Rheological studies on the effect of different thickeners in texture-modified chicken *rendang* for individuals with dysphagia

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Abstract Texture-modified food has become an important strategy in managing dysphagia. Pureed food is proven to be the safest texture due to its high viscosity which can slow down the rate of the food bolus during swallowing. In this study, texture-modified chicken *rendang* was developed according to Texture C (smooth puree) as described by the Australian standard for texture-modified food. Samples were added with five different thickeners (sago starch, tapioca starch, modified corn starch, xanthan gum and carboxymethyl cellulose gum) at three different concentrations (10, 20 and 30% w/w). Their rheological effects were analyzed through dynamic and steady shear test. Results obtained reveals that samples contained xanthan gum have higher structure rigidity and shear thinning behaviour, while carboxymethyl cellulose gum provides the highest viscosity as well as yield stress than other samples. In terms of concentration, a strong dependence of structural rigidity and viscosity of all prepared samples with amount of thickeners added was observed. Overall, based on its rheological properties, the addition of carboxymethyl cellulose gum at 30% concentration was found to be the most suitable thickener, to be incorporated in the texture-modified chicken *rendang*. Selecting a suitable food thickener in developing food for individual with dysphagia plays an important role to ensure the right texture and consistency for their safe consumption.

Keywords Texture-modified food · Dysphagia · Rheological test · Thickener · Starch · Gum

Introduction

Texture-modified food (TMF) has been used as an important strategy to manage those who encounter chewing and swallowing problem, which is known as dysphagia. The term texture-modified food refers to any food that has undergone mechanical alterations by changing the consistency of the original food so that it will be easier to consume. The modification processes include chopping, mincing, grinding or blending of the normal texture food.

The level of food textural modification for each individuals with dysphagia would depend on the severity of the problem in which only can be prescribed by the health professionals (Dietitians Association of Australia and the Speech Pathology Association of Australia Limited 2007). Categories of TMF ranged from extensively modified (such as puree) to the least modified (soft) have been published and used in many developed countries (Cichero et al. 2013). Among all TMF, puree has been proven as the safest texture to be consumed by individuals with dysphagia (Aviv et al. 2000).

Pureed food has a higher viscosity than liquid, proven to increase the duration of the oral transit time, reduces the pharyngeal delay time and also slows down the time during the pharyngeal transit (Bisch et al. 1994). Viscosity is a very important parameter in controlling the flow rate of food bolus, to avoid the risk of aspiration and choking (Kuhlemeier, Palmer and Rosenberg 2001). Pureed food has been suggested as a texture that can be easily tolerated by individuals with dysphagia, exhibited through fiberoptic endoscopic evaluation of swallowing method (FEES) (Aviv et al. 2000). In this method, an endoscope and a camera is used to view foods or liquids that goes through the pharynx during the swallowing process.

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Individuals with dysphagia usually encounter malnutrition due to limited food intake. Therefore, high protein diet such as meat based product would help to increase their nutritional intake. A study done by Cardello et al. (1985), concluded that people have higher acceptability towards a familiar food rather than a newly developed one. For that reason, chicken *rendang*, a well known Malaysia's traditional dish was selected as a model based on its popularity and its high protein nature. A texture-modified chicken *rendang* (TMCR) was developed as alternative food for individuals with dysphagia especially in Malaysia.

Most dysphagia-oriented food products contains thickening agents to improve viscosity and cohesion between food particles (Seo and Yoo 2013). The common thickener used are of starch-based, gum-based or a combination of both (Yoon and Yoo 2016). However, the commercial thickeners sold in Malaysia are rather expensive and only available in selected stores. Therefore, the search for a suitable thickener at an affordable price to be used in dysphagia-oriented food is in great need.

In this study, five different types of thickeners namely sago starch, tapioca starch, modified corn starch, xanthan gum and, carboxymethyl cellulose gum at three different concentrations (10%, 20%, 30%) were added into the TMCR. Sago and tapioca starch were selected as starch-based thickener candidate because these starch are the two major starches available in Malaysia and widely being used in any food preparation (Khatijah and Patimah 1998). The sample stability was analyzed rheologically using the dynamic oscillatory as well as the steady flow measurement. Data obtained was compared and analyzed to confirm its suitability to be use as cheaper food thickener for dysphagia-oriented product, particularly in TMCR.

Materials and method

Preparation of TMCR

Chicken *rendang* was prepared according to manufacturer's instruction as stated on the packaging of the commercial *rendang* paste (brand Mak Nyonya, Segamat, Johor, Malaysia) purchased from a local supermarket. Prior to cooking, chicken breast meat (60 g) was ground until fine using a bowl cutter mixer R5 (Robot Coupe, France) for 5 min. *Rendang* paste and minced chicken meat were heated on a slow fire using cooking stove for 3 min. Coconut milk and water were then added and further heated for 4 min. The chicken *rendang* was left to cool at room temperature for about 30 min before being processed into puree form using food processor (Model MK-5087 M, Panasonic, Osaka) for 30 s. All ingredients for chicken

Table 1 Ingredients of TMCR

Ingredients	Weight (g)		
Minced chicken breast meat	30	30	30
<i>Rendang</i> paste	20	20	20
Coconut milk	15	15	15
Water	24.8	14.8	4.8
Salt	0.2	0.2	0.2
Gelatinized starch	10	20	30
Total weight	100	100	100

rendang preparation was listed in Table 1, calculated based on the percentage of total weight of all ingredients.

Commercial thickener (modified corn starch (MC), brand Valens Thixer), sago (S) and tapioca starch (T), xanthan gum (XG) and carboxymethyl cellulose gum (CMC) in gelatinized form were later added into chicken *rendang* puree, at 10%, 20% and 30% concentrations (w/w) (based on the total weight of all ingredients). The starch gelatinization was carried out using starch to water ratio of 1:10 by heating it on a cooking stove. Meanwhile, XG and CMC were prepared by mixing both gums individually with reverse osmosis water using gum to water ratio of 0.5:10. The samples were blended for 30 s. The proposed concentrations were selected based on a preliminary study using Line Spread Test (LST), to ensure its compliance with Texture C (smooth puree) of the Australian standard for texture-modified food (Dietitians Association of Australia and The Speech Pathology Association of Australia Limited 2007). LST is a test to measure consistency of a food product based on its spreadability on a sheet of a glass panel. Beneath the glass panel, a piece of paper with a few numbers of concentric circles were outlined at a distance of 1 cm apart. In each test, the tube was lifted to allow the sample to flow and the readings were taken at the leading edge of the sample after 1 min at every 90° angles of the circles (Ilhamto 2013). Meanwhile, TMCR without any addition of thickener was used as the control sample. All samples were sieved through a 0.841 mm opening to remove large particles before analysis.

Rheological measurements

A small amplitude of dynamic measurement and a steady shear measurement were conducted using a controlled stress rheometer (AR1000, TA Instruments, New Castle, DE, USA) equipped with Rheology Advantage Data Analysis Program (TA, version V5.7.0). A 20 mm parallel plate with a gap of 1 mm was used. All rheological measurements were carried out in triplicate. Measurements

were conducted at 37 °C in order to mimic the body temperature during food consumption.

Dynamic oscillatory test

Stress sweep was performed in the range of 0.0001–10000 Pa at a frequency of 1 Hz to determine the product's linear viscoelastic range (LVR). Frequency sweep was carried out between 0.1 and 10 Hz at 0.2% strain (based on LVR). Storage modulus (G') and loss modulus (G'') were recorded. The viscoelastic properties were presented as the power law model (Eq. 1).

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

Steady state flow test

Steady state shear experiments were conducted at shear rate range of 0.1–100 s^{-1} with a linear mode. All samples were pre-sheared for 2 min at 50 s^{-1} . The flow behaviour was modelled using the power law model (Eq. 1) and Casson model (Eq. 2).

$$\sigma^{0.5} = K_{0c} + K_c(\dot{\gamma})^{0.5} \quad (2)$$

in which σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), K is the consistency index (Pa s^n) and n is the flow behavior index (dimensionless). Casson yield stress (σ_{0c}) was determined as the square of the intercept (K_{0c}) obtained from the linear regression of the square roots of shear rate-shear stress data. Power law model reports the data of shear thinning or shear thickening while Casson model have been heavily used to describe the time independent shear flow for food suspension that displays sample's shear thinning behavior, yield stress and high shear viscosity.

Data analysis

Data were reported as the mean value with a standard deviation from triplicate reading, analyzed through Analysis of Variance (ANOVA) using SPSS version 23 (IBM Corp., Armonk, NY). Tukey post hoc test was conducted to determine differences within the types of thickeners and its concentrations.

Results and discussion

Viscoelastic behaviour

Oscillatory measurements was carried out to investigate physical properties of a sample, in terms of minor structural level changes (e.g. crosslinking, phase separation,

molecular aggregations) without damaging its structure (Mandala and Palogou 2003). Small deformation test gave initial textural impression inside the mouth during consumption (Funami 2011). Storage modulus (G') and loss modulus (G'') are the important parameters to determine the viscoelastic behaviour of a sample during application of stress. G' refers to the elastic energy stored in the sample while loss modulus (G'') refers to the energy that was dissipated from the structure and sometimes called the viscous response (Saha and Bhattacharya 2010).

Figure 1a, b illustrate the rheograms of TMCR without the addition of thickening agent (control), as well as those incorporated with thickeners at three different concentrations. G' value was considerably higher than G'' throughout the frequency range and both moduli were seen increasing along with the frequency. This result presents a weak gel behaviour which is one of the rheological criteria to achieve ease of swallowing properties (Ishihara et al. 2011).

The sample possesses both viscous and elastic behaviour (viscoelastic) with storage modulus (G') being larger than the loss modulus (G''). Purees are classified as a suspension of solid matter in a fluid media (Rao 1986). Results from this study showed that all thickened samples reveal a higher G' and G'' values than control. The value of G' for all thickened samples at 20 and 30% concentrations were doubled than the value of G'' , hence can be categorized as a concentrated suspension and highly elastic materials. Higher values of both moduli clearly indicate that thickeners play a role in the structure forming process by strengthening the food structure (Zhang and Barbut 2005). This finding was in accordance with Genccelep et al. (2015) which concluded that thickeners contribute to the properties of meat emulsions.

Table 2 summarizes the effect of different types and concentrations of thickeners on the oscillatory test of TMCR. An increasing trend in the structure's rigidity, given by the value of storage modulus (G') at all concentrations with T being the lowest, followed by S, MC, CMC and XG indicate greater structure rigidity as the concentration increased. Rheological behaviours of food thickeners are very much dependent on their types and concentrations (Seo and Yoo 2013), while the swelling ability of starch also influenced its strengthening ability. Kim and Lee (1987) showed that potato starch had a higher strengthening ability than wheat starch due to its higher swelling power. Based on studies by Khatijah and Patimah (1998), sago starch had higher granule swelling power and higher thickening power than tapioca starch. For samples with addition of modified corn starch (commercial thickener), the samples' structure seems to be less rigid compared to sago starch but higher than tapioca starch. In contrast to starch, the act of thickening by gums is through

Fig. 1 **a** Oscillatory rheograms of control and thickened samples for storage modulus (G') at 30% thickener's concentration. **b** Oscillatory rheograms of control and thickened samples for loss modulus (G'') at

30% thickener's concentration. Control = sample without starch, S = sago starch, T = tapioca starch, MC = modified corn starch, XG = xanthan gum, CMC = carboxymethyl cellulose gum

the entanglement of polymer molecules which lead to the presence of a new network structure (Vilardell et al. 2016). Besides, an interaction between the carboxyl groups (negatively charge) in both gums with meat protein's amino acids (positively charge) causes an increased in the XG and CMC sample's rigidity (Chatotong et al. 2007). Structural rigidity were seen higher in XG than CMC. The dynamic oscillatory was found to be a suitable test to study the behaviour of XG due to its stiffer polymeric structure and long relaxation time compared to those of flexible macromolecules with simple molecular entanglements (Mandala and Palogou 2003).

The regression coefficients from Table 2 show that both storage modulus (G') and loss modulus (G'') data fitted adequately ($R^2 > 0.87$) for all samples. All thickened samples possesses a solid like characteristic as displayed by higher A value of G' , as compared to A value for G'' . Result shows that when concentration increased, there was no specific trend observed in the corresponding b value (slopes) which ranged between 0.15–0.80 and 0.12–0.54 for G' and G'' respectively. According to Ahmed and Ramaswamy (2007) when $b > 0.09$, it indicates that both moduli experienced small increase in value as the frequency increased (i.e. a slight dependency on the

Table 2 Effect of different types and concentrations of thickeners on the oscillatory test of TMCR

Thickener	Conc. (%)	G'			G''		
		A (Pa s ^b)	b (–)	R ²	A (Pa s ^b)	b (–)	R ²
C		2.49 ± 0.77	0.80 ± 0.41	0.97 ± 0.01	0.61 ± 0.07	0.54 ± 0.06	0.94 ± 0.01
S	10	47.03 ± 1.95 ^{Aa}	0.34 ± 0.01 ^{Aa}	0.97 ± 0.01	42.14 ± 2.33 ^{Aa}	0.29 ± 0.07 ^{Aa}	0.94 ± 0.01
	20	147.19 ± 29.92 ^{Ba}	0.29 ± 0.03 ^{Aab}	0.90 ± 0.03	70.46 ± 25.65 ^{Ba}	0.23 ± 0.04 ^{Aab}	0.98 ± 0.03
	30	331.13 ± 22.67 ^{Ca}	0.24 ± 0.05 ^{Aab}	0.88 ± 0.04	102.37 ± 7.65 ^{Ca}	0.20 ± 0.02 ^{Aa}	0.98 ± 0.01
T	10	27.27 ± 4.44 ^{Aa}	0.24 ± 0.05 ^{Ac}	0.989 ± 0.01	18.33 ± 4.88 ^{Aa}	0.27 ± 0.06 ^{Aa}	0.99 ± 0.01
	20	135.79 ± 23.0 ^{Ba}	0.31 ± 0.04 ^{Ab}	0.99 ± 0.004	49.89 ± 7.76 ^{Ba}	0.23 ± 0.02 ^{Aab}	0.99 ± 0.004
	30	185.29 ± 14.34 ^{Cb}	0.24 ± 0.03 ^{Aab}	0.89 ± 0.03	65.47 ± 5.5 ^{Cb}	0.25 ± 0.02 ^{Abd}	0.95 ± 0.07
MC	10	93.39 ± 4.62 ^{Ab}	0.26 ± 0.02 ^{Ac}	0.87 ± 0.01	46.40 ± 4.08 ^{Ab}	0.20 ± 0.04 ^{Ab}	0.97 ± 0.01
	20	343.55 ± 19.91 ^{Bb}	0.15 ± 0.04 ^{Ba}	0.88 ± 0.04	105.11 ± 3.47 ^{Bb}	0.17 ± 0.04 ^{Ab}	0.96 ± 0.02
	30	528.44 ± 26.97 ^{Cc}	0.26 ± 0.02 ^{Ab}	0.87 ± 0.01	122.26 ± 16.22 ^{Cc}	0.21 ± 0.01 ^{Aab}	0.97 ± 0.01
XG	10	138.52 ± 28.35 ^{Ac}	0.16 ± 0.01 ^{Ab}	0.98 ± 0.02	82.13 ± 10.29 ^{Abc}	0.14 ± 0.01 ^{Ab}	0.98 ± 0.02
	20	735.26 ± 20.08 ^{Bc}	0.16 ± 0.03 ^{Aa}	0.96 ± 0.03	189.11 ± 13.49 ^{Bc}	0.16 ± 0.01 ^{Ab}	0.96 ± 0.02
	30	873.36 ± 21.41 ^{Cd}	0.16 ± 0.01 ^{Aa}	0.97 ± 0.02	208.15 ± 3.88 ^{Cd}	0.12 ± 0.01 ^{Ac}	0.95 ± 0.03
CMC	10	102.61 ± 22.28 ^{Ac}	0.25 ± 0.03 ^{Ac}	0.97 ± 0.02	75.37 ± 16.0 ^{Ac}	0.24 ± 0.03 ^{Ac}	0.99 ± 0.01
	20	420.88 ± 22.44 ^{Bd}	0.26 ± 0.03 ^{Aab}	0.97 ± 0.01	158.47 ± 10.11 ^{Bd}	0.28 ± 0.01 ^{Aa}	0.99 ± 0.01
	30	635.84 ± 16.88 ^{Cc}	0.25 ± 0.02 ^{Ab}	0.97 ± 0.02	259.12 ± 14.36 ^{Cc}	0.28 ± 0.01 ^{Ad}	0.99 ± 0.004

A = values of storage modulus (G') and loss modulus (G''), b (–) slopes of storage modulus and loss modulus, R = coefficient of determination. Values with different letters (A–C) and (a–e) represents significant different ($P < 0.05$) for different thickeners and different concentrations respectively

frequency). The increased in G' and G'' can be seen in Fig. 1a, b.

Flow behaviour

Figure 2 depicted a steady flow curves of all samples at a shear rate of 0.1–1000 s^{–1}, observed at 37 °C. All samples were fitted to power law model as well as the Casson model

Fig. 2 Steady state flow curves of control and thickened samples at 30% thickener's concentration. Control = sample without starch, S = sago starch, T = tapioca starch, MC = modified corn starch, XG = xanthan gum, CMC = carboxymethyl cellulose gum

using the shear stress-shear rate data. All data reveal an acceptable determination coefficients ($R^2 = 0.875\text{--}0.999$) (Table 3). The flow behaviour index (n), decreased as the concentration increased. It was ranged between 0.22 and 0.31 for all samples, exhibiting viscoplastic shear thinning behaviour with $n < 1$. Flow behaviour index (n) is an index of deviation from the Newtonian flow. Shear thinning property usually can be found in heterogeneous systems containing dispersed phase. During resting phase, all particles are bound together by weak forces. As hydrodynamic forces are sufficiently high when the shearing process took place, the inter-particle bonds break, hence reducing the size of the structural unit and causes it to have low resistance to flow upon shearing (Van Hecke et al. 2012). All thickened samples possessed higher magnitude of shear thinning (0.22–0.30) than control sample (0.31). Addition of thickeners proved to have an impact on the shear thinning behaviour of the thickened samples.

On the contrary, the flow test (Table 3) reveals that CMC exhibited the highest value of consistency (K) as well as yield stress (σ_{OC}). The increased amount of thickener lead to more entanglements between macro-molecular chains in gums, as well as higher swelling of starch granules (Moraes et al. 2011). Gums are known to be more viscous than starch. Their viscosity are greatly affected by the molecular mass, chain rigidity and the electrostatic charge density (Saha and Bhattacharya 2010). CMC displayed higher viscosity due to its greater linear molecular

structure compared to XG. Therefore CMC has higher tendency to form entangled conformation in solutions (Hui and Sherkat 2005). Based on the flow test, it can be concluded that 30% of CMC addition has a greater structure stability compared to other samples.

During oral consumption, it involves large deformation for structural breakdown which can be imitated by large deformation measurements, using steady state flow test (Janssen et al. 2007). Funami (2011) stated that the steady shear viscosity is a great parameter to measure the rate of flow for food bolus, as higher value for yield stress indicates thicker bolus which is easier for swallowing. Based on Table 3, as the thickeners' concentration increased, both K and σ_{OC} values were increased except for the n value. According to Nishinari et al. (2011), a high degree of shear thinning given by low n value is important to reduce the risk of aspiration. The addition of xanthan in this study produced a high shear thinning behaviour in which Szczesniak and Farkas (1962) described it as feeling less slimy in the mouth. As proposed by Quemada (1998), the breakdown of a sample's structure caused shear thinning behaviour in concentrated suspension. The consistency index (K) is defined by the value of viscosity (or stress) at a shear rate of 1.0 s^{-1} , which can be use to differentiate low and high viscosity foods (Wendin et al. 2010). Cho and Yoo (2015), have used the K as a parameter to compare the viscosity of various thickened drinks. Apart from shear thinning behaviour, another factor that determines the

Table 3 Steady shear rheological properties of TMCR incorporated with different types and different concentrations of thickeners

Thickener	Conc. %	R^2	Power Law		Casson yield stress, σ_{OC} (Pa)
			n (–)	K (Pa s^n)	
C		0.985 ± 0.011	0.31 ± 0.06	16.79 ± 0.74	33.27 ± 6.94
S	10	0.994 ± 0.004	$0.30 \pm 0.04^{\text{Aab}}$	$24.59 \pm 0.23^{\text{Aa}}$	$30.56 \pm 1.38^{\text{Aab}}$
	20	0.993 ± 0.001	$0.29 \pm 0.01^{\text{Aa}}$	$58.41 \pm 7.54^{\text{Ba}}$	$75.48 \pm 10.90^{\text{Ba}}$
	30	0.985 ± 0.011	$0.26 \pm 0.02^{\text{Aa}}$	$82.20 \pm 13.73^{\text{Ca}}$	$100.81 \pm 12.09^{\text{Ca}}$
T	10	0.989 ± 0.001	$0.30 \pm 0.02^{\text{Ab}}$	$19.58 \pm 0.63^{\text{Aa}}$	$22.77 \pm 2.61^{\text{Aa}}$
	20	0.997 ± 0.001	$0.28 \pm 0.04^{\text{Aab}}$	$54.41 \pm 7.54^{\text{Ba}}$	$70.61 \pm 10.73^{\text{Ba}}$
	30	0.989 ± 0.003	$0.27 \pm 0.01^{\text{Aa}}$	$79.75 \pm 12.49^{\text{Ca}}$	$91.39 \pm 5.88^{\text{Ba}}$
MC	10	0.994 ± 0.002	$0.29 \pm 0.03^{\text{Aab}}$	$28.32 \pm 4.21^{\text{Aab}}$	$37.20 \pm 6.01^{\text{Ab}}$
	20	0.996 ± 0.002	$0.26 \pm 0.01^{\text{ABab}}$	$80.96 \pm 8.54^{\text{Ba}}$	$80.96 \pm 8.54^{\text{Bab}}$
	30	0.996 ± 0.002	$0.23 \pm 0.01^{\text{Ba}}$	$126.97 \pm 8.54^{\text{Ca}}$	$150.53 \pm 10.19^{\text{Cb}}$
XG	10	0.997 ± 0.001	$0.28 \pm 0.01^{\text{Aab}}$	$36.65 \pm 2.36^{\text{Abc}}$	$49.02 \pm 3.81^{\text{Ac}}$
	20	0.996 ± 0.001	$0.23 \pm 0.01^{\text{Ba}}$	$90.10 \pm 0.36^{\text{Bb}}$	$106.03 \pm 1.14^{\text{Bb}}$
	30	0.994 ± 0.003	$0.22 \pm 0.03^{\text{Ba}}$	$157.02 \pm 12.44^{\text{Cb}}$	$177.0 \pm 11.06^{\text{Cb}}$
CMC	10	0.998 ± 0.001	$0.29 \pm 0.01^{\text{Aa}}$	$43.61 \pm 5.58^{\text{Ac}}$	$52.98 \pm 5.28^{\text{Ac}}$
	20	0.999 ± 0.001	$0.26 \pm 0.01^{\text{Ba}}$	$141.50 \pm 10.07^{\text{Bc}}$	$181.93 \pm 13.60^{\text{Bc}}$
	30	0.992 ± 0.002	$0.26 \pm 0.01^{\text{Ba}}$	$273.47 \pm 11.61^{\text{Cc}}$	$338.40 \pm 12.32^{\text{Cc}}$

R = coefficient of determination, n = flow behaviour index, K = consistency index, σ_{OC} = yield stress. Values with different letters (A–C) and (a–c) represents significant different ($P < 0.05$) for different thickeners and different concentrations respectively

effectiveness of dysphagia treatment is product's viscosity (Wendin et al. 2010). Higher viscosity food proven to provide individuals with dysphagia enough time to prepare food bolus in time for swallowing, while protecting food bolus from entering the airway (Hanson et al. 2012).

Hamlet et al. (1996), reveals that more than half of the normal subjects who participated in a swallowing study prompt a second swallow spontaneously on a thickened apple juice (1100cP) compare to a plain water with a single swallow. This second swallow was found to have cleared the food residues which remained in their mouth. This demonstrates that a thicker bolus is easier to swallow than a thin liquid. Behzadfar et al. (2009) state that higher viscosity of suspensions was primarily caused by the existence of local structures in the media that immobilize the fluid and restraining it from getting involved in the hydrodynamic flow. The author concluded that as the amount of thickener in the sample increased, it will lead to higher particles concentration and aggregation in the system, thus producing higher viscosity.

Another rheological parameter that determine the ease of swallowing of food bolus is the yield stress (Yoon and Yoo 2016). It refers to the minimum value of shear stress during the materials transition from 'solid like' to 'liquid like' characteristic which correlate to the point at which the material starts to flow (Ahmed and Ramaswamy 2007). Existence of yield stress is an indicator of a concentrated suspension in which its magnitude relies on the particle–particle interactions and the obtained micro-structure. In simple words, the strength of the network structure can be measured by knowing the yield stress value (Moelants et al. 2014). Theoretically, the higher the yield stress value, the greater the particle–particle interaction, indicating higher resistance of material to flow. In this study, 30% of thickener's concentration was found to exhibit the highest yield stress value, as it possess the strongest interaction between particles. Such interaction is important to form a cohesive bolus, in order to minimize disintegration of food matrices, hence minimizing the risk of aspiration.

Conclusion

Rheological properties of TMCR were studied through the dynamic and steady shear measurement. Both results showed that the TMCR possesses weak gel property with shear thinning behaviour. The swelling ability of starch is the main reason that influenced the strengthening of the samples' structure. On the other hand, for gums, it was caused by the entanglement of polymeric molecules, as well as the interaction between carboxyl groups from gums and the amino acids from meat protein. As expected, the consistency index as well as the yield stress increases along

with the thickener's concentration due to higher particles content that leads to particles aggregation in the system. Overall, incorporation of 30% carboxymethyl cellulose gum proves to be suitable for the developed TMCR, based on its structural stability (measured through yield stress and storage modulus), exhibiting the highest value of viscosity and a favourably high shear thinning behaviour upon mechanical shearing. These criteria are crucial to achieve 'safe-swallow bolus', helping to provide safe swallowing experience for individuals with dysphagia.

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