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Investigation of rheological behavior of Marshmallow seed (*Althaea officinalis*) mucilage under different temperature, concentration, and shear rate conditions

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ABSTRACT

Food products could be exposed to heat treatments during manufacture, storage, and distribution chains which can affect the rheological properties of hydrocolloid solutions. Viscosity is an important factor for quality evaluation in many food products. In the current study marshmallow seed mucilage, as a potential new source of hydrocolloid, was prepared at concentrations of 4, 6, and 8 % (w/v) and subjected to heat treatments at 30, 55, and 80 °C. Afterward, time-independent rheological behaviors of examined concentrations were assessed by using a rheometer. The findings revolved around that marshmallow seed mucilage showed a pseudoplastic behavior ($n<1$) as well as in the power low model. In the mentioned model the consistency coefficient (K) of all analyzed concentrations significantly has been increased at different temperatures ($p\leq0.01$). Also, the flow behavior index value changed from 0.5092 to 0.7934 and showed a significant decrease at higher temperatures (55 and 80 °C) and also as a result of increasing in concentration. The concentrations of 4 % and 8% showed the highest temperature-dependency of consistency coefficient and flow index, respectively. In contrast, the lowest temperature dependency of consistency coefficient and flow index were detected at 6 and 4 % mucilage solution, respectively. At low concentrations, Bingham and at high concentrations Casson models, in addition, Hershel-Bulkley model best fitted with the mucilage solution.

1. Introduction

Hydrocolloids are widely used in food and other industries due to providing unique characteristics to different types of products. Hence recently food scientists and suppliers search to find new sources because of the high demand for cost-effective and naturally available sources of hydrocolloids (1). Seeds are traditional classic sources of gums. Most seeds contain high starch content for shoot growth and many of them contain polysaccharide polymers with similar characteristics to those gums with good sources for extraction of hydrocolloids .Seed mucilage and plant polysaccharides are easily available and natural with therapeutic properties and reasonable prices (2). Traditionally, the seeds of Quince, Plantago, Locust Bean, Guar, Tara, Tamarind, and Mustard are used as gum sources. While only some of these gums have found food and industrial applications, galactomannans play the most important roles. Various studies have been conducted to find new gum sources and examine their functional properties. There are potential sources of hydrocolloids in Iran that have been traditionally used. Seeds of Cress, *Lepidium perfoliatum*, *Alyssum homolocarpum*, and wild sage (*Salvia macrosiphon Boiss*) are among native seeds containing high gum content with a great potential for production of food hydrocolloids (3). The utilization of great plant resources in our country using economic methods has been always

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considered. Marshmallow (*Althaea officinalis*) belongs to *Malvaceae* family largely distributed in tropical regions. Marshmallow contains 11% pectin, 25 to 35% starch, 10% sucrose, 10% monosaccharide and disaccharide, 5% mucilage, flavonoids (hypolatein-8-glucoside, isoquercetin, pecoma, Caffeic acid), coumarin, scopolatin, phytosterol, tannin, asparagine, and many other amino acids. It is a wild annual plant with its flower, fruit, and root showing therapeutic properties. It has branched yellow sweet root containing mucilage. Marshmallow is among the desirable medical plants. It is interesting to know that its Latin name, *Althea* is derived from the Greek word *Althino* meaning cure (4). Its leaves infusion is rich in mucilage. The roots contain about 5-11% water-soluble polysaccharides, flavone glycosides, starch, and tannin (5). *Malvacee* family members are widely used for therapeutic purposes in the Middle East. Marshmallow has two genera; *Althea* and *Alcea*. Both genera are applied in medicines, food, cosmetics, and petroleum industries (6). This plant is reported to be useful for mitigating throat irritation due to its polysaccharides (7). Previous studies have shown that the plant species *Althaea officinalis* has antimicrobial, anti-inflammatory, immune-boosting, soothing, and calming properties, anti-cough, and many other medicinal effects. The plant species *Althaea rosea* also has many medicinal effects, including antimicrobial, cardiovascular, anti-kidney stone formation, anti-estrogenic, cytotoxic, and immune-boosting effects (8, 9). Samavati et al. (10) showed that the polysaccharides in Malva sylvestris were extracted and their antioxidant properties were investigated. The results showed that the polysaccharides in the cheese plant have strong radical inhibitory properties and have a high potential for use in the pharmaceutical and food industries (10). The other research carried out extraction and determination of terpene, phenols, and mucilage content in the stem, leaves, plants, and seeds of marshmallows (*Althaea officinalis*) and compared their mucilage percentage (11). The result showed that these organs contain high mucilage content; however, their seeds contain the highest mucilage percentage. Investigation and determination of physicochemical properties of different varieties of hydrocolloids may provide a basis for their comparison showing their potential for manufacture and development of existing food, medicine, cosmetics and chemical products or novel ones. On the other hand, during manufacture, storage, and distribution, food products are subjected to heat treatments which affect rheological properties of hydrocolloid solutions. Viscosity is also an important factor for the evaluation of foods quality influencing their behavior characteristics as an emulsifier, stabilizer, or suspending agent. The aim of this study was to determine the rheological behavior of marshmallow seed mucilage as a new hydrocolloid source at concentration of 4, 6, and 8 % (w/v) mucilage solution at different temperatures (35, 60, 80°C).

2. Materials and methods

2.1. Extraction of Marshmallow seed mucilage

Marshmallow seeds were purchased from (Pakan-bazr Co, Isfahan, Iran). To extract Marshmallow seed mucilage a slightly modified method (12) was used. Marshmallow seeds were ground and hydrated (seed powder: water, 1:50 w/v at room temperature for all night. Then the mixture was centrifuged with (Rotofix 32 A, Germany) at 4000 rpm for 20 min at 25°C to separate the mucilage. The gum solution, then, was separated, dried at 50°C, ground, and then packed in hermetically sealed plastic bags and kept in a cool and dry place for later experiments.

2.2. Preparation of hydrocolloid solutions

Marshmallow seed gum was extracted and dried. The powder then was weighted by a laboratory balance with 0.0001 accuracies to which doubled distilled deionized water was added gently and mixed by a magnetic stirrer. To assess the flow, mucilage solution at concentration of 4, 6, 8 % (w/v) were prepared by dispersion of the required amount of mucilage in deionized water by gentle stirring at room temperature. All samples were stored overnight (16 h) at 4 °C for completing dehydration before experiments. To measure rheological properties a rheometer (Anton Paar, MCR300, CC 27, Austria) was used. The effect of shear rate on the rheological behavior of hydrocolloid solutions within the range of 0.1-1000 s^{-1} was studied. Data (shear stress - shear rate) were fitted with the following models (13).

2.3. Power low model

In this model, n is the flow behavior index (dimensionless), in the Power-law model, the viscosity term from the Newtonian model is replaced with a constant, K, termed as the consistency index, which attends as a viscosity index of the system. The consistency index has the uncommon set of units of Force-sn /Area. In addition, the shear rate term is raised to the nth power, hence the term Power law.

$$\tau = K_p \, \mathring{\gamma}^{n_p} \qquad \text{Eq. 1}$$

2.4. Herschel–Bulkley model

The Herschel-Bulkley model corrects this absence by replacing the plastic viscosity term in the Bingham model with a Power-law expression as follows (14):
In this model, τ_{0H}, K_H and n_H represent yield stress (pa), consistency coefficient (pa.sn), and flow behavior index, respectively.

$$\tau = K_H \, (\mathring{\gamma})^{n_H} + \tau_{0H} \qquad \text{Eq. 2}$$

2.5. Bingham model

Fluids that exhibit Bingham plastic behavior are considered by a yield point (τ0) and a plastic viscosity (μp) that is independent of the shear rate (15).

$$\tau = \eta_B \mathring{\gamma} + \tau_{0B} \quad \text{Eq. 3}$$

2.6. Casson model

In this model, K_0c is the matrix width in the graph $(\tau^{0.5})$ - $(\mathring{\gamma})^{0.5}$ and Kc is the gradient**.** In addition, the Casson equation is generally used to express the non-Newtonian behavior of activated sludge (16):

$$\tau^{0.5} = K_{0c}^{0.5} + K_c\,(\mathring{\gamma})^{0.5} \quad \text{Eq. 4}$$

$$K_c^2 = \mu_c \text{ and } (K_{0c})^2 = \tau_{0c}$$

Casson viscosity (pa.s) and Casson yield stress (pa), respectively.

2.7. Effect of temperature and concentration on mucilage solution

The effect of concentration on consistency is represented by the power equation:

$$k = a\,C^{b} \quad \text{Eq. 5}$$

where, a and b are constants, and c is concentration.

The effect of temperature on consistency coefficient (k) and flow behavior index (n) were evaluated by the modified method of Turian through regression analysis (17):

$$\log k = \log k_0 - A_1 T \quad \text{Eq. 6}$$

$$n = n0 + A2T \quad \text{Eq. 7}$$

A_1 and A_2 are gradients in Turian models. The higher A_1 and A_2, the higher the temperature dependency of k and n.

According to Eyring's theory, there is space inside the fluids for molecules to move and molecules require energy for continuous movement in these spaces. At higher temperatures, there is sufficient energy in the system to provide the required activation energy for the free movement of molecules and the development of fluid flows. Previous studies showed temperature dependency for other polysaccharides (18, 19). Temperature dependency of apparent viscosity was assessed by fitting the Arrhenius model (17). Temperature-dependent behavior was examined at 30, 55, and 85°C:

$$\eta_a = A \times \exp(E_a/RT) \quad \text{Eq. 8}$$

The above equation is shown logarithmically here:

$$\text{Ln}\,\eta_a = \text{Ln}\,A + E_a/RT \quad \text{Eq. 9}$$

η_a is apparent viscosity, R is gases constant, T indicates thermodynamic temperature, A is constant and E_a is activation flow energy reflecting the required energy for polymer until movement under shear.

Arrhenius model is suggested by Sengul (20), as follows:

$$k = k_0 \cdot \exp(E_a / RT) \quad \text{Eq. 10}$$

$$\text{Ln}\,K = \text{Ln}\,K_0 + E_a/RT \quad \text{Eq. 11}$$

K_0 is proportion constant (consistency coefficient at reference temperature), E_a is the activation energy, R is global gases constant and T is the absolute temperature.

2.8. Statistical analyses

The data obtained from the measurements were subjected to univariate analysis one-way variance analysis (ANOVA) to determine significant differences among the samples and values were compared by use of Tukey's test defined at $p \leq 0.01$. All measurements were carried out in triplicate and reported as mean ± SD from independent trials. Data analysis was performed by SPSS software (version 20; IBM Corporation, Armonk, NY, USA).

3. Results and discussion

3.1. Effect of temperature on rheological properties: using Arrhenius and Turian models

Fitted parameters of the power law model for marshmallow mucilage solution are displayed in Table 1. The consistency coefficient (KP) of marshmallow mucilage solution indicating the viscosity of the solution was 0.448-0.063 pas^n obtained by use of this model. The highest and the lowest KP values were found for 8% mucilage concentrations at 80°C and 4% mucilage concentrations at 55°C respectively.

Table 1. Rheological parameters of power-law model for marshmallow mucilage solution.

Concentration (%)	Temperature (C°)	Parameters		
		K_P (pa.s^n)	n_P	R^2
4%	30	0.063± 0.001^b	0.784±0.010^{ef}	0.987
	55	0.031±0.000^a	0.757±0.010^d	0.991
	80	0.050±0.010^{ab}	0.566±0.010^b	0.967
6%	30	0.245±0.100^d	0.768± 0.010^{de}	0.997
	55	0.251±0.100^d	0.573± 0.010^b	0.959
	80	0.214±0.100^c	0.530±0.010^a	0.953
8%	30	0.371±0.001^e	0.794±0.010^f	0.991
	55	0.380±0.010^e	0.611±0.010^c	0.973
	80	0.448±0.010^f	0.509±0.010^a	0.956

Note. [1-]Results are represented as mean of three replications ± SD
[a-b:] Significant difference between the columns.

According to Table 1 and Fig. 1, KP significantly increased (p≤0/01) as the concentrations increased at all temperatures, as the highest and the lowest KP values were observed for 8 and 4 % mucilage concentrations, respectively. Ssimilarly, KP values decreased significantly (p≤0.01) because higher KP was observed at lower temperatures and conversely. However, KP was at 30 and 55°C. Researchers studied the rheological properties of *Abyssinica cordia* gum as a novel hydrocolloid at different temperatures (30-50°C) and stated that K value increased as the temperature rose. Askari et al. (21), investigated the rheological properties of the hydrocolloid extracted from Plantago seed husk at 1, 2, 4 and 6 % (w/v) concentrations at 5, 15, 25, 40, 50, and 60 °C and stated that the K value increased as the temperature increased showing a significant difference (p≤ 0.01).

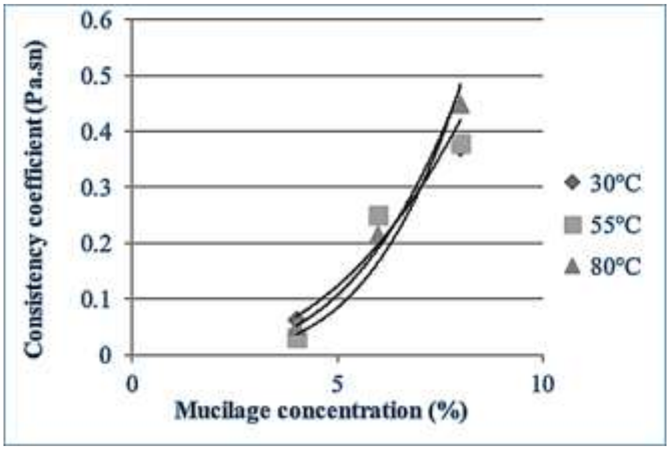

Fig. 1. The effect of various concentrations of Marshmallow mucilage solution on consistency coefficient at different temperatures.

According to Table 1, the flow behavior index (n) of all mucilage samples was (<1) confirming the shear thing behavior of samples. It should remember that as the flow index approaches unity, the behavior of fluid is closer to that of Newtonian fluids and when it approaches zero, the behavior is closer to that of non-Newtonian fluids. The same behavior has been observed for many hydrocolloids (8), resulting from their polymer structure and high molecular weight. The results showed that the flow behavior index changed from 0.05092 to 0.7934. According to Table 1, the flow index significantly decreased as the temperature rose. This decrease was more pronounced at the highest concentration 8 % and at the lowest concentration; there was no significant difference between 30 and 55 °C (p≤0/01). Also, flow index behavior showed no significant difference at the intermediate concentration (p≤0/01). At higher temperatures (55 and 80°C), the n value significantly decreased as the concentration increased, while at 30°C, the flow index increased initially and then decreased but not significantly (p≤0.01). researchers observed that the flow behavior index of control samples i.e., salep–free guar, alginate, and xanthan solutions, decreased as guar and alginate concentration increased and that no certain trend was found for xanthan gum. The addition of salep to gum solutions resulted in a decrease in the glacier behavior index of guar gum however there was no significant effect on xanthan gum (22). Researchers investigated the rheological properties of *Cordia abyssinica* gum as a novel hydrocolloid at different temperatures (30-50°C) and reported that the n value decreased as the temperature increased (23). Askari et al. (21). examined the rheological properties of extracted hydrocolloid from Plantago seed husk at 10, 2, 4, and 6 % and 5, 15, 25, 40, and 60 °C and stated that the n value decreased as the concentration increased (20). Fig. 2 shows the dependency of concentration and apparent viscosity of marshmallow seed mucilage. A Diagram of variations of Shear rate and viscosity VS. Shear rate at different temperatures and concentrations revealed that the rheological behavior of solutions at different concentrations depended on temperature as viscosity and shear stress decreased with increasing temperature. As the shear rate increased, the apparent viscosity of marshmallow seed mucilage at all concentrations decreased. Also, apparent viscosity increased as the concentration increased. In addition, apparent viscosity sensitivity to the shear rate increased with increasing concentration. Such pseudoplastic behavior was observed in other studies (22, 24, 25). Also, the viscosity of samples increased as the concentrations increased. In a study on the viscosity of solutions containing salep and guar salep and xanthan, it was shown that the apparent viscosity of all treatments increased with increasing gum concentration (23). A decrease in apparent viscosity may be attributed to destroyed molecular bonds. This decrease with increasing shear rate has also been attributed to enhanced polysaccharides direction caused by shear rate (26, 27). At all temperatures, apparent viscosity reduced as the temperature rose. It could be explained by the fact that increased temperature affects apparent viscosity by thinning the solution, i.e., the kinetic energy of molecules increases weakening the molecular bonds, thus, the solution shows less resistance against the flow. Previous studies on zedo and tragacanth gums reported a similar trend (28). These results are supported by the studies conducted by Samavti et al. (10), who investigated different rheological models for tragacanth gum suspensions at two concentrations of 0.5 and 1% (w/v). As the shear rate and shear stress increased, viscosity decreased indicating the breakage of particles aggregates caused by shear. As the concentration increased, the viscosity increased and water suspensions decreased because of more bonding points. The results showed that the power low model provided the best description of the flow behavior of suspensions (10). In general, factors such as molecular weight, number of lateral and longitudinal chains of polysaccharides in gum solution affect η0 and other rheological properties of hydrocolloids extracted from plantain seed husk at 0.1, 0.2, 0.4, and 0.6% concentrations (w/v), and at 5, 15, 25, 40, 50 and 60°C temperatures and reported that the shear dilution behavior of fluids with their viscosity decreases with increasing shear rate. Their viscosity significantly changed and the rheological behavior of the solution at different concentrations was temperature-dependent as viscosity and shear stress decreased with increasing temperature. In a study on the effect of drying method and conditions on the theology and texture of basil gum, Salehi *et al* prepared 0.6% solutions and examined their rheological properties at different shear rates. The results revealed that as the shear rate increased in all samples, apparent viscosity decreased due to thinning behavior with time (pseudoplastic). Also, the Hershel-Balkly model was suitable for the examination of flow characteristics. Rheological properties of *Cordia abyssinica* gum as a novel hydrocolloid at different temperatures (30-50°C) were studied. Apparent viscosity considerably changed with time (from 234.9 to 7.46 pa.s). It was pseudoplastic showing nearly

Newtonian behavior at 50C. Hershel – Balkley model is best fitted with empirical data. Apparent viscosity of *Cordia gum* was followed by the Arrhenius model where η0 increased and activation energy decreased as the shear rate decreased from 330 to 15 S. Low activation energy suggested that *Cordia* gum could maintain its viscosity at higher temperatures as compared to basil seed gum and xanthan (23). The result suggested that it showed Newtonian behavior at low concentrations as the rotation rate increased with apparent viscosity being constant. However, at higher concentrations (2-2.5%) as the rotation rate higher concentrations, apparent viscosity decreased due to pseudoplastic behavior with increasing rotation rate. Researchers investigated the rheological properties of apricot tree bark gum at five concentrations (0.5-2.5%) and five temperatures (20-60°C) and eighteen levels of rotation rate (up to 200 rpm). The results showed that at low concentrations (0.5-1.5%), apparent viscosity was nearly constant and a Newtonian behavior was observed as rotation rate increased, while at higher concentrations (2-2.5%) as rotation rate increased, apparent viscosity decreased because of pseudoplastic behavior. Also in all treatments, apparent viscosity increased and decreased as the temperature rose and rotation rate decreased (23). In another study, tragacanth was compared with two commercials of widely used gums such as guar and xanthan. Within the applied range of shear rate, all three gums showed pseudoplastic behavior (29).

3.2. Effect of concentration on rheological properties

Fitted parameters of Bingham. Hershel-Balkley and Casson models are given respectively in Tables 2, 3, and 4. In this model there is yield stress in all samples of 8 % solution at 30 °C. The yield stress value in Herschel–Balkley model was 0.0022-0.1721 Pa. Consistency coefficient was 0.01673-0.38592 Pa S^n. The flow behavior index was <1 ranging from 0.6853 to 0.8921. Previous studies reported the flow index for xanthan gum as 0.24 and 0.23 by Herschel-Balkley model.

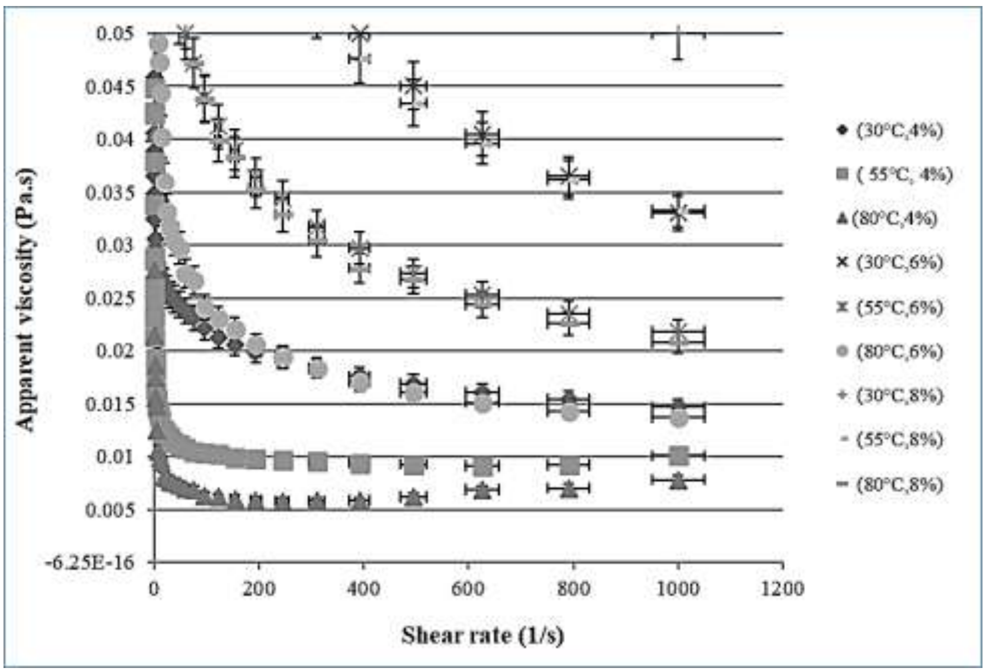

Fig. 2. Compare the apparent viscosity of 4-8% Marshmallow mucilage solution at temperature of 30-80°C.

A high correlation coefficient (R^2) obtained from fitting Hershel -Balkley model with empirical data suggests that this model is able to predict the behavior of marshmallow seed mucilage at high concentrations (30, 31). In general, the results showed that at low concentrations Bingham and Casson models and at high concentrations Herschel-Balkley model best fitted with mucilage solution. Activation energy is an indicator of consistency coefficient sensitivity to temperature. Lower activation energy reflects intra and extra polysaccharide chain interactions at a certain concentration. Hydrocolloid viscosity is highly dependent on temperature. Temperature is an important factor that not only changes apparent viscosity but changes flow behavior. The activation energy (Ea) and K_0 as well as correlation coefficients for different concentrations of mucilage solutions were calculated and shown in Table 5. Lower Ea indicates intra and extra- polysaccharide chain at a certain concentration. Ea increased from 0.0023 J/mol at 6 % to 0.0041 J/mol at 6% (Fig. 3). Increased Ea generally enhances the effect of temperature on viscosity (32). Increased Ea as a result of increased concentration is attributed to a decrease in flexibility of the flow chain (33). Another study investigated the rheological properties of *cordia abyssinica* gum at different temperatures (30-50°C) and showed that Herschel-Balkley best fitted with empirical data (23). In the present study, temperature–dependency of viscosity was traced by use of the Arrhenius model as Ea decreased as the shear rate decreased from 330 to 15 S. low Ea indicated that *cordia gum* could retain its viscosity at higher temperature as compared to basil seed gum and xanthan. Temperature–dependency of flow behavior index was shown by using the Turian model (Eq. 7). Higher A1 and A2 indicate the greater dependency of K and n on temperature. According to Eyring's theory, there are spaces inside the fluids for molecular movement requiring energy for continuous movement in these spaces. At higher temperatures, there is enough energy to provide activation energy for free molecular movement and the development of fluids flow. Previous studies showed temperature – dependency of other polysaccharides (18).

Table 2. Rheological parameters of Bingham model for marshmallow Mucilage solution.

Concentration (%)	Temperature (C°)	Parameters		
		τ0B (Pa)	ηB (Pa.s)	R^2
4%	30	0.179±0.010^{b}	0.015±0.001^{ab}	0.9903
	55	0.019±0.001^{a}	0.009±0.000^{a}	0.9975
	80	0.010±0.001^{a}	0.007±0.000^{a}	0.9872
6%	30	1.637±0.001^{a}	0.037±0.000^{c}	0.9637
	55	0.604± 0.010^{d}	0.023±0.010^{e}	0.9692
	80	0.379±0.010^{c}	0.014±0.001^{ab}	0.9804
8%	30	2.554±0.010^{h}	0.058±0.001^{d}	0.9510
	55	1.105±0.010^{f}	0.037±0.010^{f}	0.9552
	80	0.862±0.010^{e}	0.0225±0.001^{b}	0.9638

Note. [1-]Results are represented as the mean of three replications ± SD
[a-b:] Significant difference between the columns.

Table 3. Rheological parameters of Herschel-Balkley model for marshmallow Mucilage solution.

Concentration (%)	Temperature (C°)	Parameters			
		τ0H (pa)	KH (pa.sn)	nH	R^2
4%	30	0.002±0.000^{a}	0.0396±0.000^{b}	0.874±0.010^{f}	0.991
	55	0.002±0.000^{a}	0.034±0.000^{b}	0.892±0.010^{f}	0.996
	80	0.008±0.000^{a}	0.0167±0.000^{a}	0.807±0.010^{d}	0.921
6%	30	0.097±0.001^{c}	0.246±0.010^{f}	0.750±0.010^{c}	0.964
	55	0.043±0.001^{b}	0.0784±0.001^{c}	0.849±0.010^{e}	0.973
	80	0.038±0.001^{b}	0.0897±0.001^{c}	0.719±0.010^{b}	0.997
8%	30	-	0.385±0.010^{g}	0.757±0.010^{c}	0.936
	55	0.044±0.001^{b}	0.209±0.010^{e}	0.757±0.010^{c}	0.990
	80	0.172±0.010^{d}	0.180±0.010^{d}	0.685±0.010^{a}	0.997

Note. [1-]Results are represented as mean of three replications ± SD
[a-b:] Significant difference between the columns.

Table 4. Rheological parameters of Casson model for marshmallow mucilage solution.

Concentration (%)	Temperature (C°)	Parameters		
		τ0C (Pa)	ηC (Pa.s)	R^2
4%	30	0.009±0.000^{a}	0.015±0.000^{d}	0.994
	55	0.003±0.001^{a}	0.009±0.000^{b}	0.999
	80	0.007±0.000^{a}	0.006±0.001^{a}	0.989
6%	30	0.314±0.010^{e}	0.037±0.001^{g}	0.953
	55	0.092±0.001^{b}	0.022±0.001^{f}	0.981
	80	0.092±0.001^{b}	0.013±0.001^{c}	0.978
8%	30	0.324±0.010^{e}	0.061±0.001^{h}	0.937
	55	0.162±0.010^{c}	0.037±0.001^{g}	0.975
	80	0.288±0.010^{d}	0.019±0.001^{e}	0.975

Note. [1-]Results are represented as mean of three replications ± SD
[a-b:] Significant difference between the columns.

As shown in Table 5 and Fig. 4 and 4 and 8 % of solutions had the highest temperature-dependency of consistency coefficient and flow behavior index respectively. 6 and 4 % solutions showed the lowest temperature – dependency of consistency coefficient and flow index with the relationship between consistency coefficient and flow index with temperature being converse.

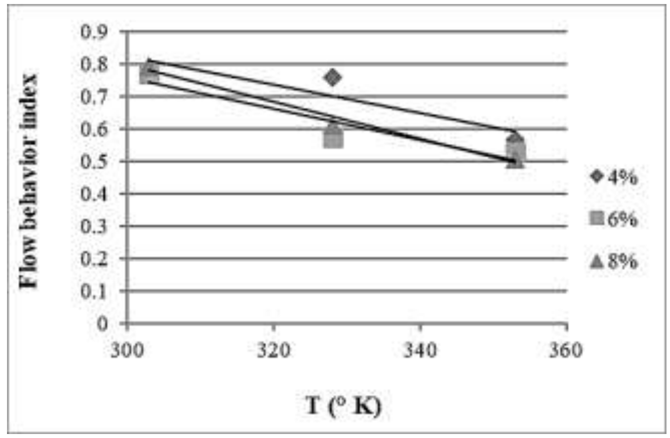

Fig. 3. The effect of different temperatures on flow behavior index for Marshmallow mucilage solution at concentrations of 4-8%.

Table 5. Consistency coefficient as a function of temperature for marshmallow Mucilage solution in various concentrations based on the Arrhenius equation

Concentration (%)	K0 (Pa.sn)	Ea (J/mol)	R^2
4	0.0117	0.0041	0.8616
6	0.099	0.0023	0.6000
8	0.115	0.0033	0.8694

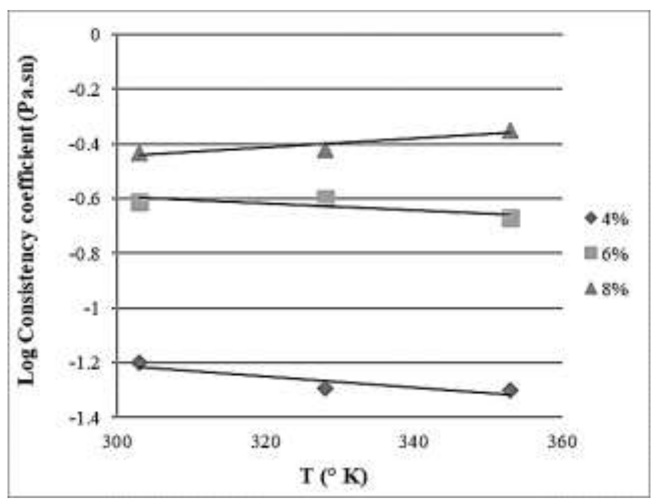

Fig. 4. The effect of different temperature on consistency coefficient for Marshmallow mucilage solution at concentrations of 4-8%.

3.3. Evaluation of other fitted models

To determine the effect of concentration on the consistency coefficient, the power equation (Eq. 5) was used. According to

Table 6, temperature dependency of consistency was higher at 30C. A study was carried out on the consistency index of solutions containing Salep+guar, Salep+Xathan, and Salep+ alginate, and it was found that the consistency index increased as the gum concentration increased. Also, a higher consistency index was observed for Salep-containing solutions as compared to control samples (18).

Table 6. Parameters of power-law model for marshmallow mucilage solution at different temperatures.

Temperature (C°)	a (pa sn)	b (-)	R^2
30	0.0018	2.6110	0.9598
55	0.0002	3.7169	0.9284
80	0.0006	3.1912	0.9922

4. Conclusion

Researchers extracted mucilage content in stem, leaves, petals, and seeds of Althea officinalis and compared their mucilage percentage. The results revealed that its organs contain high amount of mucilage with the seeds having the highest mucilage content. The results of this study suggested that marshmallow seed mucilage showed pseudoplastic behavior (n<1). In the power-law model consistency coefficient (K) significantly increased as the concentrations increased at all temperatures. Also, the flow behavior index changed from 0.5092 to 0.7934 and significantly decreased at higher temperatures (55 and 80°C) as the concentrations increased. At low concentrations Bingham and Casson models and at high concentrations Herschel-Balkley model best fitted with mucilage solution. 4 and 8 % mucilage solutions showed the highest temperature-dependency of K and n values respectively and 6 and 4 % mucilage solutions had the lowest temperature – dependency of K and n values respectively with the relationship between K and n being at all concentrations. The results of this study showed that marshmallow seed mucilage can be used in a variety of food products.

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