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# Investigation of the Changes in Rheological Properties of Purple Basil Sherbet Samples Concentrated by Ohmic Heating at Different Voltage Gradient[#]

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ABSTRACT

Purple basil is widely used medicinally and aromatically due to its essential oil properties, and it is a plant that stands out with its antibacterial, antimutagenic and antioxidant properties. It has been determined that purple basil has positive effects on health such as appetizing, insomnia, sputum, diuretical and antispasmodic. Purple basil contains high concentrations of anthocyanins and with these properties it stands out as a potential new source of stable red pigments for the food industry. In recent years, it has been seen that purple basil has been processed into different products such as tea and sherbet in order to benefit from its functional properties. With the processing of purple basil into different products, it is seen that the consumption of basil and basil products has increased by consumers. In this study, purple basil sherbet samples were concentrated at different voltage gradient values (14, 17 and 20 V/cm) under atmospheric conditions with ohmic heating up to 25% soluble solid content (SSC) and the changes in their rheological properties during the concentration process was investigated. The changes in the rheological properties of the purple basil samples were determined in the range of 1-148 $s^{-1}$ shear rate values and measurement temperature was 25°C. The compatibility of different rheological models (Newton, Power-Law and Herschel-Bulkley) to the experimental data was statistically evaluated to determine the flow behavior index of the purple basil sherbet samples. It has been determined that the shear stress values increased as the shear rate values increased in all the process conditions. Similarly, at the same shear rate values, it was determined that the shear stress values increased as the SSC values increased. It has been determined that the best suitable rheological model was Herschel-Bulkley Model for all purple basil sherbet concentrates. It is thought that the results obtained will provide important data to the food and machinery industry for the installation of pilot and industrial scale ohmic heating systems.

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## Introduction

Basil (*Ocimum basilicum* L.) which belongs to the Lamiaceae family, which is widely used in medicinal and aromatic plants, is one of the Ocimum genus plants known as "King of herbs" in the plant kingdom. Basil is a natural plant which is producing all around the world but originally it came from wide region of Asia and Africa especially India. Basil has been cultivated and it can be economically produced all around the world and our country for a long time (Karataşoğlu et al., 2021; Flanigan and Niemeyer, 2014; Szymanowska et al., 2015). Basil has over 65 species in the world. Two of them are the most produced around the world first one is green basil which has green leaves and white flowers and second one is purple basil which turns purple and this colour changes cause to accumulation of anthocyanins in its leaves and flowers (Prinsi et al., 2020). Basil has exclusive aroma because of its aroma basil has been used in many ways to use in foods such as salads, pizza, soup marine products. Basil has high phenolic compounds, antioxidant properties and anthocyanin materials which make basil to very healthy product. Also, basil contain about %0.1-2 essential oil (Faydaoğlu and Driveroğlu, 2013; Yiğitvar, 2017). Basil leaves consist of many phenolic materials such as rosmarinic acid, cisoric acid, gallic acid and it's also containing secondary metabolites which is produced by plants such as linalool, ursolic acid, methyl kavicol, apigenin eugenol. Purple basil contains higher levels of total phenolic content and higher antioxidant capacity and because of the colour it contains many anthocyanin items than other types (Princsi, 2020; Flanigan and Niemeyer, 2014). Purple basil contains high concentrations of anthocyanins and with this feature it stands out as a potential new source of stable red pigments for the food industry (Simon et al., 1999). Basil known as healthy food because of its healthier components from ancient times and it's used for some disorders such as appetizing, relieving insomnia, sputum, diuretic, stimulating and antispasmodic, as well as for their tonic effect that strengthens the nerves and body (Mishra et al., 2022; Ekren et al., 2012; Amrani et al., 2006; Akgül and Ayar, 1993). With the growing technology and new trends the consumption of healthier food many foods start the conversion to rather than original food. Its also affect the basil conversion to new products such as tea and sherbet to consume functional properties of basil. In recent years, it is seen that the consumption of products obtained from basil has increased with the tendency towards aromatic plants.

Sherbet has an important place in Turkish culinary culture which was consumed from Ottoman period as an exhilarating, thirst quenching and used to cure in many diseases (Sarıoğlan and Cevizkaya, 2016). Sherbet was the first choose drink of many cultures before fruit juice consumption increase across the board (Sürücüoğlu and Özçelik, 2007). Sherbets are obtained by adding sugar and water to various fruits, flowers, plants, roots, bark, or seeds and it's also concentrated and stored in syrup form to have a longer shelf life (Akçiçek, 2002).

Ohmic heating is an electrical heating method which is new and alternative to conventional heating methods and it is based on the principle of passing the electric current throughout the food. It allows a fast and homogeneous heating process, especially in liquid foodstuffs with high thermal resistance (Icier, 2003). Energy production and heating rate vary depending on the applied voltage gradient and the electrical conductivity value of the foodstuff. To achieve higher temperatures in a short time is possible with ohmic heating, and this properties of ohmic heating effects the food quality became better than conventional heating methods (Darvishi et al., 2011; Icier et al., 2017). Ohmic heating method is widely used in the food industry such as heating, cooking, extraction, evaporation, and thawing of foodstuffs (Icier et al., 2017; Sabanci et al., 2021; Cokgezme et al., 2021; Göksu et al., 2022; Karakavuk et al., 2022).

When preparing a production line for big scale manufacturing its highly important to know physical properties of food materials. Rheological properties are very critical physical properties for liquid and semi-liquid foodstuffs. Rheology is a branch of science that studies the flow and deformation of foodstuffs. Depending on the changes in the shear stress values obtained against shear rate in the classification of liquid foodstuffs, the flow behavior index is divided liquid foods into two groups as Newtonian and Non-Newtonian type fluids (Steffe, 1996).

Determining the rheological properties of foodstuffs is extremely important in determining the parameters such as mixing, pumping and process control applied during the production of food materials (Steffe, 1996; Krokida et al., 2001). Studies examining the changes in the rheological properties of different foodstuffs in the literature have been reported by many researchers (Bozkurt and Icier, 2009; Cevik et al. 2016; Cevik et al. 2020; Sabanci and Icier, 2020). However, within the knowledge of the authors, no study has been found in the literature examining the changes in the rheological properties of purple basil sherbet samples concentrated using ohmic heating method under atmospheric conditions.

The aim of this study is to determine the change in the rheological properties of purple basil sherbet samples concentrated to different %SSC contents (15, 20 and 25 SSC%) at different voltage gradients.

## Material and Method

### *Material*

Fresh purple basil samples were obtained from a local producer. After purchasing samples, they were removed from their stems and other foreign materials, and they were washed, and excess water was removed with coarse filter paper. To produce sherbet, 375 g purple basil leaves and 0.2% lemon salt and 0.2% cinnamon stick were added to the pre-boiled hot water (3000 ml). The resulting mixture was kept closed for 90 minutes, and then the water was filtered. Then, 375 g of sugar was added to the water obtained by filtration and the resulting mixture was left to cool. Before the concentration process (raw material) of the purple basil sherbet samples, the SSC content was determined as 8.7±0.1%.

### *Evaporation Method*

Ohmic heating system was used to perform the evaporation process. Ohmic heating assisted evaporation system consists of isolated transformer/variac unit, test cell made of Teflon material (7×8×12 cm), custom-made microprocessor, 2x2 mm thick titanium electrodes, teflon coated T-type thermocouple, measuring materials, electrical/electronic connections, and computer system. Detailed information about the ohmic heating system is given in Cevik (2021).

Purple basil sherbet samples were heated from 20°C to 100°C and continued at a constant evaporation temperature of 100°C±2°C until they reached different SSC% contents (15, 20, and 25% SSC). For each evaporation process 75 ml of sample was transferred to the test cell and ohmic heating was applied at three different voltage gradients (14, 17 and 20 V/cm). Temperature values of samples measured during the evaporation process by using Teflon coated T-type thermocouple.

### *Rheological Measurements*

The changes in the rheological properties of the purple basil sherbet samples were measured with Anton Paar MCR 301 (Anton Paar Gmbh, Graz, Austria) rheometer using a concentric cylindrical measuring apparatus. Rheological measurements were carried out using a concentric cylindrical measuring apparatus at a constant measuring temperature of 25 °C in the range of 1-148 $s^{-1}$ shear rate values.

To determine the flow behavior index, shear rate and shear stress values were measured and the compatibility of different rheological models (Newton, Power-Law and Herschel-Bulkley) with the experimental data was determined statistically (Equation 1-3) (Cevik et al., 2016).

$$\tau = \eta * \dot{\gamma} \quad (1)$$

$$\tau = K * \dot{\gamma}^{n} \quad (2)$$

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

where, $\tau$ is the shear stress value (Pa), $\tau_0$ is the initial shear stress (Pa), $\gamma$ is shear rate value ($s^{-1}$), K is the consistency coefficient ($Pa.s^n$), $\mu$ is the viscosity value (Pa.s), and n is the flow behavior index (unitless).

***Statistical Analysis***

The effects on the rheological properties of purple basil sherbet samples concentrated to three different (15, 20 and 25%) SSC contents using three different voltage gradients (14, 17 and 20 V/cm) were determined by ANOVA and DUNCAN tests using SPSS 14.0 package program (IBM, USA). The confidence level was taken as 95%. The compatibility of the experimental shear stress values with different rheological models was tested using nonlinear regression analysis. For each rheological model, the related equations (root mean square error (RMSE), chi-square ($\chi^2$) and $R^2$ values) were calculated using the MATLAB package program. The most suitable rheological model evaluated by consideration the mean square root of the least squares of error (RMSE) (Eq. 4), chi-square ($\chi^2$) (Eq. 5) values and the highest $R^2$ values (Eq. 6) (Cevik et al., 2016). All experiments were applied in 3 replications.

$$\mathrm{RMSE} = \left[\frac{1}{\mathrm{N}}\sum_{i=1}^{n}(\mathrm{TV}_i - \mathrm{EV}_i)^2\right]^{0.5} \quad (4)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(\mathrm{TV}_i-\mathrm{EV}_i)^2}{\mathrm{N-n}} \quad (5)$$

$$R^2 = \frac{\mathrm{N}\sum_{i=1}^{N}\mathrm{TV_iEV_i} - \sum_{i=1}^{N}\mathrm{TV_iEV_i}}{\sqrt{\left(\mathrm{N}\sum_{i=1}^{N}\mathrm{TV_i}^2 - \left(\sum_{i=1}^{N}\mathrm{TV_i}\right)^2\right)\left(\mathrm{N}\sum_{i=1}^{N}\mathrm{EV_i}^2 - \left(\sum_{i=1}^{N}\mathrm{EV_i}\right)^2\right)}} \quad (6)$$

TV is the theoretical value, EV is the experimental value, N is the number of observed data, n is the number of coefficients in the model.

## Results and Discussion

The experimental shear stress-shear rate changes obtained for purple basil sherbet samples concentrated to different soluble solid content with different processing conditions are given in Figure 1. It was determined that the shear stress values increased as the SSC increased at similar shear rate values ($p < 0.05$). As expected, the amount of free water of the product decreased as the SSC increased and hydroxyl bonds are formed accordingly. These formed hydroxyl bonds cause restriction of the movement of the liquid product, causing the shear stress values to increase as the SSC increase at the same shear rate values (Constenla et al., 1989). The purple basil sherbet produced by different ohmic voltage gradient at the same SSC and shear rate values similar shear stress observed ($P>0.05$). There is no information about the study of purple basil sherbet evaporation process performing using ohmic heating method and its rheological properties within the knowledge of the authors.

Table 1. Statistical evaluation of the experimental shear rate-stress values and the rheological models of purple basil sherbet samples concentrated to different SSC% values by ohmic heating process at 14 V/cm voltage gradient

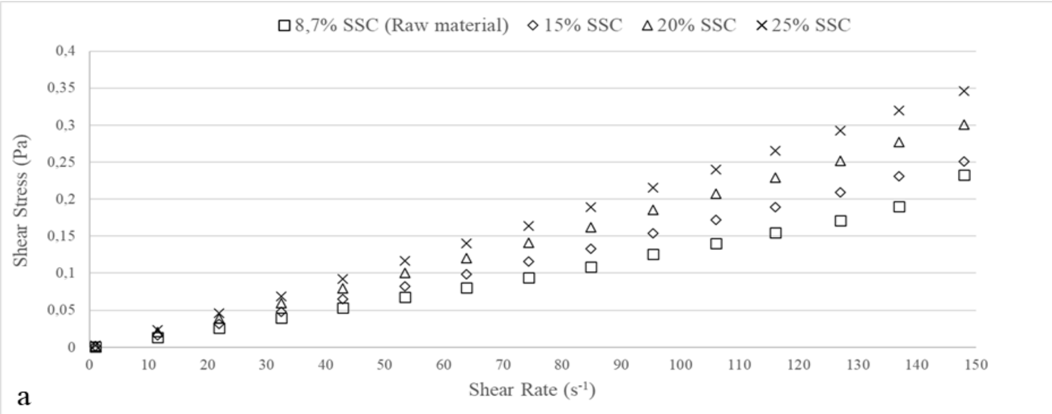
| % SSC | Statistical Criteria | Models | | |
|---|---|---|---|---|
| | | Newton Model | Power-Law Model | Herschel-Bulkley Model |
| 8.7 | $R^2$ | 0.952±0.002 | 0.981±0.001 | 0.991±0.001 |
| | RMSE | 0.0108±0.0003 | 0.0068±0.0002 | 0.0048±0.0002 |
| | $\chi^2$ | 0.0001302±0.0000061 | 0.0000583±0.0000035 | 0.0000328±0.0000027 |
| 15 | $R^2$ | 0.953±0.001 | 0.981±0.001 | 0.991±0.001 |
| | RMSE | 0.0107±0.0001 | 0.0067±0.0002 | 0.0047±0.0002 |
| | $\chi^2$ | 0.0001263±0.0000011 | 0.0000561±0.0000025 | 0.0000323±0.0000024 |
| 20 | $R^2$ | 0.994±0.001 | 1.000±0.000 | 1.000±0.000 |
| | RMSE | 0.0048±0.0001 | 0.0012±0.0001 | 0.0008±0.0000 |
| | $\chi^2$ | 0.0000253±0.0000006 | 0.0000561±0.0000025 | 0.0000009±0.0000000 |
| 25 | $R^2$ | 0.996±0.001 | 1.000±0.000 | 1.000±0.000 |
| | RMSE | 0.0049±0.0008 | 0.0012±0.0000 | 0.0008±0.0002 |
| | $\chi^2$ | 0.0000274±0.0000079 | 0.0000018±0.0000003 | 0.0000010±0.0000005 |

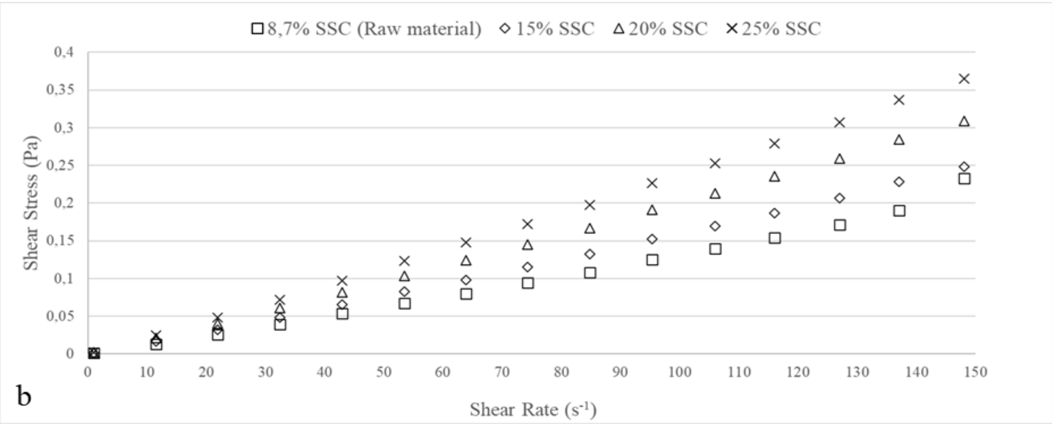
Table 2. Statistical evaluation of the experimental shear rate-stress values and the rheological models of purple basil sherbet samples concentrated to different % SSC values by ohmic heating process at 17 V/cm voltage gradient

| % SSC | Statistical Criteria | Models | | |
|---|---|---|---|---|
| | | Newton Model | Power-Law Model | Herschel-Bulkley Model |
| 8.7 | $R^2$ | 0.952±0.002 | 0.981±0.001 | 0.991±0.001 |
| | RMSE | 0.0108±0.0003 | 0.0068±0.0002 | 0.0048±0.0002 |
| | $\chi^2$ | 0.0001302±0.0000061 | 0.0000583±0.0000035 | 0.0000328±0.0000027 |
| 15 | $R^2$ | 0.993±0.001 | 0.999±0.000 | 1.000±0.000 |
| | RMSE | 0.0045±0.0002 | 0.0013±0.0000 | 0.0008±0.0001 |
| | $\chi^2$ | 0.0000225±0.0000018 | 0.0000022±0.0000000 | 0.0000008±0.0000001 |
| 20 | $R^2$ | 0.995±0.001 | 1.000±0.000 | 1.000±0.000 |
| | RMSE | 0.0048±0.0001 | 0.0012±0.0001 | 0.0008±0.0000 |
| | $\chi^2$ | 0.0000261±0.0000016 | 0.0000018±0.0000003 | 0.0000008±0.0000001 |
| 25 | $R^2$ | 0.995±0.000 | 1.000±0.000 | 1.000±0.000 |
| | RMSE | 0.0054±0.0000 | 0.0013±0.0001 | 0.0008±0.0001 |
| | $\chi^2$ | 0.0000326±0.0000005 | 0.0000022±0.0000004 | 0.0000010±0.0000003 |

Table 3. Statistical evaluation of the experimental shear rate-stress values and the rheological models of purple basil sherbet samples concentrated to different % SSC values by ohmic heating process at 20 V/cm voltage gradient

| % SSC | Statistical Criteria | Models | | |
|---|---|---|---|---|
| | | Newton Model | Power-Law Model | Herschel-Bulkley Model |
| 8.7 | $R^2$ | 0.952±0.002 | 0.981±0.001 | 0.991±0.001 |
| | RMSE | 0.0108±0.0003 | 0.0068±0.0002 | 0.0048±0.0002 |
| | $\chi^2$ | 0.0001302±0.0000061 | 0.0000583±0.0000035 | 0.0000328±0.0000027 |
| 15 | $R^2$ | 0.992±0.001 | 0.999±0.001 | 1.000±0.000 |
| | RMSE | 0.0048±0.0002 | 0.0012±0.0001 | 0.0009±0.0001 |
| | $\chi^2$ | 0.0000045±0.0000007 | 0.0000020±0.0000004 | 0.0000011±0.0000003 |
| 20 | $R^2$ | 0.995±0.001 | 1.000±0.000 | 1.000±0.000 |
| | RMSE | 0.0049±0.0001 | 0.0012±0.0001 | 0.0008±0.0000 |
| | $\chi^2$ | 0.0000272±0.0000011 | 0.0000018±0.0000002 | 0.0000008±0.0000001 |
| 25 | $R^2$ | 0.995±0.001 | 1.000±0.000 | 1.000±0.000 |
| | RMSE | 0.0054±0.0002 | 0.0012±0.0001 | 0.0008±0.0001 |
| | $\chi^2$ | 0.0000324±0.0000021 | 0.0000018±0.0000003 | 0.0000009±0.0000003 |



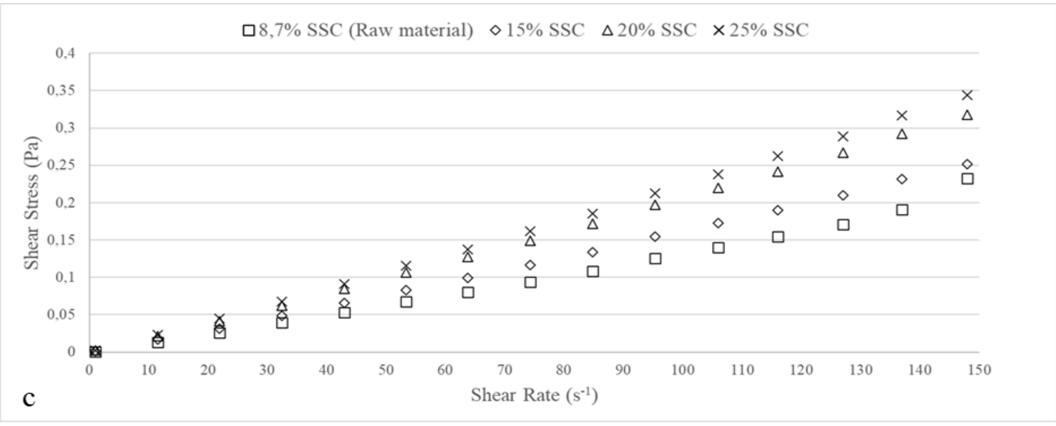




Figure 1. The changes in shear stress-shear rate values of basil syrup samples concentrated to different SSC% content during the different evaporation conditions;
a) 14 V/cm voltage gradient; b) 17 V/cm voltage gradient; c) 20 V/cm voltage gradient

When the studies for different foodstuffs are examined, many researchers reported that the shear stress values tended to increase as the SSC content of the samples increased (Altan and Maskan, 2005; Cevik et al., 2016; Cevik et al., 2020; Sabanci and Icier, 2020). For producing purple basil sherbet different process conditions applied. Examining this sherbet samples empirical shear stress (Pa) and shear rate ($s^{-1}$) values determined for the different rheological models (Newton, Power-Law and Herschel-Bulkley model) this experimental data investigated by using non-linear regression analysis (Table 1-3). To make a more detailed comparison between the rheological models of different SSC content of purple basil sherbets, the models values studied statistically and compared by RMSE and $\chi^2$ values. It has been determined that the Herschel-Bulkley model has higher $R^2$, and lower RMSE and $\chi^2$ values compared to Newton and Power-Law models (Table 1-3). Similarly, Parmar et al. (2018) investigated the changes in rheological properties of cow, buffalo, and cow-buffalo mixture (50:50) milk samples which concentrated using a constant voltage gradient (13.33 V/cm). Researchers reported that the most suitable rheological model was the Herschel-Bulkley model for the concentrated milk samples. Many researchers reported that the most appropriate rheological model is the Herschel-Bulkley model in studies conducted with different foodstuffs (Sary mai, apple juice, quince juice, reconstituted whey) (Bozkurt and Icier, 2009; Icier, 2009; Ozyurt et al., 2019; Iskakova and Smanalieva, 2020).

In this study, it was determined that the most suitable model coefficients for the initial purple basil sherbet sample (raw material) consistency coefficient, flow behavior index and yield stress values were 0.000007 Pa.s$^n$, 2.031 and 0.049 Pa, respectively. The values of the rheological model constants of the purple basil sherbet samples concentrated under different processing conditions are given in Table 4. It was determined that the consistency coefficient values in all different processing conditions tended to increase as the SSC content of samples increased. The n values for the initial purple basil sherbet samples (raw material) were greater than 1, in other words, the raw material samples showed a dilatant flow behavior index. It was determined that the n values tended to decrease depending on the increase in the SSC% values of the samples, but the n values were above 1 in all concentrated samples. This situation caused both raw material and concentrated purple basil sherbet samples show dilatant flow behavior. It can be said that examining the changes in the rheological properties of sherbet samples concentrated with current technologies will be important for characterizing the effects on the consistency of the samples and for the design of the necessary production lines.

Table 4. Model constants obtained from different rheological models of purple basil sherbet samples concentrated to different % SSC values by ohmic heating process at different voltage gradients

| Voltage Gradients | Models | % SSC | Newtonian viscosity (Pa×s) | $\tau_0$ (Pa) | k (Pa.s$^n$) | n |
|---|---|---|---|---|---|---|
| 14 V/cm | Newton Model | 8.7 | 0.00138±0.00001 | - | - | - |
| | | 15 | 0.00138±0.00001 | - | - | - |
| | | 20 | 0.00198±0.00001 | - | - | - |
| | | 25 | 0.00229±0.00001 | - | - | - |
| | Power-Law Model | 8.7 | - | - | 0.00045±0.00002 | 1.238±0.007 |
| | | 15 | - | - | 0.00045±0.00002 | 1.234±0.006 |
| | | 20 | - | - | 0.00131±0.00001 | 1.088±0.001 |
| | | 25 | - | - | 0.00158±0.00009 | 1.078±0.012 |
| | Herschel-Bulkley Model | 8.7 | - | 0.049±0.001 | 0.000007±0.000001 | 2.031±0.037 |
| | | 15 | - | 0.049±0.001 | 0.000008±0.000000 | 2.005±0.006 |
| | | 20 | - | 0.016±0.002 | 0.000745±0.000038 | 1.190±0.010 |
| | | 25 | - | 0.016±0.000 | 0.000939±0.000015 | 1.174±0.003 |
| 17 V/cm | Newton Model | 8.7 | 0.00138±0.00001 | - | - | - |
| | | 15 | 0.00162±0.00001 | - | - | - |
| | | 20 | 0.00204±0.00000 | - | - | - |
| | | 25 | 0.00241±0.00003 | - | - | - |
| | Power-Law Model | 8.7 | - | - | 0.00045±0.00002 | 1.238±0.007 |
| | | 15 | - | - | 0.00101±0.00003 | 1.100±0.005 |
| | | 20 | - | - | 0.00135±0.00002 | 1.087±0.003 |
| | | 25 | - | - | 0.00164±0.00002 | 1.082±0.001 |
| | Herschel-Bulkley Model | 8.7 | - | 0.049±0.001 | 0.000007±0.000001 | 2.031±0.037 |
| | | 15 | - | 0.018±0.001 | 0.000450±0.000001 | 1.248±0.000 |
| | | 20 | - | 0.017±0.002 | 0.000771±0.000069 | 1.189±0.016 |
| | | 25 | - | 0.019±0.001 | 0.000965±0.000038 | 1.178±0.006 |
| 20 V/cm | Newton Model | 8.7 | 0.00138±0.00001 | - | - | - |
| | | 15 | 0.00165±0.00001 | - | - | - |
| | | 20 | 0.00209±0.00000 | - | - | - |
| | | 25 | 0.00226±0.00001 | - | - | - |
| | Power-Law Model | 8.7 | - | - | 0.00045±0.00002 | 1.238±0.007 |
| | | 15 | - | - | 0.00099±0.00003 | 1.107±0.005 |
| | | 20 | - | - | 0.00139±0.00002 | 1.086±0.002 |
| | | 25 | - | - | 0.00150±0.00003 | 1.087±0.003 |
| | Herschel-Bulkley Model | 8.7 | - | 0.049±0.001 | 0.000007±0.000001 | 2.031±0.037 |
| | | 15 | - | 0.015±0.001 | 0.000514±0.000054 | 1.228±0.018 |
| | | 20 | - | 0.017±0.001 | 0.000806±0.000025 | 1.186±0.006 |
| | | 25 | - | 0.016±0.002 | 0.000917±0.000049 | 1.177±0.009 |

SSC%: Soluble solid content; $\tau_0$: Yield stress; k: Flow coefficient; n: Flow behavior index

## Conclusion

In this study, the changes in the rheological properties of purple basil sherbet samples concentrated at different SSC values using ohmic heating under atmospheric conditions at different voltage gradients was determined. It was determined that the shear stress values of purple basil sherbet samples concentrated under different processing conditions increased as SSC content values increased. It was determined that the Herschel-Bulkley model was the most suitable rheological model for all purple basil sherbet samples concentrated at different SSC% content. For all sherbet samples, the consistency coefficient values tended to increase depending on the increase in the SSC%. It was observed that the flow behavior index (n) values of purple basil sherbet samples were above 1 under all processing conditions, in other words, they showed a dilatant flow behavior index. It is thought that this study will fill the lack of information needed to determine the changes in the rheological properties of basil syrup samples concentrated by ohmic heating assisted evaporation under atmospheric conditions. In addition, it is thought that the results of the study will provide valuable data in the design of industrial-scale evaporation systems.

## Conflict of interest

The authors of the paper declare that there is no conflict of interest.

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