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# Investigation of Rheological Behavior of Malva Flower Mucilage under Different Temperature, Concentration and Shear Rate Conditions

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ABSTRACT: Hydrocolloids, playing different roles including thickening, stabilizing, gelling and improving texture of foods are among additives widely used for improvement of quality in food industry. Recently, demand for hydrocolloids with special functional properties has grown, therefore, finding new sources of gums with proper attributes is of enormous importance. Therefore, this study aimed at investigating the effect of variables including temperature (30-80°C), concentration (5-9%) and shear rate (0.1-1000 $s^{-1}$) on apparent viscosity and flow behavior of malva flower mucilage solution. The results showed that malva flower mucilage was rheologically pseudoplastic with this behavior being enhanced at higher concentrations (<n). The effect of temperature and concentration on flow index and consistency coefficient was also significant ($p \leq 0.05$). At low concentrations, power law model and at high concentrations, casson and bingham models best fitted with mucilage solution. Also mucilage solution at 5% and 9% concentrations showed the lowest and the highest temperature dependency, respectively.

**Keywords**: Apparent Viscosity, Malva Flower, Mucilage, Rheology.

## Introduction

Hydrocolloids act as emulsifiers and stabilizers in emulsified drinks. They stabilize the emulsions via viscosity effects, spatial barrier properties as well as electrostatic interactions. Proper hydrocolloids should have high solubility in cold water, low viscosity in solution, high emulsifying capacity without any hardening and gelling effects over time (Tan, 1990). There are different types of hydrocolloids, however since the consumers' demand has changed with time and their understanding of functional properties of gums in industry has improved, increased demand for hydrocolloids with special functional properties has resulted in seeking for new sources of gums having desirable characteristics among which plant

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polysaccarides are found to be important given their easy availability, increased demand for plant derivatives and reasonable price (Williams and Phillips, 2000; Imeson, 2010). Malva is an annual, biennale or hardly perennial plant belonging to malvaceae family. It originated from middle asia and now is grown nearly all over the world including Iran. Malva flowers contain anthocyanins and mucilage and all parts of this plant especially it's flower have healing effects on respiratory system resulting from its high mucilage content (Wichtl, 1994). Malva is rich in vitamins A, B and C and is effective in mitigating cold symptoms especially coughing as well as respiratory, urinary ducts and digestive inflammation and skin pimples. The results of some studies on antimicrobial properties of malva suggest that it has antibacterial, antifungal and antiviral activity against human pathogens (Shale *et al*., 2005). Rheological properties of gums are essentially very important especially when they are incorporated into foods developing texture of the product. These properties are important with regard to their effect on the quality of food products. These properties are exploited in selection of size and type of pumps, extraction method, filters use, etc. (Kayacie and Dogan, 2006). The objective of this study was to examine the effect of variables including temperature (30-80°C), concentration (5-9%) and shear rate (0.1-1000 $s^{-1}$) on apparent viscosity and flow behavior of malva flower mucilage solution.

## Materials and Methods

### - *Materials*

Malva flowers were purchased from a local market in Tehran, Iran. The debris were separated from the flowers and then packed in hermetic sealed plastic bags and kept in cool and dry place until extraction.

### - *Extraction of malva flower mucilage*

To extract malva flower mucilage a slightly modified method of Farahnaky *et al*., (2013) was applied. Malva flowers were washed, ground and hydrated (flower powder: water, 1:20 w/v) before stirring at room temperature for 1 h. It was placed in a mixer with abrasive blades and subjected to mechanical tension for 30 s. By rotation of these sharp blades, a hetero genus mixture of flower powder and mucilage was obtained. Then the mixture was then centrifuged at 4000 rpm for 20 min at 25°C to separate the mucilage. The gum solution was then separated dried at 50°C, ground and placed in dry and cool place for later experiments (Farahnaky *et al*., 2013).

### - *Rheological properties*

Inorder to measure rheological properties a rheometer (Anton Paar, MCR300, CC 27) was used. The effect of shear rate on rheological behavior of hydrocolloid solutions within range of 0.1-1000 $s^{-1}$ was studied. Data (shear stress - shear rate) were fitted with the following models (Steffe, 1996):

1- Power law model

n is flow behavior index (dimension less), K represents fluid viscosity and h represents fluid behavior.

$$\tau = K_p \, \mathring{\gamma}^{n_p} \qquad (1)$$

2- Herschel–Bulkley model

In this model, $\tau_{0H}, K_H$ and $n_H$ represent yield stress(pa), consistency coefficient (pa.sn) and flow behavior index, respectively.

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

3- Bingham model

$\eta_B$ is Bingham plastic viscosity (pa.s) and $\tau_{0B}$ is Bingham yield stress(pa).

$$\tau = \eta_B \mathring{\gamma} + \tau_{0B} \quad (3)$$

4- Casson model

$K_{0c}$ is matrix width in graph ($\tau^{0.5}$)-($\mathring{\gamma}$)$^{0.5}$ and $K_c$ is the gradient.

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

$K_c^2 = \mu_c$ and $(K_{0c})^2 = \tau_{0c}$ represent Casson viscosity (pa.s) and Casson yield stress (pa), respectively.

- ***Effect of temperature and concentration on mucilage solution***

To assess the flow, mucilage solution at concentration of 5, 7, 9 % (w/w) were prepared by dispersion of the required amount of mucilage in deionized water by gentle stirring at room temperature and stored at 4°C for 18 h for completing the dehydration. The effect of concentration on consistency is represented by power equation:

$$k = a C^{b} \quad (5)$$

where a and b are constants and c is concentration.

Effect of temperature on consistency coefficient (k) and flow behavior index (n) were evaluated by modified method of Turian through a regression analysis (Turian, 1964).

$$\log k = \log k_0 - A_1 T \quad (6)$$

$$n = n_0 + A_2 T \quad (7)$$

$A_1$ and $A_2$ are gradients in Turian models. The higher $A_1$ and $A_2$ , the higher temperature dependency of k and n. According to Eyring theory, there are 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 required activation energy for free movement of molecules and development of fluid flows. Previous studies showed temperature dependency for other polysaccharides (Ma *et al*., 2014; Rincon *et al*., 2009; Koocheki *et al*., 2009). Temperature dependency of apparent viscosity was assessed by fitting Arrhenius model (Ma *et al*., 2014). Temperature dependent behavior was examined at 30, 55 and 85°C:

$$\eta_a = A \times \exp (E_a/RT) \quad (8)$$

Above equation is shown logarithmically here:

$$\text{Ln } \eta_a = \text{Ln } A + E_a/RT \quad (9)$$

$\eta_a$ 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 (2005) as follows:

$$k = k_0 \cdot \exp (E_a / RT) \quad (10)$$

$$\text{Ln } K = \text{Ln } K_0 + E_a/RT \quad (11)$$

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

- ***Statistical analysis***

The data obtained from the measurements were subjected to univariate one-way variance analysis (ANOVA) to determine significant differences among the samples and values were compared by use of Tukey's test defined at $P \leq 0.05$. All measurements were carried out in triplicate and reported as mean ± SD from independent trials. Data were analyzed by MINITAB statistical software, version 13.2 (MINITAB Inc., state college, PA, USA).

## Results and Discussion

### - ***Extraction of malva flower mucilage***

Figure 1 shows the dependency of concentration and apparent viscosity of malva flower mucilage. Increasing mucilage solution concentration resulted in increase in apparent viscosity. Accelerated decrease in apparent viscosity was observed at higher concentrations pseudoplastic nature of mucilage and commence of twisting caused by shear thinning result in more considerable increase in concentration (Khandari *et al.*, 2002). Also, the correlation between viscosity and concentration for Colocasia esculenta is due to very branched structure of the gum and cohesiveness and doubled aggregation point among the molecules of gum (Lin and Huang, 1993). In another research observed that as the amount of solid matters increased, viscosity increased due to molecular movements and formation of internal film (Maskan and Gogus, 2000). According to some studies linear and hard molecules had the same hydrodynamic magnitude leading to high viscosity and pseudo plasticity of gum solution (Vardhanabhuti and Ikeda, 2006). Apparent viscosity of mucilage decreased as the shear rate reduced indicating their non-Newtonian shear thinning behavior. The results of power law model (Figure 1) also suggest the pseudoplastic behavior (n<1) of malva flower mucilage solution. The same behavior could be observed for most of hydrocolloid solutions indicating the tendency of fluid towards Newtonian behavior and non- Newtonian behavior is indicated by tendency towards zero (Barnes, 2008).

Decreased apparent viscosity in high shear rate processes such as pumping and filling facilitates the process and develops a good mouth feel by increasing apparent viscosity (Tada *et al.*,1998). This behavior, of course, is important when flow behavior index is < 0.6 (Chinnan *et al.*, 1985). Which holds true for cod 3 (5%-80°C) and cod 6 (7%-80°C) treatments. This treatments up to concentration of 7% at high temperature (Table 1). Also these characteristics are important in the formulation of o/w emulsions since they prevent particles from separating due to gravity force retaining the stability of emulsion although the emulsion flows freely when poured from the container (Taherian *et al.*, 2007).

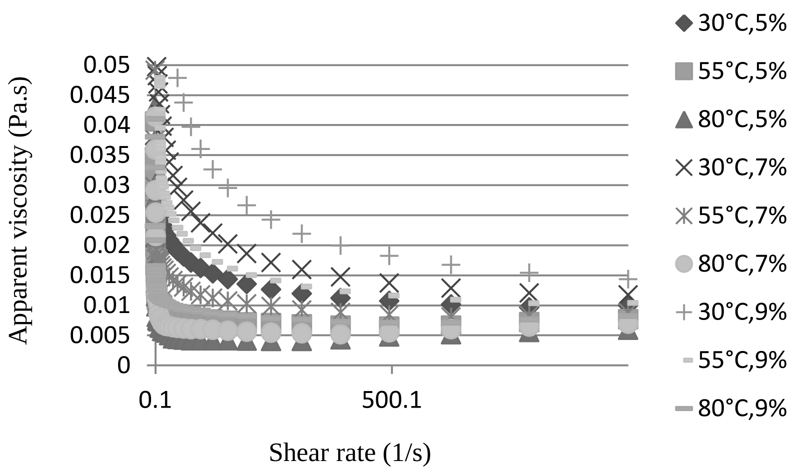


**Fig. 1.** Compare the apparent viscosity of 5-9% malva flower mucilage solution at temperature of 30-80°C

Means comparison showed that concentration had significant effect on flow index (Table 1) and consistency coefficient (Table 1) and that when mucilage concentration increased viscosity increased and thinning behaviors enhanced at low temperature and decreased at high temperature. The reason may be the network formation and stronger structure in the presence of malva flower mucilage. As the concentration increased, dimension less flow index (n) decreased at 30°C increased at 55°C and showed an uncertain trend at 80°C as it decreased up to 7% concentration and then increased to 9% (Table 1). Several authors reported that n value changed with concentration largely depending on the molecular size. When concentration or molecular weight increased, n decreased and k increased (Hamza-Chaffai, 1990; Speers and Tung, 1986; Wu *et al*., 2009).

In general, increased solid matters content results in an increase in viscosity largely due to increased molecular entrapment and formation of interface films (Maskan and Gogus, 2000). Another studies showed that increased xanthan gum concentration resulted in an increase in consistency coefficient and a decrease in flow index (Mandala *et al*., 2004). Also some research reported that increased linseed gum concentration resulted in increased viscosity and thinning behavior in emulsions stabilized by soybean protein isolate (Wang *et al*., 2011). Also, means comparison revealed that the effect of temperature on flow index (Table 1) and consistency coefficient (Table 1) was significant. As shown in Figure 2 and Table 1, as the temperature increased, consistency coefficient ($K_P$) of malva flower mucilage, an indicator of viscosity, increased at low concentration (5%) and decreased at high concentration (9%). It showed an uncertain trend at 7% as it decreased initially and then increased. This finding is consistent with the results obtained by (Marcotte *et al*., 2001 a, b) who studied xanthan, carrageenan, pectin and starch. Also they found a similar empirical behavior for the gum extracted from a plant as well as salep (Farhoosh and Riazi, 2007; Vardhanabhuti and Ikeda, 2006). The result is comparable with the findings who compared cress and xanthan gums and reported that as the temperature increased, it increased for cress gum having lower consistency coefficient while it decreased for xanthan gum having higher consistency coefficient (Naji *et al*., 2012).

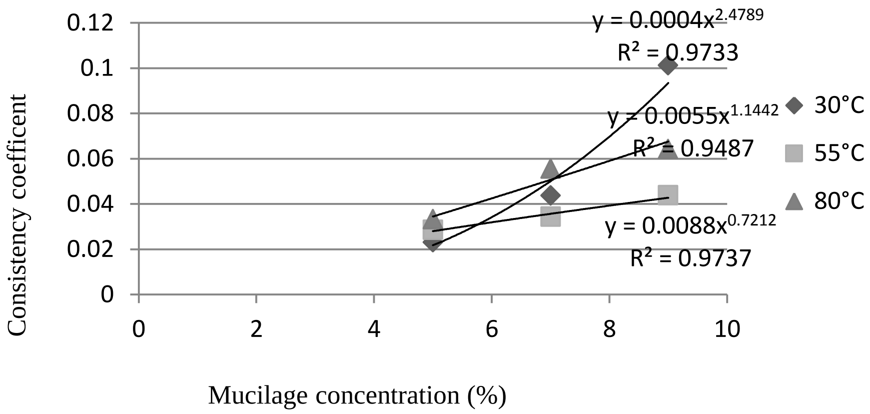


**Fig. 2.** The effect of various concentration of malva flower mucilage solution on consistency coefficient at different temperatures.

**- *Rheological properties***

Rheological models with yield stress including Herschel-bulkley, Bingham and Casson were used for investigation of rheological properties of malva flower mucilage solution (Tables 4, 5 and 6). The results showed that at low temperature of 30°C, Power law model is suitable for a description with high $R^2$ ($R^2_{\sim}$ 1) and for other treatments, Bingham and Casson are fitted well. By using Bingham and Casson models, it was shown that the lower temperature and the higher concentration, the greater yield stress as the greatest yield stress was observed for 9%-30°C and the lowest yield stress was found for 9%-80 °C, 5%-80°C and 5%-55°C. yield stress in the above gums solution may be the result of large number of hydrogen bonds in their helix structure which develop a stable conformation resisting to the flow (Steffe, 1996). yield stress in gum solutions is crucial when they are used as connectors for retaining the formulation components (Rao and Keney, 1975). Bingham viscosity ($\eta_B$) and Bingham yield stress ($\tau_{0B}$) of malva flower mucilage decreased with temperature increasing and increased as the concentration increased. Also research stated that the parameters of Bingham model for xanthan significantly decreased with the decrease being more pronounced at higher temperature (Naji *et al.*, 2012).

**Table 1.** Rheological parameters of power law model for malva flower mucilage solution

| Concentration (%) | Temperature (C°) | Parameters | | |
|---|---|---|---|---|
| | | $K_P$ (pa.s$^n$) | $\eta_P$ | $R^2$ |
| 5% | 30 | 0.0231±0.04[a] | 0.9193±0.00[g] | 0.9897 |
| | 55 | 0.0285±0.08[b] | 0.6965±0.07[c] | 0.9707 |
| | 80 | 0.0332±0.05[c] | 0.5489±0.03[b] | 0.9003 |
| 7% | 30 | 0.0436±0.00[d] | 0.8732±0.05[f] | 0.9917 |
| | 55 | 0.0343±0.01[c] | 0.743±0.08[d] | 0.9858 |
| | 80 | 0.0555±0.02[e] | 0.4854±0.02[a] | 0.8435 |
| 9% | 30 | 0.1012±0.00[g] | 0.7929±0.03[e] | 0.994 |
| | 55 | 0.0438±0.01[d] | 0.7879±0.04[e] | 0.9953 |
| | 80 | 0.0642±0.05[f] | 0.7564±0.03[d] | 0.9808 |

*Note.* [1-]Results are represented as mean of three replications ± SD
Values in the same column shown with similar letters are not significantly different ($p < 0.05$).

**Table 2.** Rheological parameters of Herschel – bulkley model for malva flower mucilage solution

| Concentration (%) | Temperature (C°) | Parameters | | | |
|---|---|---|---|---|---|
| | | $\tau_{0H}$ (pa) | $K_H$(pa.s$^n$) | $n_H$ | $R^2$ |
| 5% | 30 | - | 0.0193±0.02[c] | 0.939±0.01[f] | 0.953 |
| | 55 | 0.0032±0.02[d] | 0.014±0.05[b] | 0.876±0.05[d] | 0.982 |
| | 80 | 0.0093±0.05[e] | 0.0064±0.01[a] | 0.9243±0.03[f] | 0.948 |
| 7% | 30 | - | 0.0493±0.00[f] | 0.8242±0.01[b] | 0.967 |
| | 55 | 0.0022±0.00[c] | 0.0224±0.06[d] | 0.853±0.07[c] | 0.997 |
| | 80 | 0.0204±0.05[f] | 0.0059±0.02[a] | 0.994±0.01[g] | 0.988 |
| 9% | 30 | - | 0.1054±0.01[g] | 0.747±0.03[a] | 0.966 |
| | 55 | 0.0012±0.04[a] | 0.0359±0.00[e] | 0.837±0.00[b] | 0.988 |
| | 80 | 0.0018±0.01[b] | 0.0140±0.03[b] | 0.898±0.09[e] | 0.993 |

*Note.* [1-]Results are represented as mean of three replications ± SD
Values in the same column shown with similar letters are not significantly different ($p < 0.05$).

**Table 3.** Rheological parameters of Bingham model for malva flower mucilage solution

| Concentration (%) | Temperature (C°) | Parameters | | |
|---|---|---|---|---|
| | | $\tau_{0B}$ (pa) | $\eta_B$(pa.s) | $R^2$ |
| 5% | 30 | 0.1534±0.01[d] | 0.0101±0.02[d] | 0.9879 |
| | 55 | 0.0073±0.03[a] | 0.0072±0.08[bc] | 0.9945 |
| | 80 | 0.0325±0.00[b] | 0.0054±0.05[a] | 0.9858 |
| 7% | 30 | 0.3045±0.04[f] | 0.0124±0.01[e] | 0.9722 |
| | 55 | 0.0779±0.03[c] | 0.0085±0.00[c] | 0.9948 |
| | 80 | - | 0.0063±0.04[ab] | 0.9896 |
| 9% | 30 | 0.5756±0.02[g] | 0.0157±0.03[f] | 0.9458 |
| | 55 | 0.1971±0.01[e] | 0.0107±0.00[d] | 0.9829 |
| | 80 | 0.0199±0.05[ab] | 0.0077±0.01[bc] | 0.9953 |

*Note.* [1-]Results are represented as mean of three replications ± SD
Values in the same column shown with similar letters are not significantly different ($p< 0.05$).

**Table 4.** Rheological parameters of Casson model for malva flower mucilage solution

| Concentration (%) | Temperature (C°) | Parameters | | |
|---|---|---|---|---|
| | | $\tau_{0C}$(pa) | $\eta_C$(pa.s) | $R^2$ |
| 5% | 30 | 0.0090±0.02[e] | 0.0104±0.09[d] | 0.9865 |
| | 55 | 0.0027±0.05[b] | 0.0067±0.05[bc] | 0.998 |
| | 80 | 0.0024±0.01[a] | 0.0046±0.00[a] | 0.9874 |
| 7% | 30 | 0.0281±0.01[g] | 0.0128±0.01[e] | 0.9727 |
| | 55 | 0.0070±0.00[c] | 0.0083±0.04[c] | 0.995 |
| | 80 | 0.0072±0.05[d] | 0.0053±0.00[ab] | 0.9906 |
| 9% | 30 | 0.0778±0.08[h] | 0.0162±0.03[f] | 0.9521 |
| | 55 | 0.0161±0.03[f] | 0.0109±0.05[d] | 0.9844 |
| | 80 | 0.0023±0.00[a] | 0.0073±0.07[c] | 0.998 |

*Note.* [1-]Results are represented as mean of three replications ± SD
Values in the same column shown with similar letters are not significantly different ($p< 0.05$).

The effect of concentration on consistency coefficient (Equation 5) is shown in Figure 2. The results suggest that consistency coefficient increased in a non-linear manner as the concentration increased. The reason could be the increase in water binding capacity (Gomez-Diaz and Navaza, 2003).

Table 5 shows parameters a and b in regression model. Power law model indicates the consistency coefficient's dependency on concentration. As shown in the Table, parameter an increased at temperature of 30 to 80°C and decreased within the range 55-80°C. However, it increased within the range of 30 to 80°C. Increased parameter an indicates an increase in concentration-dependency of consistency coefficient (Marcotte *et al.*, 2001a).

**- *Effect of temperature on flow behavior***

In general, investigation of the effects of temperature on rheological properties of gums solution is important because there is a wide range of temperature during processing and storage of foods containing gums. According to Eyring's theory, there are space in fluids where the molecules move requiring energy for Constant movement. At high temperature, there is sufficient energy to provide required activation energy for free movement of molecules and enhancement of fluid flow suggesting temperature-dependency of polysaccharides (Anvaria *et al.*, 2015). It is essential to know the effect of temperature on viscosity of hydrocolloids because of the presence of a temperature range in most of continuous heating processes. The effect of temperature on apparent viscosity of 5, 7 and 9% solution of malva flower mucilage is shown in Figure 3. When the temperature increased from 30 to 80°C, viscosity decreased indicating the temperature-dependency of the hydrocolloid. This decrease may be attributed to molecules kinetic energy loss and decreased molecular interactions which, in turn, decrease the energy required for flow there by decreasing hydrodynamic interferences (Bohdanecky and Kovar, 1982; Lapasin and Pricl, 1995).

Also the study on the effect of temperature on wild almond gum revealed that heating could destroy molecules via hydrolysis or interfering with natural physical interactions in the gum (Zakaria and Rahman, 1996). Temperature effects, however, on the viscosity of hydrocolloids is varied depending on the hydrocolloid source. For example, xanthan gum is able to maintain viscosity at high temperature (Sworn, 2000), while increased temperature results in considerable decrease in viscosity of monoi leaves, salep, hsian-tsao and Alyssum homolocarpum seed (Farhoosh and Riazi, 2007; Feng *et al.*, 2007; Koocheki *et al.*, 2009; Vardhanabhuti and Ikeda, 2006). The dependency of flow behavior index on temperature variations is shown by using Turian model (Equation 7). 7% mucilage solution showed the highest temperature-dependency of flow behavior index (Table 6 and Figure 4). At all concentrations, flow index increased as the temperature was lowered. By use of Turian model (Equation 6), it was shown that the highest temperature-dependency of consistency coefficient occurred at 9% concentration and the lowest at 7%. Also the highest temperature-dependency of flow behavior index was observed at 7% concentration and the lowest at 9%. Consistency coefficient and flow behavior index showed a converse relationship with temperature at all concentration (Table 6 and Figure 3).

Temperature-dependency of viscosity was studied by using Arrhenius model (Equations 8, 9, 10, 11 and Table 7). Examination of activation energy ($E_a$) regarding high value of explanation coefficient ($R^2$) revealed that temperature-dependency of consistency coefficient especially at low concentrations followed Arrhenius model. Activation energy for malva flower mucilage increased from -6.4641 J/mole at 5% to +8.6283 J/mole at 9%. Activation energy, generally, increases as the concentration increases (Figure 5).

**Table 5.** Parameters of power law model for malva flower mucilage solution at different temperatures

| Temperature (C°) | a (pa $s^n$) | b (-) | $R^2$ |
|---|---|---|---|
| 30 | 0.0004 | 2.4789 | 0.9733 |
| 55 | 0.0088 | 0.7212 | 0.9737 |
| 80 | 0.0055 | 1.1442 | 0.9487 |

**Table 6.** Parameters of Turain for malva flower mucilage solution at various concentrations

| Concentration (%) | Log $m_0$ | $A_1$ | $n_0$ | $A_2$ |
|---|---|---|---|---|
| 5% | -2.5868 | -0.0032 | 3.1514 | -0.0074 |
| 7% | -2.0478 | -0.0021 | 3.2445 | -0.0078 |
| 9% | 0.1146 | -0.004 | 1.0185 | -0.0007 |

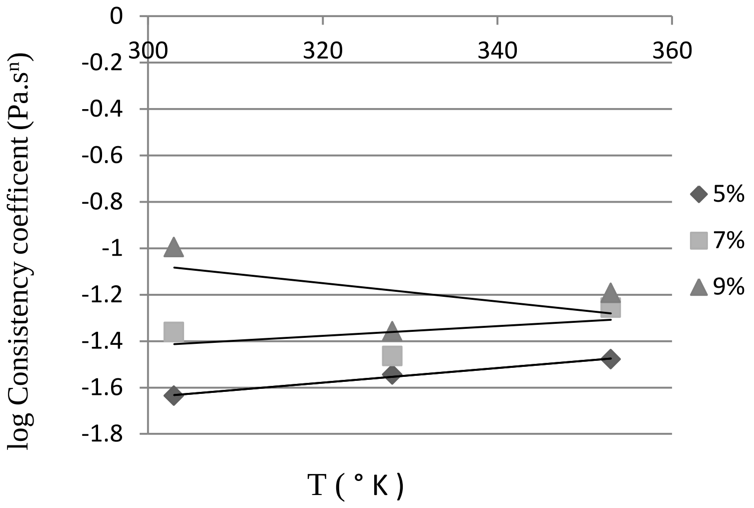


**Fig. 3.** The effect of different temperature on consistency coefficient for malva flower mucilage solution at concentrations of 5-9%

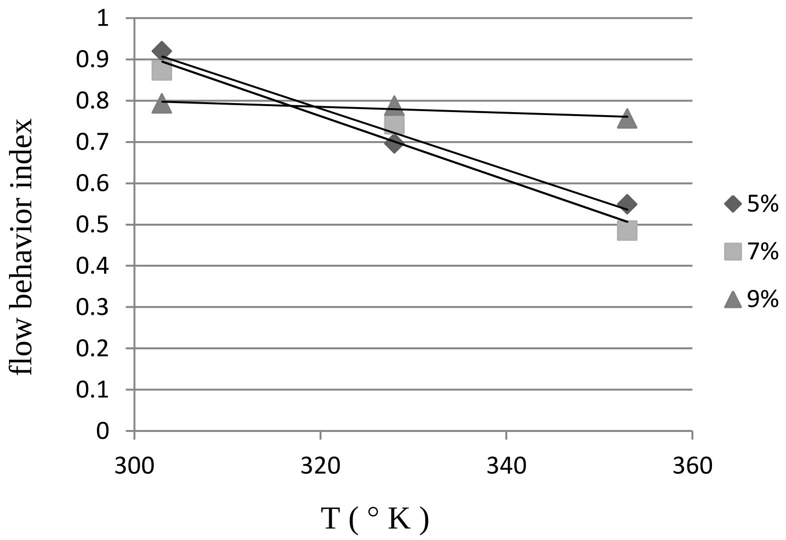


**Fig. 4.** The effect of different temperature on flow behavior index for malva flower mucilage solution at concentrations of 5-9%

**Table 7.** Consistency coefficient as a function of temperature for malva flower mucilage solution in various concentrations based on the Arrhenius equation

| Concentration (%) | $K_0$ ( $Pa.s^n$ ) | $E_a$ (J/mol) | $R^2$ |
|---|---|---|---|
| 5% | 0.30 | -6.4641 | 0.99 |
| 7% | 0.19 | -3.9583 | 0.80 |
| 9% | 0.003 | 8.6283 | 0.83 |

Increased $E_a$ as a result of increased concentration contributes to decrease in chain flexibility for flow process (Nielson, 1977). In general, increasing the activation energy increases the effect of temperature on the viscosity (Koocheki *et al.*,2009).

Thus, it could be said that $E_a$ increases with increasing concentration. The findings are in agreement with the results obtained by Marcotte (2001a) and Huei Chen and Yuu Chen (2001) showing a similar trend for carrageenan and green laver. In contrast to these results, some research reported a decrease in $E_a$ for xanthan salep and Alyssum homolocarpum seed as the concentration increased (Marcotte, 2001a; Farhoosh and Riazi, 2007; Koocheki *et al.,* 2009). In general, increase $E_a$ results in enhanced effect of temperature on viscosity (Medina-Torres *et al*., 2000). Increase in $E_a$ as a result of increased concentration contributes to reduced flexibility of process flow chain (Nielsen, 1977).

At concentrations of 5% and 7%, $E_a$ is negative, i.e. reaction rate decreases as the temperature rises with the decrease being greater at 5% than 7%, whereas at 9%, $E_a$ is positive indicating a direct relationship between temperature and reaction rate.

$K_0$ is a proportion constant which depends on factors such as collisions number and particles direction. Our results showed that 5% and 9% mucilage solution had the lowest and the highest temperature-dependency, respectively. Also, they revealed that control of temperature for 9% mucilage solutions is very crucial.

## Conclusion

The results of this study showed that apparent viscosity of malva flower mucilage decreased as shear rate increased indicating non-Newtonian behavior with thinning shear. Also pseudoplasticity increased as the concentration of mucilage increased. Thin treatments up to 7% concentration at high temperature (80°C) showed flow behavior index less than 0.6 being suitable for processes with high shear rate and on the consumption. Consistency coefficient ($K_P$) of malva flower mucilage increased at low concentration (5%) and decreased at high concentration (9%) as the temperature rose. It showed an uncertain trend at 7% as it decreased initially and then increased. At low concentrations, power law model and at high concentrations, Casson and Bingham models showed the greatest fit with malva flower mucilage solution. At 5% and 7%, $E_a$ is negative with the decrease in reaction rate being greater at 5% than 7%, while at 9%, $E_a$ is positive indicating a direct relationship between temperature and reaction rate. Also 5% mucilage solution and 9% solution showed the lowest and the highest temperature-dependency, respectively.

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