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# The Effect of Glucose Syrup on Rheological Properties of Sago Starch

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**Abstract**

The effect of glucose syrup on the rheological properties of sago starch was examined. The glucose syrup (30 - 75 g) was mixed with sago starch 100 g and baked at 60 °C for 16 h. The sago starch formulas 1 - 10 were analyzed rheological properties using a strain sweep test for evaluated Linear Viscoelastic Range (LVR) used for studied temperature test and frequency test. The result showed that the G' values of the sago starch formulas 1 - 10 decreased respectively which indicated an increase in the amount of glucose syrup resulting in the storage modulus within the starch structure decreasing causing agglomeration. In addition, in the temperature range of 70 - 95 °C, the sago starch formula 1 - 10 began to gelatinize and then stabilize. It indicated that the sago starch slurry was more similar to the solid. When the temperature was lowered from 95 to 30 °C, the G' and G" values of the sago starch formulas 1 - 10 gradually increased and then decreased because the starch solution during heating is agglomerated into large particles. The flexibility of solids within the powdery structure is very high and very viscous, so that during the initial decrease in temperature, the G' and G" values increase. After a while, when the temperature inside the structure begins to decrease, which causes the value of G' and G" to decrease. In the analysis of texture characteristics of the sago starch formulas 1 - 10, it was found that Hardness, Gumminess and Chewiness decreased significantly as the ratio of glucose syrup was increased in the formulations of the sago starch. The lower hardness value of the sago starch formulation with more added content of glucose syrup. Adhesiveness, cohesiveness and springiness values were not different between all the sago starch formulations.

**Keywords:** Glucose, Glucose syrup, Rheological properties, Sago starch

## Introduction

Sago starch is produced from the sago palm tree. It is a food that is widely used in South Asia [1]. Sago starch is sticky, easily digestible, tasteless and is usually flavored with other foodstuffs [10]. Sago starch contains polymer chains of glucose units with a high degree of regularity, crystalline cluster of double helices which consist of 2 glucans: Amylopectin and amylose [16]. Amylopectin is the major component in the most starches. It is the extensively branched structure and is composed of short chains of α-(1,4)-linked D-glucosyl units that are interconnected through α-(1,6)-linkages [17]. Amylose is a minor component and is essentially longer linear chains than amylopectin [16]. Sago starch contains about 21.4 - 30.0 % amylose [19]. Amylose content and internal structure of amylopectin will determine some functional and physicochemical properties of starch [20]. Sago starch granules are usually 10 - 50 μm in diameter and most of them exhibit a smooth ellipsoidal shape with few pitting [21]. Sago starch granules are oval with a temple bill-like oval shape. Scanning electron microscopy provided a shape and sized of native sago starch granules from Leyte, Philippines, which varied from 8 to 240 μm in diameter with the mean value of 37.59 μm [18].

Sago starch can be used to cook many foods such as bread, desserts, pearls, etc. Sago starch can be applied to many dessert food products which most contain sugar glucose syrup. Sugar glucose syrup is considered to use in many foods and beverage desserts. Glucose syrup can serve different purposes including liquid thickening, suspension of particles, increasing viscosity, giving desirable body and exceptional mouth feel, improving sensorial properties and enabling fiber. The sago starch properties are essential to apply in food products. Selection and use of starch in food products for consistent product quality and for innovative new products require a good understanding of starch properties and their interaction with other food components, as well as their behavior during processing and storing [12].

Rheological information is valuable in product design in the food industry [2]. The rheological properties of sago starch are important in the production process and design of food products in the food industry.

Many studies have been conducted on the physicochemical properties [3,9], and rheological properties of sago starch [4-6,11]. However, studies on the rheological properties of sago starch mixed with glucose syrup are limited. The rheological properties of food can be tested in a variety of ways depending on the characteristics of the sample to be analyzed. Most of the food is viscoelastic which the material will not immediately change into a new shape and when releasing force, the material cannot be returned to its original condition. Therefore, this research was to study the rheological properties of both formulas of sago starch with viscoelastic properties suitable for oscillatory tests. Studying the rheological properties of sago starch mixed with glucose syrup will be a guideline for its application in a variety of foods in the future.

## Materials and methods

### Materials

Sago starch packed in plastic bags was obtained from a food store in Phatthalung Province, Thailand. Glucose syrup was purchased from Chemical Corporation Co., Ltd. Furthermore, Glucose syrup was made from tapioca which contained dextrose equivalent (DE) 80 %. Distilled water was used in the preparation of all dispersions. Deionized water was used to prepare samples for rheometer analysis. The samples were stored at 25 °C. The moisture contents of the samples averaged 17.06 ± 0.157 as determined by the AOAC [7] procedures.

### Sample preparation

#### *Sago starch and glucose preparation*

Glucose syrup was measured according to **Table 1** and then warmed at 60 °C. The warmed glucose syrup was mixed with sago starch 100 g. The mixed sample was baked at 60 °C in a hot air oven for 16 h. Then the sample was contained in a plastic bag and kept at room temperature (25 °C).

**Table 1** The ratio of sago starch and glucose syrup.

| Sago starch formulas | Sago starch (g) | Glucose syrup (g) |
|---|---|---|
| 1 | 100 | 30 |
| 2 | 100 | 35 |
| 3 | 100 | 40 |
| 4 | 100 | 45 |
| 5 | 100 | 50 |
| 6 | 100 | 55 |
| 7 | 100 | 60 |
| 8 | 100 | 65 |
| 9 | 100 | 70 |
| 10 | 100 | 75 |

#### *Sago starch sample preparation for analyzed rheological properties*

Sago starch sample (1 - 10) was blended in a blending machine. The sago starch powder was put into plastic bag and kept at room temperature. To analyze the sample with a Rheometer, the sago starch powder sample was mixed with DI water at a ratio of 80:20.

***Sago starch sample preparation for analyzed texture properties***

Sago starch sample (1 - 10) 50 g was mixed with hot water 200 g and kept for 5 min. Then the sago starch sample was incubated in a microwave at 750 W for 180 s. Then the sago starch sample was mixed well and kept at room temperature before analyze with a texture analyzer.

***Rheological properties of sago starch***

The sago starch sample (1 - 10) was analyzed for rheological properties using a rheometer (Rheometer, HAAKE., Germany) with parallel plate (Parallel Plate Type P20/Ti) and gab 1 mm. The start temperature was 30 °C and heated until 95 °C and decreased temperature to 30 °C. The stress value was adjusted to 0.1 - 100 % with a stress angular frequency of 10 Hz. The Linear Viscoelastic Range (LVR) was 0.1 - 0.748 % using Strain sweep test. After that, LVR was selected and the stress value 0.13 % was used for studied temperature test and frequency test further.

**Rheological properties analyzed using Frequency Sweep Test**

The heating program was set at 30 - 95 °C and cool down from 95 to 35 °C. The stress was 0.13 % and angular frequency was 0.1 - 100 Hz. The change of storage modulus (G') and loss modulus (G'') of the sago starch samples were recorded within the angular frequency.

**Rheological properties analyzed using Temperature Test**

The heating program was set at 30 - 95 °C and cool down from 95 to 35 °C. The change of storage modulus (G') and loss modulus (G'') of the sago starch samples were recorded in heated and cool downed ranges.

**Texture properties of sago starch samples**

Sago starch samples were evaluated using a texture analyzer (Stable Micro System, TA-XT plus texture analyzer). Sago starch samples 20 g were analyzed for texture profile analysis (TPA). Double compressions of 50 % deformation at a speed of 1 mm/s were performed, with a resting time of 5 s between the 2 compressions. Compression was performed with a cylinder plate P/36R with a load cell of 50 kg. After the 2 compression cycles, the following parameters were recorded: Hardness, adhesiveness, cohesiveness, springiness, gumminess and chewiness.

**Statistical analysis**

All statistical computations and analyses were conducted using SPSS version 24Windows. Experimental data were expressed as mean value ± standard deviation. A Duncan's multiple range test was conducted to assess significant differences among experimental mean values ($p < 0.05$). All measurements were conducted in triplicate.

## Results and discussion

**Rheological properties of Sago starch**

Sago starch was analyzed for rheological properties using a strain sweep test for evaluated Linear Viscoelastic Range (LVR). As a result, LVR was 0.1 - 0.748 %. After that, LVR was selected with the stress was 0.13 % which did not affect change G' and shear stress. The 0.13 % shear stress was used for the frequency sweep test. The rheological properties of sago starch were investigated when subjected to an increasing rate of loading or angular frequency by analyzing from Storage modulus (G') and loss modulus (G"). **Figure 1** shows the relationship between frequencies of G' and G" for 5 % sago starch formulas 1 - 10. When increasing the frequency, the value of G' and G" increased throughout the testing period. G' was found to be greater than G" of all samples which G' was nearly 100,000 Pa and G" was around 10,000 Pa. However, Ahmad and Williams [11] were reported sago starch samples obtained from Malaysia, Indonesia, Thailand were frequency of G' (100 - 1,000 Pa) and G" (10 - 100 Pa) [11]. The rheological properties of the sago starch mixed with glucose syrup was significantly greater than the sago starch sample with respect to the granular structure. The presence of a glucose syrup in the sago starch may also be responsible for high G' and G". High glucose syrup was a lower G' and G" especially when compare between sago starch formular 1 and 10. The lowers the G' and G" may be indicated an increase in the amount of glucose syrup resulting in the solid elasticity within the starch gel structure decreasing causing agglomeration.

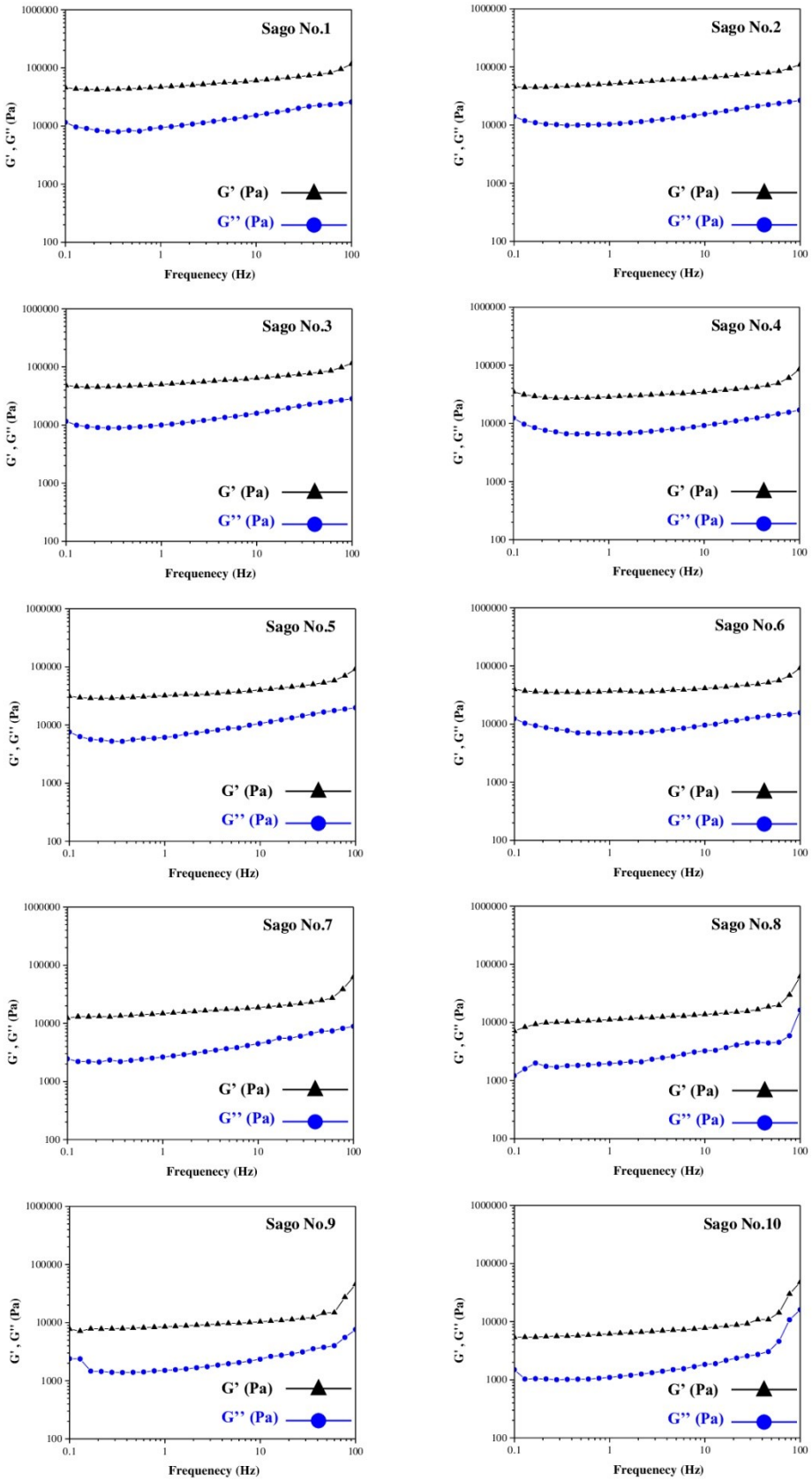


**Figure 1** Relationship between frequencies per G' and G" of sago starch samples No. 1 - 10.

Then, Temperature Test was carried out to study the rheological properties of sago starch samples that change with temperature by analyzing G' and G" values in the temperature range of 30 - 95 °C. (Shown in **Figure 2**) The relationship between the temperature of 30 - 95 °C and the G' of the samples of sago starch formulas 1 - 10 showed that the sago starch formula 1 - 10 in the temperature range of 30 - 70 °C had a constant G' value. The curve has an increasing slope, resulting in higher G' values and starting to stabilize at 70 - 95 °C. Sago starch formulas 1 - 10 had G' values of 254085.1, 46476.3, 104786.8, 53884.2, 77088.2, 27754.9, 37275.1, 28806.1, 39579.1 and 21182.5 Pa, respectively. The G' of sago starch sample progressively increases when temperature was increased to 95 °C. The initial increase in G' could be attributed to the degree of granular swelling to fill the entire available volume of the system and intergranular contact might form a 3-dimensional network of the swollen granules [15]. The result showed that in the temperature range of 70 - 95 °C, the sago starch formulas 1 - 10 was becoming starch gelatinization.

The effect of glucose syrup on the sago starch structure may be the high glucose in sago starch presented lower storage and loss modulus. However, Ahmad and Williams [11] demonstrated that G' decreases with increasing molecular mass of the amylose contents of the various sago starches [11]. For glucose-sago starch will be even more complex. This study on mixed glucose-amylose of sago starch different from sago starch alone. The glucose-amylose complex formation during gelatinization of sago starch may be cause lower the G' and G". The glucose content may be negatively correlated with G' and G".

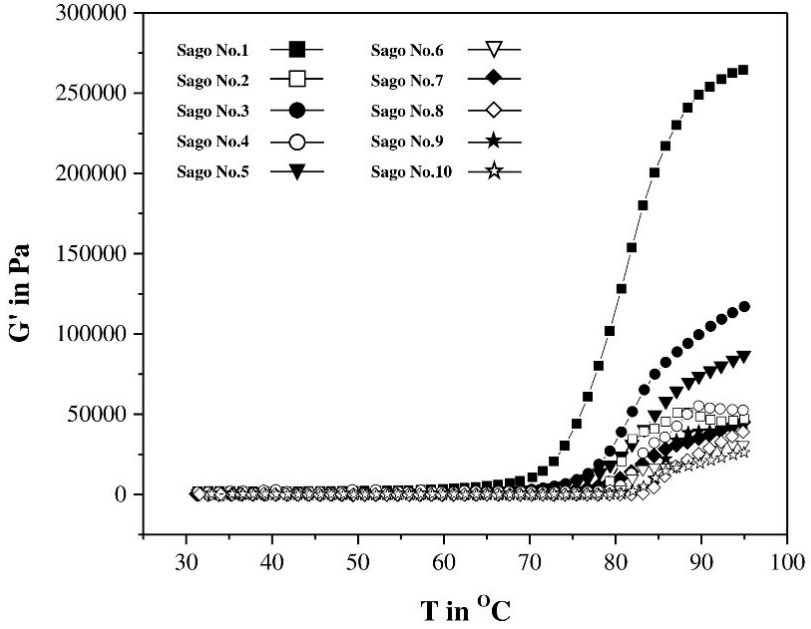


**Figure 2** The relationship between temperature at 30 - 95 °C and the G' value of samples of sago starch formula 1 - 10.

From **Figure 3**, the relationship between the temperature at 30 - 95 °C and the G" value of samples of sago starch formulas 1 - 10 showed that sago starch formulas 1 - 10 at temperatures around 30 - 70 °C had elasticity values of internal viscosity (G") constant. Then, at a temperature of 70 - 95 °C, there was an increase in the G' value, which can be observed from the graph with an increasing slope until the temperature was 85 °C. Sago starch formulas 1 - 10 had G'' values of 57126.1, 11003.5, 23985.7, 12314.4, 18898.0, 4125.6, 7895.5, 3895.5, 7950.5 and 4105.9 Pa. Therefore, from the experimental results, it shows that the G" value decreases accordingly. It shows the characteristics of sago starch formula 1, which has higher viscosity in sago starch structure than other formulas, when heated at a temperature of 30 - 95 °C.

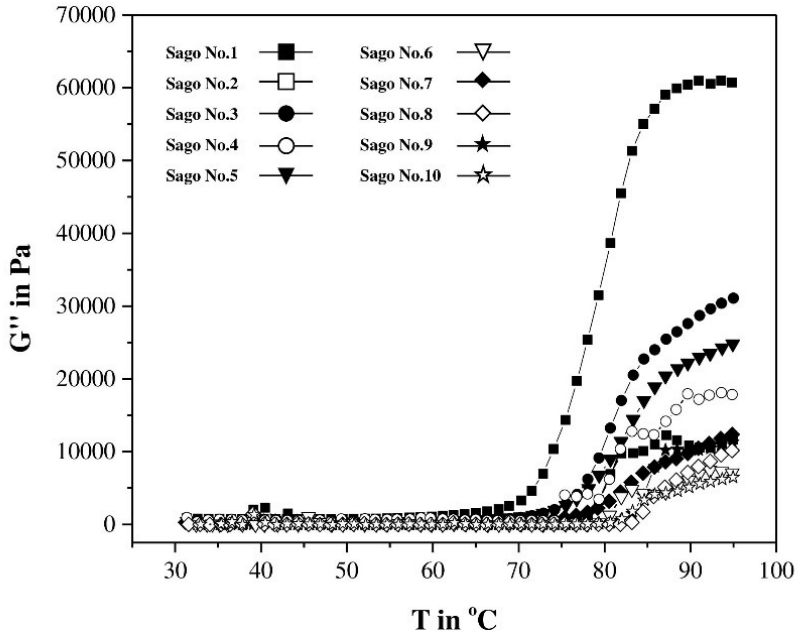


**Figure 3** The relationship between temperature at 30 - 95 °C and the G" value of samples of sago starch formulas 1 - 10.

**Figures 4** and **5** shows the relationship between the temperature at 95 - 30 °C and the G' and G" values of the sago starch formulas 1 - 10. It was found that when the temperature was lowered from 95 to 30 °C, the G' and G" values of the sago starch formulas 1 - gradually increased and gradually decreased. Because the starch solution during heating is agglomerated into large particles. The flexibility of solids within the powdery structure is very high and very viscous so that during the initial decrease in temperature, the G' and G" values increase. After a while, when the temperature inside the structure begins to decrease, which causes the value of G' and G" to decrease. From **Figure 3**, the highest G' value of formula 1 sago starch was different from other formulas, indicating the highest flexibility of solids within the starch structure. The G" value of sago starch formula 4 had the highest internal viscosity elasticity as shown in **Figures 4** and **5**.

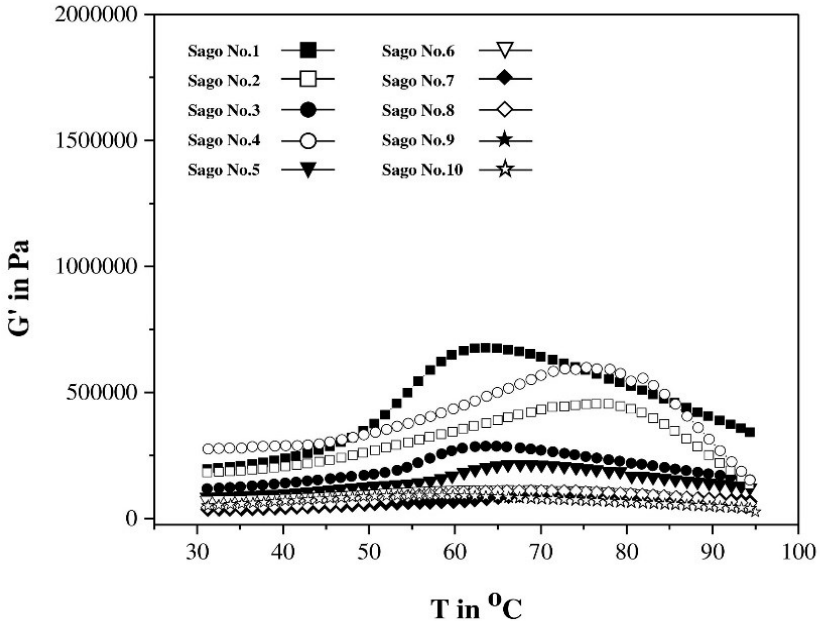


**Figure 4** The relationship between temperature at 95 - 30 °C and the G' value of samples of the sago starch formulas 1 - 10.

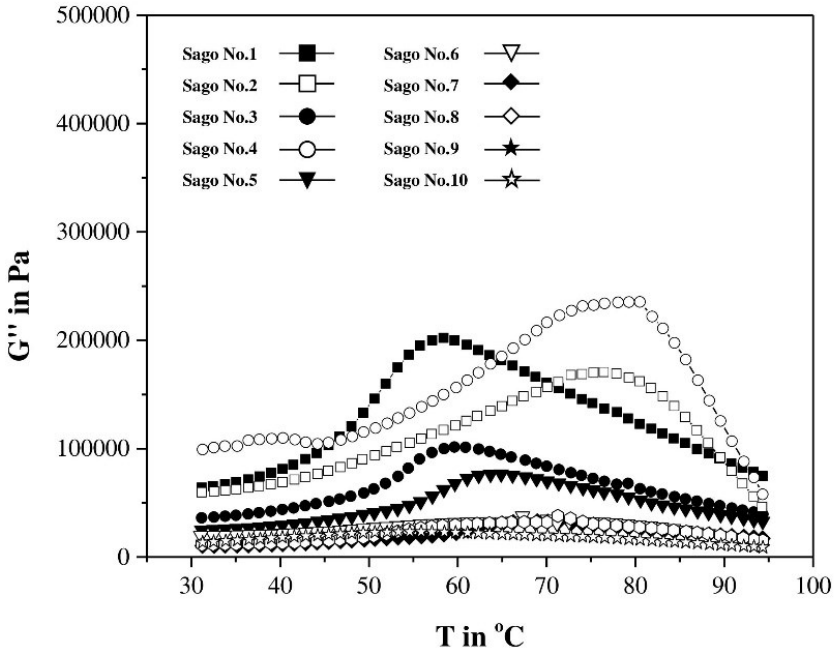


**Figure 5** The relationship between the temperature at 95 - 30 °C and the G" value of samples of the sago starch formulas 1 - 10.

**Sago starch texture profile analysis**

Texture has a great effect on food identification [13]. The textural properties of sago starch samples including hardness, adhesiveness, cohesiveness, springiness, gumminess and chewiness were determined in order to copy the way of human biting action [14]. The many amounts of glucose syrup were added to the sago starch (**Table 1**). The different textures of the sago starch formulations indicated the basic action of glucose syrup on the microstructure of the sago starch. Hardness, Gumminess and Chewiness were decreased significantly as the ratio of glucose syrup was increased in the formulations of the sago starch (**Table 2**). The lower hardness value of the sago starch formulation with more added content of glucose syrup may be due to the higher amounts of glucose. Adhesiveness, Cohesiveness and Springiness values were not different between all the sago starch formulations, however, the sago starch formular 2 had the lowest value of Adhesiveness (−120.89±40.5 mJ), Cohesiveness (0.95±0.0) and Springiness values (0.50±0.1 mm). Sopade and Kiaka [2] reported that the sago samples were generally indicates an increase in shear stress when the shear rate was increased at any temperature. This shows non-Newtonian behavior and judging from the negligible change in viscosity with time of shear, the behavior exhibited by each of the samples was time-independent.

**Table 2** Texture properties of Sago starch formulas.

| Sago starch formulas | Hardness (mN) | Adhesiveness (mJ) | Springiness (mm) $^{ns}$ | Cohesiveness | Gumminess (mN) | Chewiness (mJ) |
|---|---|---|---|---|---|---|
| 1 | 498.98±88.7$^{a}$ | −49.88±16.6$^{a}$ | 1.62±0.4 | 0.61±0.0$^{a}$ | 303.44±47.6$^{a}$ | 479.77±65.3$^{a}$ |
| 2 | 402.16±41.9$^{b}$ | −120.89±40.5$^{b}$ | 0.95±0.0 | 0.50±0.1$^{b}$ | 239.14±52.5$^{abc}$ | 320.73±59.5$^{b}$ |
| 3 | 380.82±53.3$^{b}$ | −62.01±38.1$^{a}$ | 1.29±0.5 | 0.71±0.2$^{ab}$ | 264.34±73.6$^{ab}$ | 279.45±51.0$^{bc}$ |
| 4 | 380.01±29.9$^{b}$ | −98.04±14.8 $^{ab}$ | 0.96±0.0 | 0.60±0.1$^{b}$ | 236.90±3.3$^{abc}$ | 244.96±15.7$^{cd}$ |
| 5 | 370.27±22.2$^{b}$ | −60.93±9.4$^{a}$ | 1.03±0.1 | 0.64±0.0$^{ab}$ | 223.64±52.9$^{bc}$ | 227.96±51.2$^{cde}$ |
| 6 | 351.73±64.3$^{b}$ | −80.85±30.0$^{ab}$ | 1.17±0.3 | 0.57±0.0$^{ab}$ | 201.75±38.2$^{bcd}$ | 228.56±23.0$^{cde}$ |

| Sago starch formulas | Hardness (mN) | Adhesiveness (mJ) | Springiness (mm) $^{ns}$ | Cohesiveness | Gumminess (mN) | Chewiness (mJ) |
|---|---|---|---|---|---|---|
| 7 | 344.11±49.7$^{bc}$ | −117.56±1.6$^{b}$ | 0.98±0.1$^{ns}$ | 0.56±0.0$^{ab}$ | 191.48±24.5$^{cd}$ | 186.98±25.2$^{def}$ |
| 8 | 323.61±68.8$^{bc}$ | −72.64±27.4$^{ab}$ | 1.34±0.6 $^{ns}$ | 0.72±0.3$^{ab}$ | 190.40±50.9$^{cd}$ | 181.10±53.3$^{ef}$ |
| 9 | 254.23±35.0$^{cd}$ | −73.88±35.4$^{ab}$ | 1.25±0.4 $^{ns}$ | 0.57±0.0$^{ab}$ | 143.38±14.0$^{d}$ | 179.58±65.9$^{ef}$ |
| 10 | 226.74±25.1$^{d}$ | −94.71±36.1$^{ab}$ | 1.04±0.1 $^{ns}$ | 0.60±0.0$^{ab}$ | 136.47±18.0$^{d}$ | 142.78±31.2$^{f}$ |

Notes: Different letters are significantly different according to Duncan's multiple range tests at $p < 0.05$. The results are the average of 3 replicates ± standard deviation. $^{ns}$ = non-significant ($p > 0.05$)

## Conclusions

The results of the experimental analysis of rheological properties of the sago starch formulas 1-10 showed viscoelastic behavior because when increasing the frequency, there will be a value G' > G". The behavior of the sago starch formulas 1 - 10 during heating and cooling showed that the sago starch formula 1 had the highest G' value and the sago starch formula 4 had the highest G" value different from other formulas. The different textures of the sago starch formulations indicated the basic action of glucose syrup on the microstructure of the sago starch. Hardness, Gumminess and Chewiness were decreased significantly as the ratio of glucose syrup was increased in the formulations of the sago starch. The lower hardness value of the sago starch formulation with more added content of glucose syrup. Adhesiveness, Cohesiveness and Springiness values were not different between all the sago starch formulations.

Rheological properties of Sago starch mixed with glucose syrup is significantly different from sago starch alone. The texture of the sago starch formulations indicated the basic action of glucose syrup on the microstructure of the sago starch. Rheological properties of complex food constituents such as glucose syrup mixed with sago starch is beneficial to the development of food products. These differences in rheological properties and texture of the sago starch formulas are the reasons for choosing different filling ratios of sago starch and glucose syrup for cooking.

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