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Determination of Rheological Behavior of Some Molasses-Sesame Blends

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Abstract: The aim of this study is to determine the rheological properties of some molasses-sesame paste (tahin) blends such as date syrup-tahin, mulberry molasses-tahin, grape molasses-tahin and carob syrup-tahin blends at the different ratios (20-55 %) and different temperatures (25-60°C) by using a rotary viscometer to develop models appropriate to the experimental data. The variation of viscosity of these blends with the shear rates (2.5-30 s^{-1}) showed that all considered ratios of the molasses-tahin blends were shear thinning fluids at the considered temperatures. The apparent viscosities of the blends as a function of shear strain were successfully described with the Power-law model. The model parameters such as the flow behavior index (n) and the consistency coefficient (K) of the considered blends were determined according to the experimental data. It was observed that apparent viscosities and consistency coefficients of blends increased with increasing molasses concentration and decreasing temperature. Activation energies (Ea) of the considered blends were determined. The relationship between concentration and consistency coefficient for each blend was described with both the exponential and power functions. A mathematical model was determined to describe the combined effects of temperature, concentrations of the molasses and shear strain on apparent viscosity with high consistency.

Keywords: Rheology, Modeling, Molasses-Sesame Paste Blends.

Bazı Pekmez-Tahin Karışımlarının Reolojik Davranışlarının Belirlenmesi

Özet: Bu çalışmanın amacı; deneysel verilere uygun bir model geliştirmek için döner viskozimetre kullanılarak, farklı konsantrasyon (% 20 -55) ve sıcaklıklarda (25-60 °C), hurma pekmezi-tahin, dut pekmezi-tahin, üzüm pekmezi-tahin ve keçiboynuzu pekmezi-tahin gibi bazı pekmez-tahin karışımlarının reolojik özelliklerinin saptanmasıdır. Bu karışımların kayma hızı (2.5-30 s^{-1}) ile viskozite değişimi, çalışılan sıcaklıklarda, göz önüne alınan tüm pekmez-tahin oranları kayma incelemeli akışkan olduklarını gösterdi. Kayma gerilmesinin fonksiyonu olarak karışımların görünür viskozitelerinin değişimi üs kanunu modeli ile başarılı biçimde tanımlandı. İncelenen karışımların akış davranış indeksi (n) ve kıvamlılık katsayısı (K) gibi model parametreleri deneysel verilere bağlı olarak saptandı. Karışımların görünür viskozitelerinin ve kıvamlılık katsayılarının pekmez konsantrasyonlarının artmasıyla arttığı ve sıcaklığın artmasıyla azaldığı gözlendi. İncelenen karışımların aktivasyon enerjileri belirlendi. Her bir karışım için konsantrasyon ile kıvamlılık katsayısı arasındaki ilişki hem üstel hem de üs fonksiyonlarıyla belirlendi. Görünür viskozite üzerine sıcaklık, pekmez konsantrasyonu ve kayma gerilmesinin birleştirilmiş etkisini yüksek uyumlulukla tanımlayan matematiksel model saptandı.

Anahtar Kelimler: Reoloji, Modelleme, Pekmez-Tahin Karışımları.

1. Introduction

Molasses-sesame paste blend that is mainly consumed for breakfast in cold seasons is one of a traditional food product in East Asian and Middle Eastern countries. Sesame paste has a high protein and dietary fiber content. When strengthened with high mineral and vitamin being contained in molasses might offer a promising nutritious and healthy substitute to consumers [1-3]. Molasses and sesame paste are usually available for sale separately in markets; thus, the blending process is carried out by the consumers. The ratio of molasses to sesame paste is determined according to the consumers taste and preference.

Molasses are commonly produced from grape, mulberry, fig, juniper, watermelon, apple, plum, carob, sugar beet and sugar cane. But in recent years, in addition to those, apricot and date have been used for the production of molasses by concentration of juices up to 70–80 % soluble dry matter content with an extended shelf-life [4-8]. Molasses processing operations vary according to origin of fruits used in production of molasses [6,7,9].

Sesame paste, known as tahin in Turkey and Arabic countries and ardeh in Iran, is a traditional food in the Middle East, which is produced by grinding the dehulled and heated sesame seeds [10].

Sesame paste is also a tradition food in East Asian and Middle Eastern countries, it has used in ingredients of many other dishes such as halawah, chickpeas, desserts, and some types of bakery [1,2,11,12]. In addition, the

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molasses is consumed as an ingredient in the formulation of some food items such as ice cream products, beverages, confectionery, bakery products [13].

Knowledge of rheological behavior is important for optimization of process design, quality control, consumer acceptance of a product and sensory assessment [2,8,14]. Consumer acceptance of molasses and sesame paste blends usually depends on the capacity of spreading on another material like bread. Therefore, the spreading of the blends is directly related with viscosity [1,2]. When the legitimate consistency, soundness and surface tension are the main concerns in expansion, generation and upkeep of the item, the solid rheological information is needed [2,15].

Rheological characterization of food pastes has been widely investigated by focusing at either individual samples or blend samples. Rheological properties of individual samples can be listed as sesame paste [3,8,16], sunflower tahini [17], fenugreek paste [14], tomato paste [18,19], ginger paste [20], molasses (pekmez) [4,6,21-24]. On the other hand, rheological properties of blend samples can be listed as grape pekmez/ tahin blends [1,2]; corn starch/grape pekmez blends [25], sesame paste/date syrup blends [13,26], honey/sesame paste blends [10] and poppy seed paste/grape pekmez blends [8]. The goal of concentration or pasteurization is to extend shelf life of dates, mulberry, grapes and carob juices with boiling to lessen water content [4-8].

The flow behavior, texture and sensory properties of new blends need to be determined for processing of those blends. Temperature and concentration are important factors in determining the rheological behavior of the blends. The use of different types of molasses in blending process is an essential component in the formation of a new product accepted by consumers. Some organizations such as military and police organizations require a specific blend ratio. However, much work has been done to improve the quality of food production in terms of edibility taste and texture. It can be obviously seen in the literature that the researchers have focused on blending at different concentrations of sesame paste/grape molasses and sesame paste/dates molasses at different temperature degrees in a hope to improve edibility taste, spread ability on bread and sensory properties etc. Thus, further investigation is required to determine rheological properties of the blends of sesame paste with other types of molasses such as dates, mulberry, grapes and carob juice. Subsequently, the major objective of this study is to determine rheological behaviors and activation energies of new mixtures of sesame paste with different types of molasses such as dates, mulberry, grapes and carob juice; furthermore, is to develop a single mathematical equation can be implemented for various effective parameters such as temperature, concentration of blend and shear rate on rheological behavior of a fluid.

2. Materials and Methods

2.1. Materials

The composition of sesame paste (tahin) bought from Merter Helva San. ve Tic. A.Ş., Istanbul was 60.2 % total oil, 9.7 % carbohydrate, and 26 % protein. °Brix values for date syrup bought from local market in Al Sulaymaneyah, Iraq mulberry molasses, grape molasses and carob molasses (all molasses) bought from the local market in Elazığ, Turkey were measured to be 73.2, 68.75, 60.56 and 77.5 respectively.

Brix level of each commercial molasses, soluble solid content, was determined by using a refractometer (METTLER TOLEDO RE50, Switzerland) in the local sugar beet processing plant (Elazığ Şeker Fabrikası).

2.2. Preparation of some molasses/sesame paste blends

In food system, there are two common types of emulsion, water in oil or oil in water. Blends of molasses and sesame pastes can be regarded as either water-in-oil or oil-in-water depending on molasses/tahin ratios. If amount of molasses is larger than that of tahin, it can be regarded as oil-in-water; otherwise it can be regarded as water-in-oil. The two non-miscible liquids; molasses and sesame paste form a two-phase system, molasses has water phase and sesame paste has oil phase. Oil particles are suspended within the water through the assistance of mechanical development of the emulsion [1,2]. Emulsion stability depends on oil and water interface. Proteins are amphiphilic molecules that are mostly used to stabilize emulsions in food products. Proteins have a key role to facilitate droplet breakup through homogenization and to stabilize the droplets against coalescence through emulsification and storage. The ability of a protein emulsifier is determined by its ability to reduce tension between the surfaces [28]. In the case of molasses and sesame paste blend, protein and lipids usually interact and thus the protein reduces the tension between surfaces of protein and lipids, which causes a stable emulsion to form [1,2].

In order to prepare a homogenous blend, the mixtures were blended consistently with a spatula until a homogenous blend was obtained. The blends were rested for 5 hours before subjecting to the rheological measurements. After making sure the samples free from entrapped air or air bubbles, the molasses-sesame paste blends such as blends of date syrup-sesame paste, mulberry molasses-sesame paste, grape molasses-sesame paste and carob syrup-sesame paste at the different weight ratios (20 %, 30 %, 40 % and 55 %) (wt./wt.) were sheared under different shear strains to measure viscosities of those blends as a function of the shear strain. The viscosity for each blend was measured at various temperatures (25, 30, 40, 50 and 60 °C) by using a rotary viscometer.

2.3. Measurement for Determining Rheological Behavior

Brookfield rotational viscometer (Model DV-II, Brookfield Engineering Laboratories) was utilized to measure viscosities of the blends by using spindle 28 and the sample cup with 12 ml sample volume was at different temperature and concentration.

For obtaining the rheograms for each blend, the shear stress and viscosity were directly read from the viscometer for each shear rate in ranges of 2.5 to 30 rpm. For all experiment, data collection for each specimen was finished after 5 revolutions at a set rotational speed. At that point for each progressive revolution, one point of viscosity and shear stress information on the set rotational speeds was recorded up to 5 values.

2.4. Statistical Analysis

The linear regression method by Microsoft Excel software was used to evaluate the experimental data about shear stresses, viscosities versus shear strain for some molasses-sesame paste mixtures. The used equations about viscosity of a blend as a function of shear strain, the consistency coefficient, the flow behavior index and coefficient of determination (R^2) were detailed. Any noteworthy contrast, among theoretical parameters; n and K beneath the effects temperature and molasses concentration ($\alpha = 0.03$) were evaluated with analysis of variance (ANOVA) test. A single equation which can be implemented for various parameters is a very important tool for engineering application. The effective parameters such as temperature, concentration, and shear strain on viscosity of a blend were combined into a single logarithmic model by utilizing multiple linear regression system with using lines function in Microsoft Excel software.

3. Results and Discussion

In order to evaluate the rheological behavior of some molasses/sesame paste blends at different concentrations of molasses and temperatures, the blends were prepared by adding molasses into the sesame paste in ratios of 20-55 % (wt. /wt.). During the measurement of viscosity of each blend, the temperatures were varied from 25 °C to 60 °C for each concentration and each shear rate. Five different rotational speeds were set to measure viscosity and shear stress for each blend at various temperatures.

The measured apparent viscosities of the blends versus shear rates are depicted in Figures 1–4. As can be seen in the figures the apparent viscosities decrease with increasing shear rates, which means the blends in question exhibit shear thinning behavior. Identical figures for 30 %, 40 % and 55 % of each type of molasses in tahin were depicted to save space they were not given here.

The model parameters such as the consistency coefficient and the flow behavior index can be determined by regression analysis based on the achieved results. According to the experimental finding, viscosities as a function of shear rates were finely fitted with Eq. (3.1) to determine the model parameters; where the slope of regression line represents a flow behavior index, *n*, and the intercept of the graph shows the consistency coefficient, *K*.

$$\mu_{ap} = K\,\dot{\gamma}^{n-1} \qquad \rightarrow \qquad ln\mu_{ap} = lnK + (n-1)\,ln\dot{\gamma} \tag{3.1}$$

Table 1, Table 2, Table 3 and Table 4 includes the values of *n*, *K* and the coefficient of determination, R^2 for the considered blends at the specified concentrations and temperatures. The equation for each curve in the figures were found to be in a power function since the equation for the best fitting curve to the experimental data were found to be in a general form of $\mu_{ap} = a\dot{\gamma}^b$.

The obtained model parameters namely flow behavior index and consistency coefficient in the range of the determination coefficient (R^2) indicate that the Power- law model seems to be convenient to describe the flow behavior of mixtures. The ranges of these model parameters for date, mulberry, grape, and carob molasses are shown in Tables 1, 2, 3 and 4 respectively. In all cases, it can be noticed that the determination coefficient (R^2) is higher than 0.85 and the flow behavior index are less than unity ($n < 1$) that means all blends exhibit the shear-thinning (pseudo plastic) behavior since pseudo plasticity is inversely proportional to the flow behavior index (Arslan et al.[2]).

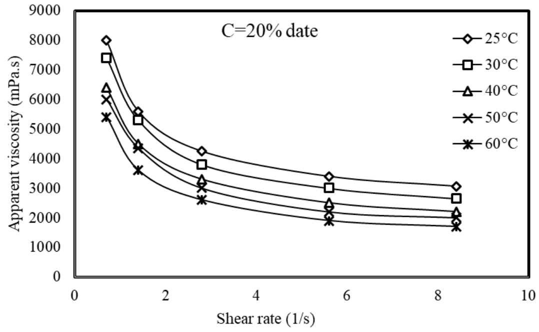

Figure 1. Variation of apparent viscosity with shear rates at different temperatures for a 20 % date molasses in sesame paste

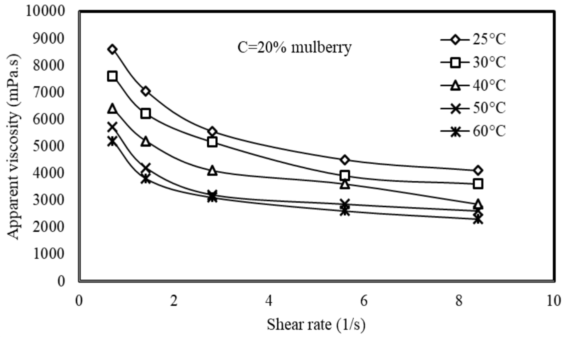

Figure 2. Variation of apparent viscosity with shear rates at different temperatures for a 20 % mulberry molasses in sesame paste

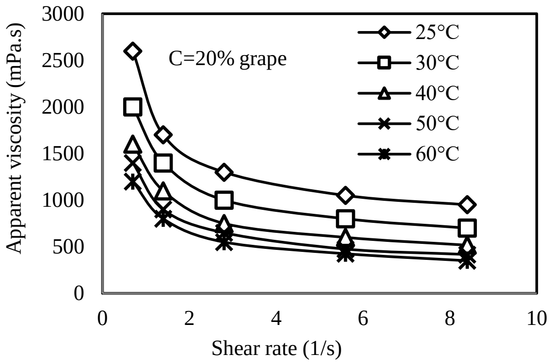

Figure 3. Variation of apparent viscosity with shear rates at different temperatures for a 20 % grape molasses in sesame paste

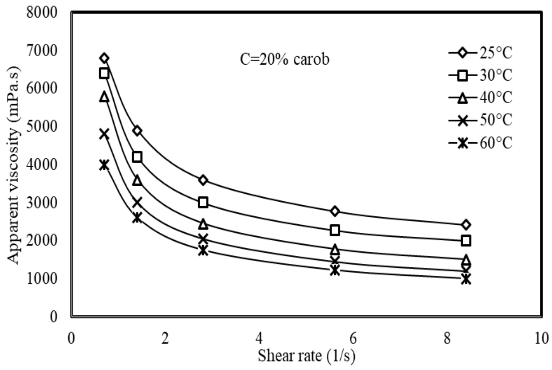

Figure 4. Variation of apparent viscosity with shear rates at different temperatures for a 20 % carob molasses in sesame paste

The major constituents of sesame paste are protein and oil whereas molasses components are mainly sugar and water. The decrease in an apparent viscosity with increasing shear rate is often explained with changing in the structure of the mixture since the uniformity level of those constituent particles increases with the shear strains [1, 29]. The structural change on the oil droplet due to the shear strains has been stated to be egg yolk stabilized mixtures by Morris[30]. More specifically, shearing leads to a gradual deformation and disruption of the oil droplets, which results in less resistance for fluid flow. Alpaslan and Hayta[1], Arslan et al.[2]); Habibi et al.[13] and Razavi et al.[26] indicated that the molasses/sesame paste blends display non-Newtonian, shear thinning behavior. Alpaslan & Hayta[1] reported that all blends of sesame paste/molasses mixtures having a molasses concentration range of 2- 6 % (wt./wt.) at the temperature variances of 30-75 °C exhibit pseudo plastic behavior. Arslan et al.[2] reported that sesame paste/molasses blends having sesame paste concentrations (20-32 %) at the various temperatures (35-65 °C) display non- Newtonian, shear thinning behavior. The date syrup /sesame paste blends, date molasses having variety solid contents of 60 and 65 °Brix, at the temperature ranges of 25-55 °C exhibit pseudo plastic behavior [13].

In the present study for all considered blends the flow behavior indices were found to be less than unity ($n < 1$), which indicate that all blends are shear thinning (pseudo plastic) fluids. The flow behavior indices of the blends such as molasses of date syrup-, mulberry molasses-, grape molasses- and carob syrup-sesame paste are in ranges of 0.52–0.64, 0.66–0.69, 0.33–0.62 and 0.44–0.59, respectively.

Although in the present study the continuous phase changes from oil to water since weight percentage of molasses in the sesame paste varies from 20 to 55 %, rheological behavior is not changed dramatically. For instance, when the percentage of a molasses in the sesame paste was increased to be larger than 50 %, a regular change in viscosity of a blend was observed.

In order to examine the effect of temperature on the rheological behavior of a few molasses/sesame paste mixes, temperature was varied from 25 °C to 60 °C. For the specified tests an increase in temperature resulted in a decrease in viscosity values (Figures 1 to 4). The noticeable decrease in viscosity of each blend was observed with increasing temperature from 25 °C to 60 °C. This property can be clarified by considering the intermolecular forces and the intermolecular spaces. When temperature of a liquid increase, the molecules in the liquid move away from one another and thus intermolecular space increases. In other words, the intermolecular spacing are essentially influenced with variation of temperature since molecular distances increases with decreasing intermolecular forces. As a result, the intermolecular forces decrease with increasing temperature. Moreover, thermal and thus kinetic energy of molecules increases with increasing temperature. Therefore, when the fluid is exposed to the shearing, molecules move over one another much more easily and the chain entanglement is also straightened out much more easily at high temperature due to low molecular forces and high kinetic energy of molecules. Consequently, the viscosity of a liquid decreases with increasing temperature.

According to the analysis of variance (ANOVA) ($\alpha = 0.03$), the flow behavior index and the consistency coefficient were strongly under the effect of temperature variance. As appeared in the Tables 3.1, 3.2, 3.3, and 3.4, the relation between the values of both n and K change with temperature inversely.

In addition, Eq. (3.2) (Arrhenius-type equation) interprets well the relation between the temperature and the consistency coefficient. According to the experimental finding, consistency coefficient as a function of temperature were finely followed with Eq. (3.2) to determine the model parameters; where the slope of regression lines from Figure 5 represents an activation energy, *Ea/R*, and the intercept of the graph shows the constants *Kt*. In order to save space, figure for date blends is given here only.

$$K = K_t e^{\left[\frac{Ea}{RT}\right]} \qquad \rightarrow \qquad lnK = lnK_t + \frac{Ea}{RT} \tag{3.2}$$

Table 5, Table 6, Table 7 and Table 8 includes the values of *Kt*, *Ea* and the determination coefficient, R^2 for the considered blends at the specified concentrations and temperatures.

The activation energy (*Ea*) decreases on increasing molasses concentration in the sesame pates. In other words, the activation energy decreases with decreasing percentage of the sesame paste in the blend. Some researchers observed similar trends about activation energy (*Ea*) and the experimental constant, *Kt*. For instance, the activation energy decreased with increasing the grape molasses or date syrup concentration in tahin (sesame paste) whereas *Kt* increased in the same investigations [1, 13, 27].

The aforementioned two cases, one is the continuous phase was added to the oil phase and other one the oil phase was added to the continuous phase. It has been concluded that increasing tahin concentration in the blend of tahin/molasses causes an increase in values of *Ea* and a decrease in values of *Kt* [2]. In the present study, concentrations of different types of molasses such as date, mulberry, grape and carob molasses were varied from 20 to 55 % in order to determine effects of concentration on the consistency coefficient, flow index and the activation energy at various temperatures. It was observed that there is a linear relationship between apparent viscosities of mixtures and molasses concentrations at any temperature. This behavior can be seen in Figures 6 at the temperature of 40 °C. It has similar trends for other temperatures.

Figures 6 illustrate the variation of the apparent viscosity as a function of shear rates at the constant temperature of 40 °C for different percentages of molasses of date. Although the identical figures were drawn for mulberry, grape and carob molasses in the sesame paste, to save space they were not given here. Figure 7 provides a comparison of the variations of apparent viscosity with shear rate for different blends at 40 °C. Date, mulberry, grape and carob molasses exhibit non-Newtonian behavior that is in accord with the study of Yogurtcu and Kamisli [6] since they showed that pekmez samples exhibit non-Newtonian behaviors. Furthermore, the apparent viscosities of molasses are inversely proportional with shear rate. This outcome affirms the discoveries by Alpaslan and Hayta [1]; Abu-Jdayil[15]; Arslan et al.[2]; Habibi et al.[13].

In order to examine the effect of each molasses concentration on the viscosity of that blend, each molasses concentration was increased from 20 % to 55 % in the tahin and viscosities of those blends were measured as a function of shear strain at a constant temperature. Although it is not shown here, it was observed that the viscosity of each blend and thus consistency coefficient of that blend increases nonlinearly with increasing ratio of a molasses in a blend.

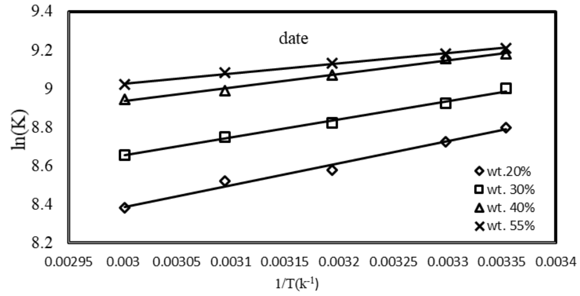

Figure 5. Variation of consistency coefficient with temperature for the various date molasses concentrations

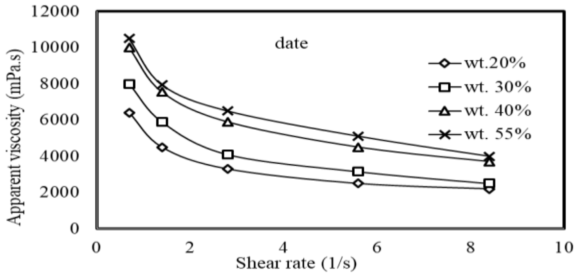

Figure 6. Effect of concentration on the apparent viscosities of date molasses/sesame paste blends at 40 °C

The effect of molasses concentration on consistency coefficient can be expressed by either exponential, $K = K_{c1}\, e^{b_1 C}$ or power function, $K = K_{c2} C^{b_2}$. As can be seen in Table 9, while the exponential model is more appropriate for the blends of date and mulberry molasses, the power model is more suitable for the blends of grape and carob molasses.

A single equation which can be implemented for various parameters is a very important tool for engineering application. Thereby, multiple linear regression of Eq. (3.5) and Eq. (3.6) is used to determine the combined effect of temperature, molasses concentration and shear rate on the apparent viscosity of molasses/sesame paste. The multiple linear regression of Eq. (3.5) and Eq. (3.6) determines variable coefficients, determination coefficients and standard error estimation.

$$\mu_a = f(\gamma, \dot{C}, T) = K\, exp\left[\frac{Ea}{R}\left(\frac{1}{T}\right) + b\, C\right]\, \dot{\gamma}^{n-1} \tag{3.5}$$

$$\mu_a = f(\gamma, \dot{C}, T) = K\, exp\left[\frac{Ea}{RT}\right]\, C^b\, \dot{\gamma}^{n-1} \tag{3.6}$$

The coefficients of determination show that both models (Eq. (3.5) and Eq. (3.6)) are convenient for the date molasses. However, Eq. (3.6) is much more appropriate than Eq. (3.5) since Eq. (3.7) has a high quality of fit ($R^2 = 0.9694$); thereby, it is suggested that the following single model can be used for date molasses blends.

$$\mu_a = 40.74135\, exp\left[\, 960.9952\, \left(\frac{1}{T}\right)\right].\, C^{0.606021}.\, \dot{\gamma}^{-0.41826} \tag{3.7}$$

The determination coefficients indicate that both models (Eq. (3.5) and Eq. (3.6)) are convenient for the mulberry molasses blends. However, Eq. (3.5) is much more appropriate than Eq. (3.6) since value of R^2 (0.974849) is greater for Eq. (3.5); therefore, it is advised that the following single model equation can be used for mulberry molasses blends.

$$\mu_a = 66.34463\;\, exp\left[1320.318\left(\frac{1}{T}\right) + 0.011674\, C\right].\, \gamma^{-0.31125} \tag{3.8}$$

The determination coefficients point out that both models (Eq. (3.5) and Eq. (3.6)) are convenient for the grape molasses blends. However, Eq. (3.6) is much more appropriate than Eq. (3.5) since Eq. (3.6) has a high quality of fit ($R^2 = 0.9681$); therefore, it is suggested that the following single model can be used for grape molasses blends.

Table 1. Parameters of power-law for the date blends at the various temperatures and concentrations

	date											
	20 %			30 %			40 %			55 %		
T(˚C)	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2
25	0.617	6626.9	0.9855	0.538	8113.3	0.9897	0.629	9719.3	0.9878	0.639	10013	0.9927
30	0.585	6166.3	0.9914	0.532	7505.5	0.9901	0.612	9468.6	0.9908	0.641	9704	0.9888
40	0.569	5315	0.9948	0.536	6798.7	0.9976	0.607	8712.6	0.9984	0.629	9231.4	0.9892
50	0.544	5013.1	0.9924	0.535	6308.8	0.9982	0.594	8014.5	0.9939	0.606	8813.1	0.9753
60	0.532	4365.1	0.991	0.522	5744.7	0.9903	0.595	7664.6	0.9988	0.573	8269.7	0.9942

Table 2. Parameters of power-law for the mulberry blends at the various temperatures and concentrations

	mulberry											
	20 %			30 %			40 %			55 %		
T(˚C)	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2
25	0.659	7714	0.9977	0.698	8057.4	0.9972	0.699	8597.7	0.9755	0.69	10207	0.9953
30	0.691	6868.1	0.9942	0.69	7165.5	0.979	0.683	7769.1	0.9846	0.682	9401	0.9844
40	0.690	5753.2	0.9837	0.69	6311.9	0.9862	0.68	6981.9	0.9917	0.676	8418.7	0.9732
50	0.689	4809.9	0.9648	0.679	5513.6	0.9689	0.679	6168.7	0.99	0.674	7905.6	0.987
60	0.683	4461.1	0.9886	0.671	4657.2	0.9906	0.67	5792	0.987	0.661	7351.5	0.9959

Table 3. Parameters of power-law for the grape blends at the different temperatures and concentrations

	grape											
	20 %			30 %			40 %			55 %		
T(˚C)	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2
25	0.604	2084.5	0.9715	0.525	2906.5	0.9927	0.512	3254.4	0.9964	0.496	4218.2	0.9931
30	0.579	1647.4	0.9886	0.508	2421.8	0.9945	0.462	3033.4	0.9953	0.46	4100.6	0.9982
40	0.546	1300.1	0.9869	0.456	2232.7	0.9976	0.62	2782.3	0.9943	0.461	3809.7	0.9984
50	0.515	1113.7	0.9899	0.418	2033.9	0.9971	0.382	2582	0.9942	0.389	3709.5	0.9976
60	0.511	966.88	0.9928	0.374	1876.5	0.9985	0.331	2446.5	0.9986	0.336	3496.6	0.986

Table 4. Parameters of power-law for the carob blends at the various temperatures and concentrations

	carob											
	20 %			30 %			40 %			55 %		
T(˚C)	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2	*n*	*K* (mPa.s^n)	R^2
25	0.583	5714.8	0.9963	0.599	7001.6	0.9964	0.547	11290	0.9982	0.546	17480	0.9853
30	0.534	5123.2	0.9881	0.558	6007.1	0.9667	0.556	10671	0.9933	0.527	15808	0.9905
40	0.460	4515.9	0.991	0.492	5769.1	0.9847	0.562	9176.6	0.9838	0.528	14660	0.9876
50	0.447	3762.7	0.9949	0.485	4894.4	0.9926	0.529	8390.3	0.9964	0.475	13479	0.9813
60	0.444	3194.4	0.9981	0.476	4397	0.9978	0.528	8213.7	0.9963	0.451	12990	0.996

Table 5. Finding of parameters in Eq. (3.8) for the various date molasses concentrations

C (%date)	K_t (mPa.s^n)	*Ea* (J/mol)	R^2
20	142.35	9499	0.9855
30	337.04	7851.1	0.9932
30	905.6	5894.7	0.9921
55	1713.68	4378.15	0.9941

Table 6. Finding of parameters in Eq. (3.8) for various mulberry molasses concentrations

C (% mulberry)	K_t (mPa.s^n)	*Ea* (J/mol)	R^2
20	36.474	13216.68	0.9841
30	54.293	12366.11	0.9935
40	200.52	9259.827	0.9841
55	481.84	7514	0.9801

Table 7. Finding of parameters in Eq. (3.8) for the various grape molasses concentrations

C (%grape)	K_t (mPa.sn)	*Ea* (J/mol)	R^2
20	1.75	17378.08	0.9646
30	62.446	9367.084	0.9287
40	219.862	6639.023	0.9865
55	729.968	4340.986	0.9850

Table 8. Finding of parameters in Eq. (3.8) for the various carob molasses concentrations

C (% carob)	K_t (mPa.s^n)	*Ea* (J/mol)	R^2
20	25.186	13444.5	0.9949
30	47.39	10249.25	0.9607
40	442	7991.538	0.9494
55	1099.378	6779.038	0.9566

Table 9. Determining of parameters in Eq. (3.3) and Eq. (3.4) for various concentrations of each molasses

	Exponential function (Eq. (3.3)		Power function (Eq. (3.4)	
	Values of A_1 and d_1 and the corresponded equation	R^2	Values of A_2 and d_2 and the corresponded equation	R^2
date	$Ea = 1503e^{-0.023\,C}$	0.994	$Ea = 101997C^{-0.776}$	0.971
mulberry	$Ea = 19268e^{-0.017C}$	0.959	$Ea = 80857C^{-0.584}$	0.917
grape	$Ea = 33428e^{-0.039C}$	0.962	$Ea = 100000C^{-1.361}$	0.997
carob	$Ea = 18901e^{-0.02C}$	0.955	$Ea = 106737C^{-0.693}$	0.992

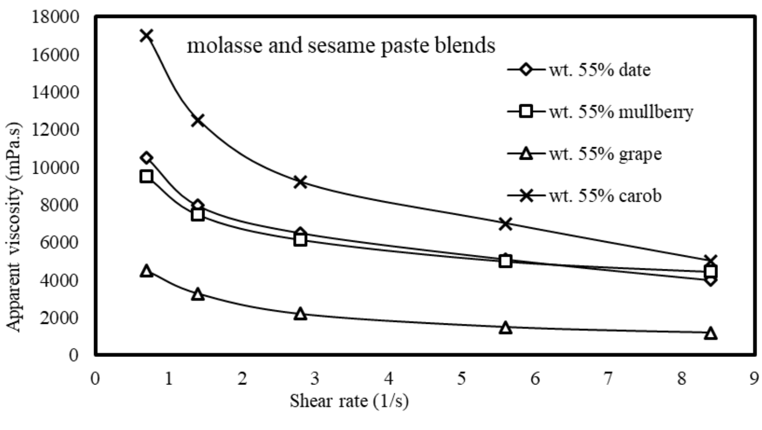

Figure 7. Variation of apparent viscosity with shear rate for date, mulberry, grape and carob molasses /sesame paste blends at the constant concentration (55 %) and temperature (40 °C)

$$\mu_a = 0.793932\,exp\left[1533.303\left(\frac{1}{T}\right)\right]\,C^{0.888077}\,\dot{\gamma}^{-0.53582} \quad (3.9)$$

Similarly, the determination coefficients point out that both models (Eq. (3.5) and Eq. (3.6)) are convenient for the carob molasses blends. However, Eq. (3.5) is much more appropriate than Eq. (3.6) since the value of R^2

(0.974528) is larger for Eq. (3.5); therefore, it is recommended that the following single model can be used for carob molasses blends.

$$\mu_a = 21.89981\, exp\left[\, 1419.017\, \left(\frac{1}{T}\right) + 0.036663\, C\right]\, \dot{\gamma}^{-0.4837} \tag{3.10}$$

4. Conclusions and Recommendations

In this study the flow behavior of some molasses/sesame paste mixtures at four different molasses concentrations (20-55 %) and various temperatures in range of 25-60 °C was investigated at various shear rates in the range of 2.5-30 s-1.

This study concludes that the apparent viscosity of the mixture of some molasses/sesame pastes gains a higher value with increasing molasses concentration and reducing temperature. The power-law model can be successfully used to express the relationship between apparent viscosity and shear rate of the mixtures. In addition, the experimental results indicate that the all blends considered here exhibit non- Newtonian, shear thinning behavior.

It was observed that the model parameters such as the flow behavior index and the consistency coefficient are strongly dependent on temperature. The relationship between flow behavior index and temperature are not able to formalize; however, the Arrhenius–type equation has a good interpretation of the relation between the temperature and the consistency coefficient. The impact of molasses concentration on consistency coefficient is quite large. It appears that both exponential and power functions can be utilized to describe the relationship.

Finally, in the present study four model equations were proposed to describe the combined effect of temperature, molasses concentration and shear rate on the apparent viscosity of the mixture. It was observed that the model equations are quite appropriate to define relationship among the concentration of each type of molasses (date, mulberry, grape, and carob), shear rate and temperature.

It is concluded that the obtained experimental data suggested that the model equations can be used in quality control, sensory evaluation of the product, process control applications and in designing equipment for the mixtures.

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