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Rheology of The Glutinous Rice Flour, Coconut Milk, and Palm Sugar Mixed System in A Traditional Food *Dodol Ulame*

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Abstract*— Triple mixed of glutinous rice flour, coconut milk, and palm sugar paste with ratio of 1.0:2.5:0.5, 1.0:2.0:1.0, 1.0:1.5:1.5, 1.0:1.0:2.0, 1.0:0.5:2.5 were studied using rapid visco-analyzer (RVA), rheometer, and polarized light microscope to investigate its pasting properties, flow behavior index, dynamic rheology, and microstructure respectively. The power-law and Herschel-Bulkley models were used to evaluate its steady rheological properties. The RVA profile shows low viscosity profile and low breakdown viscosity for all ratio of *dodol ulame* paste. The lowest breakdown viscosity occurred at the ratio of 1.0:2.5:0. Meanwhile, the highest setback viscosity occurs at the ratio of 1.0:0.5:2.5. Indicating the highest riqidity due to high sugar content. The apparent viscosity decreased with increasing shear rate for all triple mixed exhibited a typical shear-thinning behaviour (n<1) of the system. Increasing the proportion of coconut milk decreased the consistency coefficient, k, and increased the flow behaviour index, n of the system. The dynamic rheology resulted in the higher G" value over the entire frequency. Maltese crosses disappeared at 90 °C for the ratio of system 1.0:0.5:2.5 and 1.0:1.0:2.0 and 80 °C for the ratio of system 1.0:1.0:2.0, 1.0:1.5:1.5 and 1.0:1.0:2.0. The study suggests that coconut milk and palm sugar had an important role on the rheology of *dodol ulame* paste, consequently it affects the gelatinization, viscosity, and gel-like behaviour of the glutinous rice flour, coconut milk, and palm sugar mixed system. Further study on the preference and nano structure is undertaken to reveal its possibility to produce better quality *dodol ulame*.

***Keywords*— apparent viscosity; dynamic rheology; gelatinization; flow behavior; starch.**

I. INTRODUCTION

Rheology plays an important role in food system because rheology is often used in studying the structure of materials [1] and reveals the key factors to produce good quality and mouthfeels of foods. The processing, shelf life, appearance, texture, and mouthfeel of this food product are influenced by the rheology of its system [2]. For that reason, it can be used to identify the process of designing, quality control, stability measurements of the product, and products development with target textures [3]. Rheology of the system is dependent on its constituents. Each constituent has its certain functional properties, creating a complex multi-component system that influenced the flow behavior and viscosity of the emulsions. Each constituent also plays important roles and brought some rheological impacts on the product's texture and microstructure. Moreover, each constituent is also interacted to each other and influencing the thermal and physical properties of the system, which are manifested in the product's structure, appearance, mouthfeel, and final taste [4]. Starch, fat, and sugar were majority ingredient on Indonesia traditional food like *dodol ulame*. *Dodol ulame* made from white glutinous rice flout (GRF), coconut milk (CM), and palm sugar (PS). It was a complex system a particular involving starch, fat, sugar and other component. Processing *dodol ulame* in principle entails structural modification which depending on the formulation and process conditions. The principle step of *dodol ulame* making is boiling all ingredients mix together until it turned into a thick paste. Starch when heated at critical temperatures in the presence of excess water will absorb a water, swell and dissolve in a solution marked by loss of birefringe [5], the changes is called gelatinization. Gelatinization affects the increase in viscosity and rheological properties of starch as indicated by an increase in firmness or rigidity [6].

The presence of CM and PS in the *dodol ulame* mixture system is thought to have influenced the starch gelatinization process. Several studies have shown that sugar affects the gelatinization temperature and caused the delay on the initial gelatinization point of the starch [7], [8]. Lipid affected pasting properties of starch, but the effect was influenced by the length of the lipid's fatty acid chain [9]. Sugars were also found to increase the viscosity of wheat starch–milk paste and caused the apparent viscosity of the wheat starch-milk-sugar paste higher than the viscosity of wheat starch–water–sugar pastes [10]. At 5% starch concentration and 0-6% sugar concentration, starch flow index approaching unity (n = 1), the increase in sugar concentration and constant heating time result in the flow index to decrease and shows shear thinning behavior [11]. Cassava starch will transition from the antiplastic regime to the plastic regime with the addition of sugar [12] . Meanwhile, the effect of fat shows a different result on the rheological properties of the system. Recent studies show that the apparent viscosity of waxy maize starch treated with shortening and sunflower oil were increased [3]. The addition of MGM on the cake influences the rheology, while the starch-MGM pastes have more elastic structures with increased G' and the decrease of tan values [13]. Although, the research on the effect of sugar and fat on starch rheology has been carried out so far, it still did not explain the effect of PS and CM on the rheology of mixed system, especially those of the traditional starch-based food products.

In case a good understanding of the rheological properties of *dodol ulame*, it was important step to maximize the material and the processing process, in order to get well standarize and quality product. The objective of this experiment was to reveal the rheological properties of the tripple mixed system of *dodol ulame*, including its pasting properties, flow behavior, dynamic rheology, and microstructure. The ratio of CM and PS in this study were varied and the results were compared with control that follows the typical levels used in traditional cooking of *dodol ulame*.

II. Material and Method

A. Material

A local *Sibujing* glutinous rice variety, mature coconuts and palm sugar were used. Preparation of the GRF was done by grinding the glutinous rice using a disk mill in Technopark Laboratory of IPB University with a 100 mesh size stainless steel sieve size at a constant speed of 10,000 rpm. PS was sliced before used to make it more spreadable in the mix. Coconuts were subjected to deshelling, paring, and removal of the coconut water. The coconut kernel was collected manually and grated using a rotary wedge cutting machine. Water was added to the grated coconut with a ratio of 2: 1 (w / w), blended for 2 minutes in a high rotor speed blender, pressed in and passed through cloth filters to get the CM.

B. Chemical Composition of Materials.

The moisture, carbohydrate, ash, crude protein, crude fat and crude fiber contents of the GRF, CM, and PS were determined according to [14] methods. The fatty acid analysed using Gas Cromatography [15]. The GRF, CM, PS Samples were analyzed in triplicate. The glutinous rice starch content was determined using Luff-Schoorl methods, and the amylose content was measured using spectrophotometry method [16]. Analysis of amylopectin content of the sample was determined by difference, an i.e. result of starch content deducted with the amylose content.

C. Pasting Properties.

Pasting properties of glutinous rice flour were determined using a Rapid Visco Analyzer (Model RVA-4D, Newport Scientific, Narrabeen, Australia) interfaced with the attached computer equipped with thermocline software (Newport Scientific). To study the binary pastes of GRF-CM and GRF-PS mixes, each proportion of 3% to 15% of CM, likewise the PS, based on the dry basis of the GRF were prepared. To study the ternary paste (GRF-CM-PS paste), GRF, CM, and PS with the ratios of 1.0:2.0:0.5, 1.0:2.0:1.0, 1.0:1.5:1.5, 1.0:1.0:2.0, and 1.0:0.5:2.5 (% dry basis) were prepared. Deionized distilled water was added to make up to a total weight of 28.5 g. The experiment was conducted according to [17], each 28.5 g sample mix suspension was stirred by RVA rotating plastic paddle for 15 to 30 sec to diffuse the sample uniformly and to clear away starch lumps before the measurement. All measurements were replicated three times. Parameters recorded were pasting temperature, peak viscosity, final viscosity (viscosity at 50°C), breakdown viscosity (the difference between peak viscosity and trough viscosity) and setback viscosity (the difference between final viscosity and trough viscosity).

D. Rheological Properties.

Rheological measurements of the GRF, CM, PS mixed system in various ratio were analyzed using an MCR 302 controlled-stress rheometer (Anton Paar Physical). The steady-flow experiment followed a previous report with minor modifications [18]. The GRF, CM, and PS were weighed with the ratio of 1.0:2.5:0.5, 1.0:2.0:1.0, 1.0:1.5:1.5, 1.0:1.0:2.0, and 1.0:0.5:2.5. The mixed slurry was prepared and heated until the temperature reaches 90 °C and stand it for 5 minutes. The hot paste was then transferred onto the rheometer plate equipped with a cone geometry of 50 mm diameter and 1^o cone angle, at a fixed gap of 1 mm. The rheometer was also equipped with a Peltier temperature controller. The paste was equilibrated for 5 min at 25 °C before shearing rates from 0.01 to 300 per second, to describe the steady rheological properties of the sheared samples. The data were fitted into two mathematical models, i.e., the Power law and the Herschel-Bulkley, to find the flow behavioral index as follows

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

$$\tau = \tau_0 + K \gamma^n \quad (2)$$

Where τ is shear stress (Pa), τ_0 is yield stress (Pa), K is consistency coefficient ($Pa \cdot s^n$), γ is the shear rate (s^{-1}), and n is flow behavior index (dimensionless) [19].

Dynamic oscillatory or viscoelastic measurements were preferred to evaluate the gelation kinetics and texturizing properties of the *dodol ulame* paste adapted from [20]. All measurements were conducted in triplicates. The same sample (gelatinized paste) is poured onto a 50 mm plate-and-plate geometry with both upper and lower surface crosshatched with a 0.5 mm deep texture and equipped with Peltier temperature control. Before measurements, samples were covered by a thin layer of paraffin oil on the edge of the sample to avoid evaporation during measurements, with a fixed gap of 1 mm. Sample poured onto the MCR 302 plate and was difined cooling temperature sweep test from 80 °C down to 10 °C (at 2 °C/min) at a frequency of 0.4 Hz for 30 min to guarantee that the system blows an equilibrium state. Next, the sample was submitted to a frequency sweep, from 100 to 0.01 Hz at a constant shear strain in the linear viscoelastic region (LVE), at 0.2% fixed increment sweep rate. To ensure that viscoelastic measurements were carried out in the LVE domain, the strain sweep experiments were conducted from 0.01% to 200% at 0.4 Hz. All measurements conducted in three replicate.

E. Microscopy observation.

Polarized light microscope was used to observe the microstructure of GRF, CM, PS mixed system. GRF, CM, and PS were prepared with the ratios of 1.0:2.0:0.5, 1.0:2.0:1.0, 1.0:1.5:1.5, 1.0:1.0:2.0, and 1.0:0.5:2.5. The mixture placed in a 200 ml beaker glass equipped with a magnetic stirrer and stirred for 15 minutes until homogeneous. The beaker glass content was tranferred placed into a 2 liter beaker glass filled with distilled water and heated on a hot plate equipped with a thermometer to record the temperature. The temperature was increased at a rate of 2°C per minute. Samples were taken at a temperature of mixtures 50°C, 60°C, 70°C, 80°C, 90°C. Each specimen was observed under a polarized light microscope (Vanox BHS-2, Olympus Corp., Japan) equipped with a digital camera connected to Toupview software.

F. Statistical Analysis.

The *results* were organized using Microsoft Excel software and further analyzed using SPSS version 12.0 and expressed as means ± standard deviation (SD). A one-way analysis of variances was performed to determine the relationship between samples to the pasting properties.

III. Results and Discussion

A. Chemical Composition of Glutinous Rice Flour, Coconut Milk, and Palm Sugar.

The data on the chemical composition of GRF, CM, and PS are summarized in Table 1. The GRF var. *Sibujing* contained carbohydrates and 62.68 ± 00.00 % starch, of which 90.21% is amylopectin and 9.79% is amylose. The amylose content was higher than those in the previously reported studies, whereby the reported amylose content on waxy rice starch was in the range of 0-2% [21]. The GRF var. *Sibujing* also contained 10.65±00.05 % proteins (d.b). The CM used in this research contained high moisture and low-fat contents as seen in Table 1. The lauric acid was the dominant fatty acid in this study as it widely found in CM. The PS contained a large amount of total carbohydrate, i.e., about 89.47 %, which is mostly of monosaccharides and disaccharides. Fat content in coconut milk contributed significantly to the smoothness formation of dodol texture. It determines the rheological characteristics of coconut milk associated with apparent viscosity where the consistency coefficient value, k, and apparent viscosity reached the maximum in coconut milk mix with a 30% fat content preheated at 90 °C [22]. The palm sugar contains a large amount of total carbohydrate, i.e., 89.47±00.02 %, which is mostly of monosaccharides and disaccharides. According to [23], PS contains sucrose and reducing sugars, which are glucose and fructose.

TABLE I
The Chemical Composition Of GRF, CM, And PS

Parameter	GRF	CM	PS
Moisture (% w/w)	12,10±0.02	89,87±0.24	8,66±0.07
Fat (% w/w)	02,77±0.07	07,34±0.03	0,25±0.04
Fatty Acids (% of total fatty acid)	-	44.21±0.01	- -
- Lauric acid (%)	-	19.30±0.00	-
- Meristic acid (%)	-	05.90±0.03	-
- Palmitic acid (%)	-	00.39±0.06	-
- Stearic (%)	-	02.69±0.01	-
- Oleate (%)	-	00.97±0.02	-
- Linoleic (%)	-	00.00±0.00	
- Linolenic (%)	-	00.00±0.00	
Protein (% w/w)	10,65±0.05	01,02±0.04	00,72±0.01
Ash (% w/w)	00,63±0.02	00,07±0.01	00,91±0.05
Carbohydrate (% w/w)	73,85±0.05	01,70±0.24	89,47±0.02
Starch	62,68±0.000	-	-
- Amylose content (% of total starch)	9,79±0.03		
- Amylopectin content (% of total starch)	90,21±0.00		

Means ± SD (n = 3).

B. Pasting Properties GRF-CM Paste and GRF-PS Paste.

The pasting temperature, peak viscosity, breakdown viscosity, and final viscosity of the GRF in this study were 69.4±00.20 °C, 1772±05.00 cP, 728±03.00 cP, 1590.5±21.50 cP, respectively. This result showed that the GRF var. *Sibujing* was classified as low gelatinization temperature (<70 °C). The effect of the addition of CM and PS individually to the GRF pasting properties parameters is clearly presented in Table 2.

TABLE II
RVA Profile For GRF-PS And GRF-CM Paste

Con. (%)	Pasting Temp. (°C)	Peak Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback
Palm Sugar					
3%	70.0 ± 00.4^{a}	1702.0 ± 65.0^{a}	690.0 ± 35.0^{b}	1535.0 ± 34.0^{a}	523.0 ± 04.0^{a}
6%	$71.4+00.2^{b}$	1702.5 ± 19.5^{a}	666.0 ± 29.0^{b}	1581.0 ± 01.0^{a}	544.5 ± 08.5^{a}
9 %	72.7 ± 00.2^{c}	1770.0 ± 06.5^{a}	696.5 ± 06.5^{b}	1667.5±12.5b	$594.0 \pm 18,0^{b}$
12 %	74.1 ± 00.4^{d}	1880.5 ± 04.0^{b}	660.0 ± 04.0^{bc}	1887.5 ± 59.5^{c}	667.0 ± 29.0^{c}
15 %	74.5 ± 00.0^{d}	1779.0 ± 22.9^{b}	615.5 ± 06.1^{a}	$1821+11.4^{d}$	$657.5+28.2^{c}$
Coconut Milk					
3%	70.4 ± 00.1^{a}	1651.5 ± 26.2^{c}	704.0 ± 16.0^{a}	1474.5 ± 23.3^{b}	522.3 ± 16.2^{b}
6%	70.8 ± 00.1^{b}	1684.5 ± 49.5^{cd}	665.0 ± 27.0^{b}	1606.5 ± 42.5^{ac}	580.3 ± 20.0^{c}
9 %	71.2 ± 00.0^{c}	1708.0 ± 00.0^{d}	629.5 ± 08.5^{c}	$1740.5+02.5^{b}$	662.0 ± 11.0^{e}
12 %	72.2 ± 00.2^{d}	1473.5 ± 05.5^{b}	444.0 ± 15.0^{d}	$1653.5+20.5^{d}$	624.0 ± 00.0^{d}
15%	74.3 ± 00.3^{e}	1040.0 ± 10.0^{a}	158.0 ± 00.0^{e}	$1223.0+14.0^{e}$	341.0 ± 04.0^{a}

Mean ± standard deviation values followed by different small letters are significantly different ($p < 0.05$).

The gelatinization temperature were increased by the addition of PS individually. Some explanation had been proposed to explain the effect of sugar on the starch pasting temperature which was more due to the competition between sucrose and starch in water restricted conditions of the starch hydration. The lack of available water had caused starches difficult to swell and gelatinize and hence requires higher energy for the gelatinization process in the mixed system

[24], [25]. In other hand, we found that the peak viscosity, final viscosity, and setback viscosity values were increased at 3%, 6%, 9%, 12%, and slightly decreased at 15% PS. The highest peak viscosity (1880.50±00.40 cP), final viscosity (1887.50±59.50 cP), and set back (667.00±29.00 cP) were observed in the 12% PS mix (ρ < 0.05) (Table 2). These results were in agreements with the result of ref. [26]. They reported an increase in peak viscosity, final viscosity and breakdown viscosity of corn starch with fructose addition. However at a concentration of 50-70% the peak viscosity, final viscosity and breakdown viscosity decreased. The sugar can interact with starch that effect the amylose leaching [27].

The gelatinization temperature was also increased by the increase of CM concentration in the GRF-CM paste. The highest gelatinization temperature 74.30±00.20 °C was observed in the 15 % of CM mix. Increasing of CM concentration in the mix have caused the lipid amount in the starch-lipid system increased. The lipid embraced into the starch granule through some hydrophobic interactions between hydrocarbon chain and intra-helix spaces of amylose prevented the water molecules entering the starch granules even when the mix was heated [28]. On the GRF-CM paste, the highest peak viscosity (1708.00±00.00 cP), final viscosity (1740.50+02.50 cP), and set back viscosity (662.00±11.00 cP) were observed in the 9 % CM (ρ < 0.05) (Table 2). The addition of 3 % and 9 % of CM individually increased the peak, breakdown, final, and setback viscosities gradually but decreased at the concentration of 12% and 15%. Similar result have been reported by Chen et al. [5] who reported a decrease of peak viscosity, final viscosity, breakdown viscoity, and set back viscosity of normal rice starch and normal rice flour by addition of 30-40 % maize oil in the system. These might be due to two mechanisms, i.e., the first one is due to the starch saturation by the addition of a certain amount of fatty acid. As shown in table 1, coconut milk contains 20 % of fat. A certain amount of lipids in the system caused a decrease in viscosity and the ability of the slurry to retreat. Ref [28], had reported that the maximum pasting value increased by the addition of palmitate fatty acid to the constant amount of defatted starch, but at 0.75% of fatty acid the pasting value decreased slightly. The second one may be due to the amylose-lipid complex. A lipid with certain chain lengths could interact with amylose to form an amylose-lipid complex. These impacts were noticed not only on the starch pasting properties but also influences the gel texture behavior [29].

The ternary paste was prepared to study the effect of the ratio to the system pasting profiles. Proportion of the mixes, i.e., GRF, CM and PS were prepared at the ratios of 1.0:2.5:0.5, 1.0:2.0:1.0, 1.0:1.5:1.5, 1.0:1.0:2.0, and 1.0:0.5:2.5 (% dry basis). All of the mixes systems showed almost the same higher pasting temperature (74,44 °C). This proved that the presence of coconut milk and sugar with various ratio result in the inhibition of the gelatinization process. Previous researcher found that in the ternary system of starch/carrageenan/casein, preferred interactions between carrageenan/casein micelles appear in corresponding to carrageenan/starch. Meanwhile, starch is bounded in the arrangement of more-or less-disrupted granules dispersed in a "continuous phase" [30]. This study showed that ternary mixes have very low breakdown viscosity. The breakdown viscosity decreased by the increasing CM and decreasing PS ratio gradually. The lowest breakdown viscosity occurred at the highest CM ratio of the ternary mix, i.e. 1.0:2.5:0.5. It's indicated that the stability of starch paste during the heating process will decrease with the decreased amount of CM used. The final viscosity of the ternary paste showed an increase with increasing PS and decreasing CM ratio on the ternary paste. The highest final viscosity occurred at a ratio of 1.0:1.0:2.0 mix. Meanwhile, the setback value also decreased by the increasing PS in the paste. The highest set back viscosity was found in a ratio of 1.0:0.5:2.5. Lower setback value indicated lower/short-retrogradation and syneresis of the GRF-CM-PS paste.

C. Flow Behavior of GRF-CM-PS paste.

The apparent viscosity as a function of shear rate was presented in Fig 1. The apparent viscosity decreased with increasing the shear rate exhibited a typical shear-thinning behavior. The declined curve indicated the action of shear thinning on polymer molecules (or a long chain material). These findings are in agreement with the finding of Chuah et al. [6] reporting the traditional *dodol* from Malaysia had strong shear-thinning behavior. Ref [10] also reported on the shear thinning behavior on wheat starch-milk-sugar pastes. With increasing shearing stress, the molecules that are normally irregular begin to form a long plateau in the direction of flow. It reduces the material resistance and results in a greater rate of shear at each subsequent shearing stress as well. However in this study, subsequently a sharp decline, the viscosity change was flatten at high shear rates (at 1.2 s-1 the viscosity changed to smoothed style). This indicates that the onset of shear thinning appears at a lower shear rate for all samples.

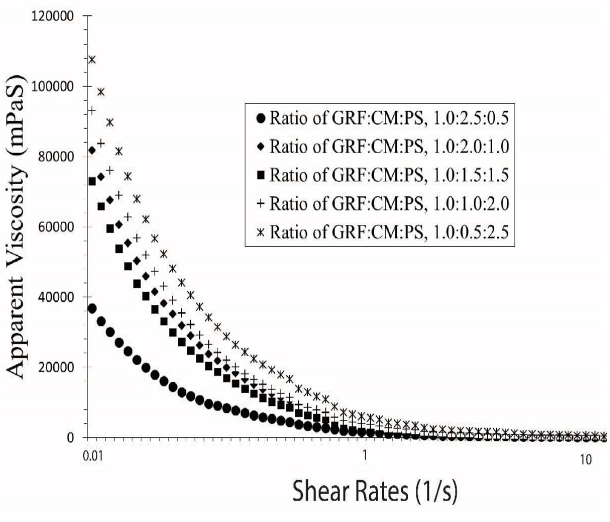

Fig 1. Apparent viscosity of ternary pastes of shear rate on the ratio of GRF, CM, and PS were 1.0:2.5:0.5, 1.0:2.0:1.0, 1.0:1.5:1.5, 1.0:1.0:2.0, and 1.0:0.5:2.5.

The addition of CM and PS changed the body of GRF-CM-PS paste. The highest apparent viscosity of the system was reached on the highest ratio of PS in the ternary mix, i.e. 1.0:0.5:2.5, and the lowest apparent viscosity was reached on the highest ratio of CM i.e. 1.0:2.5:0.5. This result indicates that more sugar and less CM on the *dodol ulame* system will increase the apparent viscosity. Very likely that this was due to the increased in solid mass of the triple mix. Conversely, the more CM and the less sugar would decrease the apparent viscosity. Coherently with the decrease in solid mass of the mix. In addition this could be explained as follows: Sucrose and reducing sugar on PS have a gelling and anti-plasticizing effect that can increase the glass transition temperature Tg and subsequently the gelatinization temperature Tgel [31], causing the enhancement of paste viscosity. Meanwhile, the fat on the CM has a lubricating effect between the particles, and its flow becomes relatively unhindered [6]. The dominant effect was largely determined by the amount of material in the system. Additionally, an interaction between components like proteins, fats, and sugar with carbohydrate chains during processing would push the chemical reactions affecting the viscosity. The chemical reactions include Maillard reaction, caramelization, and amylose-lipid complexes. During the cooking process, PS would produce other components as a result of the Maillard reaction and caramelization. These components can be volatile components, namely hydroxymethylfurfural and melanoidin. The breakdown in melanoidin is the main factor causing pseudoplastic behavior in vinegar Balsamic acid. Its level depends on the volume of the fraction dispersed in melanoidin and composition of bulk vinegar fraction [32]. Liquid PS also has melanoidin content formed due to Maillard reaction. Consequently, it can also play a role in influencing the behavior of liquid PS flow. The possibility of Amylose-lipid complex formation also plays an important role in decreasing viscosity because this formation could inhibit amylose network development [33].

The Power-law and the Herschel-Bulkley model were used to evaluate the flow properties of ternary paste from the steady shear experiment data (Table 3). The flow behavior index of the samples was found to be between 0.1-0.3 (n<1) indicating their pseudo-plastic behaviour. As the ratio of CM was higher than PS, the flow behaviour index, n, increased. The increase of the flow behaviour index, n, indicating the paste became more shear thinning. The proportion variability of CM and PS in the ternary mixes gives a little change to flow behavior index, n. This result is in agreement with Navarro *et al.* [3] that found weak modification of flow index (n) of waxy starch with addition sunflower oil. Increased PS ratio increased the flexibility of molecule in *dodol ulame* system. However, the proportion variability of CM and PS affects the consistency coefficient, k, of the GRF-CM-PS pastes. When the ratio of PS was higher than CM, the consistency coefficient, k, increased. It mean that the more sugar ratios were used, the greater the viscosity of the system. This finding is in agreement with the findings of Abu-Jdayil *et al.* [10] for the effect of sugar on the consistency coefficient, k. They reported that the increase in sucrose or glucose concentration caused the consistency coefficient to increase.

Table 2 shows an increase of yield stress τ_0 with the increasing PS ratio and decreasing CM on the system. That related to the presence of suspended particles in concentrated suspension. The yield stress, τ_0, was caused by contact between adjacent particles which must be immobilized before. The total dissolved solids in PS higher than the total dissolved solid on CM [34]. In this case, the increasing PS ratio increases the volume fraction of solids. There is an increase the solids volume fraction in starch dispersion and this experience to an enhancement of yield stress [35]. "The yield stress (σy) increased with an increase in the solid concentration, and it was also affected by the hydration temperature"[36]. The correlation coefficients (R^2) for Herschel Buckley model created a higher correlation coefficient (R^2) value than the Power-law model for the ratio of GRF: CM: PS 1.0: 2.5: 0.5, 1.0: 2.0: 1.0, and 1.0: 1.5: 1.5. Meanwhile, the correlation coefficients (R^2) of the Power-law model created a higher value at the ratio of GRF: CM: PS 1.0: 0.5: 2.0. It can be concluded that the Herschel Buckley model is more acceptable to describe the flow behaviour of *dodol ulame* with a higher CM ratio, while the Power-law model is more efficiently used to describe the flow behaviour of *dodol ulame* with a higher PS ratio.

TABLE III
PARAMETERS OF POWER LAWS AND HERCHEL-BULKEY MODEL FOR TERNARY PASTE GRF-CM-PS PREPARED AT 95 °C.

GRF:CM:PS ratio	Flow parameter			Power law's equation	R^2	
	τ_0	*k*	*n*		Power law's	Herchel Buckley
1.0:2.5:0.5	9.8	24.49	0.265	$24.49\gamma^{0.3}$	0.95	0.99
1.0:2.0:1.0	19.5	40.99	0.203	$40.99\gamma^{0.2}$	0.95	0.99
1.0:1.5:1.5	19.4	48.98	0.209	$48.98\gamma^{0.2}$	0.98	0.96
1.0:1.0:2.0	22.8	49.42	0.144	$59.42\gamma^{0.2}$	0.91	0.91
1.0:0.5:2.5	28.6	49.41	0.109	$59.41\gamma^{0.1}$	0.85	0.75

D. Rheology Dinamic Properties

Dodol ulame was a viscoelastic materials which exhibit behavior somewhere in between that of purely viscous and purely elastic materials. Therefore dynamic rheological properties and the gelation kinetics of the ternary mixes were investigated by using an Oscillatory rheometer. The G' and G" as functions of strain can be seen in Fig 2. The G' value decreased slightly and then became gentler with increasing strain. Otherwise, the G" value decreased more gently with increasing strain for all samples, except the ratio of GRF: CM: PS 1.0:2.5:0.5 showing a significant elevation. The ratios of CM and PS on the GRF-CM-PS system influenced the G' and G". Fig 2. shows that the highest of G' and G" occurred at the ratio of 1.0:2.5:0.5 or when the CM concentration was higher than GRF and PS. The lowest of G' and G" occurred at the ratio of 1:0:0.5:2.5 or when the PS concentration was higher than GRF and CM.

The tan δ (G"/G') as a function of strain was also observed in this research. The tan value is an important rheological parameter that can reflect the viscous or elastic behaviour of the viscoelastic sample, referring to the ratio between the modulus loss (G") and the modulus storage (G') [18]. All samples showed changes of tan δ (G"/G') along with the increasing frequency and strain. The highest tan δ (G"/G') values were those of the ratio 1.0:2.5:0.5 compared to those of all the others. Solid-like behavior gel properties (well-organized or structured) was noticed at tan δ < 1 (G"<G') strong), whereas tan δ > 1 (G">G') indicated a pure liquid-like behavior (less structured) [20]. This research result that tan δ < 1 (G"<G') indicates a solid-like behavior at low strain and changes into liquid-like behavior at high strain. The present consistent with the flow behavior of the system. Changes from the gel to liquid behavior occurred in the Osc. Strain (%) 42, 56, 52, 44, and 30 for the ratios of 1.0:2.5:0.5, 1.0:2.0:1.0, 1.0:1.5:1.5, 1.0:1.0:2.0, 1.0:0.5:2.5 respectively.

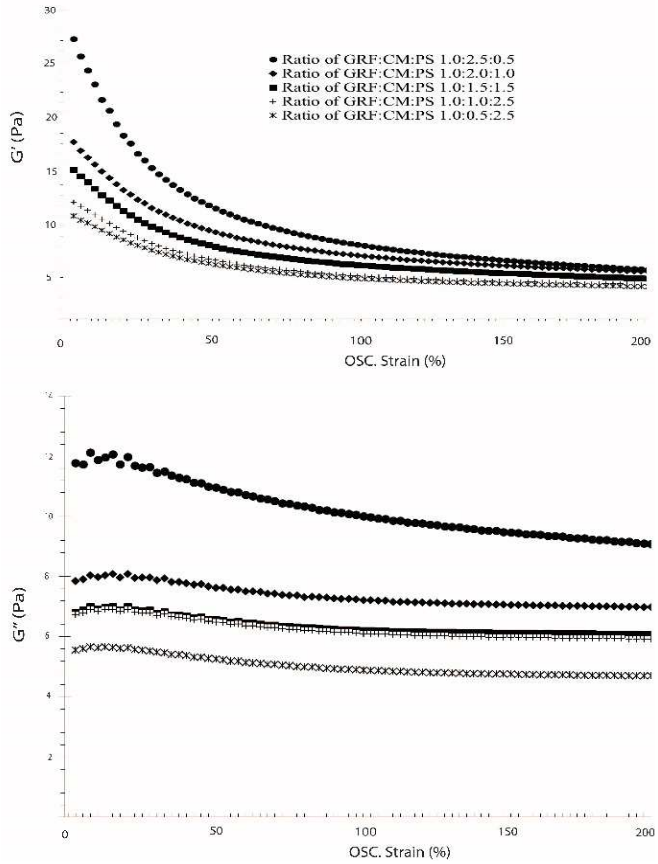

Fig 2. Storage modulus (G') (A) and loss modulus (G") (B) of ternary paste (GRF-CM-PS paste) as a function of strain.

The variations of storage modulus (G') and loss modulus (G") during cooling (from 80 °C to 10 °C) is shows in Fig 3. All samples displayed increasing the G' and a decrease of the G" with increasing temperature. This research found three different phases during the cooling regime. The phase were: a liquid-like behavior zone corresponds to the zone where G" values negligible reflecting the liquid-like behavior. The sol-gel transition zone corresponded to an intermediate zone where G' increased between the cooling points of 49 °C and 36 °C, globally [20]. That well-known as it represents the regions where the system exhibits liquid-like properties transitioning into a gel state. And the phase corresponded to the zone where G' values were remarkably higher compared to the other and tend to show a plateau behavior up to 10 °C. The gelation curve profile evidenced in this phase indicates substantial internal rearrangements of the network structure of the gels, which leads to a well-formed gel at the end of the cooling ramp. In the direction of the initial temperature (25 °C), all samples perform like a viscous liquid (G" > G'), but then transition to an elastic gel (G' > G") happened at a higher temperature. It was just like a thermal gelation phenomenon, whereby this transition occured due to the development of a cross-linked three-dimensional network of material [37]. All the samples indicate nearly similar G' and G" trends. The gelation temperature data, TGEL, (determined by tan δ = 1 or G' = G") recorded from the cooling ramps of all samples, showed that the 1.0:2.5:0.5 mix ratio occurred at higher temperature (55 °C) and the 1.0:0.5:2.5 mix ratio occurred at lower temperature (40 °C). The increasing fatty acid addition on the corn starch mixture significantly increased the corn starch gel glass transition temperature [29].

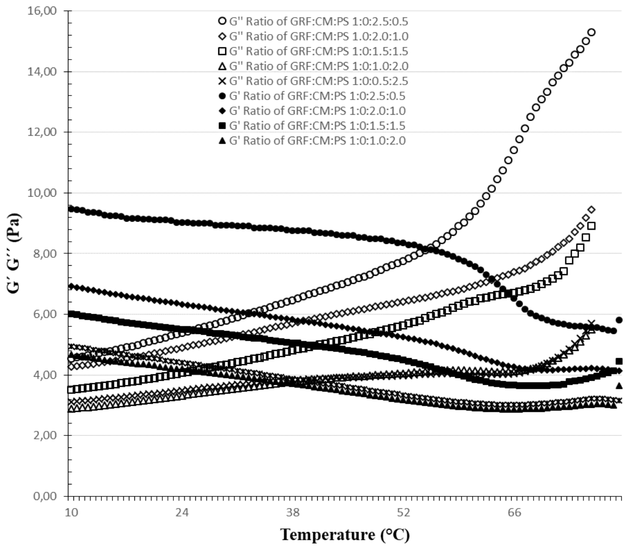

Fig 3. Storage modulus (G') and loss modulus (G") of ternary paste (GRF-CM-PS paste) as a function of temperature. G' filled symbols, G" empty symbols. The oscillatory rheometer was run at a cooling rate of 20°C/min; frequency of 0.4 Hz; strain amplitude of 0.2%.

E. Microstructure of GRF-CM-PS paste.

The result of polarization microscope observation are show in Fig 4. Fig 4 shows that in each treatment granular birefringence of the starch appeared somewhat weaker in this observation. It may caused of GRF used in this experiment still contain such as protein and fat along with a small size. In literature, a glutinous rice starch had a polyhedral shape with the smooth and not cracked surface [38] granule diameter was smaller than rice flour, which is 125-250 µm [39]. Besides the starch granule (polyhedral shape), that also spherical circles which are thought as fat globules from coconut milk. The Maltese crosses of GRF disappeared when sample was heated at 80 °C. Although at temperature of 70 °C the birefringence of swollen starch granule is still visible but is faint. It means total gelatinization of GRF occurred before 80 °C. The Maltese crosses of ternary paste with the ratio of GRF: CM: PS 1.0:1.5:1.5, 1.0:1.0:2.0 and 1.0:0.5:2.5 disappeared at 80 °C. Moreover at temperature of 70 °C the birefringence of swollen starch granule still could be seen clearly. Perhaps the total gelatinization of those ratio happen at higher temperature than GRF. Likewise those of the GRF: CM: PS ratio of 1.0:1.0:2.0 and 1.0:0.5:2.5 the maltese crosses disappeared at 90 °C. These suggested that total gelatinization of starch occurred at high temperature in the mixture with higher CM and lower PS ratio. Thus the presence of CM and PS in the ternary system (GRF: CM: PS) clearly affected gelatinization and rheological behavior of the triple mix system.

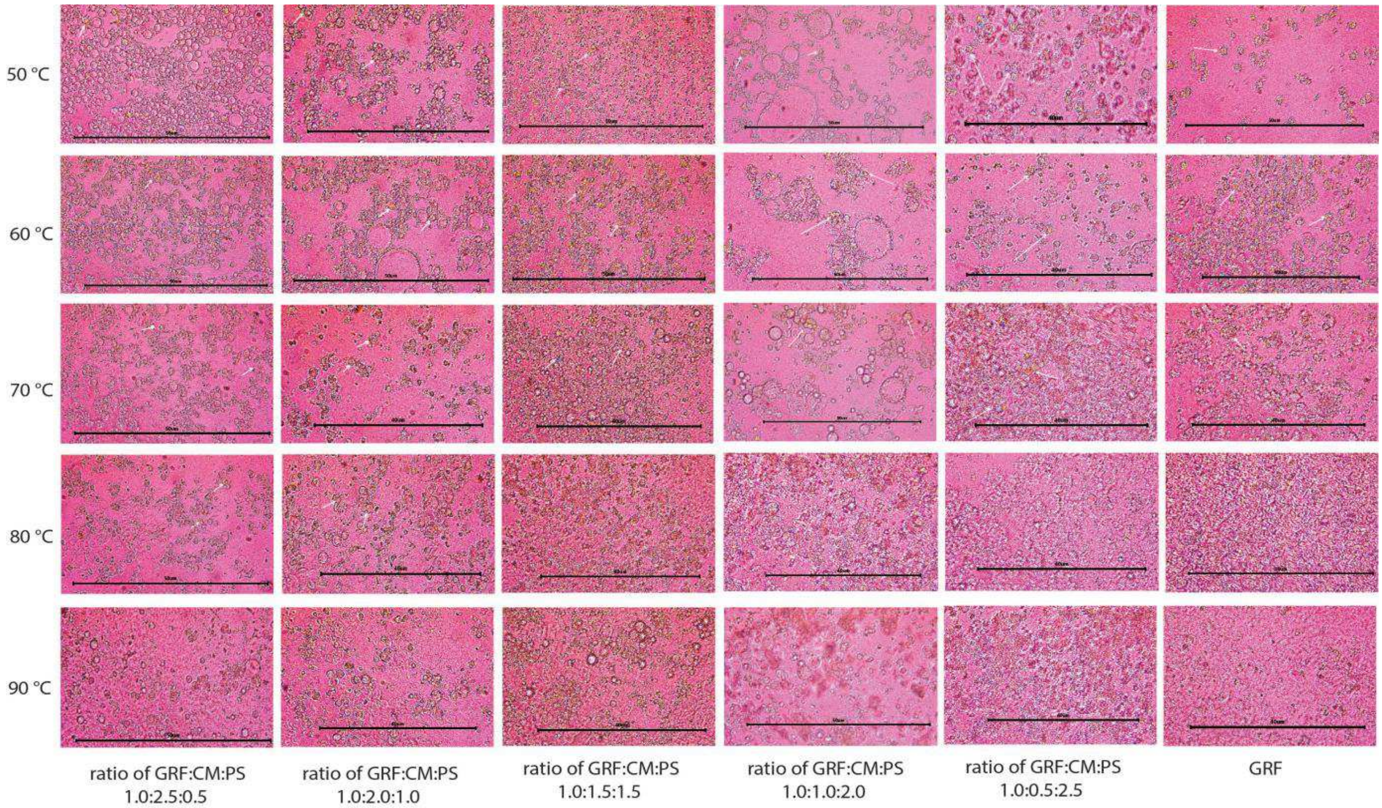

Fig 4. Effect of GRF, CM, PS ratio to polarized microscopy images of GRF-CM-PS paste under different temperature treatment (50 ºC, 60 ºC, 70 ºC, 80 ºC, 90 ºC). The white arrow indicates starch granule birefringe which disappear at 90 °C for the ratio of GRF:CM:PS 1.0:2.5:0.5, and 80 °C for the ratio of GRF:CM:PS 1.0:1.5:1.5, 1.0:1.0:2.0, and 1.0:0.5:2.5. This verified that total gelatinization occurred at high temperature with the high CM ratio on the system.

IV. Conclusions

Individually, the addition of palm sugar dan coconut milk increased the gelatinization temperature. In the ternary system, the presence of a mixture of sugar and coconut milk tended to lower down the viscosity profile. The lowest breakdown viscosity occurred at the ratio of the ternary mix, i.e. 1.0:2.5:0.5. Meanwhile, the highest final viscosity, set back viscosity was found at the ratio of 1.0:1.0:2.0, 1.0:0.5:2.5 respectively. The mixed system in *Dodol ulame* had a strong shear thinning behavior indicated by decreasing apparent viscosity with the increasing shear rate. Increasing the amount of coconut milk results in lower apparent viscosity of the mix compared to the high sugar ratio. The proportion variability of CM and PS gives a little change to flow behavior index, n. The increasing PS ratio and decreasing CM on the system increased the yield stress τ_0. The G' and G" as functions of angular frequency show that the pastes with the highest coconut milk ratio behaves more viscously with increasing frequency. Consistently, the tan δ indicates a solid-like behavior at low strain, and changes into liquid-like behavior at high strain. All samples showed increasing G' and decreasing G" with increasing temperature. The gelation temperature data show that the 1.0:2.5:0.5 mix ratio occurred at higher temperature (55 °C) and the 1.0:0.5:2.5 mix ratio occurred at a lower temperature (40°C). Observation using polarized light microscope confirmed that glutinous starch granule requires higher temperatures for totally gelatinized with larger amount of coconut milk in the system. Its clearly shows that the rheology properties of *dodol ulame* system affected by CM and PS ratio.

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