Extraction and characterization of mucilage in *Ziziphus mauritiana* Lam.

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Abstract: The aim of this study was to characterize the mucilage from jujube. Extraction conditions of the highest mucilage yield can derive from the following process: incubating jujube for 9 days, mixing jujube pulp with water in ratio of 1:7 at water temperature of 60°C, and precipitating the mucilage solution with ethanol in ratio of 1:3. Functional properties analysis of mucilage powder showed that it had brightness in similar value with xanthan gum but higher than guar gum. Water holding capacity was 11.77 g dry weight. The values of oil absorption were 9 and 6 times higher than guar gum and xanthan gum, respectively. Emulsion capacity was analogous to that of guar gum but less than xanthan gum. Rheological properties of mucilage solution exhibited pseudoplastic as same as guar gum. This research also examined that higher concentration of mucilage solution caused larger values of viscosity, but increasing the pH and temperature led to the decrease of viscosity.

Keywords: mucilage, pseudoplastic, *Ziziphus mauritiana* Lam., jujube, viscosity

Introduction

Jujube has scientific name of *Ziziphus mauritiana* Lam. and is in family of RHAMNACEAE. There is an evident showed about plantation of this fruit in Thailand. It said that in the Ayutthaya kingdom, native jujube tree can be found widely in some areas like Lopburi and Ayutthaya city, but nowadays it can be seen in every region of country. This fruit has pharmaceutical property and is one of traditional drug that related with improvement of blood and nervous system as well as relief of insomnia symptom. Ripe fruit has sweet and sour taste which can expel phlegm, relieve cough and be laxative. In last 70 years, there was import of different varieties from India and Pakistan to grow and mix with Thai variety. This brought about many new varieties with great properties. The popular variety named Somros was seen widely in many provinces because it can be grown in almost all types of soil. Its shape is round; skin color is dark green in young stage and turns to be light green or yellow-green in mature stage; meat is white to yellow-white and becomes red with shrink skin in ripe stage. Samros jujube is popular to consume freshly but the excess productivity and less consumption it to be processed in chip, paste, candy, and preserved food but in only small scale industry.

There were only researches of jujube in China, for example, Li et al. (2007) identified 5 jujube varieties for soluble sugars (fructose, glucose, rhamnose, sorbital and sucrose). They found high amount of fructose, glucose, potassium, phosphorus, calcium manganese and vitamin C including soluble and insoluble dietary fiber. In 2005, Li et al. revealed the antioxidant properties in jujube with different contents of phenolic and other phytochemicals like ascorbic acid, tocopherol and pigments in different varieties, including a finding of plenty of mucilage. However, there was no study about the exact content of mucilage (complex polysaccharide of carbohydrate with branch structure comprising L-arabinose, D-glucose, L-rhamnose, D-xylose and galacturonic acid in different ratios (Saenz, 2004)). Zhao et al. (2007) found water-soluble polysaccharide with molecular weight more than 2000 kDa jujube by HPLC analysis. In addition, it also contained galacturonic acid and rhamnose in ratio 8.1:1 (m-hydroxydiphenyl method).

There were studies in mucilage extraction of many plants and their application. For example, mucilage in *Opuntia ficus indica* was extracted by water and precipitated with alcohol. This extraction was done by the ratio of fruit pulp and water as 1:7 which can yield mucilage content higher than ratio of 1:5. Then precipitation by ethanol led to more mucilage content than using isopropyl alcohol and the outcome was 19.4 g/100 g dry sample weight (Sepulvuda et al., 2007). Medina-Torres et al. (2000) reported that mucilage of *Opuntia ficus indica* had flow behavior as pseudoplastic or shear thinning which the viscosity

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of 10% mucilage solution was similar to 3% xanthan gum solution. Moreover, it was found that an increase of pH in mucilage solution affected to increment of viscosity, but rising temperature and ionic strength had effects in opposite way. This showed that mucilage is a negatively charged polysaccharide molecule. Patel et al. (2007) extracted mucilage from *Ocimum americanum* Linn. seeds by water and did the precipitation by acetone; the mucilage content obtained was 14 g/100 g dry sample weight. This mucilage can dissolve and swell totally in water but only some part in organic solvents. When applied in drug mixture, it was found that 10% w/w mucilage led to less disintegration time than using starch base, showing a property of being a good binder of the mucilage. Ruangchakrpet and Anprung (2002a) reported that the optimal preparation condition for mucilage powder extracted from *Ocimum canum* Sims. seeds was wet extraction by soaking in water 60°C for 1 h, discoloration by Alkaline Hydrogen Peroxide method using 30% H_2O_2 at pH 9.0 for 3 h, and hot air oven at 50°C. The obtained powder had off-white color with high in water holding capacity and total dietary fiber content. In the same year, Ruangchakrpet and Anprung (2002b) studied in characteristic of mucilage powder of Ocimum canum Sims. seeds compared with guar gum, xanthan gum and locus bean gum. They revealed that coarse powder had lower oil absorption than fine one, but higher in lightness and emulsifying property. Flow behavior of this powder at any condition showed the same character with guar gum solution. The sugar content and pH cannot affect to viscosity but rising temperature, shear rate and NaCl concentration can cause less viscosity. Romanchik-cerpovicz et al. (2002) extracted mucilage from okra by water and did the precipitation in ethanol, then used in chocolate bar cookies instead of margarine and egg yolk. The result indicated that this type of mucilage can maintain product moisture, including being excellent fat substitute and emulsifying agent. Tilmon et al. (2001) reported that using mucilage replaced 93% margarine in chocolate cookies had the same total acceptance score in sensory test with using margarine as normal formula.

From the information above, it can be seen that mucilage is a type of hydrocolloid with more interest to study as gum substitute because of its similar function with some types of gum especially guar gum and xanthan gum which have been used as hydrocolloid in food industry for decades. Its rheological behavior is pseudoplastic that can be used to enhance viscosity and stability in many food products, for example, used as stabilizer in ice-cream, sauce and salad dressing (Nussinovitch, 1997). This present paper studies on mucilage extraction by water and the product properties such as flow behavior, water holding capacity, oil absorption and emulsion capacity, including comparison of its functional properties with guar gum and xanthan gum, commercial gums, to see trend in further application.

Materials and Methods

Materials

Jujube cultivar Samros from Ayutthaya, Thailand harvested at 60 days after full bloom and samples of commercial hydrocolloids like guar gum and xanthan gum (T.C.S Pacific, Thailand) were used.

Methods

Selection of ripe jujube to use as raw material Jujubes cultivar Samros were ripened at 32±2°C for 3, 6 and 9 days, leading to 3 levels of ripe stage as following: first level (3 days), second level (6 days), and third level (9 days). Then they were prepared to find mucilage content by heating whole ripe fruit with steam until reaching 85°C for 3 min to inhibit enzymatic browning reaction. Subsequently, basic extraction was done by using ratio of pulp (heated fruit) and water as 1:3, temperature of water as 30°C, blending (Cucina HR 1799, Philips, Natherlands) for 1 min, then filtering with fine cloth. The filtrate was centrifuged (IEC multi RF, 220/224 Thermo IEC, USA) with 10000xg for 30 min. After that mucilage yield was calculated to select the ripe stage of jujube with highest mucilage content. This experiment was done in 3 replicates, designed as CRD; and the mean values were compared by Duncan's New Multiple Rang Test at 95% confidence level. The chosen ripe jujube was then analyzed for chemical properties such as contents of fat, protein, moisture, ash, carbohydrate, soluble and insoluble dietary fibers (AOAC, 1995).

Extraction of the mucilage

The ratio of ripe jujube pulp and water was varied into 4 levels as 1:3, 1:5, 1:7 and 1:9, as well as temperature of water was varied into 4 levels as 30°C, 45°C, 60°C and 75°C. The mixture was blended by blender (Cucina HR 1799, Philips, Natherlands), filtered with fine cloth, and centrifuged (IEC multi RF, 220/224 Thermo IEC, USA) with 10000xg for 30 min. After that the mucilage solution or supernatant liquid was precipitated in ethanol with ratio of 1:3, and centrifuged with 10000xg for 10 min. The derived sediment was used for calculating the yield of mucilage, then selected the condition with the highest yield and analyzed using the factorial in

CRD with 3 replications . For precipitation condition, there was varying the ratio of mucilage solution and ethanol in 4 levels as 1:2, 1:3, 1:4 and 1:5, then centrifuged with 10000xg for 10 min; and the mucilage yield was calculated to select the condition with the highest yield. This experiment was done in 3 replicates, designed as CRD, and the mean values were compared by Duncan's New Multiple Rang Test at 95% confidence level.

Preparation of mucilage powder

The extracted mucilage was purified by separating ethanol out following the method modified from Wu et al. (1995). The experiment was done by dialysis of mucilage with distilled water (20 fold) for 48 hrs. The distilled water should be renewable in every 6 hrs by using cellulose tubular membrane (molecular weight cutoff 12,000-14,000, Membrane filtration products, Inc., USA). Then mucilage was bleached following AHP method used by Abdel-Aal et al. (1996), and dried by freeze dryer (Heto FD8-55, Denmark) as well as crushed and sieved via 50 mesh. The mucilage powder was analyzed for chemical properties such as contents of fat, protein, moisture, ash, carbohydrate, soluble and insoluble dietary fibers (AOAC, 1995) including the functional properties.

Functional properties of mucilage powder

Color

Mucilage powder was used to measure color value by Chroma Meter (Minolta CR-400, Japan). The results were then compared with guar gum and xanthan gum.

Water Holding Capacity

Mucilage powder was used to determine the water holding capacity and compared with guar gum and xanthan gum by method modified from Chau and Cheung (1998). The samples were accurately weighed (0.25 g), added with 25 ml distilled water, mixed by magnetic stirrer for 15 min, and centrifuged at 10000xg for 30 min. Then the supernatant was removed, the wet samples were weighed and used in calculating the water holding capacity by the following equation:

$$\text{Water Holding Capacity (g water/g dry sample weight)} = \frac{\text{Wet sample weight} - \text{Dry sample weight}}{\text{Dry sample weight}}$$

Oil Absorption

Mucilage powder was used to determine the oil absorption and compared with guar gum and xanthan gum by method modified from Raghavendra et al. (2007). The samples were accurately weighed (0.5 g) into centrifuge tube, added with 10 ml refined oil, mixed by vortex stirrer for 1 min, kept at room temperature for 30 min and centrifuged at 10000xg for 30 min. Then the supernatant was removed, and the tube was kept upside down for 1 min. Finally weighed the oil absorbed sample weight and calculated the oil absorption by the following equation:

$$\text{Oil Absorption (g oil/g dry sample weight)} = \frac{\text{Oil absorbed sample weight} - \text{Dry sample weight}}{\text{Dry sample weight}}$$

Emulsion Capacity

Mucilage powder was used to determine the emulsion capacity and compared with guar gum and xanthan gum by method modified from Obatolu et al. (2001). The samples were accurately weighed (1.0 g), dissolved in 50 ml distilled water, and added with 50 ml refined oil. Then prepared the emulsion by homogenizing for 1 min with hand homogenizer (Model x 10/25, Ystral homogenizer, Netherlands), and centrifuged with 4100xg for 5 min. Finally measured the height of emulsified layer compared with the height of whole layer and calculated the emulsion capacity by the following equation:

$$\text{Emulsion Capacity (\%)} = \frac{\text{Height of emulsified layer x 100}}{\text{Height of whole layer}}$$

Rheological properties

Mucilage powder was dissolved in distilled water to prepare mucilage solution concentration of 5%, 7% and 9% (w/w). Then the solution was kept at 4°C for 12 hrs to complete the hydration. The obtained solution was used to study rheological properties including influence of concentration, pH and temperature on viscosity, compared with guar gum (concentration of 0.5%, 1% and 2% (w/w)) and xanthan gum (concentration of 0.5%, 1% and 2% (w/w)) by method modified from Medina-Torres et al. (2000) with Bohlin Rheometer (model C-VOR, Malvern Instruments Ltd., UK), using the probe of cone and plate geometry sensor (40 mm diameter, 4°cone angle) and measuring the shear rate in range of 0.1-250 $^{s-1}$ at 25°C within 180 second.

Results and Discussions

Mucilage extraction

From selection of jujube ripe stage to use as raw material, it was found that ripe stage had effects on mucilage content as shown in Table 1. Ripening at

Table. Table 1 Mucilage content from 3 levels of ripe jujube.

Ripe stage	Mucilage conten (% dry weight)
level 1 (ripe at 3 days)	3.97 [c] ± 0.11
level 2 (ripe at 6 days)	5.34 [b] ± 0.30
level 3 (ripe at 9 days)	11.37 [a] ± 0.19

**Results are expressed as the mean ± SD for three replications.
Mean values in the same column with different subscripts are significant different ($p<0.05$).

Table 2. Chemical component of ripe jujube.

Chemical component (g/ 100 g)	Content
Fat	0.34 ± 0.04
Protein	1.05 ± 0.02
Ash	1.46 ± 0.07
Moisture	87.22 ± 0.01
Carbohydrate	3.08 ± 0.02
Soluble dietary fiber	2.82 ± 0.05
Insoluble dietary fiber	4.03 ± 0.04

**Results are expressed as the mean ± SD for three replications.

Table 3. Chemical component of mucilage powder.

Chemical component (g/ 100 g)	Content
Fat	0.12 ± 0.05
Protein	0.27 ± 0.03
Ash	1.03 ± 0.09
Moisture	ND
Carbohydrate	8.82 ± 0.07
Soluble dietary fiber	89.76 ± 0.03
Insoluble dietary fiber	ND

**Results are expressed as the mean ± SD for three replications.

Table 4. Color values of mucilage powder, xanthan gum and guar gum.

Sample	Color value		
	L	a^*	b^*
Mucilage powder from Jujube	89.10 [b] ± 0.01	-1.55 [c] ± 0.01	12.08 [c] ± 0.08
Xanthan gum	90.76 [a] ± 0.09	-0.72 [a] ± 0.07	9.95 [b] ± 0.19
Guar gum	84.15 [c] ± 0.09	-0.75 [b] ± 0.04	12.56 [a] ± 0.09
Mucilage powder from *Ocimum canum* Sims. seeds[1]	81.84 ± 0.17	0.88 ± 0.00	17.58 ± 0.11

[1]Ruangchakrpet and Anprung (2002b)
**Results are expressed as the mean ± SD for three replications.
Hunter color value : L^* = Lightness (100 = light, 0 = dark);
a^* = + show redness, - show greenness;
b^* = + show yellowness, - show blueness

Table 5. Water holding capacities of mucilage powder, xanthan gum and guar gum.

Sample	Water holding capacity (g water/g dry sample weight)
Mucilage powder from Jujube	11.77 ± 0.84
Xanthan gum	true solution
Guar gum	true solution
Mucilage powder from *Ocimum canum* Sims. seeds [1]	157.09 ± 5.53

[1]Ruangchakrpet and Anprung (2002b)
**Results are expressed as the mean ± SD for three replications.

Table 6. Oil absorption of mucilage powder, xanthan gum and guar gum.

Sample	Oil absorption (g oil/g dry sample weight)
Mucilage powder from Jujube	$4.96^{a} \pm 0.05$
Xanthan gum	$0.79^{b} \pm 0.05$
Guar gum	$0.57^{c} \pm 0.03$
Mucilage powder from *Ocimum canum* Sims. seeds [1]	3.83 ± 0.04

[1]Ruangchakrpet and Anprung (2002b)
**Results are expressed as the mean ± SD for three replications.
Mean values in the same column with different subscripts are significant different ($p<0.05$).

Table 7. Emulsion capacities of mucilage powder, xanthan gum and guar gum.

Sample	Emulsion capacity (%)
Mucilage powder from Jujube	$52.22^{c} \pm 0.48$
Xanthan gum	$100.00^{a} \pm 0.00$
Guar gum	$59.72^{b} \pm 0.48$
Mucilage powder from *Ocimum canum* Sims. seeds [1]	74.41 ± 0.06

[1]Ruangchakrpet and Anprung (2002b)
**Results are expressed as the mean ± SD for three replications.
Mean values in the same column with different subscripts are significant different ($p<0.05$).

Table 8. The yield stress (τ0), consistency coefficient (K) and flow behavior index (n) of mucilage, guar gum and xanthan gum solutions at any different concentrations

Concentration (w/w)		τ_0 (Pa)	K (Pa s^n)	n
Mucilage	**5%**	-	0.783±0.02	0.689±0.02
	7%	-	1.746±0.04	0.645±0.06
	9%	-	6.873±0.03	0.543±0.05
Guar gum	**0.5%**	-	1.128±0.02	0.435±0.06
	1%	-	10.894±0.06	0.261±0.08
	2%	-	58.258±0.02	0.199±0.03
Xanthan gum	**0.5%**	0.019±0.04	1.588±0.04	0.283±0.01
	1%	0.337±0.01	3.296±0.01	0.310±0.07
	2%	0.399±0.04	7.155±0.03	0.289±0.05

**Results are expressed as the mean ± SD for three replications.

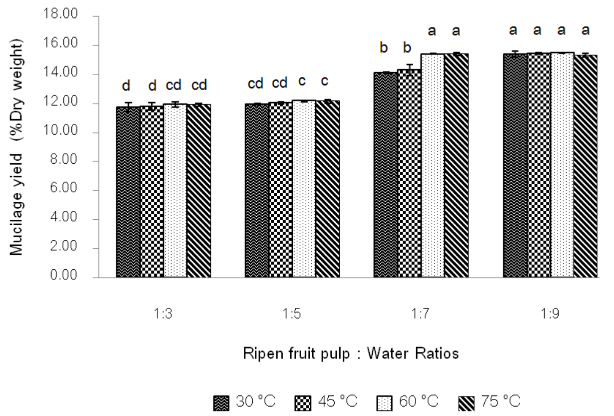

Figure 1. Mucilage content from any different extraction conditions.

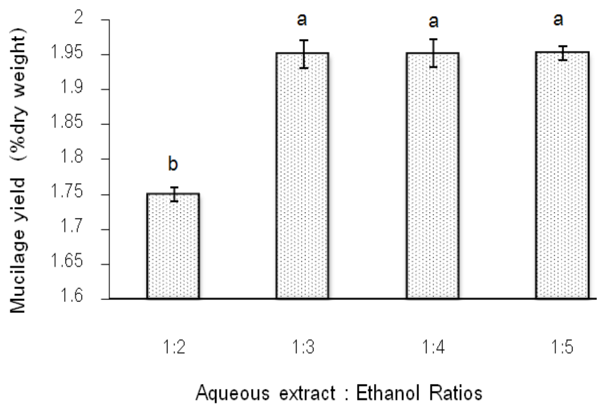

Figure 2. Mucilage content from any different precipitation conditions.

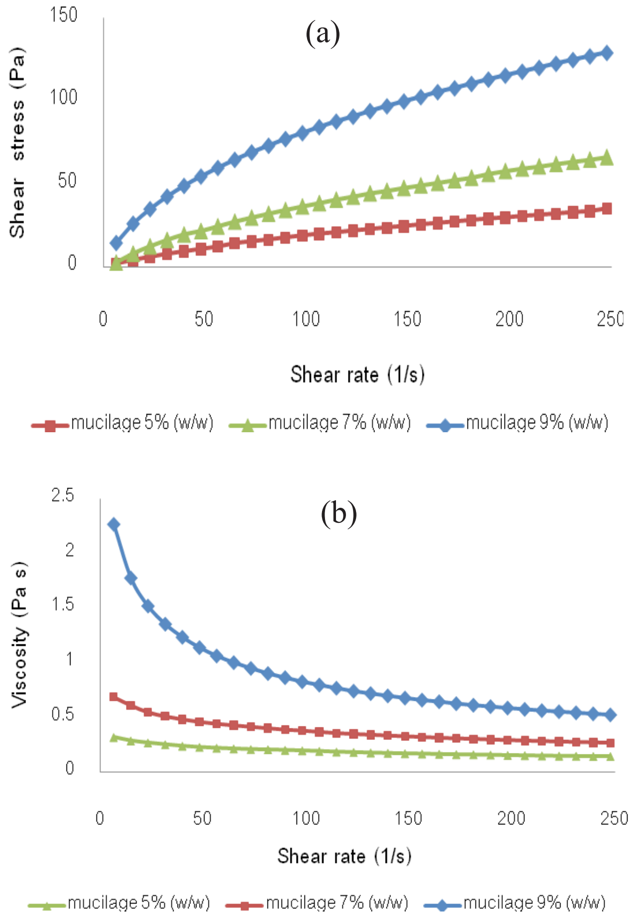

Figure 3. Rheograms of mucilage solution at any different concentrations (a) relationship between shear stress and shear rate (b) relationship between viscosity and shear rate.

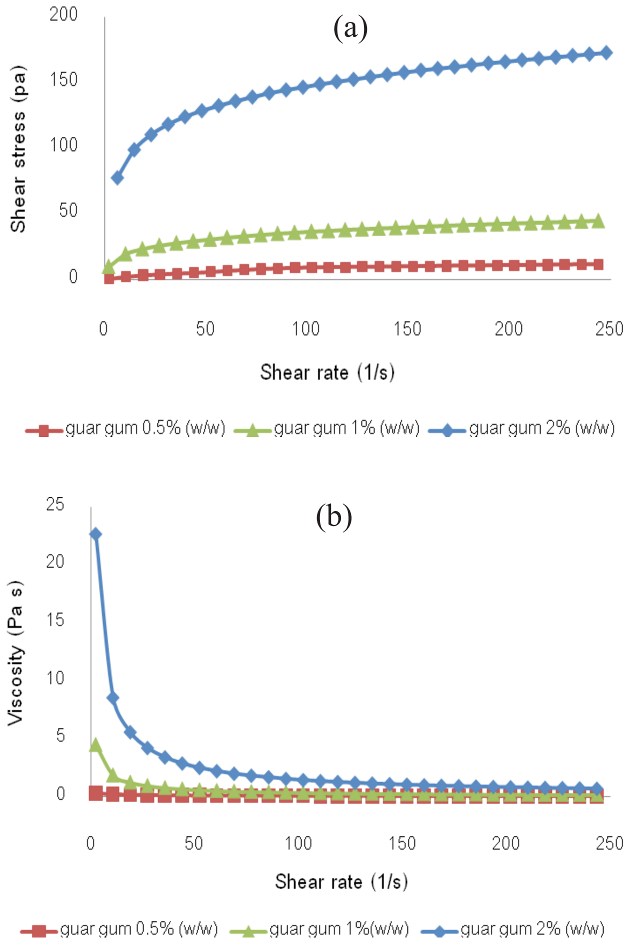

Figure 4. Rheograms of guar gum solution at any different concentrations (a) relationship between shear stress and shear rate (b) relationship between viscosity and shear rate.

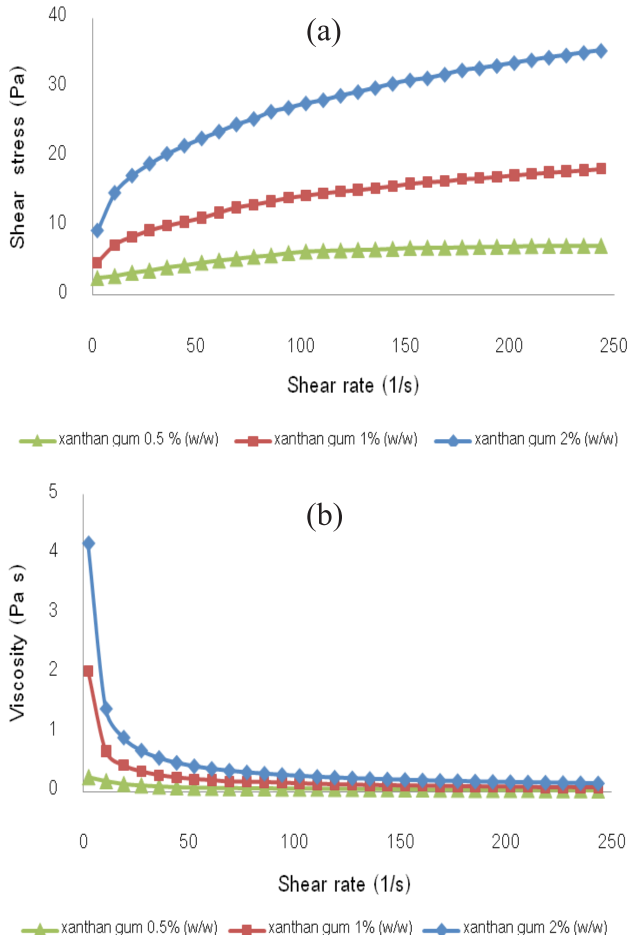

Figure 5. Rheograms of xanthan gum solution at any different concentrations (a) relationship between shear stress and shear rate (b) relationship between viscosity and shear rate.

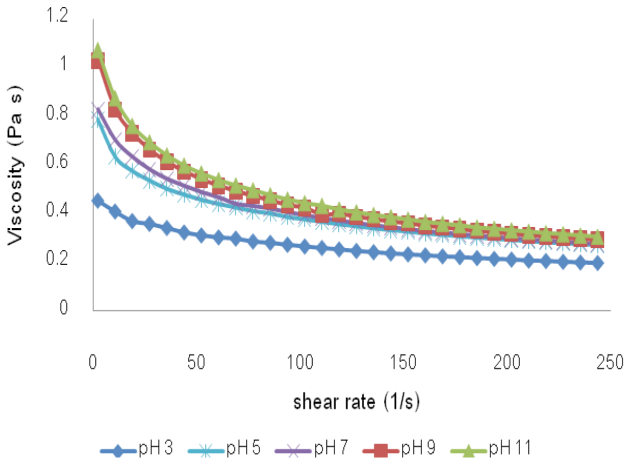

Figure 6. Relationship between viscosity and shear rate of mucilage solution at any different pH values.

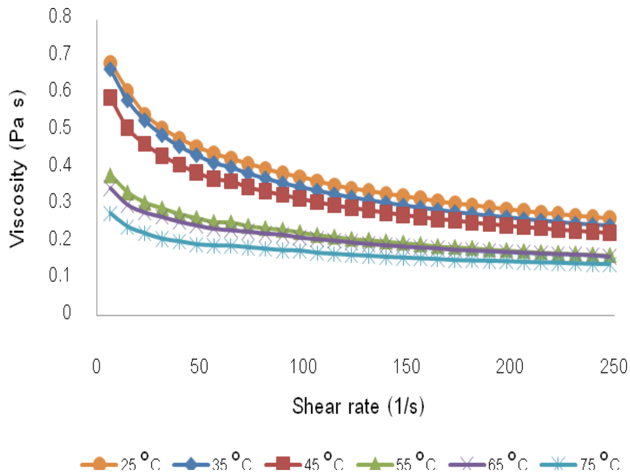

Figure 9. Relationship between viscosity and shear rate of mucilage solution at any different temperature levels.

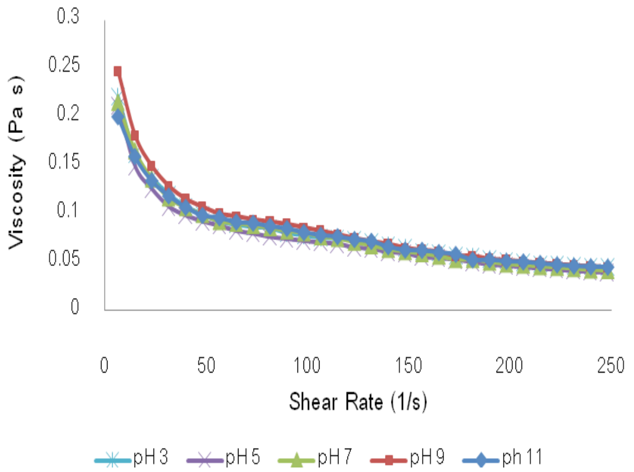

Figure 7. Relationship between viscosity and shear rate of guar gum solution at any different pH values.

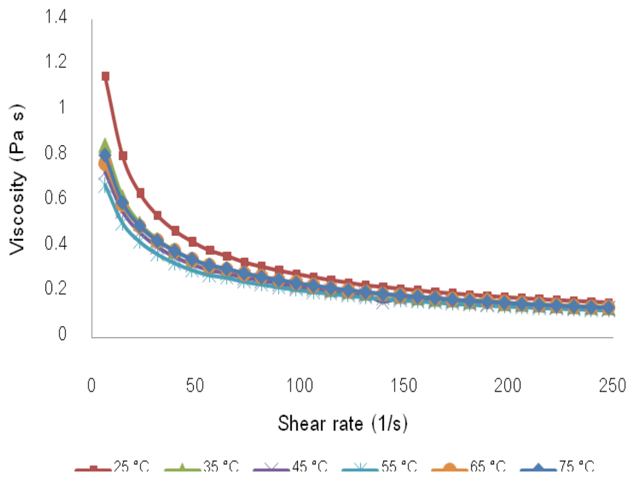

Figure 10. Relationship between viscosity and shear rate of guar gum solution at any different temperature levels.

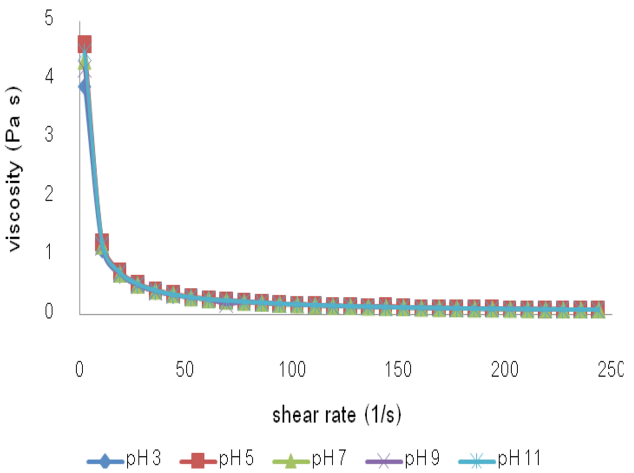

Figure 8. Relationship between viscosity and shear rate of xanthan gum solution at any different pH values.

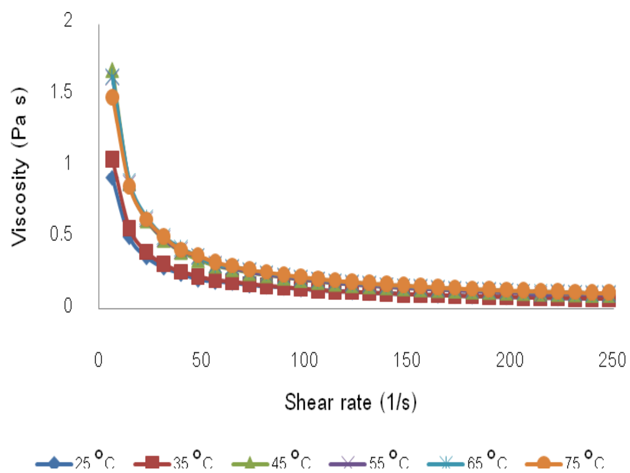

Figure 11. Relationship between viscosity and shear rate of xanthan gum solution at any different temperature levels.

32±2°C for 3, 6 and 9 days showed that the third ripe stage or 9 days had the highest content of 11.37 % dry weight. The statistical analysis revealed that mucilage content in third level was significantly different from first and second levels ($p \leq 0.05$). The third level (ripe at 9 days) was the highest ripening stage because jujube with longer time than this can become rotten and off-flavor. This third level exhibited more mucous content than first and second levels, respectively. This mucous thing was the mucilage of jujube, corresponding with the obtained result. The chosen ripe jujube was analyzed for chemical component and found that it composed of 2.82 g/100 g soluble dietary fiber and 4.03 g/100 g insoluble dietary fiber as shown in Table 2.

The optimal mucilage extraction was observed by varying 4 ratios of pulp and water as 1:3, 1:5, 1:7 and 1:9 including 4 levels of water temperature as 30°C, 45°C, 60°C and 75°C. The best condition yielded the highest mucilage content as 15.40 (% dry weight) was the ratio of 1:7 at 60°C. Results from statistical analysis showed the significant difference of this condition from the others ($p \leq 0.05$), and ratio of pulp and water had no interaction with water temperature as shown in Figure 1, corresponding with a research of Sepulveda et al (2007) that revealed the higher mucilage content from ratio of 1:7 than 1:5.

The precipitation condition of mucilage was studied by varying the ratio of mucilage solution and ethanol in 4 levels as 1:2, 1:3, 1:4 and 1:5. It was found that the lowest mucilage yield can derive from ratio of 1:2 that was significantly different from the other ratios ($p \leq 0.05$); but there was no difference among the ratios of 1:3, 1:4 and 1:5 as shown in Figure 2. Therefore, the optimal precipitation condition was ratio 1:3 as using the little amount of ethanol to get the high % mucilage yield with no difference from 1:4 and 1:5 conditions.

After finding the extraction condition of mucilage from jujube cultivar Samros to use in production of mucilage powder following with the chemical component analysis, it was found that there was soluble dietary fiber content of 89.76 g/100 g which higher than mucilage powder from *Ocimum canum* Sims. seeds (Ruangchakrpet and Anprung, 2002b). This can be implied that mucilage extraction with water as used in this research involved quite low contamination of mucilage that led to containing high content of soluble dietary fiber compared with mucilage extraction from *Ocimum canum* Sims. seeds as shown in Table 3.

Functional property of mucilage powder

Color

The color analysis of mucilage powder showed that powder sieved via 50 mesh had L^* value similar to xanthan gum but higher than guar gum as shown in Table 4. This can be concluded that pretreatment or anti-browning reaction by steaming and bleaching brought about mucilage product with lightness in similar value with xanthan gum. Moreover, it was found that mucilage powder from jujube cultivar Samros had higher lightness than that from Ocimum canum Sims. seeds (Ruangchakrpet and Anprung, 2002b).

Water Holding Capacity

For the water holding capacity, mucilage powder sieved via 50 mesh had the value as 11.77 g water/g dry sample weight which was more than tha from okra (Ndjouenkeu et al., 1997) but less than that from *Ocimum canum* Sims. seeds (Ruangchakrpet and Anprung, 2002b) as shown in Table 5. In contrary, xanthan gum and guar gum cannot be measured for water holding capacity because both become true solution in water that cannot be separated at any high rate of centrifugation. The water holding capacity had an effect on texture of food product which Romanchik-cerpovicz et al. (2002) found that chocolate cookies with okra mucilage substituting for margarine and egg yolk (normal formular) had higher acceptance for moisture of product after 48 h storage than normal cooking significantly ($p<0.01$). This can be seen that mucilage had great capacity in holding water or can retain moisture of product well.

Oil Absorption

For the oil absorption, mucilage powder sieved via 50 mesh had the value as 4.96 g oil/g dry sample weight which was more than guar gum and xanthan gum around 9 and 6 times, respectively, and more than mucilage powder from okra (Ndjouenkeu et al., 1997) but similar to that from *Ocimum canum* Sims. seeds (Ruangchakrpet and Anprung, 2002b) as shown in Table 6. Oil absorption was about the ability of absorption on surface of sample. Mucilage had high value of oil absorption because many non-polar molecules of mucilage can trap high amount of oil particles. This property had a lot of effects on food texture, for example, if oil absorption was high in meat product, it helped to reduce the losses of flavor and oil during cooking the meat (Thebaudin et al., 1997).

Emulsion Capacity

For the emulsion capacity, mucilage powder sieved via 50 mesh had the lowest value of 52.22% as shown in Table 7. Xanthan gum showed the good emulsion capacity by non-separating of liquid layers after centrifugation. The emulsion capacity of mucilage powder was analogous to that of guar gum but less than xanthan gum. Ruangchakrpet and Anprung (2002b) reported that mucilage powder from *Ocimum canum* Sims. seeds had the emulsion capacity of 74.41%. This emulsion capacity related with stability of product such as in salad dressing product because it can enhance formation of small droplets and reduce the rate at which droplets coalesce (Benhura and Chidewe, 2004).

Rheological properties

Concentration effect

Prediction of flow behavior of mucilage solution by power law model (Ostwald-de-Waele) expressed the results in values of consistency coefficient (K) and flow behavior index (n) as shown in following equation (1) :

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

It was found that mucilage solution in concentration of 5%, 7% and 9% (w/w) exhibited flow behavior as pseudoplastic or shear thinning as shown in Figure 3. The higher shear rate led to the higher shear stress as well as the lower viscosity of mucilage solution. From the structure of mucilage as polymer with long molecule chains connected and trapped water inside, the little force can cause polymer rearrangement in the same direction with the input force and also flowing following the high force. Increasing the flow rate related with the decrease of viscosity (Marcotte et al., 2001). At the same shear rate, the shear stress and viscosity of mucilage solution at high concentration were higher than that of lower concentration. From power law model, consistency coefficient (K) related with viscosity of liquid and flow behavior index (n) exhibiting flow character of liquid were derived as shown in Table 8. The results of higher concentration of mucilage solution were an increase of consistency coefficient (K) and the value less than 1 of flow behavior index (n) which tended to be decreased with the much higher concentration. Flow behavior of mucilage solution was similar to guar gum solution that was pseudoplastic predicted by Power law model (Ostwald-de-Waele) as shown in Figure 4. Sasithorn and Pranee (2002b) found that mucilage from *Ocimum canum* Sims. seeds showed pseudoplastic. The research of Medina-Torres et al. (2000) revealed the same flow behavior in mucilage from *Opuntia ficus indica* including a finding that viscosity of mucilage solution would be higher following the increase of concentration.

Prediction of flow behavior of mucilage solution by Herschel-Bulkley model expressed the results in values of yield stress (τ_0), consistency coefficient (K) and flow behavior index (n) as shown in following equation (2):

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

It was found that xanthan gum solution in concentration of 0.5%, 1% and 2% (w/w) exhibited flow behavior as pseudoplastic with yield stress as shown in Figure 5. The yield stress (τ0) is a measure of the lowest shear stress needed to break the structure and start the flow. The higher concentration of solution led to the higher yield stress (τ_0) as shown in Table 8.

Effect of pH

The viscosity of mucilage solution in different pH values (pH 3 – pH 11) was investigated compared with guar gum and xanthan gum solution by measuring at shear rate in range of 0.1-250 s^{-1} at 25°C within 180 s. It was revealed that an increase of pH led to the higher viscosity; and the lowest value was found at strong acid condition (pH 3) as shown in Figure 6, representing the inappropriate circumstance for mucilage solution. However, an increase of pH cannot affect greatly to viscosity of guar gum and xanthan gum as shown in Figures 7 and 8. These gums can be durable with strong acid, so their viscosities at low pH were not different from the basic condition (Wang et al., 2000; Nussinovitch, 1997). Medina-Torres et al. (2000) revealed that viscosity of mucilage from Opuntia ficus indica increased with rising pH of solution, corresponding with a finding of Chen and Chen (2001) that showed the influence of higher pH of mucilage solution from green laver on higher viscosity.

Temperature effect

The effect of an increase of temperature on viscosity of mucilage solution in range of 25°C-75°C compared with guar gum and xanthan gum solution by measuring at shear rate in range of 0.1-250 $^{s-1}$ within 180 s was studied. It was revealed that viscosity of mucilage declined with the higher temperature as shown in Figure 9. Medina-Torres et al. (2000) revealed that viscosity of mucilage from *Opuntia ficus indica* decreased with rising temperature of solution, corresponding with a finding of Chen and Chen (2001) that showed the effect of higher temperature of mucilage solution from green laver on lower viscosity. This was a result of high temperature that caused polymer conformation changed into random coil structure, leading to the less molecule combination followed with decreasing solution viscosity. However, an increase of temperature cannot affect to viscosity of guar gum and xanthan gum solutions as they can be stable in high temperature condition (Nussinovitch, 1997) as shown in Figures 10 and 11.

Conclusion

This study can be concluded that jujube cultivar Samros harvested at 60 days after bloom and ripen for 9 days was the optimal raw material in production of mucilage due to the derived yield of the highest mucilage content. The optimal extraction condition was the ratio of ripe jujube pulp and water as 1:7 at water temperature of 60°C, including the precipitation of mucilage solution with ethanol in ratio of 1:3 that can also yield the highest mucilage content. Comparison of functional properties of jujube cultivar Samros mucilage powder with guar gum and xanthan gum, it was found that mucilage powder had brightness in similar value with xanthan gum but higher than guar gum. Water holding capacity and emulsion capacity were lower than guar gum and xanthan gum. The oil absorption of mucilage powder was 9 and 6 times higher than guar gum and xanthan gum, respectively. Then rheological properties were observed and found that mucilage solution exhibited pseudoplastic or shear thinning as same as mucilage from *Opuntia ficus indica* and *Ocimum canum* Sims. seeds, while xanthan gum showed pseudoplastic with yield stress. Furthermore, the concentration of solution, pH and temperature can affect to viscosity of mucilage solution, similar with other mucilages from *Opuntia ficus indica* and green laver. The higher concentration of mucilage solution led to the higher viscosity, same trend with guar gum and xanthan gum. In contrary, the higher value of pH and temperature brought about the lower viscosity, different with guar gum and xanthan gum that these factors had no effect on viscosity.

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