



Influence of honey types and heating treatment on the rheological properties of glutinous rice flour gels

Eng-Keng Seow¹ · Chee-Yuen Gan² · Thuan-Chew Tan¹ · Lai Kuan Lee¹ · Azhar Mat Easa¹

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Abstract Present study compared the rheological properties of glutinous rice flour (GRF) gel (33.3%, w/v) added with raw bee honey (RBH) or stingless bee honey (SBH) with/without heating treatment. RBH (diastase activity: 12.14 Schade) and SBH (1.53 Schade) significantly reduced the network of GRF gel by lowering the gel viscosity, with RBH having the highest rate of viscosity decrease (-2.74×10^{-5} Pa). As the addition of heated-SBH or heated-RBH did not reduce gel viscosity, it was hypothesised that active diastase played a major role to weaken gel network. This was further supported by the significant and the lowest storage modulus (G') value of RBH-GRF gel (5.99 ± 0.02 Pa), as compared to SBH-GRF (6.27 ± 0.04 Pa) and control (6.33 ± 0.04 Pa). A detail of rheological behaviour of the gels was further explained using power law. Overall, this GRF gel model has successfully demonstrated the potential of honey diastase in weakening network of starch-based food.

Keywords Glutinous rice flour · Raw honey · Stingless bee honey · Diastase · Starch thinning

Introduction

Honey has been used to replace sugar in starch-based food products, such as bread, muffin, and biscuit (Strait 1997; Babajide et al. 2014; Filipčev et al. 2014). Interestingly, honey amylase (diastase) was found to exhibit its potential in degrading food starch as evident by the viscosity drop (Babacan et al. 2002). Diastase consists of both α - and β -amylase, which cleaves the branched chains into shorter chains through α -1,4 linkages, at an internal site, and in a stepwise trend initiating from the non-reducing end, respectively (Thomas and Atwell 1997; da Silva et al. 2016). It was hypothesised that a softened starchy product with retarded texture deterioration could be achieved through the disruption of normal reassociation process of glucan chains during cooling or storage, due to the shorter chains. Diastase is thermolabile, and therefore an indicator of honey freshness and thermal effect (da Silva et al. 2016). Stingless bee honey (SBH) or locally known as “kelulut” honey in Malaysia, and raw bee honey (RBH) are two honey types commonly consumed. However, SBH contains lower diastase activity and a higher acidity value as compared to RBH (Chuttong et al. 2016). These differences may cause impact on the textural and rheological properties of starch-based foods which worth the effort for further investigation.

Glutinous rice, or better known as sweet rice or sticky rice, is a staple crop commonly cultivated in mainland of Southeast Asia (Golomb 1976). Glutinous rice is a type of waxy rice, that waxy starch generally contains more than 95% of amylopectin (Thomas and Atwell 1997). Owing to its sticky and desirable natural sweet taste, it is normally used in making traditional snacks or desserts in Asia. For instance, waxy rice has been used in making *mochi* (Chuang and Yeh 2006), *hangwa* and *injeolmi* (Choi et al.

✉ Azhar Mat Easa
azhar@usm.my

¹ Food Technology Division, School of Industrial Technology, Universiti Sains Malaysia (USM), 11800 Penang, Malaysia

² Analytical Biochemistry Research Center, Universiti Sains Malaysia (USM), 11800 Penang, Malaysia

2001), *dodol* (Chuah et al. 2007), and *Bhoja chaul* (Dutta et al. 2016), in Taiwan and Japan, Korea, Malaysia and Indonesia, and India, respectively. Hence, this widely used rice flour was chosen as a starch model to compare the effect of honey types and heating treatment on the rheological properties of flour gels. RBH is a food ingredient typically used for sweetening purpose. SBH, on the other hand, is slowly gaining popularity, but less established and is rarely used in food. Hence, present study was conducted to compare the rheological properties of GRF gel added with SBH or RBH with/without heating treatment. Findings on the comparison of the rheological properties of GRF gel would be useful for starchy food product development using honey. Raw honey can be used not only for its sweetening and flavouring purposes, but it is also useful as a potential texture-modifier in development of starchy food products. Addition of honey enhance the product quality as it could soften the texture and delay the hardening (retrogradation) of starchy products. In addition, lowering the viscosity of flour gel owing to the shortened starch chains produced helps the bakery at industrial level as it aids the mixing of other ingredients during the production process.

Materials and methods

Materials

Three bottles of stingless bee honey (SBH) or three bottles raw bee honey (RBH) samples were purchased from the local suppliers. Upon acquisition, diastase activity and pH values were determined using Phadebas[®] Honey Diastase Test and Harmonized Methods of the International Honey Commission, respectively. SBH (1.53 ± 0.38 Schade, pH 2.8 ± 0.01) and RBH (12.14 ± 0.78 Schade, pH 4.4 ± 0.01) were either used as they were or were heated at 100 °C for 30 min, which were then denoted as heated-SBH (0 Schade, pH 2.7 ± 0.01) or heated-RBH (0 Schade, pH 4.3 ± 0.02), respectively. Glutinous rice flour (GRF) (Erawan Brand, Thailand) and coarse grain sugar (MSM Prai Berhad, Malaysia) were purchased from Sim Company Sdn. Bhd., Penang. A sugar solution with 81°Brix of total soluble solids (TSS) content was prepared (similar TSS as RBH), and was measured by a digital refractometer (HI 96801, Hanna Instruments Inc., Woonsocket, USA).

Rheological analyses

Real time behaviour of all rheological analyses were controlled and monitored by Rheology Advantage Instrument Control AR (TA Instruments, New Castle, USA). Experimental data obtained were analysed using Rheology

Advantage Data Analysis software V5.4.8 (TA Instruments, New Castle, USA).

Transient flow property

GRF dispersion (33.3%, w/v) was stirred at room temperature for 30 min before being transferred into a rheometer (AR-2000EX, TA Instruments, New Castle, USA) with a standard size aluminium double concentric cylinder with a gap distance of 1000 μm for determination of transient flow property. This analysis aimed to observe the overall process from flour dispersion to the gel, and after addition of raw honey, heated honey or sugar solution (81°Brix) for 30 min of reaction. It consisted of two steps, in which both steps started with a conditioning step of pre-shearing for 1 min at the shear rate of 10 s^{-1} . Step 1 began with heating 925 μL GRF dispersion from 30 to 75 °C at angular velocity of 20 rad/s with the temperature ramp rate of 4.5 °C/min. GRF dispersion was held for 10 min at 75 °C before it was cooled down to 55 °C with the temperature ramp rate of 4 °C/min. Twenty-five μL (8% per flour weight basis) of sugar solution, heated-SBH, heated-RBH, SBH, and RBH were added into the gelatinised GRF, respectively, in subsequent analyses. The addition at 8% per flour weight basis was based on preliminary study (data not shown), whereby GRF gels added with honey (8% per flour weight basis) was found to be effective in softening the texture of these gels, i.e. lower hardness value in texture profile analysis.

Step 2 began immediately after the addition, and it was held at 55 °C for 30 min. The viscosity (Pa s) change with time (s) was plotted, whereby the slope of linear curve indicated the rate of viscosity decrease (Pa), as yielded by the addition of raw honey, heated honey or sugar solution.

Flow and viscoelastic properties

Preparation of flour dispersion

A total of 50 g of GRF and 150 mL of deionised water (33.3%, w/v) were mixed in beakers for 30 min at room temperature until the flour was completely dispersed using magnetic stirrer (Chun and Yoo 2004). Beakers were heated in a water bath (Mettmert, Schwabach, Germany) at 60 °C for 5 min to pre-gelatinise the GRF dispersions with manual stirring every 15 s, to prevent sedimentation of flour that causes a separation and leads to formation of two layers. Then, they were transferred to a shaking thermostatic water bath (WB22-16X2501, Mettmert, Schwabach, Germany) at 95 °C for 30 min with a mild agitation (Chun and Yoo 2004; Kim and Yoo 2017) provided by water bath shaker to minimize settling of flour particle. Gelatinisation that occurs during cooking allows leaching of amylopectin

from starch granules for enzymatic hydrolysis due to high susceptibility of gelatinised starch to enzymatic action (Holm et al. 1988; Thomas and Atwell 1997). Hot gels were left to cool to around 55 °C before 4 g (8% per flour weight basis) of SBH, RBH, heated-SBH, heated-RBH, and sugar solution were added, respectively. To ensure homogenous flour gels were produced for fair comparative rheological studies, the gels were stirred mildly at 200 rpm (the lowest speed) for 1 min using an overhead stirrer (RM20 digital, Ika, NC, USA) before they were immediately transferred to the rheometer plate for measurement of their flow and viscoelastic properties at 55 °C. Mild stirring was applied to all gels to avoid shear thinning caused by stirring that yields misleading false positive results, which could be inferred by the decrease of viscosity after addition of honey. Every sample was freshly prepared prior to loading to minimise the effect of short-time starch retrogradation.

Time sweep test

Oscillatory time sweep test was performed to investigate the gel formation behaviour of the GRF gel under continuous oscillation (direct strain) of 0.5% and angular frequency of 6.283 rad/s at 55 °C. Storage modulus (G') and loss modulus (G'') were presented on a log scale on the y-axis versus the time on the x-axis.

Strain sweep test

The flow and viscoelastic properties of GRF gel was carried out using a AR-2000EX rheometer equipped with a cone plate geometry of 20 mm in diameter at a gap distance of 1000 μm . Strain sweep test was performed over the range of 0.01–10,000% of strain set at log mode, to determine GRF gels' linear viscoelastic region (LVR) at 55 °C and angular frequency of 6.283 rad/s. Analysis was initiated with a conditioning step of pre-shearing the gel for 30 s at a shear rate of 1 s^{-1} and followed by equilibration for 1 min. Behaviour of the structure applied by different % strain were determined.

Peak hold flow test

Peak hold flow test was conducted at 55 °C with a shear rate of 20 s^{-1} for 30 min to examine the viscosity of GRF gels as affected by the addition of raw honey enzyme over time. Prepared gels on the rheometer plate were pre-sheared at 1 s^{-1} for 30 s and were equilibrated for 1 min before the first sampling point was taken.

Steady state flow test

Steady state flow test profile was plotted by shear stress (Pa) against shear rate (s^{-1}) for determination of steady shear rheological properties of GRF gels. This test was performed at shear rate over the range of 0.01–1000 s^{-1} at 55 °C, and it made up of two steps: ramp up and ramp down. Continuous ramp shear rate for Step 1 began from 0.01 to 1000 s^{-1} , and followed by the reverse trend (from 1000 to 0.01 s^{-1}) in Step 2. This analysis was conditioned with a pre-shearing at 1 s^{-1} for 30 s and 1 min of equilibration.

Statistical analysis

All rheological analyses were measured in triplicates ($n = 3$) and reported as mean \pm standard deviation, whereby one reading each was taken from the three individually prepared GRF gels. Experimental data obtained from transient flow property, time sweep test, peak hold flow test, and steady state flow test were subjected to one way analysis of variance (One-way ANOVA), followed by Tukey's test for multiple comparisons, using IBM SPSS v22 for Windows (IBM SPSS Inc., Chicago, IL). A significant level of $p < 0.05$ was maintained throughout the study.

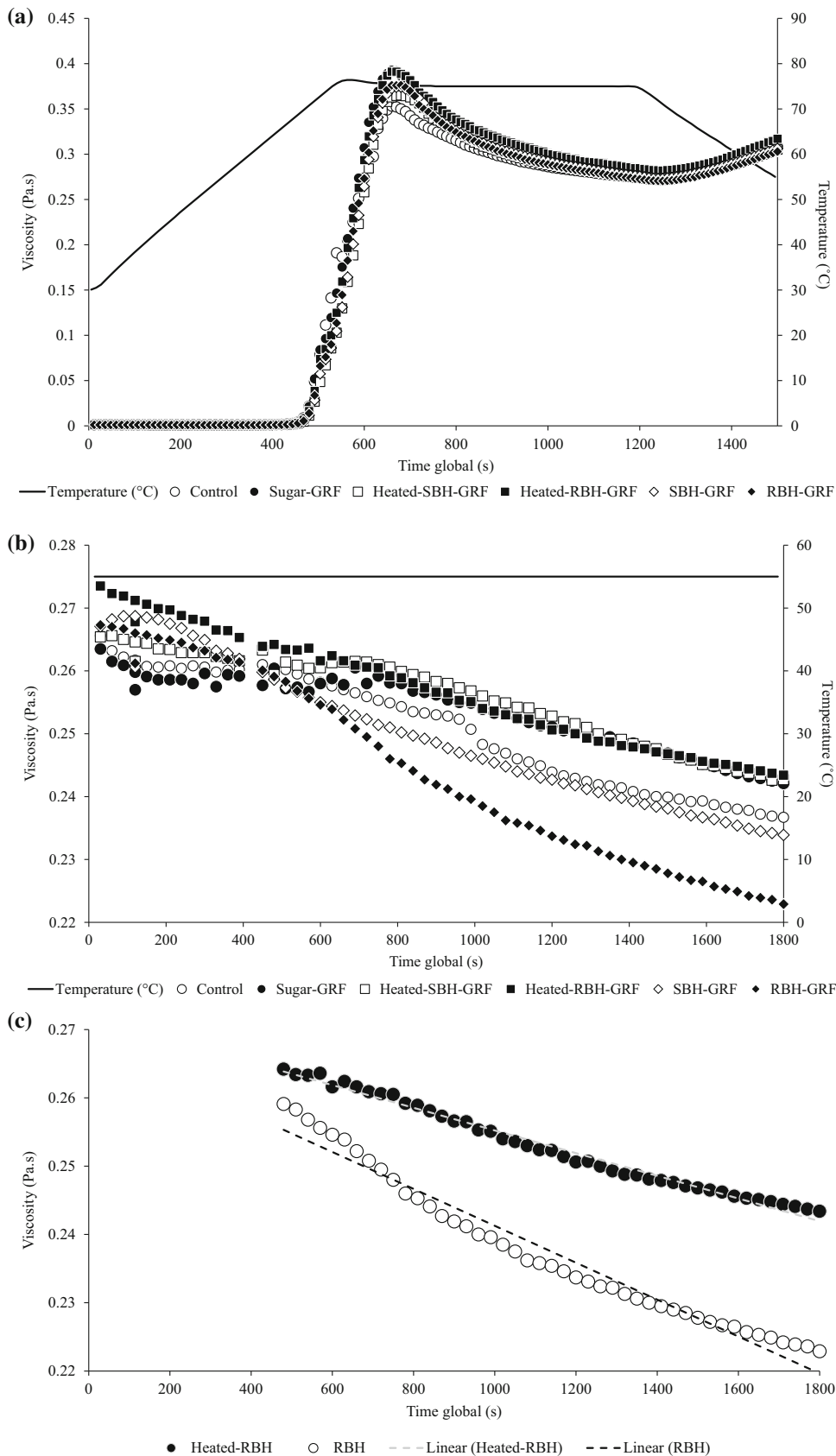
Results and discussions

Transient flow property

GRF dispersion was cooked in a double concentric cylinder until it gelatinised as shown in Fig. 1a. Gelatinisation begins with the swelling of starch granules during heating, and breaking of intra- and inter-molecular hydrogen bonds within, follows by leaching of amylose (Singh et al. 2007). Further increase of temperature causes disintegration of starch granular structure and dissolution of amylopectin with a higher degree of orientation which is evident with the increase of viscosity (Thomas and Atwell 1997; Chung et al. 2006). Waxy starch granules disintegrated more easily when swollen and were less rigid. Maximum viscosity was achieved at around 750 s, and the viscosity continued to drop slowly owing to the shear thinning effect and it implied destruction of gel structure (Singh et al. 2007). Hot gels were allowed to cool to 55 °C because it is the optimum temperature for diastase to react (Babacan et al. 2002).

Pre-determined amount of sugar solution, heated-SBH, heated-RBH, SBH, and RBH were added to the gelatinised GRF gel in concentric cylinder, respectively, to compare the effect of honey types and heating treatment of honey on

Fig. 1 Transient flow property analysis with **a** viscosity profiles of development from flour dispersions to gelatinised flour gels, which cooked from 30 °C, held at 75 °C for 10 min, and cooled down to 55 °C, **b** viscosity profiles of flour gels with/without the addition of sugar solution, raw honey and heated honey, maintained at 55 °C for 30 min, **c** comparison of the rate of viscosity decrease of flour gels due to addition of raw and heated bee honey, as indicated by the steepness of the slopes from 480 to 1800 s



viscosity of GRF. A conditioning step wherein pre-shearing (which determines a zero-time of shear) of GRF gel was carried out for 1 min to eliminate any structure history before loading, as loading affects the rheological properties of sample structure network (Rønholt et al. 2014). Time-dependent viscosity of GRF gel was measured at a constant shear rate and temperature was maintained at 55 °C for 30 min, as depicted in Fig. 1b. All flour gels exhibited non-Newtonian behaviour, and shear thinning (thixotropic) occurred in which the viscosity decreased over time under constant shearing. Viscosity of all gels for the first 480 s did not show any noticeable change. Different types of honey may cause different effects to the gel viscosity due to the varied composition and properties. Diastase activity and acidity are two factors that may affect the gel viscosity through enzymatic and acid thinning reaction, respectively. Compared to RBH, SBH contains lower diastase activity and a higher acidity value (Chuttong et al. 2016). It was speculated that addition of RBH with high diastase activity or SBH with low pH (high acidity) cause the gel viscosity to decrease. Variation in honey diastase activity could be associated to the floral sources used by the bees, and the regional and climatic conditions. Acidity of honey is yielded by the presence of gluconic acid in equilibrium with esters or lactones, and phosphate and chloride. The difference in organic acids and inorganic ions due to extraction season contribute to the variation in acidity of different types of honey (Singh and Bath 1997, 1998). It is known that acidic environment can cause dramatic impact on gel viscosity (Thomas and Atwell 1997). Addition of SBH which was more acidic (pH 2.75), yielded gel that showed a slightly lower viscosity over time, as compared to the control gel (without addition of raw honey, heated honey or sugar solution). However, it was apparent that the viscosity of RBH-GRF gel gradually decreased after 480 s of shearing and showed the most drastic drop of viscosity. Final viscosity of RBH-GRF gel (0.222 Pa s) was

significantly lower ($p < 0.05$) than that of SBH-GRF gel (0.234 Pa s) as shown in Table 1. RBH with a significant higher ($p < 0.05$) diastase activity than SBH, exerted a more prominent effect on gel viscosity drop. The impact of diastase activity was found to be more substantial than acidity of honey on gel viscosity.

Interestingly, GRF gels incorporated with sugar solution, heated-SBH, and heated-RBH yielded flour gels with a significant higher ($p < 0.05$) viscosity than control gel (Table 1). It was proposed that the sugar present in these three solutions attached to the existing starch chains and increased the molecular weight. Heated honey with its active diastase inactivated by heating at 100 °C for 30 min (Ulfah and Rahmadi 2018), did not contribute to the viscosity loss over time. This was consistent with findings from previous study by Babacan et al. (2002), whereby honey diastase decreased the viscosity of starch pastes by causing starch degradation. Diastase that consists of both α - and β -amylase hydrolyses the branched chains into shorter chains. Both α - and β -amylase hydrolyses the starch chains at α -1,4 glucosidic linkages, yielding dextrin and maltose, respectively (da Silva et al. 2016). Compared to SBH-GRF and RBH-GRF gels, it is likely that the amylopectin in control gel had a higher molecular weight due to the longer starch chains, thus showed a significant higher ($p < 0.05$) viscosity (Table 1).

As RBH showed the most pronounced effect on the viscosity of GRF gels, the viscosity changes of RBH-GRF and heated-RBH-GRF are shown in Fig. 1c to compare the rate of viscosity decrease caused by raw honey versus that of heated honey. It was evident that RBH has caused a higher rate of viscosity drop than the heated honey. Heating treatment altered the composition and properties of honey by causing an increase in hydroxymethylfurfural (HMF), total acidity, free acids and lactone content, and decrease in pH value and diastase activity (Singh and Bath 1998; Bath and Singh 1999). Honey with a lower pH value

Table 1 Comparison of final viscosity, equation, coefficient of determination, and rate of viscosity decrease of GRF gels with/without addition of honey, heated honey, and sugar solution

Flour gel	Final viscosity* (Pa s)	Equation	Coefficient of determination (r^2)	Rate of viscosity decrease (Pa)
Control	0.237 ± 0.001 ^b	$y = - 2 \times 10^{-5}x + 0.269$	0.973	$- 1.80 \times 10^{-5}$
Sugar-GRF	0.242 ± 0.001 ^a	$y = - 1 \times 10^{-5}x + 0.270$	0.960	$- 1.38 \times 10^{-5}$
Heated-SBH-GRF	0.242 ± 0.000 ^a	$y = - 2 \times 10^{-5}x + 0.272$	0.967	$- 1.26 \times 10^{-5}$
Heated-RBH-GRF	0.243 ± 0.000 ^a	$y = - 2 \times 10^{-5}x + 0.272$	0.986	$- 1.58 \times 10^{-5}$
SBH-GRF	0.234 ± 0.000 ^c	$y = - 2 \times 10^{-5}x + 0.265$	0.989	$- 1.87 \times 10^{-5}$
RBH-GRF	0.222 ± 0.001 ^d	$y = - 3 \times 10^{-5}x + 0.268$	0.964	$- 2.74 \times 10^{-5}$

GRF glutinous rice flour, SBH stingless bee honey and RBH raw bee honey

*Values are expressed in mean ± standard deviation (n = 3). Means within the same column followed by different superscript lowercase letters indicate significant differences at $p < 0.05$ by Tukey’s multiple comparisons test

have a higher rate of HMF formation (Singh and Bath 1997; Bath and Singh 1999). However, SBH was found to have a possible resistance to HMF formation as HMF can only be quantified after a prolonged heating treatment. Compared to RBH, SBH has high acidity that delays Maillard reaction and thus decreases HMF formation (Biluca et al. 2014). Nevertheless, increase in HMF formation and decrease in pH value in heated honey did not contribute to the significant viscosity drop as demonstrated by raw honey. Heating treatment has inactivated the active honey diastase that addition of heated honey did not show significant starch thinning effect in gels. To ease the comparison and evaluation of the viscosity changes for all gels, the rate of viscosity decrease of the flour gels were all tabulated in Table 1. The coefficient of determination of the linear regression ranged from 0.960 to 0.989 implying that the data were fairly well fitted. The rate of viscosity decrease in an increasing trend was: heated-SBH < sugar < heated-RBH < control < SBH < RBH.

Time sweep test

As illustrated in Fig. 2, oscillatory time sweep test was performed to investigate the gel formation behaviour in real time, i.e. if material properties are changing over time, and the time required to form a stable structure. This

oscillation method is destruction free as existing network structures will be preserved at a sufficiently low deformation amplitude (Kulicke et al. 1996). Both G' and G'' increased with time, and G' was higher than G'' at any time for each type of gels (Fig. 2), which implied the solid-state behaviour (elastic nature) of the gel. It was worth noting that incorporation of both honey did not seem to influence G'' . Hence, discussion will mainly focus on G' . It was observed that SBH contributed to the slight decrease in G' value. However, the effect of RBH addition apparently have yielded a gel that exhibited the lowest G' value, particularly after approximately 15 min of sweeping, demonstrating a more liquid phase behaviour than other gels. Control and SBH-GRF gels, on the other hand, behaved slightly more like elastic or solid materials. G' values of control, SBH-GRF, and RBH-GRF gels measured after 30 min of testing were 6.33 ± 0.04 , 6.27 ± 0.04 , and 5.99 ± 0.02 Pa, respectively. Thus, G' values of GRF gels were significantly lower ($p < 0.05$) after the addition of RBH containing high activity of diastase enzyme, as compared to SBH-GRF and control gels.

The aforementioned behaviour could probably be attributed to the network structure and rigidity of flour gel (Shim and Mulvaney 1999; Chuang and Yeh 2006). Owing to its low amylose content in waxy rice starch, formation of

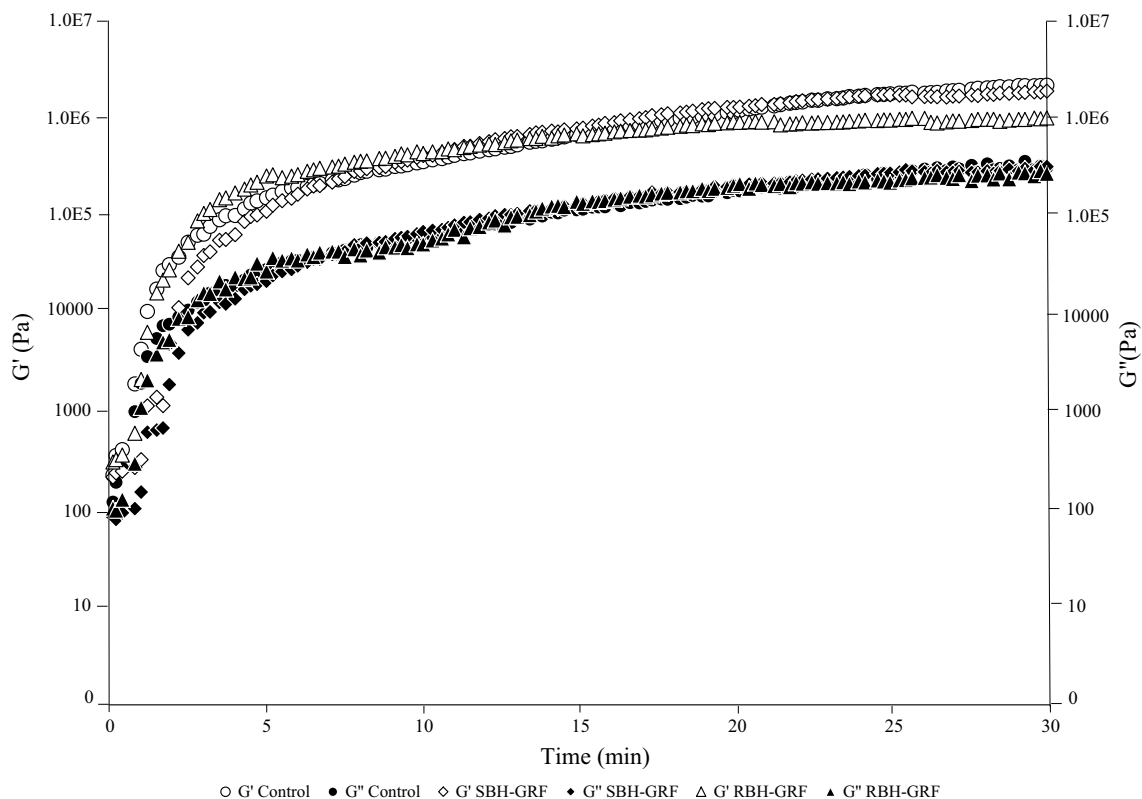


Fig. 2 Time sweep average curves of flour gels with/without honey addition, maintained at 55 °C for 30 min

gel structures (mainly recrystallization of amylopectin) is spontaneous during cooling (Chung et al. 2006). Starch retrogradation occurs with the molecules in the gel rearranged into a more ordered manner (from amorphous to crystalline state), as well as the reinforcement of the entanglement of molecules (Eerlingen et al. 1994; Chung et al. 2006). Nevertheless, the course of gel forming depended on the average chain length distribution, whereas waxy rice starch with more side chains than waxy maize starch required much lesser concentration to exhibit a gel forming ability in a previous study (Kulicke et al. 1996). This supports our hypothesis that diastase had shortened the amylopectin chain length and weakened the gel network, as evidenced by the lowest G' value of RBH–GRF gel. A lower G' value implies a weaker gelling ability (Singh et al. 2007). Moreover, the G' curves of control and SBH–GRF gels showed an increasing trend, whilst that of RBH–GRF gel gradually exhibited a plateau. During time sweep test, starch retrogradation had occurred and contributed to the greater storage modulus as indicated by the increase in G' values. Amylopectin retrogradation reinforces the rigidity of starch network and the continuous starch network induced by the formation of double helices of outer branches and recrystallised amylopectin, respectively (Hug-Iten et al. 2003). Retrogradation of gels with low molecular weight amylopectin is slower as compared with gels of high molecular weight amylopectin (Perdon and Juliano 1975). Hence, it was suggested that addition of RBH managed to form a soft yet stable structure, which delayed the starch retrogradation.

Strain sweep test

Oscillatory strain sweep was performed on control, SBH–GRF, and RBH–GRF gels to study the integrity of gel structure whereby changes in their G' and G'' values as functions of the % strain (Fig. 3). Determination of shear stress and shear rate are crucial as all measurements of subsequent analyses have to be made within the linear viscoelastic region (LVR). LVR is a region whereby both G' and G'' are independent of the % strain (Noisuwan et al. 2009). It was found to fall within 0.1 to 10% of strain stress, in which strain stress applied beyond 10% had damaged the stable structure network wherein the interacting forces (hydrogen bonds and glycosidic linkages) between particles within had been disrupted. It was worth noting that both G' and G'' values of RBH–GRF gel below 0.1% of strain stress were quite scattered, which implied that the structure of the gel was weak. GRF which is a waxy starch with low amylose content demonstrated the weak gel behaviour (Singh et al. 2007). Weak gels are generally isotropic and disordered. It was evident for each gel type that G' were all higher than G'' , which indicated

that the flour gels were all more elastic (solid like). Addition of SBH slightly decreased the G' values, however, the lowest G' values were observed for RBH–GRF gel. Thus, the addition of RBH in the GRF gel has yielded the most viscous (liquid like) material amongst the three gels. Presence of higher diastase activity in RBH has showed a more pronounced effect on the viscoelastic properties of GRF gel.

Peak hold flow test

Viscosity of GRF gels shows a highly shear thinning response, as displayed in Fig. 4. Initial viscosity of RBH–GRF gel measured was slightly lower than control and SBH–GRF gels, which suggests that viscosity started to decrease upon the addition and mixing of RBH. Although SBH–GRF gel also showed decreasing trend with time, the drop in viscosity throughout the whole analysis period was more prominent in RBH–GRF gel. Final viscosity of control, SBH–GRF, and RBH–GRF gels was 15.54 ± 0.12 , 14.37 ± 0.14 , and 10.49 ± 0.06 Pa s, respectively. Viscosity of RBH–GRF gel was significantly reduced ($p < 0.05$). This result was in agreement with the trend as illustrated in Fig. 1c. The decrease in viscosity of gel over time under constant shear can be attributed to the loss of structure (Turabi et al. 2008). It was hypothesised that RBH with a higher diastase activity (12.14 Schade) contributed to the greater extent of loss in GRF gel structure, as compared to SBH with a lower diastase activity (1.53 Schade).

Steady-state flow test

Both ascending and descending curves as shown in Fig. 5 are necessary for the determination of hysteresis. It is interesting to note that all gels were best fitted into Herschel–Bulkley model when the experimental data was analysed using Rheology Advantage Data Analysis software V5.4.8. Nevertheless, Yoo (2006) has raised the concern that yield stress is not the objective in development of common flow models. Hence, additional efforts on Herschel–Bulkley model that contains yield stresses was not made. The second best fit model, i.e. the power law was employed in interpreting the sample rheological behaviour. Best fit model implies that the data can be well described by this model. Power law model provides a good estimate of the viscosity (as indicated by flow consistency index), based on the relationship between shear stress and shear rate data. Viscosity estimated by power law for control, SBH–GRF, and RBH–GRF gels was 410.0 ± 18.8 , 256.6 ± 5.7 , and 78.2 ± 7.9 Pa s, respectively. In addition, power law rate index, which indicated the shear-thinning behaviour for control, SBH–GRF, and RBH–GRF

Fig. 3 Strain sweep average curves of flour gels with/without honey addition, tested over the range of 0.01–10,000% of strain set at log mode

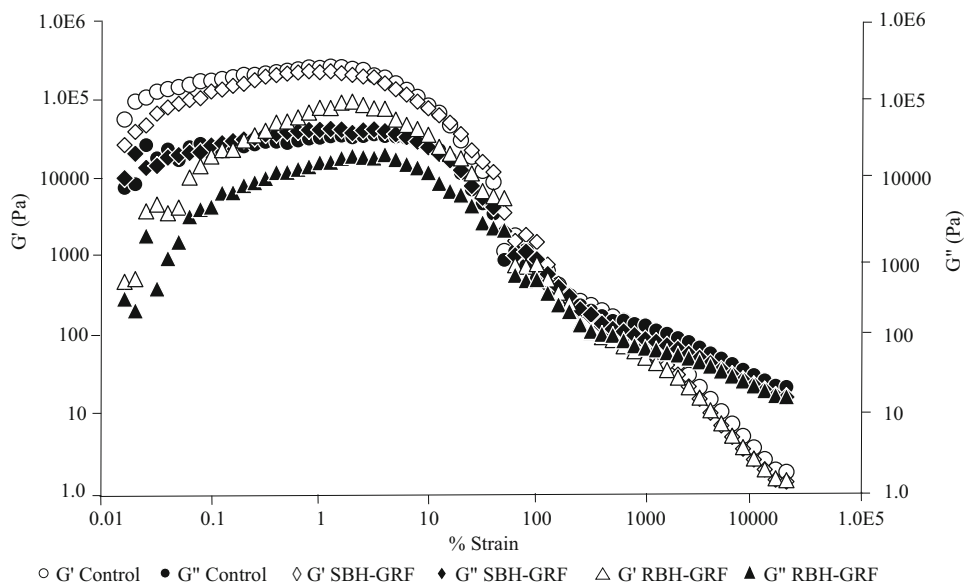
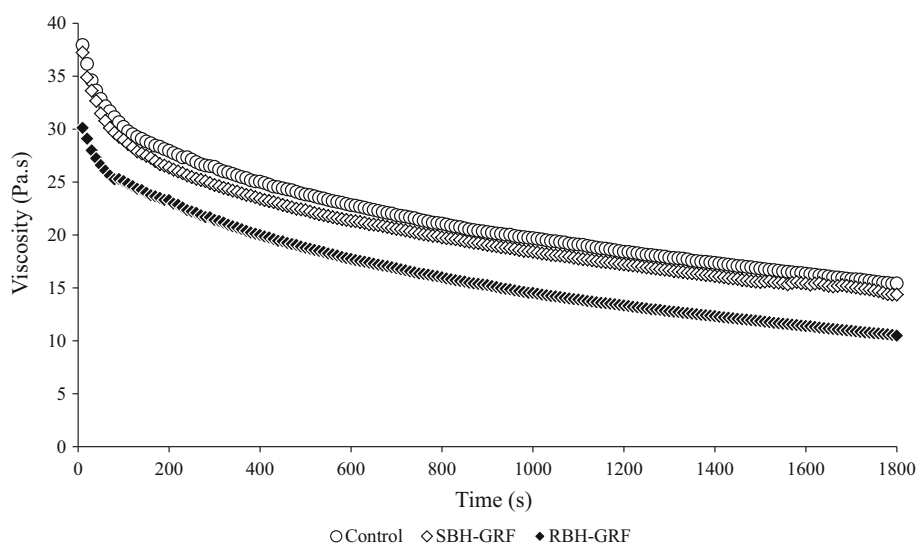


Fig. 4 Peak hold flow average curves of flour gels with/without honey addition, maintained at 55 °C for 30 min



gel, was 0.28 ± 0.01 , 0.32 ± 0.00 , and 0.45 ± 0.02 , respectively. This is in good agreement with the rheological studies of *dodol* (a sweet glutinous rice based snack) that were explained using power law, which showed rate index between 0 and 1 (Chuah et al. 2007). Thixotropic values estimated were $(8.45 \pm 0.01) \times 10^5 \text{ Pa s}^{-1}$ for control gel, $(7.20 \pm 0.00) \times 10^5 \text{ Pa s}^{-1}$ for SBH-GRF gel, and $(4.38 \pm 0.25) \times 10^5 \text{ Pa s}^{-1}$ for RBH-GRF gel, respectively. Viscosity and thixotropic values were significantly reduced ($p < 0.05$), while rate index was significantly increased ($p < 0.05$), after the addition of honey containing active diastase. The estimation using power law model was consistent with the viscosity drop trend as displayed in Figs. 1b and 4, whereby a more prominent drop in viscosity was observed in RBH-GRF gel. Interestingly, the lowest rate index (the most shear thinning)

and the highest thixotropic value were observed in control gel as the shear rate increased. It was proposed that the RBH-GRF gel already exhibited a more viscous (liquid state) behaviour that the extent of shear thinning caused by increasing shear rate was less pronounced than the shear thinning occurs under constant shear rate. All gels exhibited the same behaviour in both steps with increasing and decreasing shear rate ranged from 0.01 to 1000 s^{-1} .

Conclusion

As compared to SBH, RBH showed a more pronounced effect upon its addition into GRF gel in decreasing gel viscosity and softening gel network with evidence of the lowest viscosity and G' value, in peak hold flow test and

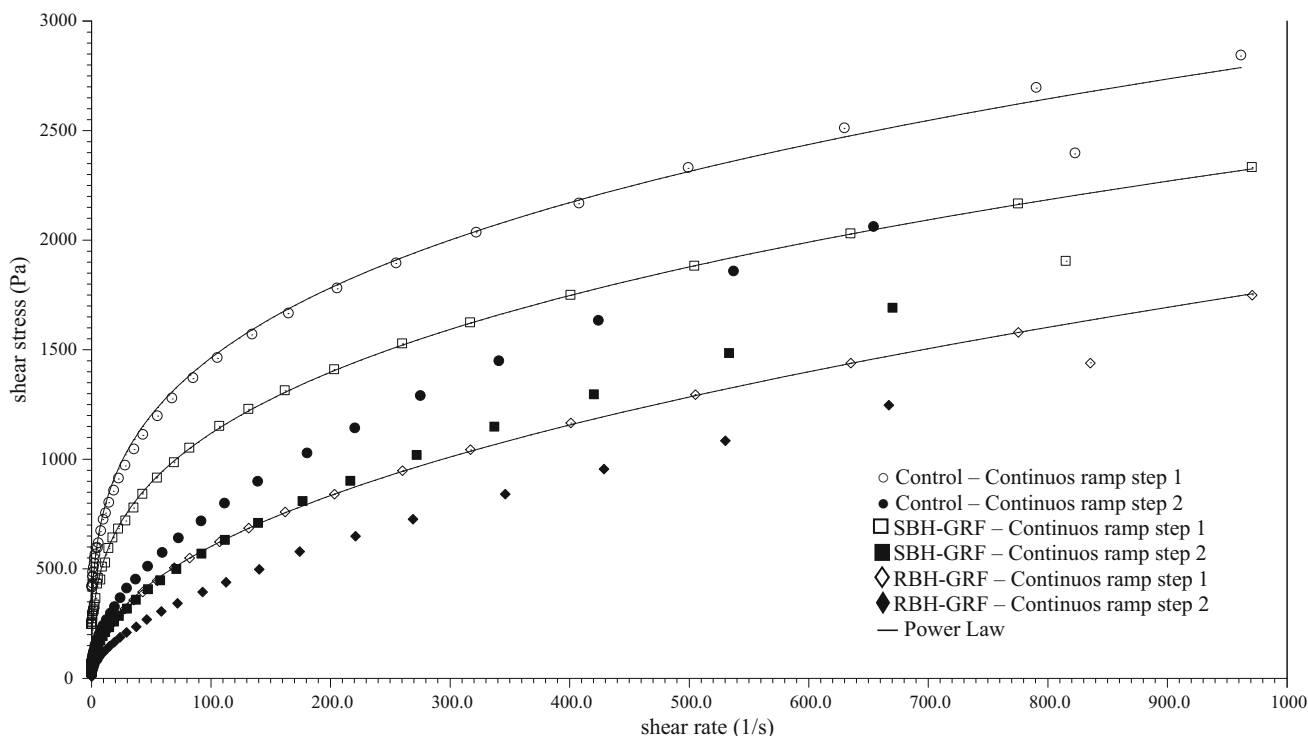


Fig. 5 Steady state flow average curves of flour gels with/without honey addition, sheared over the range of 0.01–1000 s^{-1} at 55 °C, and analysed by power law model

time sweep test. As heated-RBH failed to weaken GRF gel network, the weakening of RBH–GRF gel network was mainly due to the active diastase in the raw honey. RBH can be used not only for its sweetening and flavouring purposes, but it is also useful as a potential texture-modifier in development of starchy food products, such as *dodol* (a glutinous rice based snack in Malaysia and Indonesia). Quality of such products could be enhanced as addition of RBH could soften the texture and delay the hardening (retrogradation) of starchy products.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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