

## Influence of processing conditions on rheological properties of aqueous extract chia (*Salvia hispanica* L.) mucilage

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### Abstract

The purpose of this study was to determine the effects of soaking temperature (25 and 80°C) and different processing conditions on the rheological properties of chia seeds (*Salvia hispanica* L.) mucilage. In this study, chia mucilage was first extracted using a ratio of seed to water at 1:10 for 4 hrs for control (25°C) and treated mucilage (80°C). Both extracted mucilage were evaluated in terms of yield, color, solubility, and water holding capacity. Then, the mucilage were subjected to different processing conditions including temperatures (5, 25, 45, and 65°C), pH (3, 5, 7, 9), sucrose concentrations (10, 20, 30, 40%), and salts (NaCl and KCl from 0 to 0.172 M; CaCl<sub>2</sub> and MgCl<sub>2</sub> from 0 to 0.049 M) to determine their rheological properties. Results show that high extraction temperature (80°C) significantly affected the mucilage yield higher than control. However, lightness (*L*\*), solubility and water holding capacity of the treated sample were lower compared to control. Apparent viscosity of the 3% of mucilage for both extracts increases with temperatures and sucrose concentration. The high apparent viscosity of the treated mucilage at MgCl<sub>2</sub> (0.049 M) and CaCl<sub>2</sub> (0.049 M) concentration were found higher than 0.01 M. Meanwhile, NaCl (>0.069 M), KCl (>0.035 M), and CaCl<sub>2</sub> (<0.03 M) had decreased the apparent viscosity value of the control sample. Thus, the treated mucilage could be suitable for application as a thickening agent in food.

## 1. Introduction

Chia (*Salvia hispanica* L.) seed is an annual herb that belongs to Lamiaceae family, which is widely consumed in Mexico, Argentina, and Southwestern United States (Segura-Campos *et al.*, 2014). Chia seeds have high oil content (30-40%) which is rich in linolenic acid (54-67%) and linoleic acid (12-21%) (Ixtaina *et al.*, 2011). Nevertheless, chia seed could prevent cardiovascular disease and cancer as it contains natural antioxidants such as phenolic glycoside-Q and K, quercetin and kaempferol which have cardiac protective effects and anti-carcinogenic characteristics (Reyes-Caudillo *et al.*, 2008). Chia seed is also high in quality proteins (19-27%) with the right balance of essential amino acids, especially methionine and cysteine (Ayerza, 2013).

Previous study reported that high fibre content in chia seed mucilage contributes to the potential source of

polysaccharide gums which can be added at low concentration in aqueous solutions (Hulse, 1996). Chia mucilage has been used as a substitute for egg and oil in the cake formulations and development of mayonnaise which improves the stability and texture of the products (Borneo *et al.*, 2010). Usually, chia mucilage is used as a food thickener similar to hydrocolloids, which include pectin, gum Arabic and cellulose. Chia mucilage is recommended for industrial use due to its slimy properties and dietary fibre content (Segura-Campos *et al.*, 2014).

Nowadays, the addition of chia mucilage in food products is widely used in many food industries. Chia mucilage has been used as a replacer for stabilizers and emulsifiers in the ice cream preparations (Campos *et al.*, 2016). Chia mucilage also contributes to the reduction of the fat content by 50% in bread and chocolate cakes, which result in healthier products and preserved quality attributes (Fernandes and de las Mercedes Salas-

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Mellado, 2017). Other than that, it has also been added into the rice flour gluten-free pasta to improve the nutritional profile and act as a thickening agent (Menga et al., 2017).

Chia seeds mucilage can be extracted using several types of methods such as cold extraction using freeze drier at  $-50^{\circ}\text{C}$  with different ratio of seed to water (1:10-1:40). It was found that high mucilage yield produced at a ratio of seed to water of 1:10 (Muñoz et al., 2012). There was also an extraction of mucilage *Lepidium sativum* seed using solvents (alcohol and acetone) with a better yield, but not cost-effective (Kilor and Bramhe, 2014). Mucilage of chia seed is a complex high molecular weight polysaccharide extracted when the seeds come into contact with water; thus, it will increase the solution viscosity (Lin et al., 1994). Chia seeds convey a similar characteristic to flax and basil seed, which discharge a clear mucilaginous gel when it is soaked in water at a ratio of 1:65 (Hosseini-Parvar et al., 2010). Chia mucilage can also be extracted by hydration of chia seed with water at a ratio of 1:20 and 1:40 (Muñoz et al., 2012).

Previous study by Campos et al. (2016) studied the effect of extraction temperature (30 to  $80^{\circ}\text{C}$ ), extraction time (2 to 4 hrs) and water to seed ratio (1:30) on the yield and apparent viscosity of chia mucilage. It is stated that the optimum parameters for the extraction of chia mucilage were at  $80^{\circ}\text{C}$ , 4 hrs extraction with water to seed ratio of 1:30 to produce a higher yield of mucilage (4.95%). However, none has studied on the effect of soaking the seeds at room temperature on the yield and characteristics of the mucilage produced. Moreover, chia mucilage has rheological properties including thickening capacity (Capitani et al., 2013), adhesion and as a component for biodegradable films to increase the shelf life of foods. The rheological analysis is aimed to determine the viscoelastic behavior of hydrocolloids in the solution (chia mucilage) which could be affected by different variables such as shear rate, time, pH and temperature (Capitani et al., 2015). Apart from that, there were also study conducted on the effect of different temperatures (5, 25, 45 and  $65^{\circ}\text{C}$ ), pH (3 to 9), salt (0.035 to 0.172%) on final concentration of monovalent (NaCl and KCl) while (0.01 to 0.049%) concentration of divalent ( $\text{CaCl}_2$  and  $\text{MgCl}_2$ ) and sugar at concentration in the range of 0 to 40% of rheological properties of mucilage extracted from *Alyssum homolocarpum* seed (Koocheki et al., 2009). This finding showed a decrease in viscosity due to low temperature, low pH (Reyes-Caudillo et al., 2008), a high concentration of salt and sucrose. However, none has studied on the effect of the above processing conditions (temperature, pH, salts and sugar concentration) on properties of the chia mucilage.

Thus, the objectives of this study were to determine the effect of soaking temperature (25 and  $80^{\circ}\text{C}$ ) on yield, color, solubility, and water holding capacity of aqueous chia seed mucilage (*Salvia hispanica* L.). The final objective was to determine the effects of different processing conditions, which were temperature, pH, salts and sucrose concentration on the rheological properties of chia mucilage.

## 2. Materials and methods

### 2.1 Materials

The chia (*Salvia hispanica* L.) seed (black) was supplied by The Chia Company (Victoria, Australia). Meanwhile, all solvents involved in the proximate analysis were purchased from Sigma-Aldrich, United States.

### 2.2 Proximate analysis

The proximate analysis was carried out for raw chia seeds to determine moisture, ash contents, crude protein, fat and fibre using standard methods of Analytical Chemist methods: 934.01, 942.05, 992.15, 954.02, 978.10 (AOAC, 2000), respectively.

### 2.3 Extraction of mucilage

The extraction of chia seeds mucilage was done by soaking the seeds in distilled water with seed to water ratio of 1:10 (Campos et al., 2016). The solutions were agitated continuously using water bath shaker (Protech, Malaysia) and heated at a temperature of  $80^{\circ}\text{C}$  for 4 hrs (Campos et al., 2016). A control sample was prepared using a similar seed to water ratio (1:10) and agitated continuously using a water bath shaker (Protech, Malaysia) at room temperature for 4 hrs.

The extraction method used in this study was selected based on preliminary research using different ratio of seed to water (1:10 to 1:30) at  $80^{\circ}\text{C}$  for 4 hrs. It shows that a higher yield of chia mucilage obtained at the water to seed ratio of 1:10, which contributed to higher viscosity of mucilage.

Then, both solutions containing mucilage at sufficient amount were blended once it reached room temperature ( $25^{\circ}\text{C}$ ) until it turns milky white using a wet blender (Panasonic Blender MX-GM1011, Malaysia). Then, the mucilage solution formed was separated using a centrifuge (Kubota 3740 Model, Japan) at 3500 rpm for 75 mins (Dick et al., 2015). The samples formed three separate layers, which consist of seed coats at the bottom layer, mucilage (middle layer), and water on the top. The water was discarded out, and the mucilage was scraped out using spatula manually.

## 2.4 Yield of extraction

The extraction yield (%) of chia (*Salvia hispanica* L.) mucilage was determined with a slight modification by changing the form of a sample from mucilage powder to liquid form (Zeng and Lai, 2014).

## 2.5 Instrumental colour measurement

The colour parameters ( $L^*$ ,  $a^*$ ,  $b^*$ ), of the mucilage, were determined using a chromameter (CR-400, Konica Minolta Sensing Inc., Japan) which represents white to black, red to green, and yellow to blue respectively (Timilsena et al., 2015).

## 2.6 Solubility

Solubility (%) of the extracted mucilage followed Zeng and Lai (2014). Firstly, 50 mg of chia mucilage (W) was mixed with 10 mL of deionised water and stirred using magnetic stirrer with 250 rpm at room temperature for 24 hrs. Then, after centrifuging the sample solution (6000 x g) for 15 mins, the supernatant was poured out and the 15 mL (W1) containing precipitant of mucilage was dried at 105°C till it reached constant weight (W2). The solubility of the mucilage was calculated according to the following equation:

$$\text{Solubility (\%)} = \frac{W + W1 + W2}{W} \times 100$$

## 2.7 Water-Holding Capacity (WHC)

The water holding capacity was determined according to the method by Norlaila et al. (2015). One gram of chia mucilage was added into 10 mL of distilled water. Then, the mixture was vortexed using Vortex mixer (VTX-3000L, Japan) for 2 mins and centrifuged at 3000 rpm for 30 mins before poured out the supernatant. The WHC is calculated by dividing the weight (g) of water absorbed by 100 g of chia mucilage.

## 2.8 Rheological measurement

### 2.8.1 Preparation of solutions

The preparation of mucilage solution was done following method by Koocheki et al. (2009). The mucilage solutions were prepared at concentrations of 3% by adding 3 g of mucilage in 100 mL of distilled water and stirred manually at room temperature (Koocheki et al., 2009). The 3% of chia mucilage was chosen based on the study conducted by Koocheki et al. (2009) where the concentration of *Alyssum homolocarpum* seed showed good rheological behaviors (flow properties and viscosity) on different processing conditions (pH, salt and sugar concentrations).

### 2.8.2 Apparent viscosity

The apparent viscosity was done according to the

method by Koocheki et al. (2009) with slight modification using a rheometer with 60 mm discs probe and a heating circulator. For each test, approximately 2 to 3 mL of the sample was transferred to 60 mm of disc following by 2 mins pre-shearing at 100 s<sup>-1</sup> to obtain a uniform solution. The instrument was set to 25°C and equilibrated for 10 mins followed by two-cycle shear in which the shear rate was increased linearly from 0 to 300 s<sup>-1</sup> in 3 mins and immediately decreased to 0 s<sup>-1</sup> in the next 3 mins. The flow behavior index ( $n$ ) and consistency index ( $k$ ) value computed by fitting the power law model, using the following equation:

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

Where  $\tau$  is the shear stress (Pa), ( $\gamma'$ ) is the shear rate (s<sup>-1</sup>),  $k$  is the consistency coefficients (Pa s <sup>$n$</sup> ), and  $n$  is the flow behavior index (dimensionless)

Effects of different processing conditions (pH, temperature, salts, and sucrose) on chia mucilage samples were analyzed using a similar methodology above.

### 2.8.3 Determination of flow properties at different sugar concentrations

Sugar was dissolved in 100 mL of water to obtain 0%, 10%, 20%, 30%, and 40% of sugar concentration, then added into 3% of mucilage solutions. The flow behavior index ( $n$ ) and consistency index ( $k$ ) values were measured at 25°C (Koocheki et al., 2009).

### 2.8.4 Effects of different pH on mucilage flow properties

A 3% of chia mucilage solution was adjusted to pH 3.0, 5.0, 7.0, and 9.0 by adding either 0.1 mol/L NaOH or HCl. The viscosity and flow properties were tested at a constant temperature of 25°C (Koocheki et al., 2009).

### 2.8.5 Effects of different temperatures (5, 25, 45 and 80°C) on mucilage viscosity

A 3% of chia mucilage solution was poured on to the rheometer discs probe and analysed for 10 mins at different temperatures of 5, 25, 45 or 65°C. The temperature dependence of consistency coefficient (the indicator of the viscous nature of the sample) assessed by fitting the Arrhenius model (Sengül et al., 2005), using the following equation:

$$k = k_0 \cdot e^{(E_a/RT)} \quad (2)$$

Where  $k_0$  is proportionality constant (or consistency coefficient at a reference temperature, Pa s <sup>$n$</sup> ),  $E_a$  refers to activation energy (J/mol),  $R$  is universal law gas constant (J/mol K), and  $T$  is absolute temperature (°K).

### 2.8.6 Effects of different salt concentration on mucilage viscosity

A 3% of chia mucilage solution was tested with monovalent (NaCl and KCl) and divalent (CaCl<sub>2</sub> and MgCl<sub>2</sub>) salts where the salts were added to obtain final concentrations of NaCl and KCl (0.035, 0.069, 0.103, 0.138 and 0.172 M) while, CaCl<sub>2</sub> and MgCl<sub>2</sub> (0.01, 0.02, 0.03, 0.03 and 0.049 M), respectively. Viscosity measurements were performed at a temperature of 25°C. Different types of salt were important to determine the mucilage behaves as a polyelectrolyte and to estimate the functional rheological properties (Koocheki et al., 2009).

### 2.9 Statistical analysis

Analysed samples were taken in triplicate. All the data were analysed using one-way ANOVA in Minitab software. All values were expressed as a mean ± standard deviation to identify the significant difference among the samples under a confidence interval of 95%.

## 3. Results and discussion

The composition of chia seed, as shown in Table 1 conveys that chia seeds are high fibre and protein content. The fibre and protein content observed in this study were slightly higher than the nutritional composition, which has been reported by the National Nutrient Database for Standard Reference (USDA, 2011). The high fibre content of chia seed promotes the feeling of fullness and prevents the increase of blood sugar after eating a meal (de Souza et al., 2015). The different origin and environment conditions of chia seeds contribute to the variations in protein content of chia seeds obtained from Mexico with the range of 18.5 to 22.3% (Porrás-Loaiza et al., 2014) while in this study, the protein content of chia seed from Australia contains 26.87%.

Table 1. Composition of raw chia seed

Type of analysis	Chia seed (%)	USDA (%)
Ash	4.78±0.07	-
Moisture	4.85±0.05	-
Fat	7.70±0.08	30.74
Protein	26.87±0.08	16.54
Fibre	35.80±0.06	34.4
Carbohydrate	21.10±0.00	42.12

Table 2 shows the yield and color properties of control and treated samples. There is a significant difference ( $p<0.05$ ) between the mucilage yield of control (25°C) and treated sample (80°C). The result indicated that the extraction of chia mucilage by soaking the seeds at high temperature (80°C) gave an effect on the yield of mucilage. This result was similar to the previous

study (Muñoz et al., 2012), which had carried out the extraction of chia mucilage using the soaking method at 80°C. The study reported that extraction of mucilage at a temperature of 80°C could give high percentage yield, (53.60%) compared to the extraction at low temperature (20°C) at the ratio of seed to water (1:40). Commonly, high temperature allows water to penetrate a solid matrix of seeds and cause the release of mucilage easily (Muñoz et al., 2012). The color of chia mucilage was presented in Table 2. There was a significant difference ( $p<0.05$ ) between  $L^*$ ,  $a^*$ ,  $b^*$  value for control (25°C) and treated sample (80°C). In terms of lightness ( $L^*$ ) value, the treated sample has a significantly ( $p<0.05$ ) lower value (49.76±0.06) compared to the control (54.34±0.13). The treated mucilage formed a brownish color due to exposure of high temperature which caused by an enzymatic browning thus affecting the properties of polysaccharides (Qian et al., 2012) compared to the mucilage extracted at room temperature that has a brighter color.

Table 2. Yield and colour properties of control and treated samples

Type of samples	Yield (%)	Colour		
		L	a	b
Control	50.88±0.46 <sup>a</sup>	54.34±0.13 <sup>a</sup>	2.36±0.03 <sup>b</sup>	9.57±0.18 <sup>a</sup>
Treated	53.60±0.30 <sup>b</sup>	49.76±0.06 <sup>b</sup>	2.89±0.02 <sup>a</sup>	9.90±0.06 <sup>b</sup>

Different superscript letters in the same column indicates significant different at ( $p<0.05$ )

Control (25°C) and treated samples (80°C) were measured for its solubility in water and water holding capacity (WHC). In this study, the mucilage was completely soluble in water at room temperature compared to high temperature. This study shows that the control was significantly more soluble in water (60.52%) compared to chia mucilage extracted at high temperature (60.01%) due to the complete dispersion of mucilage at room temperature followed by the water penetration into the mucilage (Dublier and Cuvelier, 2017). This result was similar to the solubility of Larch gum, which has a solubility value of 60% at room temperature. Heat applied during the mucilage extraction able to reduce viscosity and break mucilage cells to drive out mucilage. In addition, prolonged extraction time of mucilage at a higher temperature (more than 50°C) may produce the insoluble components that caused the weakness of intermolecular interaction which retard solubility and water-binding capacity (WHC) of the mucilage. As a result, a decreased in the ability of mucilage to form dispersion in water (Korir et al., 2018). The degree of mucilage solubility was also influenced by the extraction conditions and the polysaccharide fraction that high in protein content presented in the chemical structure of

chia mucilage (Amid *et al.*, 2012). Other than that, WHC was measured to observe the ability of a substance to associate with water and hold water in producing gels or highly viscous solution (Korir *et al.*, 2018). Based on the results in Table 3, it shows that the control has a higher value of water holding capacity compared to the treated sample with a significant difference. This could be due to high extraction temperature which affects the decrease of water holding capacity of mucilage (Koocheki *et al.*, 2009). Moreover, a high value of WHC could be due to the presence of polysaccharide in chia mucilage that contributes to the greater affinity to absorb water (Noorlaila *et al.*, 2015). It can be seen that mucilage extracted at room temperature had high capacity of holding water.

Table 3. Solubility and water holding capacity properties of control and treated samples

Types of sample	Solubility (%)	Water-Holding Capacity
Control	60.52 ± 0.02 <sup>a</sup>	13.48 ± 0.28 <sup>a</sup>
Treated	60.01 ± 0.16 <sup>b</sup>	10.18 ± 0.14 <sup>b</sup>

Different superscript letters in the same column indicates significant different at (p<0.05)

The apparent viscosity of control (25°C) and extracted mucilage (80°C) was studied to determine the effect of processing conditions such as the addition of different sucrose concentrations, pH, temperatures and salts on chia mucilage as stated in Table 4 to 7. The apparent viscosity was measured using a power law

model to obtain the consistency coefficient ( $k$ ), and flow behavior index ( $n$ ) values. The flow behavior index ( $n$ ) indicates the degree of non-Newtonian characteristics of the fluid. As the fluid becomes more viscous, the consistency index ( $k$ ) increases and the flow behavior decreases. All data tabulated with the best values for the coefficient of determination, which was ( $R^2 > 0.9$ ). Increase in apparent viscosity (Pa·s) indicates that the substances are highly viscous. Chia mucilage exhibited pseudoplastic shear thinning behavior as the thickness decreased at increased in shear rate.

The apparent viscosity (Pa·s) of different sucrose concentrations on the consistency coefficient ( $k$ ), and flow behavior index ( $n$ ) was stated in Table 4. It shows that the increase in apparent viscosity of chia mucilage with an increase in the concentration of sucrose (10, 20, 30 and 40%) for both control (25°C) and treated chia seed (80°C). Nevertheless, the apparent viscosity for the solutions added with sucrose is higher than a solution with the absence of sucrose in both samples. This result was similar to the rheological behavior study conducted on *Alyssum homolocarpum* seed gum (Koocheki *et al.*, 2009). It was also supported by the previous research, which showed that the increase of apparent viscosity is due to the presence of 10% sugars (Behrouzian *et al.*, 2013). The apparent viscosity of treated mucilage, as stated in Table 4 was higher (8.9943 mPa·s) than control (8.5395 mPa·s) at a concentration of 40%. It shows that treated mucilage is more viscous than control as flow behavior index,  $n$  decreased. The  $k$  value also increased

Table 4. The Power law values of different types of mucilage at different sucrose concentrations

Type of sample	Sucrose concentration (%)	$\eta_{a,100}$ (mPa·s)	$k$ (Pa·s <sup><math>n</math></sup> )	$n$
Control	10	8.3948	472.51	0.1248
	20	8.4175	472.26	0.1255
	30	8.7561	504.79	0.1196
	40	8.5395	523.64	0.1062
Treated	10	8.3536	467.6	0.126
	20	8.6943	493.69	0.1228
	30	8.9355	528.59	0.114
	40	8.9943	548.74	0.1073

$\eta_{a,100}$  indicates apparent viscosity;  $k$  is consistency index;  $n$  is flow behavior index;

Table 5. The Power law values of different types of mucilage at different pH

Type of sample	pH	$\eta_{a,100}$ (mPa·s)	$k$ (Pa·s <sup><math>n</math></sup> )	$n$
Control	3	8.3948	472.51	0.1248
	5	8.4175	472.26	0.1255
	7	8.7561	504.79	0.1196
	9	8.5395	523.64	0.1062
Treated	3	8.3536	467.6	0.126
	5	8.6943	493.69	0.1228
	7	8.9355	528.59	0.114
	9	8.9943	548.74	0.1073

$\eta_{a,100}$  indicates apparent viscosity;  $k$  is consistency index;  $n$  is flow behavior index;

Table 6. The Power law values of different types of mucilage at different temperatures

Type of sample	Temperature (°C)	$\eta_{a,100}$ (mPa·s)	$k$ (Pa.s <sup>n</sup> )	$n$
Control	5	8.3948	472.51	0.1248
	25	8.4175	472.26	0.1255
	45	8.7561	504.79	0.1196
	65	8.5395	523.64	0.1062
Treated	5	8.3536	467.6	0.126
	25	8.6943	493.69	0.1228
	45	8.9355	528.59	0.114
	65	8.9943	548.74	0.1073

$\eta_{a,100}$  indicates apparent viscosity;  $k$  is consistency index;  $n$  is flow behavior index;

which indicates that high in sucrose contributes to an increase in viscosity (Capitani *et al.*, 2015) due to sucrose promotes hydrogen bonding between the polymer and sugar-OH groups in which sucrose may create junction zones and stabilizing the structure of gel or mucilage. Therefore, the increase in sugar concentration will cause competition between sucrose and mucilage for available water in the food system to form junction zones and promotes more viscous solution (Bayarri *et al.*, 2004) from the mucilage extracted with high temperature (80°C) and added with high sucrose concentration (40%) could increase the viscosity of mucilage solutions.

The effects of different pH values (3, 5, 7 and 9) on the apparent viscosity of control (25°C) was compared with treated sample (80°C) as shown in Table 5. The results showed that changes in pH had influenced the viscosity of chia mucilage samples when it reached a maximum value of pH 5 and decreased at higher pH values. For both control and treated mucilage, the lowest viscosity obtained at pH 3 (9.1700 and 9.0631) mPa·s while the highest value of viscosity was found at pH 5 (9.2887 and 9.2244) mPa·s, respectively. It shows that changes in pH towards alkali (pH 5 to pH 9) influenced the decreased in apparent viscosity of chia mucilage. It also can be explained that the flow behavior value of pH 5 is lower than pH 7, which indicates that pH 5 is more viscous than the pH towards the alkali. In the acidic condition, the apparent viscosity for control and treated samples were low which were 9.1700 (mPa·s), and 9.0631(mPa·s) due to polysaccharides chains tend to appear in coil state with acids groups in the free acid form at low pH (Feng *et al.*, 2007). The coils expanded with the increased in pH at 5 as a result of electrostatic repulsion between functional groups and caused the intermolecular interactions to occur hence contributes to the increase in viscosity. Apart from that, Table 5 shows a decrease in viscosity from pH 5 to 9 caused by the depolymerisation of mucilage under alkali conditions (Achi and Okolo, 2004). Comparing those two types of chia mucilage samples, resulting in higher viscosity of the control sample compared to the treated sample at

different pH. This changes caused by the temperature used during extraction where the mucilage extracted at room temperature give high in viscosity when adjusted to low pH. So, this study indicated that the pH value of 5 was more applicable in food due to its high viscosity and stability when added into food at low pH.

The effect of different temperature on the apparent viscosity of the mucilage solution was compared with control (25°C) and treated samples (80°C). Table 6 shows increased in apparent viscosity for control and treated sample as the temperature increased. It also indicates that changes in temperature had affected the viscosity, indicating it as a temperature dependence. The increase in temperature resulted in rising of consistency index,  $k$  value of treated mucilage thus indicated that  $k$  value was affected by temperature ranges from 5 to 45°C. The  $k$  value reflected the values of the viscosity while flow behavior,  $n$  value was opposite to it. This increasing pattern was due to the molecular chains that can form a gel at a higher temperature where new hydrogen bonds formed within the gum/mucilage molecules (Tabilo-Munizaga *et al.*, 2018). Meanwhile, Table 6 shows that the apparent viscosity of the treated sample was increased simultaneously from 5°C and slightly decreased at 65°C. Reduction in viscosity might be due to the thermal degradations of high molecular weight mucilage during heating (Abbes *et al.*, 2015). Therefore, it will cause a decrease in intermolecular attraction, thus contributes to the reduction of viscosity. The activation energy ( $E_a$ ) is an indicator of molecule movement, as the temperature increase, the liquid flows more quickly due to higher activation energy (Haminiuk *et al.*, 2006). The effect of temperature on viscosity could be described using the Arrhenius equation, and the values of  $E_a$  and  $R^2$  were tabulated in Table 7. Statistical analysis of  $E_a$  shows a high value of activation energy (3.184 kJ/mol)

Table 7. Arrhenius equation parameters of apparent viscosity for control and treated sample

Types of sample	$E_a$ (kJ/mol)	Coefficient determination ( $R^2$ )
Control	0.865	0.9508
Treated	3.184	0.7018

Table 8. The Power law values of different types of mucilage at different salt concentrations

Type of Salt	Type of Sample	Salt Concentration	$\eta_{a,100}$ (Pa·s)	$k$ (Pa s <sup>n</sup> )	$n$	
NaCl	Control	0	8.9531	540.47	0.1096	
		0.035	8.9369	507.91	0.1227	
		0.069	8.9821	559.99	0.1026	
		0.103	8.9302	582.72	0.0927	
		0.138	8.8574	550.94	0.1031	
		0.172	8.6865	478.9	0.1293	
		Treated	0	7.7331	349.75	0.1723
	0.035		8.721	462.35	0.1378	
	0.069		8.7756	427.44	0.1562	
	0.103		8.9057	540.84	0.1083	
	0.138		8.9369	507.91	0.1227	
	0.172		8.9868	537.78	0.1115	
	KCl		Control	0	8.9531	540.47
		0.035		9.5029	616.96	0.0912
0.069		9.2809		681.38	0.0671	
0.103		9.1954		653.99	0.074	
0.138		9.1782		622.15	0.0844	
0.172		9.0943		669.53	0.0665	
Treated		0		7.7331	349.75	0.1723
		0.035	9.3575	684.48	0.0679	
		0.069	9.2598	670.81	0.07	
		0.103	9.1511	662.63	0.0701	
		0.138	10.076	778.58	0.056	
		0.172	9.4183	694.34	0.0662	
		MgCl <sub>2</sub>	Control	0	8.9531	540.47
0.01				9.0037	599.82	0.0882
0.02	9.0663			555.69	0.1063	
0.03	9.089			590.09	0.0938	
0.039	9.4563			640.5	0.0846	
0.049	9.4907			650.28	0.0821	
Treated	0			7.7331	349.75	0.1723
	0.01		9.2444	676.52	0.0678	
	0.02		8.8514	552.35	0.1024	
	0.03		8.8499	571.4	0.0987	
	0.039		9.2432	596.79	0.095	
	0.049		9.3605	604.92	0.0948	
	CaCl <sub>2</sub>		Control	0	8.9531	540.47
0.01				9.5652	636.64	0.0884
0.02		9.4805		631	0.0884	
0.03		9.1782		622.15	0.0844	
0.039		9.6369		656.05	0.0835	
0.049		9.7208		681.24	0.0772	
Treated		0		7.7331	349.75	0.1723
		0.01	8.6191	490.75	0.1223	
		0.02	8.9207	547.52	0.106	
		0.03	9.0663	555.69	0.1063	
		0.039	9.4786	609.46	0.0959	
		0.049	9.4961	618.22	0.0932	

$\eta_{a,100}$  indicates apparent viscosity;  $k$  is consistency index;  $n$  is flow behavior index;

by a treated sample compared to control (0.865 kJ/mol). This result indicated that the viscosity of the treated sample could be changed due to differences in temperature (Feng *et al.*, 2007). However, the apparent viscosity of the solutions treated at different temperatures did not obey the Arrhenius equation as higher in temperature, causes the viscosity to increase.

The rheological data on Table 8 shows the power law which explained the flow behavior of chia mucilage samples (25°C for control and 80°C for treated) with a high determination of coefficients ( $R^2$ ) more than 0.91. The data illustrated shear thinning behavior because the values of flow behavior index ( $n$ ) were less than 1 for all concentrations. The effect of different salt concentrations on apparent viscosity was shown in Table 8. It can seem that the addition of different types of salts contributes to decrease and increase in viscosity with particular salt concentrations. Rheological behavior of chia mucilage was observed by determining the effect of adding different types of salts into control and treated samples (Table 8). It shows that the decrease in apparent viscosity for control is related to the increase of NaCl concentrations from 0.103 M to 0.172 M. This may relate to the increase of association of counter ions with the polymer molecule thus contributes to a reduction in viscosity of the control sample (Mazza and Biliaderis, 1989).

Meanwhile, the apparent viscosity of the treated sample was increased simultaneously from 0.035 M and 0.069 M, as stated in Table 8. The flow behavior index,  $n$  was decreased and the value of consistency coefficient,  $k$  was increased with the addition of NaCl in treated sample which indicates the increased in viscosity similar to the study by Behrouzian *et al.* (2013) on the effect of NaCl on rheological properties of cress seed (*Lepidium sativum*) gum. In addition, a decrease in apparent viscosity was measured after the addition of KCl for both control and treated sample as the concentration increased. This might be due to the addition of positive ion ( $K^+$ ) on the mucilage solutions which contributes to the reduction in repulsion and molecule expansion. The flow behavior for both samples was also increased which indicates the decreased in viscosity of the samples. It shows that the KCl salts are unsuitable as a thickening agent in food as it is unable to increase the viscosity of the solutions. On the other hand, results on the effects of addition of  $MgCl_2$  did contribute to the increase of apparent viscosity for control and treated chia mucilage with the rise in the concentration of salts as shown in Table 8. This result indicated that a higher level of salts led to the reduction of viscosity and caused the mucilage solution appeared more viscous. An increase in the salt concentration promoted by the  $Mg^{2+}$  caused the inter-

chain interactions between the molecules of mucilage and increased in apparent viscosity (Koocheki *et al.*, 2009). Increase in  $CaCl_2$  concentration from 0.01 M to 0.049 M had decreased the apparent viscosity of the solutions due to the presence of a high amount of salts,  $Ca^{2+}$ . Therefore, contributes to the development of junction zones which creates three-dimensional networks causing the polymer solution more viscous (Nickerson *et al.*, 2003). This result was also supported by Koocheki *et al.* (2009) which shows a decrease in apparent viscosity after adding 0.01 M to the solution of *Alyssum homolocarpum* mucilage. The  $CaCl_2$  was more effective to increase the viscosity of mucilage compared to NaCl at similar concentrations of salts (Hosseini *et al.*, 2017). In conclusion, the presence of  $Na^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$  salt could increase the viscosity of the solutions. Oliveira *et al.* (2001) obtained similar results on rheological properties of *E. contortisilliquum* gum which conveys that the presence of salts containing  $Na^+$  and  $Ca^{2+}$  able to increase the viscosity of the gum solutions. These types of salts are suitable in food application where alkali substances are used to improve the viscosity of food.

#### 4. Conclusion

This study resulted in a higher yield of the treated mucilage, darker in color and lower values of solubility and water holding capacity than control. The incorporation of high sucrose concentration (40%), acidic condition (pH 5), high temperature (65°C), NaCl salt concentrations (0.103 M) and  $MgCl$  and  $CaCl_2$  salts concentration (0.049 M) contributed to highly viscous of the chia mucilage solutions. It demonstrates that chia mucilage treated at 80°C resulted in higher viscosity than the control sample when subjected to different processing conditions.

#### Conflict of Interest

The authors declare no conflict of interest.

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