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Full Length Research Paper

Rheological and sensory properties of four kinds of jams

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The rheological properties of four kinds of jams (Kewpie strawberry, Marmalade, Blueberry and ST. Dalfour) were determined by the rheometer of MCR101. It showed that all the jam samples belonged to non-Newtonian fluid model, with thixotropy and pseudoplastic. Three jams were fit for Herschel-Bulkley model, although yield stress existed in the samples at 25°C and was calculated as 25.07, 99.13 and 103.67 Pa for ST. Dalfour, Kewpie strawberry and Blueberry, respectively. More so, three jams were fit for Arrhenius model, and the flow activation energies were 13.79, 15.10 and 21.46 kJ/mol for Blueberry, ST. Dalfour and Kewpie strawberry, respectively. The oscillatory test data were revealed due to the increase in frequency, storage modules (G′) and loss modules (G″), the decrease in viscosity (η) and the exhibition of shear thinning behavior by the jams. The G′, G″ and η of Blueberry were the highest, while those of ST. Dalfour were the lowest. According to the time dependent behavior, it was revealed that Kewpie strawberry had the most instability and ST. Dalfour had the most stability, which may be related to the flow activation energy. However, by the sensory properties, the lowest of the overall acceptability was Marmalade sample.

Key words: Jams, rheological properties, viscosity, storage modulus G′, loss modulus G’.

INTRODUCTION

Jam is a mixture of sugars, pulp and a pure drop of one or more kinds of fruit and water brought to a suitable gelled consistency (Fugel et al., 2005). According to Bureau of Indian Standards (BIS) and Prevention of Food Adulteration (PFA) specifications, jam should contain more than 68.5% total soluble solids (TSS) and at least 45% fruit (The Prevention of Food Adulteration Rules, 1955; Santanu 2010), whereas, the Codex Alimentarius Commission specifies that the finished jam should contain more than 65% TSS. Sugar constitutes more than 40% of total weight and 80% of total solids in jam (Lal et al., 1998, Santanu 2010). Commercial jam usually has an extremely variable composition. Nearly all manufacturers have a formula of their own which differs in some respects from those of other manufacturers. The ingredients affect the jam quality in terms of both subjective (sensory) and objective (textural and rheological) attributes.

China is a large agricultural country, rich in fruits and vegetables. It shows that fruits provide a sufficient source of jam. Both the labor cost of the U.S.A, Europe and Japan’s growth and the people who engaged in agricultural production becoming old have resulted to the increase in the price of fruits and vegetables. So the purchasing agent turns his attention towards the China market; as such, the Japanese demand for jam increase rapidly. According to the investigation carried out on Tokyo Customs, as compared to that carried out 7 years ago, only jam imports increased by 3 times, but the amount of imports increased by just 1.5 times. In Europe and America, jam is also the main food taken by consumers. On the one hand, owing to the food culture for centuries, bread with jam has been their most common and popular way of life; on the other hand, fast-paced modern city has given them even less time to properly prepare and enjoy their breakfast and lunch. So the convenient food has become their first choice and it has also met nutritional needs.

Rheological research in food science is therefore closely linked to the development of food products and could address the industrial production of food (stirring, pumping, dosing, dispersing and spraying), home based cooking as well as consumption of food (oral perception, digestion and well-being). For the processed food, the composition and the addition of ingredients to obtain a

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certain food quality and product performance require profound rheological understanding of individual ingredients related to food processing and final perception (Peter and Erich, 2010). Variation in ingredients or their concentration levels usually lead to changes in gel structure in jam that are often perceived by consumers through texture or mouthfeel. Texture influences the mouthfeel of a product, whereas taste is the sensory experience derived from the sensation in the mouth or on the tongue after ingestion of a food material.

The consumer judges the quality (fresh, stale, tender, ripe) when the food produces a physical sensation (hard, soft, crisp, moist and dry) in the mouth (Szczesniak, 1963; Kokini and Plutchok, 1987; Santanu 2010). Therefore, four kinds of jam products were chosen to determine the rheological properties including the static flow (Herschel-Bulkley parameters, thixotropy, and the determination of the apparent activation energy) and dynamic flow patterns (frequency, temperature and time sweep). More so, the sensory evaluation was also determined.

MATERIALS AND METHODS

The following four brands of commercial jams were purchased from JUSCO supermarket in Qingdao, China, and were preserved in refrigerator at 4°C:

(1) Kewpie strawberry jam was manufactured by Beijing Kewpie Corporation;
(2) Marmalade was manufactured by Shanghai Liang Food Corporation;
(3) Hero Blueberry was produced in Germany by Hero-Group for Hero AG, CH-5600 Lenzburg, Switzerland;
(4) ST. Dalfour was manufactured by Chambord et Cie Chateau St. Dalfour 82 Route de Bracieux Cour Cheverrny, France.

The composition of jams' samples

Moisture content, the soluble solids and ash content of the jams were determined according to the methods of Weixuan et al. (1989).

Rheological measurements

Rheological properties of the four jams were measured using a rheometer (MCR101, Austria).

Hysteresis area

The hysteresis area presents the area between two curves, which is commonly the up and down curve of a shear rate sweep (Sharoba et al., 2005). However, the steady-state rheological behavior of the four jam samples was studied at 25°C, where the shear rate was increased linearly from 0.1 to 150 s^{-1}. It was observed that the steady-state relationship between shear stress and shear rate of food materials is expressed in terms of Herschel–Bulkey model:

$$\tau=\tau0+K\gamma n \quad (1)$$

where, τ is the shear stress (Pa), τ0 is the yield stress (Pa), γ is the shear rate (s-1), K is the consistency index (Pa.sn) and n is the flow behavior index (dimensionless) signifying the extent of deviation from Newtonian behavior (Santanu and Shinhare, 2010).

Dependence of the flow behavior of fluid foods on temperature

The dependence of the flow behavior of fluid foods on temperature is taken to satisfy the Arrhenius relationship:

$$K=Ak \exp(Ek/RT) \quad (2)$$

Where, Ak is the frequency factor (Pa·sn), Ek represents the activation energy (kJ/mol), R is the gas law constant (R = 8.314 J/mol·K), and T is the absolute temperature (K). However, the flow activation energy was calculated using the Arrhenius-type equation.

Oscillatory measurement analysis

The oscillatory test, also called the dynamic rheological experiment, can be used to determine viscoelastic properties of food. The storage modulus G' expresses the magnitude of the energy that is stored in the material or that is recoverable per cycle of deformation. G'' is a measure of the energy that is lost as viscous dissipation per cycle of deformation. Therefore, for a perfectly elastic solid, all the energy are stored, that is, G'' is zero and the stress and strain will be in phase. In contrast, for a liquid with no elastic properties, all the energy are dissipated as heat; that is, G' is zero and the stress and strain will be out of phase by -90°C (Sharoba et al., 2005). Each measurement was performed with one point every 2 s for 60 points. However, measurements were performed at least in triplicate and the phase angle (δ) was calculated from the measurements of G' and G'' as tanδ=G''/G' (Karin et al., 2009).

Sensory evaluation

The samples stored at 4°C were taken out 3 h before serving. Color, taste, odor, texture,and overall acceptability of the four jam samples were evaluated by eight panelists following nine point hedonic scale (9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike,4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely) Santanu 2010; Lawless and Heymann 1998. All samples were presented before the panelists at room temperature under normal lighting conditions in 50 mL cups coded with random,three-digit numbers.

Statistical analysis

All determinations were made in triplicate, unless otherwise specified. Data were analysed by analysis of variance (ANOVA). The mean comparison was carried out by using SPSS software version 16.0 at $P < 0.05$ level.

RESULTS

The composition of jam samples

The main composition of the four jam samples is shown in Table 1. There was an insignificant difference in the ash content between the four jam samples. The lowest ash content was 0.13% of Blueberry, while the highest content was 0.25% of ST. Dalfour samples. Also, the moisture

Table 1. The main composition of jam samples.

Samples	Moisture content (%)	Ash content (%)	Soluble solid content (%)
ST. Dalfour	44.04±0.27[a]	0.25±0.01[a]	53.97±0.32[d]
Blueberry	30.55±0.53[c]	0.13±0.01[a]	64.73±0.21[b]
Marmalade	28.47±0.43[d]	0.24±0.01[a]	66.40±0.10[a]
Kewpie strawberry	34.40±0.34[b]	0.19±0.03[a]	58.83±0.76[c]

a,b,c,d Mean with different letters in the same column are significantly different ($P < 0.05$).

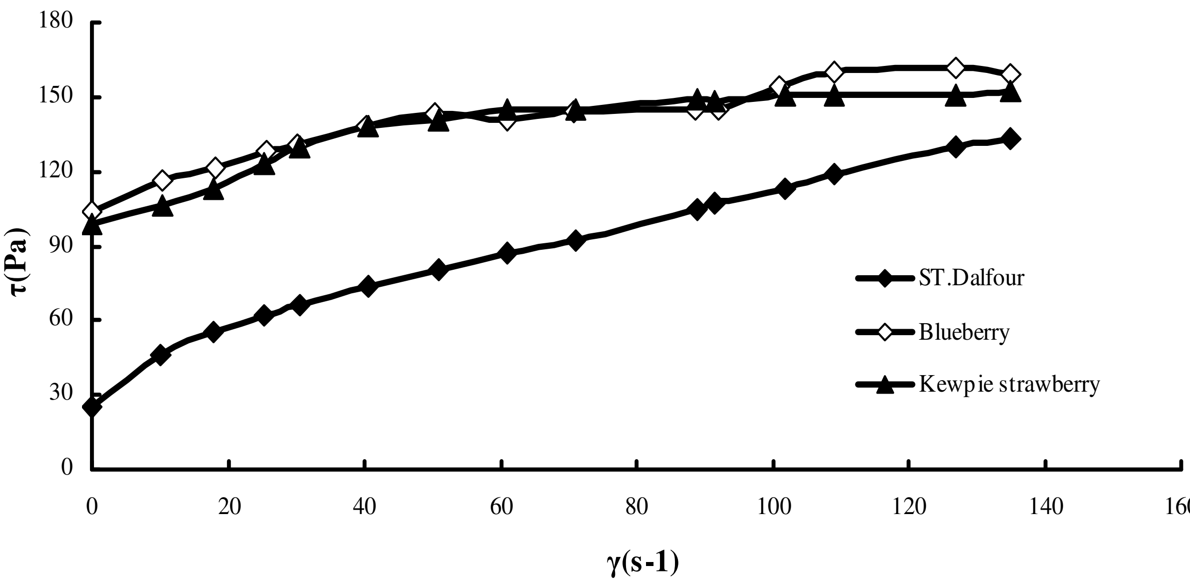

Figure 1. Changes of the shear stress with the shear rate increase.

Table 2. The Herschel-Bulkley parameters of jam samples.

Samples	σ_0/Pa	K/(Pa.s)	n	R^2
ST. Dalfour	25.07	4.77	0.63	0.9860
Blueberry	103.67	3.61	0.57	0.9509
Kewpie strawberry	99.14	2.02	0.71	0.9492

Table 3. The Arrhenius relationship parameters of jam samples.

Parameter	ST. Dalfour	Blueberry	Kewpie strawberry
Ea(KJ/mol)	15.10	13.79	21.46
R^2	0.9917	0.9678	0.9808

content and the soluble solid content of the four jam samples were presented in Table 1. The opposite variation tendency of the four jam samples appeared from the moisture content and the soluble solid content. The ST. Dalfour sample had the highest moisture content (44.04%) and the lowest soluble solid content (53.97%), while Marmalade had the highest soluble solid content (66.40%) and the lowest moisture content (28.47%).

Steady-state rheology analysis

As shown in Figure 1, the steady flow curves of ST. Dalfour, Blueberry and Kewpie strawberry were well described by the Herschel-Bulkley model, while the Marmalade sample was not fit for the Herschel-Bulkey model. The experimental values of the shear stress and the shear rate were fitted by Equation (1). The rheological parameters (σ0, K and n) of Dalfour, Blueberry and Kewpie strawberry were calculated and shown in Table 2. At 25℃, the highest value of the yield point (σ0) was found in Blueberry sample, while the lowest was found in ST. Dalfour sample. At 25℃, the K value was higher for ST. Dalfour sample and lower for Kewpie strawberry sample. All the flow index values n for the jam samples are given in Table 2, with $n<1$ indicating that the rheological behaviour is pseudoplastic.

As the temperature of the jam was increased, the viscosity of the jam samples decreased. The flow activation energies of the jam samples as listed in Table 3 were calculated at a constant shear rate of 100 1/s. The viscosity decreased with temperature. This effect of temperature on the flow behaviour of Dalfour, Blueberry and Kewpie strawberry can be described by the Arrhenius

Table 4. The sensory evaluation of jam samples.

Samples	Consistency	Colour	Taste	Odour	Overall acceptability
ST. Dalfour	5.88±0.64	6.25±1.49	5.88±1.13	5.63±1.30	6.38±1.19
Kewpie strawberry	6.00±1.20	5.50±1.07	6.13±0.99	5.63±1.19	6.00±1.07
Blueberry	6.00±0.76	5.38±1.51	5.75±1.04	5.50±1.07	6.38±0.74
Marmalade	5.88±0.99	6.25±1.49	5.75±1.58	5.50±1.20	5.63±0.92

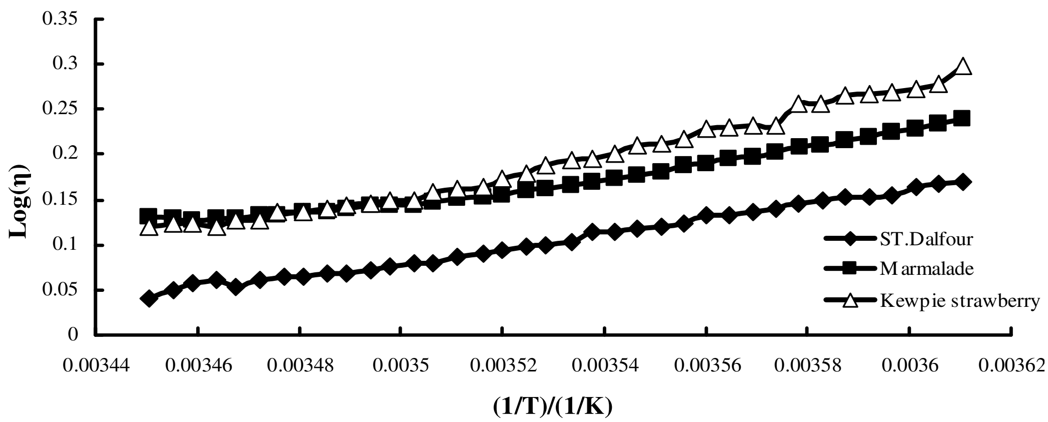

Figure 2. Effects of temperature on viscosity of the jams' samples.

relationship.

The largest of hysteresis loop area was Kewpie strawberry, while the smallest was Marmalade. The value assigned to a certain hysteresis area depends on the loop contour and the shear resistance of the sample. It can also vary according to the experimental conditions of the test (total shearing time and range of shear rates applied).

Dynamic measurement analysis

As Figure 4 shows the strain sweep, when the strain is 0.5%, the complex module (G*) is very steady. So, 0.5% strain at 3 Hz frequency is taken as the linear visco-elastic (LVE) region. The frequency sweep measurements agree with the results obtained previously. All the jam samples show G'>G" in the LVE region, which means that they all have semisolid characteristics at very low deformation. As the frequency was increased, tanδ of the jam samples were increased as well. The tanδ values decreased with an increase in temperature as shown in Figure 6. Of the jam samples, Marmalade declined most, while Blueberry was the steadiest jam. However, the value of tanδ for the jam samples ranged between 0.30 and 0.32, 0.28 and 0.30, 0.27 and 0.32, and 0.29 and 0.33 for ST. Dalfour, Blueberry, Marmalade and Kewpie strawberry, respectively.

Figure 7 shows different characters of the time dependent behavior of the four jam samples. With the exception of ST. Dalfour sample, the complex module (G*) increased rapidly with time of shearing, while the most significant increase was observed for Kewpie strawberry. The results comply with the measurements of the hysteresis loop.

Analysis of the sensory properties of jams

The results of the sensory evaluation scored are shown in Table 4. There was no significant difference for the four jam samples with regards to consistency, colour, taste, odour and overall acceptability. It was observed that the colour of Marmalade sample had the highest score, while the other three items had the lowest. Moreover, the highest score of taste and odour was observed for Kewpie strawberry.

DISCUSSION

In this study, we determined the rheological behavior of four jam samples. Some studies on the steady-shear and dynamic-shear rheological characterization of one kind of jam had been done (Sharoba et al., 2005; Santanu and Shinhare, 2010; Sesmero et al., 2009). However, the dynamic-shear rheological characterization is not complete and the differences of several jams have not been reported. Generally, the greater the intermolecular distances required, the higher the flow activation energy. So, the effect of viscosity on temperature is greater. As

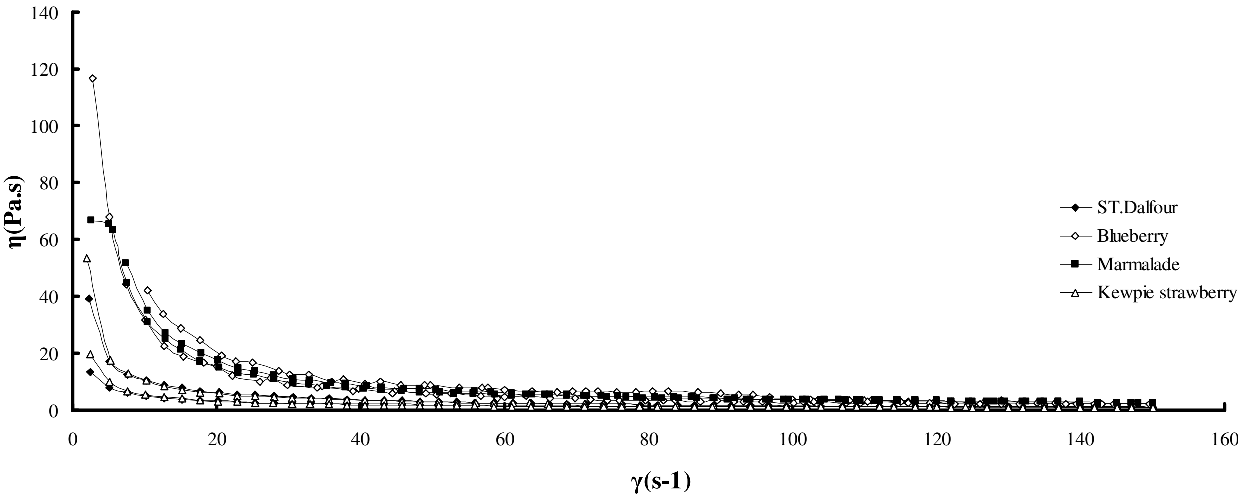

Figure 3. Hysteresis loop area of the four jams' samples.

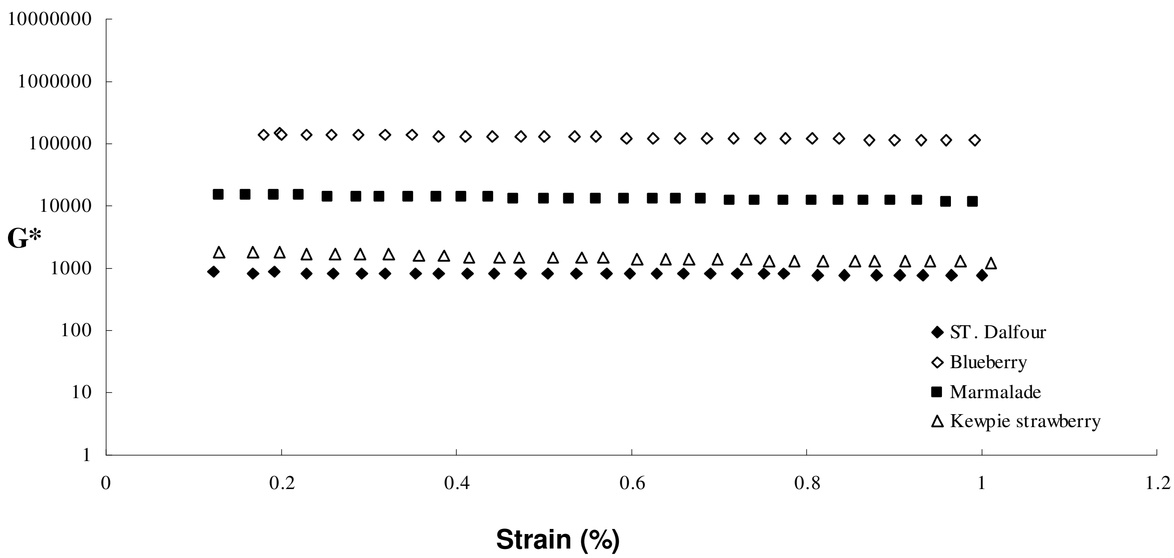

Figure 4. The linear viscoelasticity region of the four jams' samples.

the temperature increased, the intermolecular distances increased and therefore the viscosity decreased. The temperature dependence of K on Dalfour, Blueberry and Kewpie strawberry jams was well described by Arrhenius relationship (Figure 2). So far, Santanu Basu (Santanu and Shinhare, 2010) reported the flow activation energy of mogoo jam. The flow activation energies show the energies that the samples are trying to overcome. It is due to the fact that jam is a physical gel that it gave rise to more resistance to deformation.

As reported by Hernandez, a high-viscosity thixotropic fluid may show a larger hysteresis area than that with lower viscosity even if the latter undergoes a stronger structural destruction. Comparison of straight loop areas between differently viscous systems may not validate the conclusions on the extension of time-dependent structural breakdown (Tarrega et al., 2004). In this study as shown by Figure 3, Kewpie strawberry shows the largest loop area, indicating the highest resistance to flow. Assuming that a hysteresis loop area is an index of the energy needed to destroy the structure responsible for flow time dependence, the experimental data showed that Kewpie strawberry was the one needing the highest energy to breakdown, while Marmalade was the one needing the lowest energy to breakdown. For this type of soft solids, rheological properties change not only with the shear rate, but also with the time of shearing. Therefore, it is important to determine time dependent behavior. Typical time dependent rheograms revealed the thixotropic behavior and stability indicating continuous breakdown or rearrangement of structure with time of shearing. The results of time dependent behavior in Figure 7 were

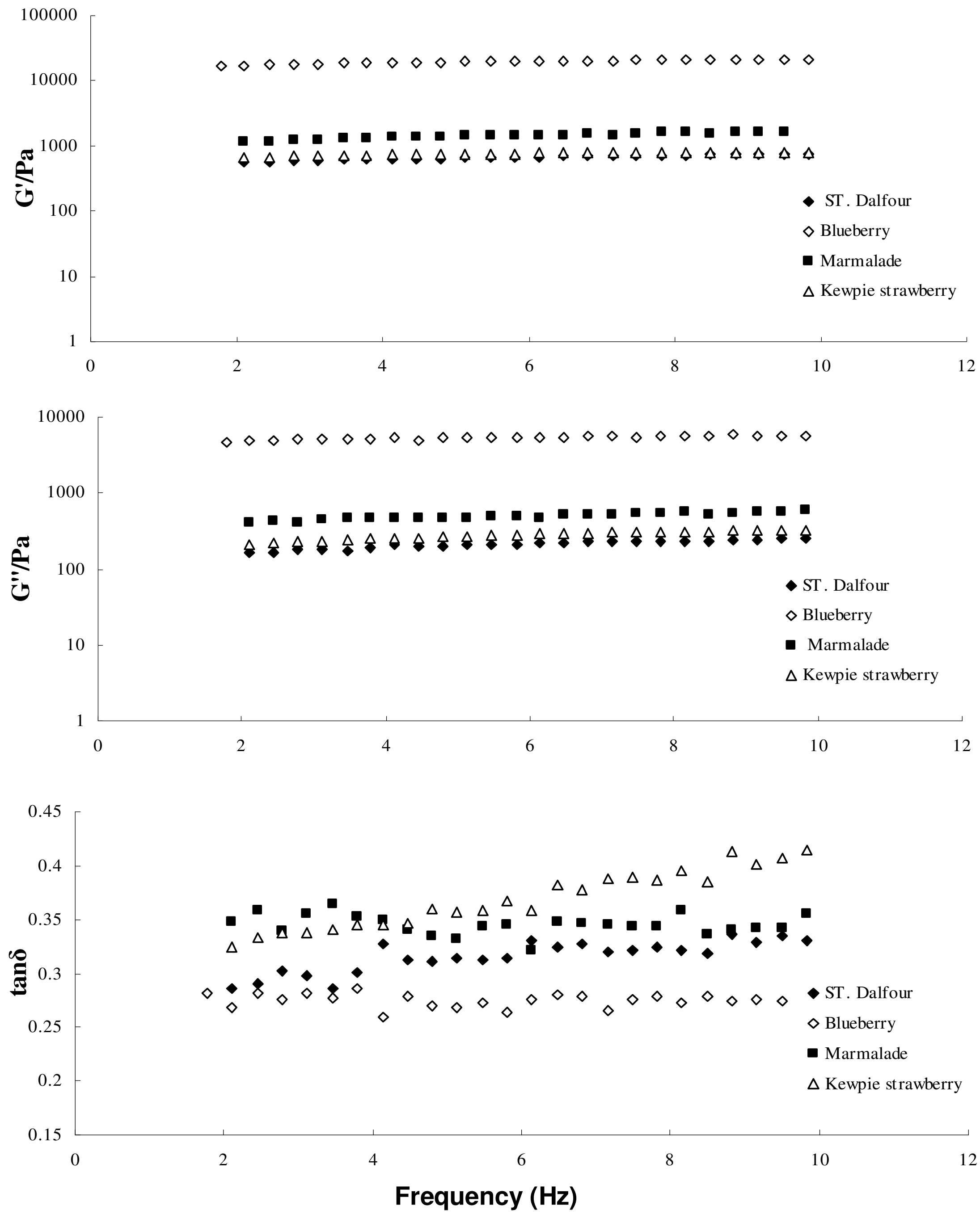

Figure 5. Frequency sweep of the four jams' samples at 25°C.

obviously consistent with that shown in Figure 3.

Dynamic rheology measure (Figure 5) revealed that the value of G' was higher than that of G", which showed that the jam samples were more elastic than viscous. Typical weak gel characteristics were observed, that is, G' was greater than G" throughout the frequency range, and the moduli showed a slight dependence on frequency (Talip and Sevim, 2003). The results of the frequency sweep analyzed showed that the jam samples are within the category of weak gel (Clark and Ross-Murphy, 1987; Sundaram and Mehmet 2000). For unlinked polymers, the values of both G' and G" fall constantly towards lower frequencies. At low frequencies (lower than 2 Hz), the bonds in the structural flow units were stretched and relaxed with very little breakage taking place. In these samples, very large particles act as an energy storing agent. Therefore, long molecules govern the behaviour of the system at low frequencies in places where the entanglement which seemed to be the mechanical interactions is probably neither chemical bonds nor

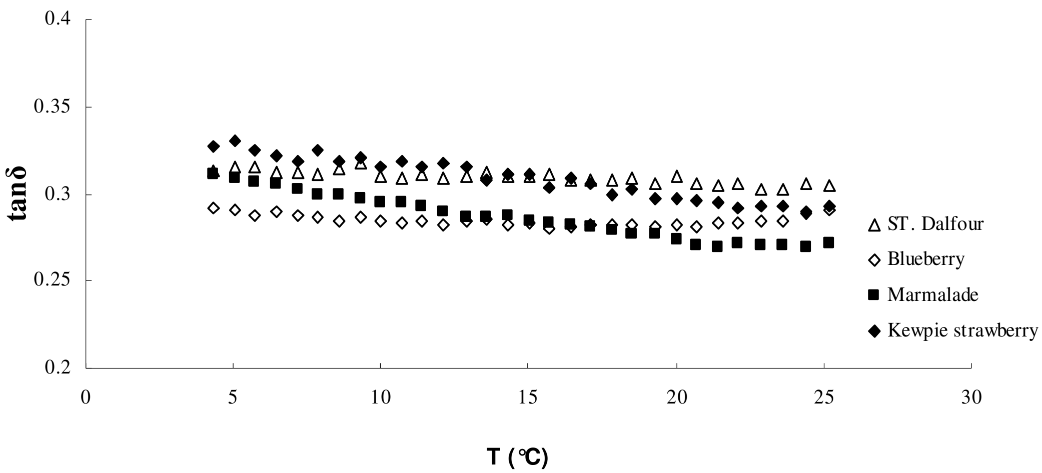

Figure 6. Temperature sweep of the four jams' samples at 3 Hz.

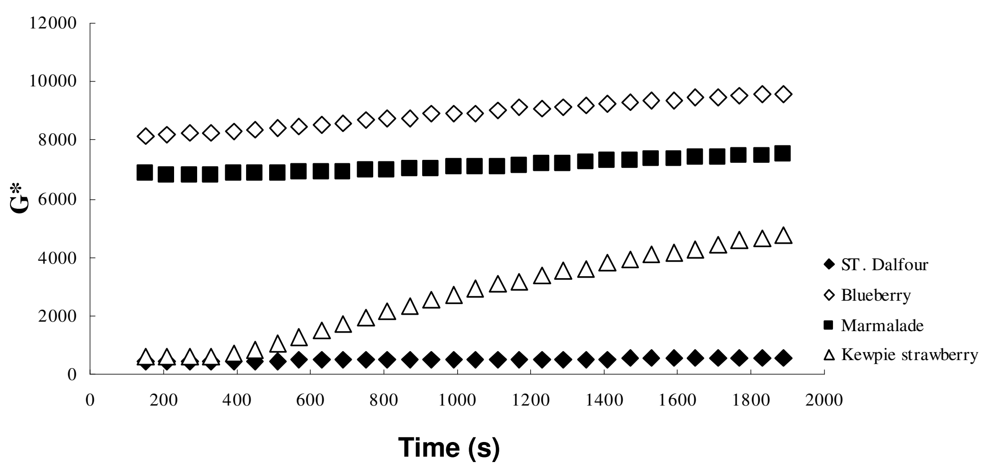

Figure 7. Time dependent behavior of the four jams' samples.

physical-chemical bonds. Hence, it has not been broken in places where solid-like behaviour predominates (G' > G") (Sima et al., 2011). The tangent of this loss angle [tan δ= G"/G'] denotes the relative effects of viscous and elastic components on viscoelastic behavior (Sundaram and Mehmet, 2000).

As the frequency was increased, the viscous character increased. By the tendency of tanδ, the solid-like characteristics of the Marmalade and Blueberry were greater than the other two jams. This may be caused by the lower moisture content of the former two jam samples, which could result in less freedom of movement for molecules (Clark and Ross-Murphy, 1987). Loss factor, tanδ= G"/G', is a dimensionless value that compares the amount of energy lost during a test cycle to the amount of energy stored during this time. Observations of polymer systems give the following numerical ranges for tanδ: very high for dilute solutions, 0.2 to 0.3 for amorphous polymers, and low (near 0.01) for glassy crystalline polymers and gels (Sharoba et al., 2005; Steffe, 1989; James and Steffe 1996). The value of tanδ for the jam samples ranged between 0.30 and 0.32, 0.28 and 0.30, 0.27 and 0.32, and 0.29 and 0.33 for ST. Dalfour, Blueberry, Marmalade and Kewpie strawberry, respectively. These differences might be due to the different particles or three-dimensional networks. The difference in loss factor could be considered as an index to distinguish the fine structure. The quantitative relation among tanδ, G' and G" and the network structure needs further investigation. It was observed that when the temperature was increased, both G' and G" decreased. However, the shape of the cures is more or less similar, showing that all the jam samples exhibit similar viscoelastic properties.

As in all foods, the organoleptic tests are generally the final guide of the quality from the consumer's point of view (Sharoba et al., 2005; Jimenez et al., 1989; David and Stuart, 2002). Thus, it is beneficial to make a comparison between the four jam samples. There was no significant difference for the four jam samples with regards to consistency, colour, taste, odour and overall acceptability.

It was observed that the colour of Marmalade sample had the highest score, while the other three items had the lowest. Moreover, the highest score of taste and odour was observed for Kewpie strawberry.

Conclusion

This study determined the detailed rheological characteristics of jams. Thus, the obtained rheological parameters could be used for processing calculations and product development. All the four jam samples belonged to non-Newtonian fluid model, with thixotropy and pseudoplastic. It was observed that three jams (ST. Dalfour, Kewpie strawberry and Blueberry) were fit for Herschel–Bulkley model, in that yield stress existed in the model. The flow activation energies were calculated for Blueberry, ST. Dalfour and Kewpie strawberry as 13.79, 15.10 and 21.46 kJ/mol, respectively. The oscillatory test data revealed the time the frequency, storage modules (G′) and loss modules (G″) increased and the time the jams exhibited shear thinning behavior.

According to the time dependent behavior, Blueberry and Marmalade increased more gently than the Kewpie strawberry, so Kewpie strawberry had the most instability and ST. Dalfour had the most stability, which may be related to the flow activation energy. By the sensory properties, there was no significant difference for the four jam samples as regards consistency, colour, taste, odour and overall acceptability. However, while the lowest of the overall acceptability was Marmalade, the hysteresis loop of Marmalade was the smallest.

ACKNOWLEDGMENTS

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