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Rheological Properties of Sübye, Traditional Beverage

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ABSTRACT

Sübye is a traditional cold beverage and consists of melon seeds, sugar and water. Sübye production is important in economic and environmental point of view since melon seeds, wastes of food production, are used as a raw material. In this study, rheological properties of Sübye were determined by fitting shear stress–shear rate data to some rheological models. Herschel-Bulkley model was the best model that fitted the experimental data (R^2=0.996, X^2=0.0245, RMSE=0.0008). Also Sübye showed time-dependent rheopectic characteristics at low and high shear rates whereas thixotropic characteristics existed at medium shear rates.

Key Words: Food waste, Modeling, Rheology, Sübye, Traditional food

Geleneksel İçecek Sübyenin Reolojik Özellikleri

ÖZET

Sübye kavun çekirdekleri, şeker ve su ile elde edilen geleneksel soğuk bir içecektir. Sübye üretimi bir gıda atığı olan kavun çekirdeklerinin hammadde olarak kullanılması ile ekonomik ve çevresel önem kazanmaktadır. Bu çalışmada, sübye'nin reolojik özellikleri kayma gerilimi ve kayma hızı verilerinin bazı reolojik modellere uyarlanması ile belirlenmiştir. Herschel-Bulkley modelinin en iyi uyumluluk gösteren model olduğu bulunmuştur (R^2=0.996, X^2=0.0245, RMSE=0.0008). Ayrıca sübyenin düşük ve yüksek kayma hızlarında reopektik, orta kayma hızlarında ise tiksotropik özellik gösterdiği tespit edilmiştir.

Anahtar Kelimeler: Gıda atığı, Modelleme, Reoloji, Sübye, Geleneksel gıdalar

INTRODUCTION

Melon (*Cucumis melo*), owned in Cucurbitaceace genus, and has fragrant and aromatic, sweet, usually round or oval-shaped, yellow, and pinky color with a greenish creeping stem [1]. It is produced in tropical and semi-tropical countries. After eating of the soft and sweet part of melon, melon seeds are evaluated as waste with their peels merely. Melon seed is rich in protein, fat, and mineral content [2]. Since it has high amount of unsaturated fatty acids, it can be useful as a functional ingredient.

In developing countries, people suffer from the foods and need more foods. Since agricultural wastes could be reused, they have economic and environmental value. Although melon seeds are known as food waste, they are to be used for the purpose of medicine in the past years [2]. Inner part of melon seeds are consumed as confectionery and snack foods in India. In Turkey, melon seeds are evaluated in a traditional beverage production. This beverage, named as 'Sübye' or 'İzmir Sherbet', is prepared from ground melon seed kernels which are diuretic and considered beneficial in chronic or acute eczema [3]. Although there is limited study on quality and nutritive feature of Sübye [3], no information is available on the rheological characteristics of Sübye, according to the best of the authors' knowledge.

Rheology science investigates the flow and deformation of the substance. Rheological characteristics are remarkable physical properties, and generally liquid foods are classified as Newtonian or non-Newtonian depending on the relationship between shear rate and shear stress [4]. Viscosity of foods has an important place in order to understand the structure of food, food processing and equipment, control of the food production [5]. Rheological data is used to determine shelf-life of foods and some basic unit operations like mixing, heating, process control, texture analyses etc. [6]. There have been a lot of recent studies to define the rheological properties of materials used in food industry [7-11]. Since Sübye could be produced as a commercial beverage, the information on its rheological properties is essential for its formulation and to design of Sübye production equipment, especially pumping and piping systems. The purpose of this study is to determine the viscous characteristics of Sübye depending on different shear rates, to fit the experimental measurements to rheological models, and to evaluate its time dependency.

MATERIALS and METHODS

Sübye

The traditional preparation method is applied as given in Karakaya et al. [3]. The sun-dried melons seeds are soaked in tap water at room temperature for 30 min, one hundred grams of the seeds are blended and sixty grams of sugar and 2 mL of water are added for a second blending process. Once again, approximately 200 mL of water is added and mixed thoroughly. The mixture is passed through a kitchen sieve into a glass container. The residue is blended again with 200 mL of water. The slurry is passed through the sieve. The blending and sieving procedure is repeated until approximately 500 mL of the beverage is obtained. Sübye has a content of approximately 13% dry matter, 1.92% fat, 1.28% protein, 0.27% ash, and 10% carbohydrate and energy value of Sübye is determined as 67 kcal/ 100g [3].

In this study, Sübye was supplied from a local traditional producer, and transported at cold conditions (+4°C) after production immediately. For the same day of production (within 3 hours), rheological measurements were performed at room temperature.

Rheological Measurement

Brookfield viscometer (Model LVDV-II Pro, Brookfield Engineering Laboratories, USA) was used for rheological measurements. During the measurements, the small device adapter was selected for the formation of a uniform shear stress-shear rate. Owing to measurement device, fluid flow in a dead zone and / or the formation of unstable flow is minimized.

Measurements were carried out in the range of 0-200 rpm rotation rate and by using spindle 18. During measurements, shear rate, shear stress, viscosity (cp) and torque (%) values were recorded.

Experimental shear stress-shear rate measurements were fitted to selected rheological models to obtain viscous rheological properties of Sübye. Four different rheological models were applied; Newton model (Eq.1), Exponential model (Eq. 2), Bingham model (Eq. 3) and Herschel-Bulkley model, (Eq. 4).

$$\tau = \eta * \dot{\gamma} \quad (1)$$
$$\tau = K * \dot{\gamma}^n \quad (2)$$
$$\tau - \tau_0 = K * \dot{\gamma} \quad (3)$$
$$\tau - \tau_0 = K * \dot{\gamma}^n \quad (4)$$

Time dependency of rheological properties of Sübye was also investigated. It's thixotropic and/or rheopectic character was determined by analyzing hysteresis loop between forward and backward shear stress-shear rate relations. If viscosity decreases as time increases and then returns to the initial level on rest after shearing, such a phenomenon is called thixotropy. The reverse phenomenon is called rheopexy [12]. The area between the upward and downward flow curves of the hysteresis loop was calculated by the Simpson's rule (Eq.5)

$$\int_a^b f(x)dx = \frac{h}{3}[(y_0 + y_n) + 4(y_1 + y_3 + .. + y_{n-1}) + 2(y_2 + y_4 + .. + y_{n-2})] \quad (5)$$

Statistical Analysis

Compatibility of the model with experimental data were determined by using a non-linear regression analysis of statistical software package SPSS (ver.20). Regression coefficient (R^2), root mean square error (RMSE) (6) and chi-square (χ^2) (7) values were calculated. Duncan test was applied as a comparative statistical analysis. The statistical criteria of having highest R^2, lowest RMSE and lowest χ^2 were chosen for selection of best model for fitting.

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}\left(KG_{theoric,i} - KG_{experimental,i}\right)^2\right]^{0.5} \quad (6)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}\left(KG_{theoric,i} - KG_{experimental,i}\right)^2}{N - n} \quad (7)$$

Where, KG; rheological data (experimental and predicted), i; observation values at i experiment; N, observation number; n, number of parameters in model.

RESULTS and DISCUSSION

The empirical data for Sübye samples obtained from the Brookfield viscometer were converted into viscosity functions (apparent viscosity and shear rate). It was found that the apparent viscosity decreased as the rate of shear increased (Figure 1). This showed non-Newtonian fluid (shear thinning or pseudoplastic) behavior for Sübye.

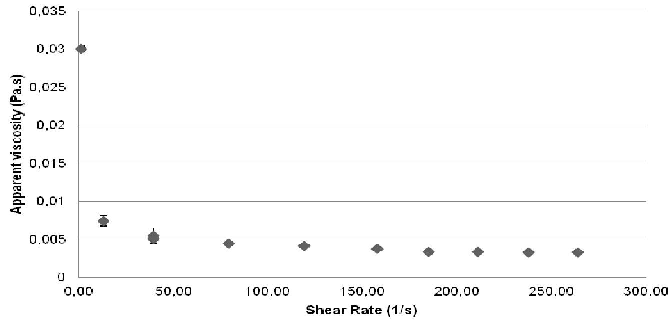

Figure.1. Change of apparent viscosity of Sübye depending on shear rate

The relationship between shear stress and shear rate for Sübye was determined (Figure 2). Shear stress of Sübye increased as the shear rate increased. Rheological constants were predicted to describe this behavior by means of fitting different rheological models (Newtonian, Bingham, Power law, and Herschel-Bulkley) to experimental data (Table 1). Since both the linearity of shear stress-shear rate relation and the constancy of apparent viscosity in the range of shear rate studied were could not be determined, the poor agreement of Newtonian model to the experimental data was found as expected (Figure 2, Table 1).

Table.1. Predicted rheological constants of Sübye

Model	μ (Pa)	K(Pas^n)	τ_0	n (Dimensionless)	χ^2	RMSE	R^2
Herschel Bulkley	-	0.011±0.0016	0.0147±0.0121	0.784±0.027	0.0245±0.0078	0.0008±0.0004	0.996
Power Law	-	0.013±0.0024	-	0.751±0.027	0.0313±0.0020	0.0011±0.0001	0.995
Bingham	-	0.003	0.0597±0.0108	-	0.0415±0.0063	0.0021±0.0006	0.988
Newtonian	0.003±0.0004	-	-	-	0.0245±0.0078	0.0008±0.0004	0.972

The regression coefficients of Newtonian and Bingham models were lower than those of Herschel Bulkley and Power Law models. Furthermore, RMSE and χ2 values of Herschel Bulkley model were lower than those of Power Law model. Since Herschel Bulkley model had higher regression coefficient and lowest error values, it was selected as best model fitting the experimental data adequately (Fig. 2).

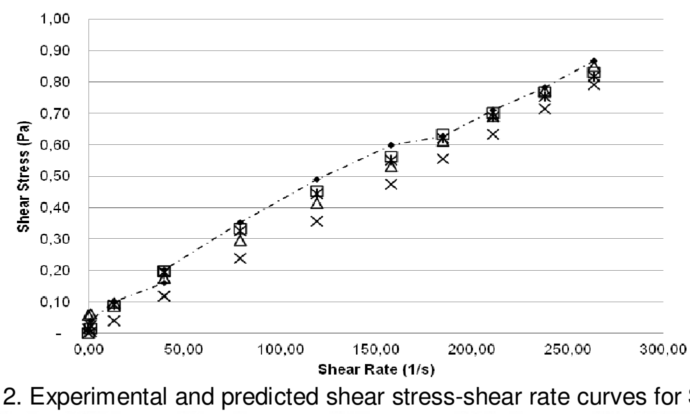

Figure 2. Experimental and predicted shear stress-shear rate curves for Sübye.

Experimantal Data   Power Law   Bingham   Newtonian   Herschel Bulkley

Herschel-Bulkley model estimation was 0.011 Pa.sn for consistency coefficient (K), 0.784 for flow behavior index (n) and 0.0147 Pa.s for yield stress of Sübye. Since flow behavior index of Sübye was lower than 1, Sübye was posted to be having pseudoplastic flow and the shear-thinning nature. It is well known that the consistency of Sübye is significantly affected by oil, protein and sugar concentration. Gabsi et al. [13] reported that rheological properties of date syrup changed with increasing of the syrup concentration. Apparent viscosity of the fruit purees (raspberry, strawberry, peach and prune) was affected by the increasing with sugar content. Ostwald Waele model and Herschel–Bulkley were suitable to define rheological properties of these fruit purees. Maskan and Göğüş [7] were investigated effects of sugar concentration to the sunflower oil-water emulsion. They reported that the emulsion obtained was determined as pseudoplastic flow, and emulsion stability was increased within increasing sugar concentration. Furthermore, they found that emulsion with sugars was fitted to Power Law model. In another study, rheological properties of sesame oil/molasses mixtures obtained by mixing different proportions, especially consumed at breakfast, were reported [14]. They found that sesame oil/molasses mixture had non-Newtonian, pseudoplastic character, and power law model was the best model describing its rheology. Similarly, since Sübye also has significant amount of sugars, oil and protein, which are come from melon seeds, it can be concluded that rheological properties of Sübye can be depending on sugar and/or oil concentration. Sübye is going to be widespread commercial product, changes of rheological properties depending on different genus of melon seeds and formulations with different sugar concentrations should be investigated further.

Rheological properties could be depending on time. Time dependency of liquid foods is especially important in design of pumping lines on its production, and in shelf life estimations. There is general acceptance that the term thixotropic refers to the time-dependent decreasing in viscosity. However, terms of rheopectic defines as increasing shear stress [15]. For Sübye, forward (0-264 s^{-1}) and backward (264-0 s^{-1}) line of shear rate experimental data was obtained (Figure 3). There was an area, which called as hysteresis area, obtained by differences between forward and backward loop. The difference showing thixotropic or rheopectic energy was calculated by Simpson method. Hysteresis character showed two different behaviors. It was determined that Sübye behaved rheopectic character with the energy of 0.315 J/m^3 at low (0-28 1/s) and with the energy of 0.195 J/m^3 at high (242-264 1/s) shear rates, however it behaved thixotropic character with the energy of 6.044 J/m^3 at medium rates (28-242).

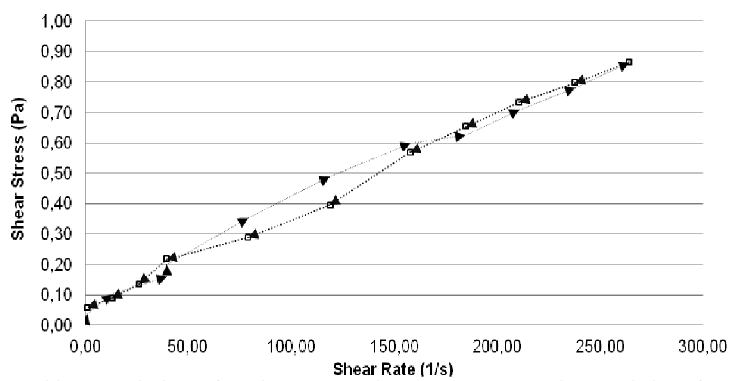

Figure.3. Hysteresis loop for shear rate-shear stress experimental data for Sübye

Forward Shear Rate   Backward Shear Rate

Similarly, time dependent shear thinning behavior had been observed by steady-shear flow experiments for both tomato juices with and without soy [8]. They reported that addition of soy protein significantly affected the time-dependent rheological behavior of tomato juice. In the case of plain juice, a slight thixotropic behavior had been observed. The tomato juice with added soy exhibited a thixotropic behavior at low shear rates followed by a transition to rheopectic behavior at higher shear rates. In another study, transition between thixotropic and rheopectic character had been found in rheological properties of concentrated kiwi juice [16]. It was reported as pseudoplastic fluid and fitted to the Power Law model. Time dependency character was thixotropic at low shear rates followed by a transition to rheopectic behavior at higher shear rates. In another study, it was reported that traditional beverage kefir had pseudoplastic behavior and the time-dependent characters, namely thixotropic [10].

Changes of time dependency are especially important to characterize the changes of consistency of liquid foods during their shelf-life. The data obtained in this study will give benefits on future studies conducted on evaluation of rheological quality of Sübye and its shelf-life determination.

CONCLUSION

The rheological behaviour of Sübye was analyzed by fitting of different rheological models to experimental data. Herschel Bulkley model fitted the experimental data best, with higher R^2, the lowest RMSE and lowest χ^2. Non-Newtonian shear thinning behaviour was obtained for Sübye. In addition, Sübye had time dependent character; thixotropic at medium shear rates 28-242 1/s, else rheopectic at other rates. This study will provide efficient rheological data for designing of Sübye production lines and its shelf-life studies. The use of melon seed in Sübye production is highly important for drawing attention to the recovery of melon wastes.

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