that these samples are less resistance to shear and have a higher tendency to loss viscosity upon heating and holding (Nadiha, Fazilah, Bhat, & Karim, 2010). Furthermore, the significantly high breakdown of rice porridge with gum can be related to the fact that the presence of hydrocolloid can increase the shear force applied on the granules and increase the number of granular components released into the continuous phase (Mandala & Bayas, 2004). Total setback is generally identified as the degree of retrogradation of starch (aggregations of gelatinized starch), especially amylose molecules during cooling. For correct comparison among the different rice porridge powders, relative total setback was calculated instead of total setback. The rice porridge with starch (sago and tapioca) showed no significant difference in relative total setback value compared to control sample. Their relative total setback values were also higher than rice porridge with gum. Since total setback is positively correlated with the texture of products (Chantaro et al., 2013) control and starch samples which showed higher tendency to retrograde might form firmer structure after cooling.

The lower relative total setback value of rice porridge with gum indicated that the presence of gum restricts the tendency of starch to retrograde. The xanthan gum sample which had the lowest relative total setback value of was also in good agreement with Arocas et al. (2009). Leite, Nicoleti, Penna, and Franco (2012) explained such effect occurs due to competition between xanthan gum and amylose molecules to form the intermolecular bond, hence reducing the amount of amylose-amylose interactions which are responsible for starch retrogradation. Retrogradation is also linked to syneresis which is undesirable particularly in dysphagia-oriented foods because the greater the syneresis, the higher the risk of choking (Funami, 2011). Therefore, the lowest relative total setback value attained by xanthan gum sample implies higher ability to resist water separation, hence safer for patients with dysphagia.

Pasting temperature is the temperature when starch starts to swell. The results clearly show that the presence of thickener decreased the pasting temperature of rice porridge powder. The plausible explanation of this effect is the negative relationship found between pasting temperature and swelling power in this study (r = -0.895). The stronger interaction between rice starch granules, indicated by its least swelling power and peak viscosity cause more energy required to break the intra- and intermolecular bonds, resulting in a rather high pasting temperature. However, the reduced pasting temperature of samples with gum could lead to higher starch-gum interactions due to water penetration and earlier pasting (Hussain, 2015). The instantaneous swelling effect is very favorable and plays an essential role in rice porridge powder as it aims for fast preparation.

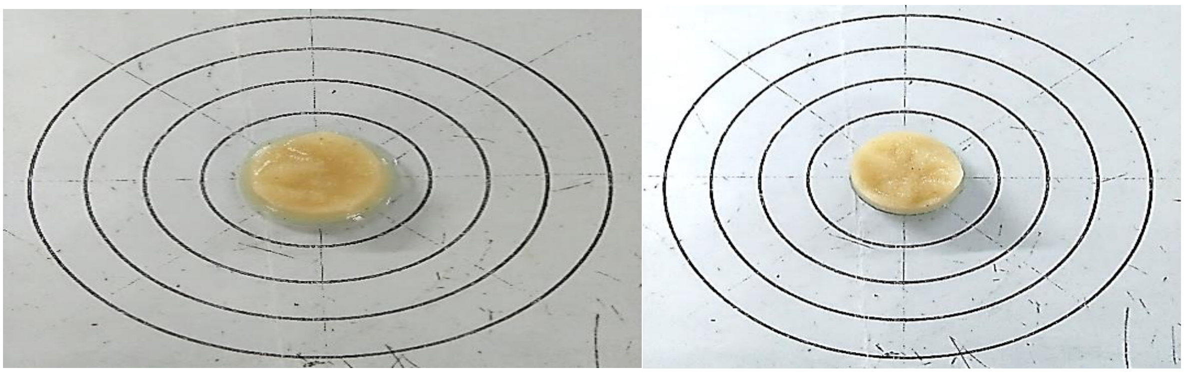
3.2. Analyses on Reconstituted Instant Rice Porridge

3.2.1. Line Spread Test

To select the most suitable ratio of rice porridge powder to hot water, a preliminary test was conducted for each sample using LST (Table 3). Since no standard has been developed for LST in the evaluation of pureed food for patients with dysphagia, the final ratio for each rice porridge powder sample was selected based on their compliance with the characteristics of pureed form listed in IDDSI framework. The properties of pureed food that suitable for patients with dysphagia should not be too thick, no water separation, and able to hold shape on a plate.

Table 3. List of suitable ratios of rice porridge powder to hot water for each sample.

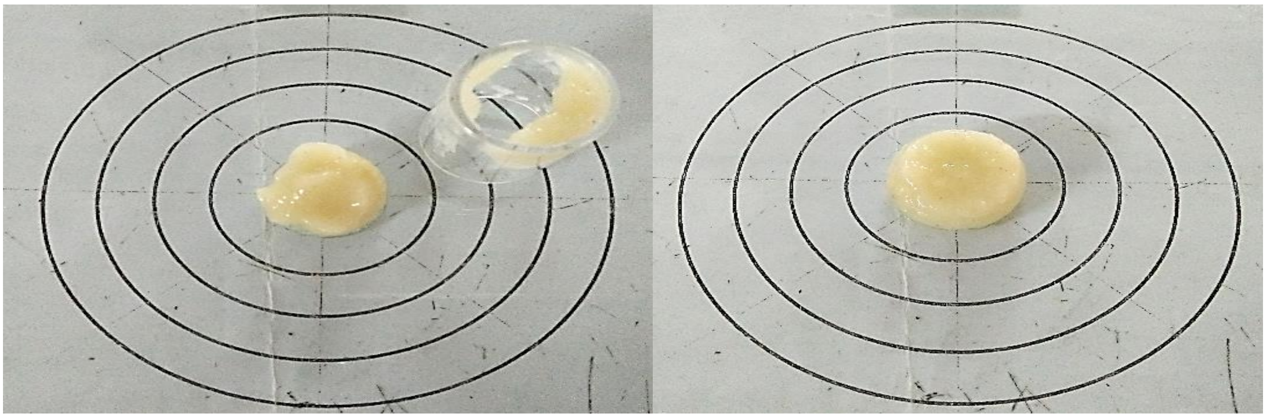
Samples	Ratio of rice porridge powder to hot water
Control	1:6
Xanthan	1:12
Guar	1:12
Sago	1:7
Tapioca	1:7



(a) (b)

Figure 1. (a) Control sample with water separation (Ratio 1:7); (b) Control sample without water separation (Ratio 1:6).

In this study, the ratio of 1:6 (rice porridge powder: hot water) was selected for control sample; ratio 1:7 for starch samples; and ratio 1:12 for gum samples. All these samples showed no spreading occurs. However, addition of higher amount of water for reconstitution purposes resulted in water separation and unable to hold shape, particularly for control and starch samples Figure 1. These samples exhibited a mixture of liquid and solid phase which may pose a choking risk for patients with swallowing difficulty. At the relatively lower amount of water, the sample became too thick or sticky for swallowing, which can be referred to Figure 2.



(a) (b)

Figure 2. Reconstituted rice porridge with guar gum (a) Too thick for swallowing and sticky texture (Ratio 1:10); (b) Not too thick and able to hold its shape (Ratio 1:12).

One of the limitations of LST test is that an increase in viscosity of thickened sample may limit its ability in measuring the distance of spread. This statement is supported by a study conducted by Ettinger, Keller, and Duizer (2014) who worked on pureed food and mentioned that thick pureed product showed non-distinguishable readings (0 cm) using LST. Therefore, further instrumental analyses like rheological measurements are needed to give more detail information on the properties of the thickened product.

3.2.2. Rheological Measurements

Table 4 illustrates that all the rice porridge powder samples with and without the presence of thickener were well fitted to the power law model with high determination coefficients (R^2 above 0.90). The yield stress was calculated by using Casson model.

Table 4. Flow properties of reconstituted rice porridge samples prepared by different thickeners at selected ratio over a shear rate range from 0.1 to 100 s^{-1}

Samples	Power law			Casson yield stress
	n	K ($Pa{\cdot}s^n$)	R^2	σ_{oc} (Pa)
Control	0.19 ± 0.00 [a]	102.76 ± 4.08 [b]	0.90 ± 0.03	91.41 ± 3.88 [b]
Xanthan	0.26 ± 0.01 [b]	74.85 ± 9.83 [a]	1.00 ± 0.01	59.03 ± 9.28 [a]
Guar	0.28 ± 0.00 [bc]	139.45 ± 6.92 [c]	0.99 ± 0.00	110.35 ± 5.28 [c]
Sago	0.34 ± 0.01 [c]	102.78 ± 5.10 [b]	0.98 ± 0.00	62.42 ± 3.38 [a]
Tapioca	0.33 ± 0.05 [bc]	152.38 ± 12.65 [d]	0.99 ± 0.01	111.54 ± 7.54 [c]

Note: Values were expressed as mean ± standard deviation of triplicate samples; values followed by the same letters in the same column were not significantly different at $p < 0.05$.

All the samples showed non-Newtonian shear-thinning behavior (as evidenced by the n less than 1) with yield stress. Such behavior also common in foods such as ketchup (Koocheki, Ghandi, Razavi, Mortazavi, & Vasiljevic, 2009), mayonnaise (Štern, Mikova, Pokorny, & Valenova, 2007), yogurt (Yu, Wang, & McCarthy, 2016) and potato puree (Alvarez, Fernández, & Canet, 2004). The lower the n value, the greater the shear-thinning behavior. The shear-thinning behavior can be explained by continuous deformation due to breakage of hydrogen bonds between amylose molecules which resulted in the reduction of flow resistance and viscosity (Rohaya, Maskat, & Ma'aruf, 2013).

Compared with the control sample (n = 0.19), the rice porridge with thickener showed significantly higher value of n in the range of 0.26-0.34. This finding indicated the control sample had most response towards shear. Consequently, it highlights the importance of thickener to reduce the rate of disruption upon shear in the reconstituted rice porridge. Based on the results, the n values of rice porridge with gum were also lower as compared to starch. The rice porridge with xanthan gum showed greater shear-thinning behavior, due to the ability of xanthan gum to form a complex aggregate with weak intermolecular forces in solution. For rice porridge with guar gum, its high degree of shear-thinning characteristic can be explained by the unique guar gum structure. The structure of guar gum consisted of a mannan main chain with alternate galactose branches which inhibit the formation of intramolecular hydrogen bonding. This keeps the molecule in an extended form and allows it to interact with amylose molecules through intermolecular bonding readily, hence makes it higher tendency to loss viscosity with increasing shear rate (Yoo et al., 2005). Besides, the *n* value of thickened food is crucial because it correlated to the sensory properties of the food. Marcotte, Hoshahili, and Ramaswamy (2001) noted that low *n* value is required if high viscosity and good mouthfeel (less slimy) characteristics are desired in food.

According to Funami (2011) and Yoon and Yoo (2016) *K* and yield stress obtained from the rheological models can be used to perceive ease of swallowing. The lowest *K* and σ_{oc} of rice porridge with xanthan gum suggest a less stiff structure, hence easier to swallow. On the other hand, the presence of tapioca starch in rice porridge contributed to highest in *K* and σ_{oc}, which can be expected to cause difficulty in swallowing. In the case of guar gum sample, its presence showed greater effects on the increase of *K* and σ_{oc} compared to xanthan gum sample. It is probable that depolymerization of guar gum molecules occur during heating and shearing conditions whereby more galactose units were removed from the main chain of mannose units, causing the number of mannose units to be increased in the sample. hence allows the formation of intramolecular bonding between gum to be increased (Bradley, Ball, Harding, & Mitchell, 1989). Moreover, it is apparent from the results that both the control sample and rice porridge with sago starch attained similar *K*, yet the latter one had lower σ_{oc} value. This observation led to the assumption that sago starch sample will be easier to swallow compared to the control sample.

The results of this rheological test revealed that the potential of xanthan gum to be used as a thickener in the instant rice porridge which can be proved by its low *n*, *K* and yield stress values.

3.2.3. Sensory Evaluation

The average scores of the attributes for each sample were shown in Figure 3.

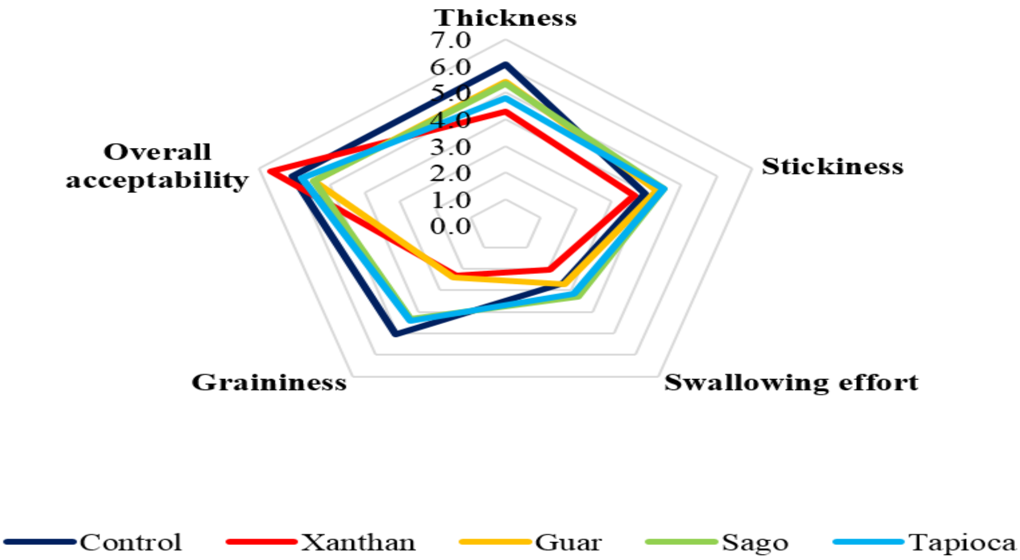


Figure 3. Mean scores of sensory attributes of the instant rice porridge samples with different thickeners among patients with dysphagia (n = 20).

The instant rice porridge with xanthan gum had the lowest score in thickness, stickiness, swallowing effort, and graininess but highest in overall acceptability rating. This result was consistent with Vickers et al. (2015) who reported that the fluid thickened with xanthan gum was lower on the thickness and adhesive-related attributes. Based on Table 5 the overall acceptability of instant rice porridge showed negative correlation with all other attributes, where stickiness recorded the highest value (*r* figuref7= -0.891). Except for xanthan gum, the presence of guar gum and both starches increased the stickiness of instant rice porridge. Due to the significantly high positive relationship found between stickiness and swallowing effort (*r* = 0.948) in this study, the results point to the probability that the less sticky texture of instant rice porridge was more accepfu by participants mainly because it is easier to swallow. This can be further strengthened by Ishihara, Nakauma, Funami, Odake, and Nishinari (2011) who proposed that swallowing effort is one of the important attributes associated with personal palatability.

Table 5. Pearson's correlation coefficients of five sensory attributes of the developed instant rice porridge samples.

Variables	Thickness	Stickiness	Swallowing effort	Graininess	Overall acceptability
Thickness	1				
Stickiness	0.229	1			
Swallowing effort	0.354	0.948	1		
Graininess	0.587	0.377	0.624	1	
Overall acceptability	-0.504	-0.891	-0.819	-0.248	1

Note: Values in bold were different from 0 with a significance level (α) = 0.05.

Apart from stickiness, the ease in swallowing can be achieved by manipulating the graininess of the instant rice porridge. The high grainy texture of rice porridge caused difficulty in swallowing among patients with dysphagia. According to Rofes, Arreola, Mukherjee, Swanson, and Clavé (2014) grainy foods that cause residues in the mouth (or throat) not only can lead to choking during swallowing, but can put the patients at risk for respiratory complications. The presence of starch and gum helped in reducing graininess of instant rice porridge, where the latter was more pronounced. As reported by many previous findings in the literature, starch-based thickener imparted a grainy texture while gum-based thickener has more therapeutic advantages because it was found to reduce granularity and thus improve the safety of swallow (Alvarez, Canet, & Fernández, 2008; Rofes et al., 2014; Vilardell, Rofes, Arreola, Speyer, & Clavé, 2016). Sharma et al. (2017) also reported that xanthan gum can help to reduce granularity in pureed carrot which perceived as being "very smooth".

Graininess was found to have a contribution to the sensory perceived thickness of instant rice porridge (*r* = 0.587) in this study. For instance, control sample was perceived to have the highest value of graininess as well as highest value of thickness. This positive relationship also was in accordance with Matta, Chambers IV, Garcia, and Helverson (2006) who reported that beverage prepared with starch-based thickener imparted grainy texture as well as higher perceived thickness compared to gum-based thickener. Besides, the thickness was negatively correlated with overall acceptability (*r* = -0.504), indicating that the increase in thickness can decrease the overall acceptability of instant rice porridge among patients with dysphagia. Similarly Zargaraan et al. (2015) reported that too high viscosity can lead to food refusal by patients with dysphagia. Furthermore, Dewar and Joyce (2006) also stressed that food with too high viscosity may aggravate swallowing and give rise to malnutrition and dehydration among patients with dysphagia. Therefore, the lower overall acceptability in instant rice porridge with sago starch than tapioca starch could be attributed to its thickness.

To sum up, the participants could accept all the instant rice porridge with different thickeners and no choking happened during sensory testing. However, instant rice porridge with xanthan gum with less thick, less sticky, low effort needed during swallowing, and less grainy was selected as the most desirable among the participants.

4. CONCLUSION

This study showed the potential of xanthan gum to be used as a thickener in instant rice porridge based on rheological study and was successfully tested on a small number of patients with oropharyngeal dysphagia. Due to such reason, application of this developed instant rice porridge appears to be promising in nursing homes and hospitals which require fast preparation and convenience. Moreover, this could indicate the possibility of introducing instant rice porridge as another food choice for patients with dysphagia, with cheaper cost to reduce their financial burden. However, the nutritional quality of this newly developed instant rice porridge should be further studied and research towards developing a new enriched pureed food for patients with dysphagia is warranted.

Funding: This research is supported by Ministry of Higher Education, Malaysia for research grant under Fundamental Research Grant Scheme (Grant number: FRGS/1/2018/STG01/USM/02/7).
Ethical Statement: This study was approved by Human Research Ethics Committee of USM (Protocol Code: USM/JEPeM/17080367).
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.

REFERENCES

Abu Zarim, N., Zainul Abidin, S., & Ariffin, F. (2018). Rheological studies on the effect of different thickeners in texture-modified chicken rendang for individuals with dysphagia. *Journal of Food Science and Technology, 55*(11), 4522-4529. https://doi.org/10.1007/s13197-018-3386-5

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. *Journal of the American Dietetic Association, 107*(7), 1176-1182. https://doi.org/10.1016/j.jada.2007.04.011

Alvarez, M. D., Canet, W., & Fernández, C. (2008). Effect of addition of cryoprotectants on the mechanical properties colour and sensory attributes of fresh and frozen/thawed mashed potatoes. *European Food Research and Technology, 226*(6), 1525-1544. https://doi.org/10.1007/s00217-007-0684-y

Alvarez, M. D., Fernández, C., & Canet, W. (2004). Rheological behaviour of fresh and frozen potato puree in steady and dynamic shear at different temperatures. *European Food Research and Technology, 218*(6), 544-553. https://doi.org/10.1007/s00217-004-0897-2

Andersen, U. T., Beck, A. M., Kjaersgaard, A., Hansen, T., & Poulsen, I. (2013). Systematic review and evidence based recommendations on texture modified foods and thickened fluids for adults (≥18 years) with oropharyngeal dysphagia. *E-SPEN Journal, 8*(4), 127–134. https://doi.org/10.1016/j.clnme.2013.05.003

Arocas, A., Sanz, T., & Fiszman, S. (2009). Improving effect of xanthan and locust bean gums on the freeze-thaw stability of white sauces made with different native starches. *Food Hydrocolloids, 23*(8), 2478-2484. https://doi.org/10.1016/j.foodhyd.2009.08.001

Bradley, T., Ball, A., Harding, S., & Mitchell, J. (1989). Thermal degradation of guar gum. *Carbohydrate Polymers, 10*(3), 205-214. https://doi.org/10.1016/0144-8617(89)90012-x

Budke, J., Garcia, J. M., & Chambers IV, E. (2008). Comparisons of thickened beverages using line spread measurements. *Journal of the American Dietetic Association, 108*(9), 1532-1535. https://doi.org/10.1016/j.jada.2008.06.434

Chantaro, P., Pongsawatmanit, R., & Nishinari, K. (2013). Effect of heating–cooling on rheological properties of tapioca starch paste with and without xanthan gum. *Food Hydrocolloids, 31*(2), 183-194. https://doi.org/10.1016/j.foodhyd.2012.10.026

Cichero, J. A. (2013). Thickening agents used for dysphagia management: Effect on bioavailability of water medication and feelings of satiety. *Nutrition Journal, 12*(1), 1-8. https://doi.org/10.1186/1475-2891-12-54

Dewar, R. J., & Joyce, M. J. (2006). The thixotropic and rheopectic behaviour of maize starch and maltodextrin thickeners used in dysphagia therapy. *Carbohydrate Polymers, 65*(3), 296-305. https://doi.org/10.1016/j.carbpol.2006.01.018

Ettinger, L., Keller, H. H., & Duizer, L. M. (2014). Characterizing commercial pureed foods: Sensory, nutritional, and textural analysis. *Journal of Nutrition in Gerontology and Geriatrics, 33*(3), 179-197. https://doi.org/10.1080/21551197.2014.927304

Fadzlina, Z. A. N., Karim, A. A., & Teng, T. T. (2005). Physicochemical properties of carboxy-methylated sago (Metroxylon sagu) starch. *Journal of Food Science, 70*(9), C560-C567. https://doi.org/10.1111/j.1365-2621.2005.tb08305.x

Funami, T. (2011). Next target for food hydrocolloid studies: Texture design of foods using hydrocolloid technology. *Food Hydrocolloids, 25*(8), 1904-1914. https://doi.org/10.1016/j.foodhyd.2011.03.010

Hanson, B., O'Leary, M. T., & Smith, C. H. (2012). The effect of saliva on the viscosity of thickened drinks. *Dysphagia, 27*(1), 10-19. https://doi.org/10.1007/s00455-011-9330-8

Houjaij, N., Dufresne, T., Lachance, N., & Ramaswamy, H. (2009). Textural characterization of pureed cakes prepared for the therapeutic treatment of dysphagic patients. *International Journal of Food Properties, 12*(1), 45-54. https://doi.org/10.1080/10942910802312157

Hussain, S. (2015). Native rice starch and linseed gum blends: Effect on the pasting, thermal and rheological properties. *Czech Journal of Food Sciences, 33*(6), 556-563. https://doi.org/10.17221/243/2015-cjfs

Ishihara, S., Nakauma, M., Funami, T., Odake, S., & Nishinari, K. (2011). Swallowing profiles of food polysaccharide gels in relation to bolus rheology. *Food Hydrocolloids, 25*(5), 1016-1024. https://doi.org/10.1016/j.foodhyd.2010.09.022

Janssen, A. M., Terpstra, M. E., De Wijk, R. A., & Prinz, J. F. (2007). Relations between rheological properties saliva-induced structure breakdown and sensory texture attributes of custards. *Journal of Texture Studies, 38*(1), 42-69. https://doi.org/10.1111/j.1745-4603.2007.00085.x

Karim, A., Tie, A. P. L., Manan, D., & Zaidul, I. (2008). Starch from the sago (Metroxylon sagu) palm tree—properties prospects and challenges as a new industrial source for food and other uses. *Comprehensive Reviews in Food Science and Food Safety, 7*(3), 215-228. https://doi.org/10.1111/j.1541-4337.2008.00042.x

Koocheki, A., Ghandi, A., Razavi, S. M., Mortazavi, S. A., & Vasiljevic, T. (2009). The rheological properties of ketchup as a function of different hydrocolloids and temperature. *International Journal of Food Science & Technology, 44*(3), 596-602. https://doi.org/10.1111/j.1365-2621.2008.01868.x

Lai, H.-M. (2001). Effects of hydrothermal treatment on the physicochemical properties of pregelatinized rice flour. *Food Chemistry, 72*(4), 455-463. https://doi.org/10.1016/s0308-8146(00)00261-2

Leite, T. D., Nicoleti, J. F., Penna, A. L. B., & Franco, C. M. L. (2012). Effect of addition of different hydrocolloids on pasting thermal and rheological properties of cassava starch. *Science Food Technology, 32*(3), 579-587. https://doi.org/10.1590/s0101-20612012005000074

Li, J.-M., & Nie, S.-P. (2016). The functional and nutritional aspects of hydrocolloids in foods. *Food Hydrocolloids, 53*, 46-61. https://doi.org/10.1016/j.foodhyd.2015.01.035

Lii, C.-Y., Tsai, M.-L., & Tseng, K.-H. (1996). Effect of amylose content on the rheological property of rice starch. *Cereal Chemistry, 73*(4), 415-420.

Lin, J.-H., Kao, W.-T., Tsai, Y.-C., & Chang, Y.-H. (2013). Effect of granular characteristics on pasting properties of starch blends. *Carbohydrate Polymers, 98*(2), 1553-1560. https://doi.org/10.1016/j.carbpol.2013.07.039

Mandala, I., & Bayas, E. (2004). Xanthan effect on swelling solubility and viscosity of wheat starch dispersions. *Food Hydrocolloids, 18*(2), 191-201. https://doi.org/10.1016/s0268-005x(03)00064-x

Mandge, H. M., Sharma, S., & Dar, B. N. (2014). Instant multigrain porridge: Effect of cooking treatment on physicochemical and functional properties. *Journal of Food Science and Technology, 51*(1), 97-103. https://doi.org/10.1007/s13197-011-0461-6

Marcotte, M., Hoshahili, A. R. T., & Ramaswamy, H. (2001). Rheological properties of selected hydrocolloids as a function of concentration and temperature. *Food Research International, 34*(8), 695-703. https://doi.org/10.1016/s0963-9969(01)00091-6

Marta, H., & Tensiska, T. (2017). Functional and amylographic properties of physically-modified sweet potato starch. *KnE Life Sciences, 2*(6), 689-700. https://doi.org/10.18502/kls.v2i6.1091

Matta, Z., Chambers IV, E., Garcia, J. M., & Helverson, J. M. (2006). Sensory characteristics of beverages prepared with commercial thickeners used for dysphagia diets. *Journal of the American Dietetic Association, 106*(7), 1049-1054. https://doi.org/10.1016/j.jada.2006.04.022

Munialo, C. D., Kontogiorgos, V., Euston, S. R., & Nyambayo, I. (2020). Rheological, tribological and sensory attributes of texture-modified foods for dysphagia patients and the elderly: A review. *International Journal of Food Science & Technology, 55*(5), 1862-1871. https://doi.org/10.1111/ijfs.14483

Nadiha, M. N., Fazilah, A., Bhat, R., & Karim, A. A. (2010). Comparative susceptibilities of sago potato and corn starches to alkali treatment. *Food Chemistry, 121*(4), 1053-1059. https://doi.org/10.1016/j.foodchem.2010.01.048

Payne, C., Methven, L., Fairfield, C., Gosney, M., & Bell, A. E. (2012). Variability of starc-based thickened drinks for patients with dysphagia in the hospital setting. *Journal of Texture Studies, 43*(2), 95-105. https://doi.org/10.1111/j.1745-4603.2011.00319.x

Qazi, I. M., Rakshit, S. K., Tran, T., Ullah, J., & Khan, Z. (2014). Effect of blending selected tropical starches on pasting properties of rice flour. *Sarhad Journal of Agriculture, 30*(3), 357–368.

Rofes, L., Arreola, V., Mukherjee, R., Swanson, J., & Clavé, P. (2014). The effects of a xanthan gum-based thickener on the swallowing function of patients with dysphagia. *Alimentary Pharmacology & Therapeutics, 39*(10), 1169-1179. https://doi.org/10.1111/apt.12696

Rohaya, M., Maskat, M., & Ma'aruf, A. (2013). Rheological properties of different degree of pregelatinized rice flour batter. *Sains Malaysiana, 42*(12), 1707-1714.

Sharma, M., Kristo, E., Corredig, M., & Duizer, L. (2017). Effect of hydrocolloid type on texture of pureed carrots: Rheological and sensory measures. *Food Hydrocolloids, 100*(63), 478-487. https://doi.org/10.1016/j.foodhyd.2016.09.040

Singh, N., Singh, J., Kaur, L., Sodhi, N. S., & Gill, B. S. (2003). Morphological, thermal and rheological properties of starches from different botanical sources. *Food Chemistry, 81*(2), 219-231. https://doi.org/10.1016/s0308-8146(02)00416-8

Steele, C. M., Alsanei, W. A., Ayanikalath, S., Barbon, C. E., Chen, J., Cichero, J. A., . . . Giosa, L. (2015). The influence of food texture and liquid consistency modification on swallowing physiology and function: A systematic review. *Dysphagia, 30*(1), 2-26. https://doi.org/10.1007/s00455-014-9578-x

Štern, P., Mikova, K., Pokorny, J., & Valenova, H. (2007). Effect of oil content on the rheological and textural properties of mayonnaise. *Journal of Food and Nutrition Research, 46*(1), 1–8.

Sun, D., & Yoo, B. (2015). Effect of tapioca starch addition on rheological thermal and gelling properties of rice starch. *LWT-Food Science and Technology, 64*(1), 205-211. https://doi.org/10.1016/j.lwt.2015.05.062

Vickers, Z., Damodhar, H., Grummer, C., Mendenhall, H., Banaszynski, K., Hartel, R., . . . Robbins, J. (2015). Relationships among rheological sensory texture, and swallowing pressure measurements of hydrocolloid-thickened fluids. *Dysphagia, 30*(6), 702-713. https://doi.org/10.1007/s00455-015-9647-9

Vilardell, N., Rofes, L., Arreola, V., Speyer, R., & Clavé, P. (2016). A comparative study between modified starch and xanthan gum thickeners in post-stroke oropharyngeal dysphagia. *Dysphagia, 31*(2), 169-179. https://doi.org/10.1007/s00455-015-9672-8

Weber, F. H., Clerici, M. T. P., Collares-Queiroz, F. P., & Chang, Y. K. (2009). Interaction of guar and xanthan gums with starch in the gels obtained from normal, waxy and high-amylose corn starches. *Starch-Stärke, 61*(1), 28-34. https://doi.org/10.1002/star.200700655

Wielinga, W. C. (2000). Galactomannans. In G. O. Phillips & P. A. Williams (Eds.) handbook of hydrocolloids. In (pp. 137-154). England and USA: Woodhead Publishing Limited and CRC Press LLC.

Yong, H. Y., Syahariza, Z. A., Uthumporn, U., & Karim, A. A. (2017). *Rheological and textural properties of texture-modified rice porridge: Comparison between starch and gum as thickener*. Paper presented at the In International Conference on Food Science and Nutrition 2017.

Yoo, D., Kim, C., & Yoo, B. (2005). Steady and dynamic shear rheology of rice starch-galactomannan mixtures. *Starch-Stärke, 57*(7), 310-318. https://doi.org/10.1002/star.200400390

Yoon, S.-N., & Yoo, B. (2016). Effect of pH on rheological properties of dysphagia-oriented thickened water. *Preventive Nutrition and Food Science, 21*(1), 73-77. https://doi.org/10.3746/pnf.2016.21.1.73

Yu, H.-Y., Wang, L., & McCarthy, K. L. (2016). Characterization of yogurts made with milk solids nonfat by rheological behavior and nuclear magnetic resonance spectroscopy. *Journal of Food and Drug Analysis, 24*(4), 804-812. https://doi.org/10.1016/j.jfda.2016.04.002

Zaidul, I., Yamauchi, H., Kim, S.-J., Hashimoto, N., & Noda, T. (2007). RVA study of mixtures of wheat flour and potato starches with different phosphorus contents. *Food Chemistry, 102*(4), 1105-1111. https://doi.org/10.1016/j.foodchem.2006.06.056

Zargaraan, A., Saghafi, Z., Hasandokht Firouz, M., Fadavi, G., Ghorbani Gorji, S., & Mohammadifar, M. A. (2015). Effect of rheological properties on sensory acceptance of two-model dysphagia-oriented food products. *Journal of Texture Studies, 46*(3), 219-226. https://doi.org/10.1111/jtxs.12131