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# INVESTIGATING THE RHEOLOGICAL AND PHYSICAL BEHAVIORS OF YOGURT DURING STORAGE

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**ABSTRACT**

As a popular fermented dairy product, yogurt enjoys a special status among the consumers and, therefore, its quality is the great interest. Investigating the viscosity, physical properties and color of yogurt in the storage time are the necessary step for improving its quality. The aim of this study is to explore the changes of $L^*$and viscosity of yogurt with the changes of variables like temperature, loading speed, type of yogurt and storage period. These tests have been performed by using of axial test to measured viscosity, as a new method, on two types of yogurts, low-fat (1% fat) and high-fat (4.2% fat). The tests were performed at loading speeds of 40, 60 and 80 *mm*/*min* and temperatures of 4 and 25 ºC. The backward extrusion axial test device and the cyclic method have been employed to determine the viscosity of yogurts. The variance analysis results related to the data of $L^*$and yogurt viscosity became significant at a probability level of 1% for the main effects and some of interaction. By increasing the loading speed, a decreasing trend in viscosity was observed. Both yogurt types had a higher viscosity at the temperature of 4 ºC than at 25 ºC. The storage period didn't have a steady and consistent influence on viscosity. The viscosity of high-fat yogurt was greater than the viscosity of low-fat yogurt at both temperatures of 4 and 25 ºC

## 1.Introduction

Yogurt is one of the most extensively used fermented milk productions, which due to its high nutritional value has a significant effect on human health, and enjoys a special dietary status. In Iran, 833 units are involved in yogurt production and produce about 1.9 million tons of yogurts per year (Karazhyan and Salari, 2012). Yogurt is produced through the fermentation of some milk components by certain microorganisms. From a nutritional standpoint, yogurt is one of the best milk products. Due to its high amounts of calcium, vitamins, minerals, low fat content, and because of its favorable effect on health and longevity, yogurt has become a popular product for general public (Kowalski et al., 2000; Rosemont, 1990). Hence, yogurt is an excellent food product; and in the regions where people do not receive sufficient protein, yogurt can be the best supplementary product. Nowadays, various types of yogurts are produced in the dairy industry, including the low-fat and high-fat, probiotic, drinkable and frozen yogurts (Aqdaei et al., 2010; Fiszman et al, 1999).

In the rheological classification of foodstuff, yogurt is classified among the semisolid materials with thixotropic properties (Khalifeh et al., 2013). In order to control the texture quality and the useful shelf life of foodstuffs and also to design the relevant processing equipment, it is necessary to know the rheological properties of these materials. Fluids such as air and water exhibit simple behaviors which are independent of performed processes on them; while foodstuffs are more complex and their flow behavior may depend on earlier processes that have been carried out on them and the storage period times (Basim and Mohameed, 2006). The rheological properties and the textures of the fermented milk products are influenced by the initial combination of the raw milk, amount of dry material, heat treatment, type of the starting culture, incubation temperature, initial milk viscosity, fermentation kinetics and homogenization, on the other hand the properties of some milk productions like yogurt dependent on fat content, storage temperature, storage time etc. (Hardi and Slacanac, 2000; Jumah et al., 2001). An important issue regarding yogurt quality is the preservation of its nutritional properties as well as its physical, textural and sensory characteristics during the storage period. It has been realized that some changes occur in pH and acidity of yogurt during storage. These changes are closely related to the sensory changes and the fluidity behavior of yogurt (Karsheva et al., 2013). Studying the behavior of yogurt enables producers and marketer to predict the properties of the final products. To be able to estimate the rheological behavior of yogurt, an appropriate rheological behavior has to be selected (Mullineux and Simmons, 2008).

Recently some of researchers are focused on properties of dairy productions that mentioned here: the physical and chemical parameters and the rheological properties of yogurt during storage were investigated by Karsheva et al. (2013). In this research the effects of storage time on the pH, acidity, lactic acid concentration, and number of microorganisms, gel firmness and the rheological parameters of yogurt were measured. Yuguchi et al. (1989) performed cyclic tests on yogurt by using a stretching and pressing apparatus for foodstuffs, and obtained some of the yogurt properties including adhesiveness, firmness and cohesion. The effect of storage time on yogurt fluidity was analyzed and modeled by Basim et al. (2006) by means of a rotational viscometer. The samples were evaluated during 14 days of storage. The apparent viscosity was measured as a function of shear rate.

The effects of hydrostatic pressure on the rheological and textural properties of low-fat probiotic yogurts prepared from different starters were explored and evaluated by Penna et al. (2006). The rheological characteristics of low-fat, high-fat and sheep milk yogurts were investigated by Khalifeh et al. (2013). The chemical, organoleptic and rheological properties of two types of yogurts made from fresh cow milk and dry milk formula during a storage period of 21 days were evaluated by Karazhyan and Salari (2012). The power law model was selected to describe the flow behavior of these samples.

The aim of this research was to determine the effects of factors like storage period, storage temperature, fat content (%) and loading speed on yogurt viscosity and color. The novelty of this study was used of axial test device and backward extrusion technique to measuring viscosity of yogurts.

## 2.Materials and methods

In this study, two types of yogurt samples, low-fat (1% fat) and high-fat (4.2% fat), produced by the Iran's dairy company (*Pegah*) were obtained. The high-fat yogurt produced by Fresh cow milk, pasteurized cream and mixed lactic starter (*Lactobacillus* of *bulgaricus* species, *Esther Ptukukus salivarius* of *thermophilus* species), low fat yogurt produced by Fresh cow milk and the same starter. In order to prevent any type of shaking during transportation, the 1.0 kg samples were carefully packed in special containers. Then the packaged yogurts were transferred to a cold room at a temperature of 4 ºC and with 65% relative humidity. The viscosity of the samples measured by means of the axial test device (Bbt1-Fro.5th.D14, Made in Germany) equipped with a force gauge (X Force Hp nominal Force: 500 N Capacity) and backward extrusion method in 3 cycle (Fig. 1).

In this experiment, a cylindrical probe with a 40 mm diameter was inserted into a cylinder with a 50 mm diameter and 60 mm height. Cylinder filled with yogurt up to a height of 40 mm. The probe was advanced to a depth of 30 mm (Fig. 1B) and then it was moved in reverse up to a certain height and this cyclical (reciprocating) movement with a course length of 30 mm was terminated in three cycles. The moving speeds of the probe were selected as 40, 60 and 80 mm/min and the penetration depth of the piston into the cylinder was chosen as 30 mm from the yogurt surface. In general, each type of yogurt was tested using combinations of the loading speeds and temperatures of 4 and 25 ºC and with three iterations for each test condition. The samples were evaluated at temperatures of 4 and 25 ºC and on the 1st, 7th, 14th and 21st days of the storage period. Eq.1 was used to determine the apparent viscosity of the yogurt samples with the backward extrusion method.

$$\eta = \frac{P\times(r_c - r_p)^3\times(r_c + r_p)}{6\times h\times(r_c^{\,2} + r_p^{\,2})\times V_P} \qquad (1)$$

Where η is viscosity (Pa.s), P is pressure (N/m$^2$), $r_c$, $r_p$ and h are radius of the container, radius of the piston and height of the piston (mm) respectively, and $V_P$ is piston speed (mm/min).

The colors of the samples were measured by using a portable colorimeter (Model HP-2 made by China) at L$^*$, brightness, (a$^*$) redness-greenness and (b$^*$) blueness-yellowness values as color scales.

The mentioned device was calibrated by standard black and white plates. Before conducting the tests, the yogurt samples were kept at two temperature levels of 4 and 25 ºC.

In this research, data were analyzed by the factorial test in a totally random format, the effects of parameters like yogurt types, temperature levels and penetration speed of the probe on brightness (L$^*$) and viscosity were investigated.

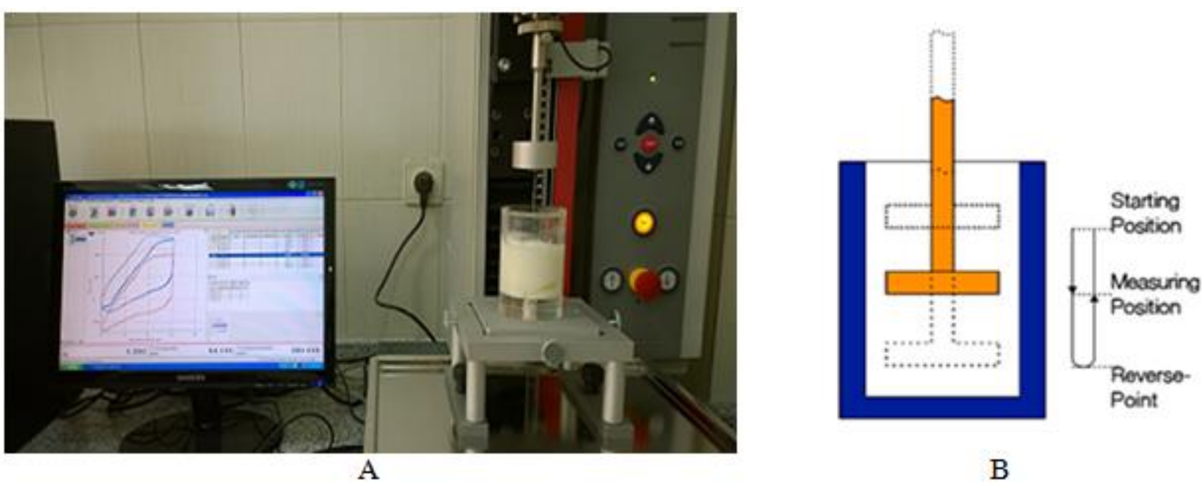


**Figure 1. A-** Universal testing machine, **B-** a schematic of the sample under loading

After determining the properties of each sample, the obtained data were normalized by means of the SPSS (19) software program and provided to determining the error variance. Also, the factorial test was employed to determine the effects of the independent variable on the dependent variables.

## 3.Results and discussions

The variance analysis results for the effects of temperature, loading speed, yogurt type and storage period on L$^*$ and viscosity of yogurt have been presented in Table 1. For L$^*$, the main effects of the yogurt types, temperature and storage duration and some of the mutual effects became significant at a probability level of 1%. Also, in view of the variance analysis table, yogurt type, temperature, loading speed and storage duration, and mutual effect of yogurt type and pressing speed have significant effects (1%) on yogurt viscosity.

**Table 1.** Analysis of variance (mean square) for effects of temperature, yogurt type, day and loading speed of probe.

| Source of variations | Degree of freedom | Sources mean-square | |
|---|---|---|---|
| | | Color index ($L^*$) | Viscosity |
| Yogurt Type | 1 | 445.94** | 905.83** |
| Temperature | 1 | 148.72** | 1339.96** |
| Day | 3 | 98.7** | 126.7 |
| Loading speed | 2 | 0 | 4776.09** |
| Type × Temperature | 1 | 165.9** | 25.52 |
| Type × Day | 3 | 404.4** | 47.61 |
| Type × Loading speed | 2 | 0 | 138.8** |
| Temperature × Day | 3 | 284.8** | 38.5 |
| Temperature × Loading speed | 2 | 0 | 24.16 |
| Day × Velocity | 6 | 0 | 102.3 |
| Type × Temperature × Day | 3 | 1384.1 | 71.2 |
| Type × Temperature × Loading speed | 2 | 0** | 8.32 |
| Type × Day × Loading speed | 6 | 0 | 18.61 |
| Significant at 1% of probability levels** | | | |

The force-displacement diagram (high-fat yogurt, 1st day of the storage period and temperature of 25 ºC) obtained with the backward extrusion test by using the cyclic method has been illustrated in Fig. 2, as an example. Table 2 shows the changes in the viscosities of low-fat and high-fat yogurts at temperatures of 4 and 25 ºC throughout the storage period. Viscosity has increased by fat content increasing, so that the maximum amount of viscosity is observed in the high-fat sample at a loading speed of 40 mm/min and the least amount of viscosity was seen in the low-fat sample at a loading speed of 80 mm/min.

**Table 2.** Changes in the viscosities of low-fat and high-fat yogurts during the storage period at temperatures of 4 and 25 ºC.

| Yogurt type | Velocity loading | Viscosity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 4 | | | | 25 | | | |
| | | 1 | 7 | 14 | 21 | 1 | 7 | 14 | 21 |
| Low fat | 40 | 31.8± 1.2 | 32.3± 1.5 | 34.7± 1.4 | 31.6± 1.75 | 25.8 ± 1.87 | 24.42± 1.58 | 28.22± 1.47 | 26.9± 1.87 |
| | 60 | 28.53± 1.5 | 27.14± 2.5 | 25.6± 0.5 | 21.9 ± 1.57 | 15.8 ± 0.67 | 13.32± 1.45 | 26.85± 1.57 | 18.03± 1.47 |
| | 80 | 19.59± 0.9 | 14.7± 2.1 | 17.9± 1.89 | 17.18± 1.64 | 12.3± 2.15 | 10.9± 1.87 | 12.7± 1.47 | 10.5± 1.32 |
| High fat | 40 | 35.33± 1.42 | 46.2 ± 1.54 | 46.4± 1.87 | 47.7 ± 1.87 | 35.09± 1.57 | 31.05± 1.54 | 33.73± 1.45 | 36.4± 1.54 |
| | 60 | 29.81± 1.2 | 29.3 ± 1.87 | 34.7± 1.57 | 28.8 ± 1.88 | 21.4± 1.54 | 19.42± 1.78 | 21.2± 1.64 | 23.3± 1.34 |
| | 80 | 25.65± 1.17 | 20.5 ± 1.25 | 23.1± 0.84 | 21.8 ± 1.24 | 15.6± 1.24 | 14.83± 1.47 | 16.96± 1.54 | 18.2± 1.54 |

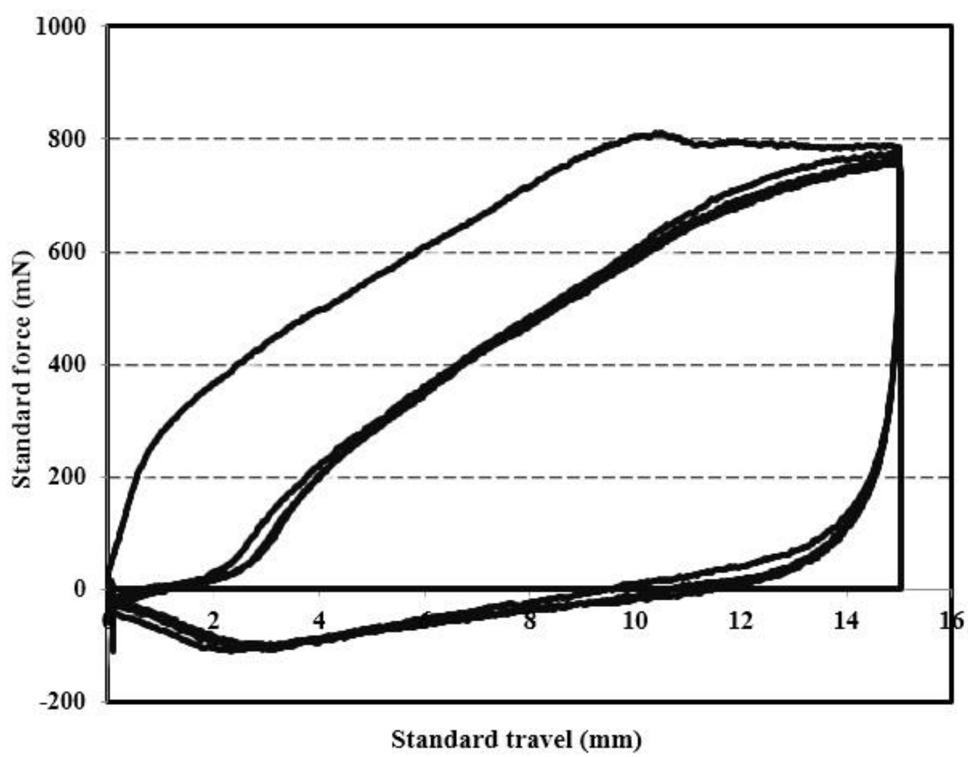


**Figure 2.** Force-displacement (yogurt, day and temperature 25 °c) in the extrusion test beck ward

### 3.1. Viscosity

Viscosity is influenced by numerous factors such as the special constituent compounds of fat and stabilizer, type and quality of components, the processing mechanism of the mixture, concentration and temperature (Rezaei et al., 2011). The statistical analysis results showed that the storage period didn't have a significant effect on viscosity; while the loading speed, temperature and the type of yogurt had a significant effect on viscosity at a probability level of 1% (Table 1). Fig. 3 shows the viscosity-loading speed diagram for the low-fat and high-fat yogurts at the 4 ºC. According to this diagram, yogurt viscosity decreased by increasing the compressing probe speed.

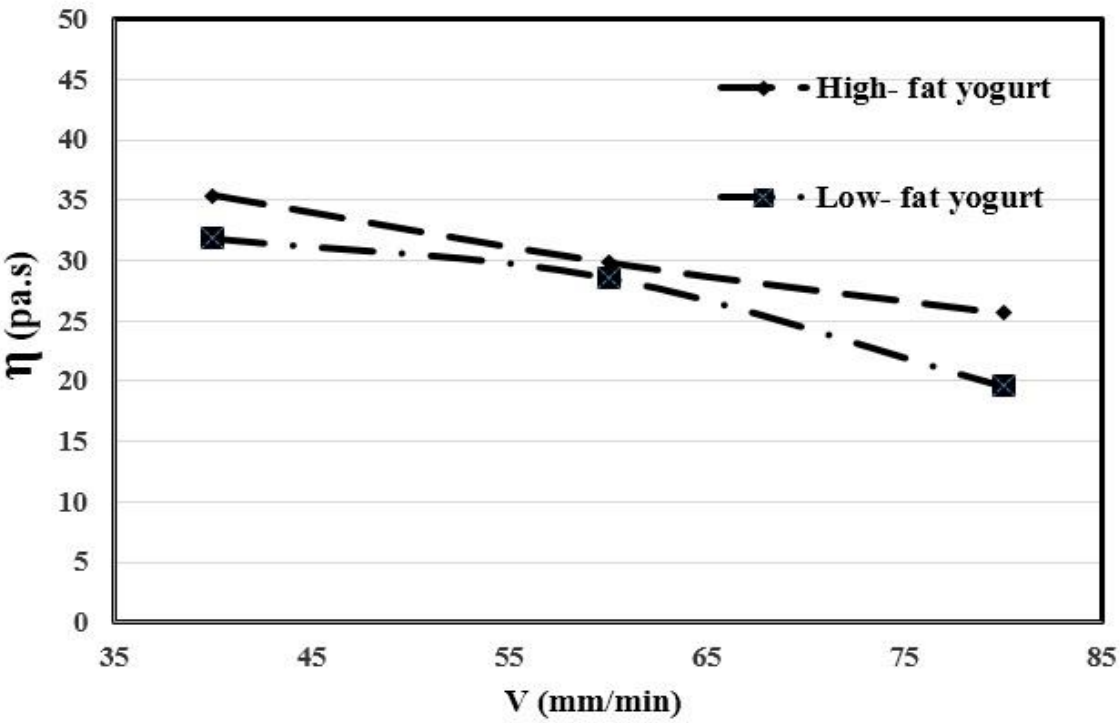


**Figure 3.** Effect of loading speed on the viscosity of yogurt samples at the 4 ºC temperature

The main effects (yogurt type, temperature and loading speed) and the mutual effects (yogurt type × loading speed) became significant on viscosity at a probability level of 1% (table 1); while other mutual effects did not have a significant influence on viscosity at the 1% probability level.

The diagram of experimental values versus predicted values by the regression model have been illustrated in Fig 4. According to this figure, there is an acceptable correlation ($R^2$ = 0.83) between the experimental and predicted values of viscosity. The models for the effects of variables on viscosity have been presented in Table 3. As indicated by the model coefficients, the loading speed and the temperature have a negative effect on viscosity, while temperature is more effective than loading speed; temperature increasing has a higher influence on the reduction of viscosity. The higher fat content has a positive influence on viscosity, and the increasing in fat content raises the viscosity of the samples. Similar results have been reported by Augustin et al. (1999). They reported when fat content increased, the amount of syneresis decreased in the samples, and then textural properties improved. The improvement of textural properties with the increasing of fat content may be due to the increasing in the total amount of dry matter and consequently may make the product firmer and raises its viscosity, because a greater amount of dry matter makes the gel lattice more stable and increases the water bonding capacity.

**Table 3.** Multiple regression equation of the "Viscosity" relation to velocity (V), day (D), temperature (T) and yogurt type (Ty) as independent variables.

| **Model*** | $R^2$ |
|---|---|
| Viscosity = (-0.266 × V) - ( 0.366× T ) + (12.68 × Ty) – (0.109 × Ty × V) + 37.04 | 0.83 |
| *: Minimum probability threshold P ≤ 0.01 | |

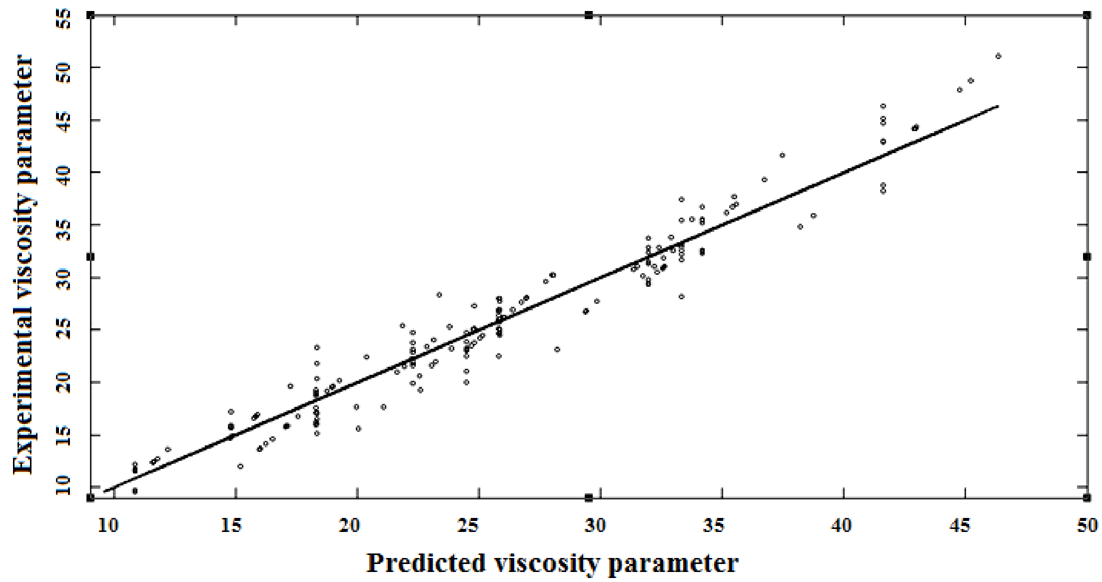


**Figure 4.** The predicted values of the viscosity parameter, "η" (PA.S) versus viscosity parameter experimental

***3.1.1. Effects of loading speed and yogurt type on the viscosity of yogurt during storage at the 4 ºC temperature***

In view of Table 1, also at storage temperature of 4 ºC, the pressing speed of probe and yogurt type has a significant effect on the samples viscosity at a probability level of 1%. By evaluating the mean values and also consideration of Fig. 5, it is observed that, when the pressing speed of the probe throughout the storage period increased, the viscosities of the high-fat and low-fat yogurts decreased. In view of Fig. 6, at the 4 ºC temperature, when the pressing speed of the probe increased from 40 to 80 mm/min, the amount of low-fat yogurt viscosity decreased by 12.26, 17.6, 16.8 and 14.5%, respectively, for the 1st, 7th, 14th and 21st days of the storage period and the amount of high-fat yogurt viscosity decreased by 9.7, 25.4, 23.28 and 25.94% for the 1th, 7th, 14th and 21th days of the storage period, respectively.

The experimental results indicate that the high-fat samples have a higher viscosity than the low-fat samples. This increasing of viscosity is directly related to the increasing of mucilage concentration, because free water molecules in the samples bonded by the hydrocolloids. Akin et al. (2007) reported an increasing in the viscosity of yogurt and frozen yogurt by increasing in the concentration of inulin (as a stabilizer and fat substitute).

Among all the samples, the highest and lowest viscosities were observed in the high-fat samples at 4 ºC on the 21st day of the storage period and in the low-fat samples at 25 ºC on the 21st day of the storage period, respectively. With the prolongation of the storage period, the viscosities of the samples decreased, but this reduction did not have a consistent trend, which is due to the rearrangement of proteins and the changes occurring in the protein-protein bonds (Sahan et al., 2008). Similar findings were reported on this subject by Karsheva et al. (2013).

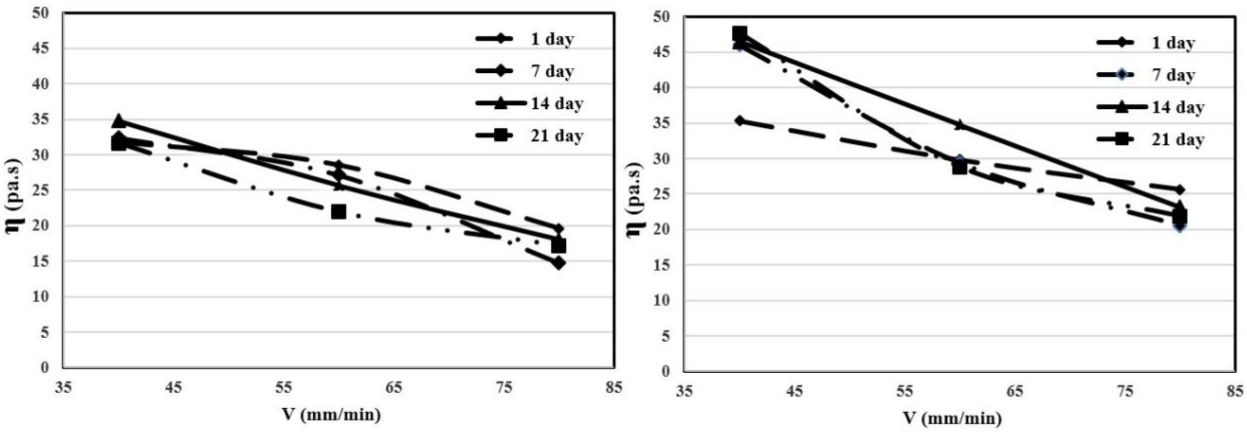


**Figure 5.** Changes in the viscosities of low-fat and high-fat yogurt samples during storage at the 4 ºC temperature

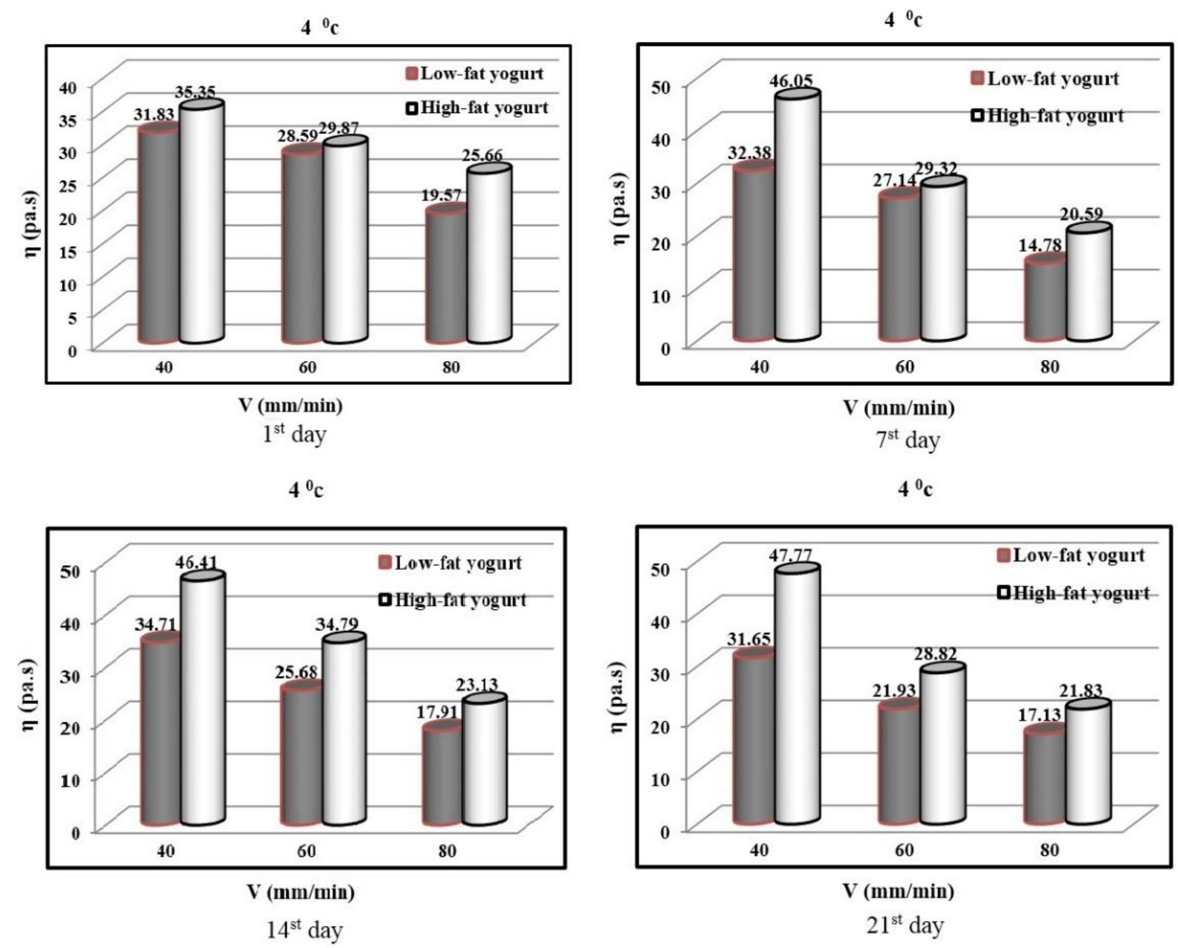


**Figure 6.** Effects of loading speed and yogurt type on the viscosity during storage period at the 4 ºC temperature

### *3.1.2. Effects of loading speed and yogurt type on the viscosity of yogurt during storage at the 25 ºC temperature*

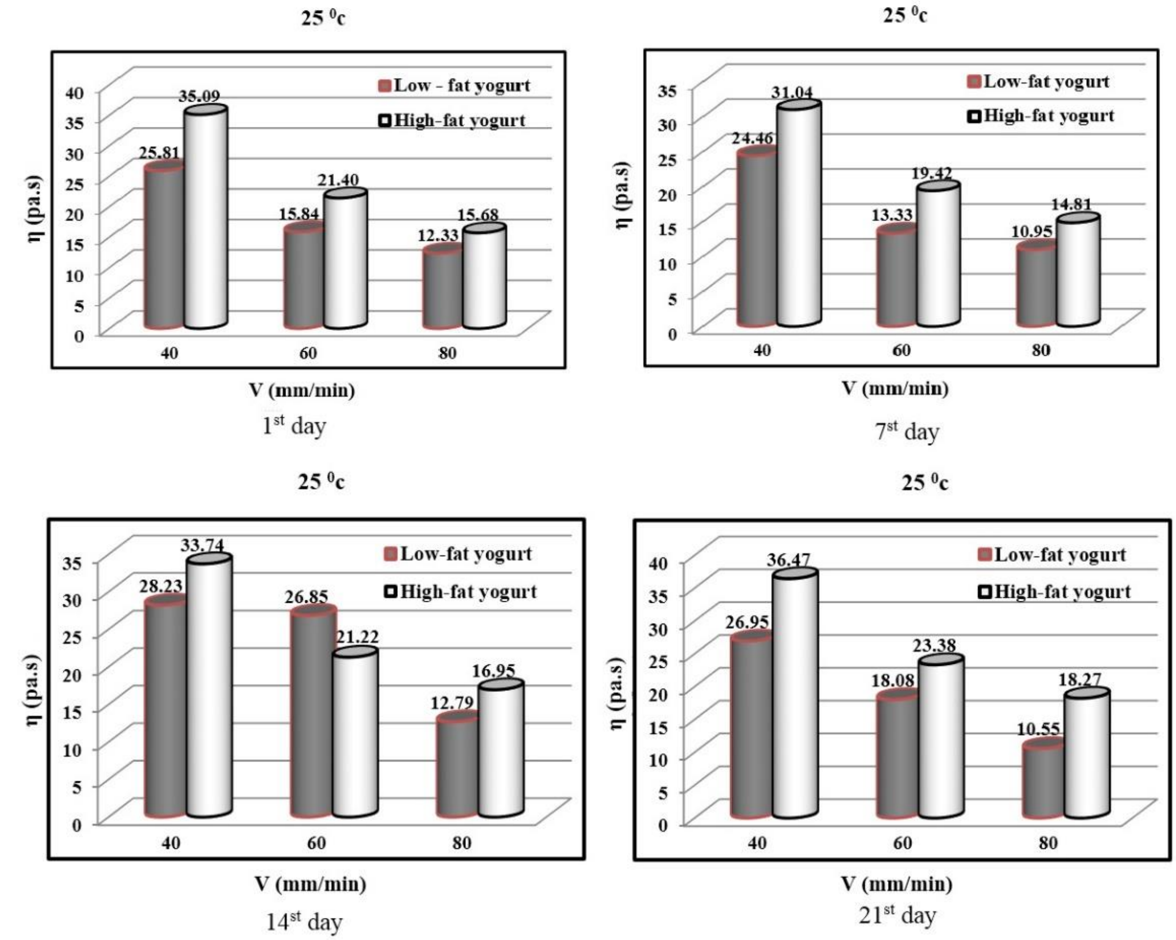


**Figure 7.** Effects of loading speed and yogurt type on the viscosity during storage period at the 25 ºC temperature

With regards to Table 1, at a storage temperature of 25 ºC, the pressing speed of probe and the yogurt type have a significant effect on the viscosity of samples at a probability level of 1%. By comparing the mean values, and in consideration of Fig. 7, it can be concluded that yogurt viscosity decreased with increasing in the pressing speed of the probe. According to Fig. 7, at the 25ºC temperature, with the increasing in pressing speed of the probe from 40 to 80 mm/min, the amount of low-fat yogurt viscosity decreased by 51.48, 13.13, 15.44 and 16.4%, respectively, for the $1^{st}$, $7^{th}$, $14^{th}$ and $21^{st}$ days of the storage period and the amount of high-fat yogurt viscosity decreased by 19.41, 16.23, 16.52 and 18.2% for the $1^{st}$, $7^{th}$, $14^{th}$ and $21^{st}$ days of the storage period, respectively. Viscosity decreased with increasing in the loading speed, which is probably due to the breakup of yogurt structure as a result of loading speed (Fig. 7). At a low loading speed, viscosity is the cause of foodstuff consolidation, while at a high loading speed; the amount of viscosity indicates a product's viscosity at various stages of the process (Morris and Taylor, 1982). The semi-solid texture of yogurt is due to the development of a 3D protein matrix during the fermentation process (Hassan et al., 1996). In both samples, viscosity decreased with the increasing in the loading speed. Therefore, both samples display a softening behavior when the loading speed increased, which could be due to the breakup of the gel structure as a result of different loading speeds (Ahmedna and Goktepe, 2007) and also due to a weakened interaction between the yogurt's lattice structures (Mohammeed et al., 2004). Similar findings have also been reported by Morris et al. (1982) under shearing conditions.

In general, under all circumstances, measurement viscosity of the high-fat yogurt was more than the viscosity of low-fat yogurt. Mohammeed et al. (2004) reported the same results, that increasing in yogurt total solid matter (fat content) has direct relation with viscosity. They stated that the increasing in the total solid matter of yogurt has definite effects on the increasing of viscosity; so that a sample with a higher amount of solid matter has a greater consolidation coefficient and a lower index (Mohammeed et al., 2004). Increasing the storage temperature of the samples from 4 to 25 ºC under similar conditions caused a dropping in the viscosity of these samples.

### 3.2. Effects of yogurt type, temperature, probe pressing speed, and storage period on $L^*$

**Table 4.** Multiple regression equation of the "Color Index" relation to velocity (V), day (D), temperature (T) and yogurt type (Ty) as independent variables.

| **Model*** | $R^2$ |
|---|---|
| Color = (0.336 × D) + (0.274 × T) – (7.29 × Ty) – (0.109 × Ty × V) – (0.014 × T × D) – (0.005 × T × V) + (0.003 × Ty × V × D) + 71.45 | 0.67 |
| *: Minimum probability threshold $P \leq 0.01$ | |

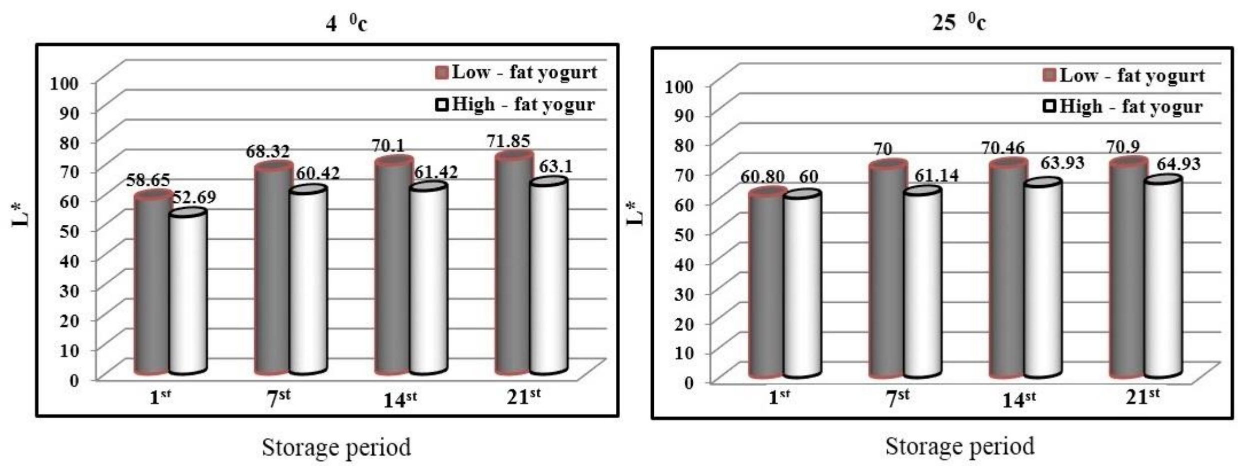


**Figure 8.** Effects of yogurt type, temperature and storage period on L*

Table 1 shows the results of variance analysis for the effects of factors like temperature, pressing speed of probe, yogurt type, and storage duration on L* of yogurt. The main effects (yogurt type, temperature, and storage period) and the mutual effects (yogurt type × temperature, storage period × yogurt type, storage period × temperature and yogurt type × temperature × pressing speed of probe) have significant relationship on the $L^*$ at a probability level of 1%.

The presented models for the effects of variables on $L^*$ have been shown in table 4. As the model coefficients indicate, temperature and storage time have a positive effect on $L^*$, while storage time has a greater influence on the increasing of $L^*$. The effect of yogurt type is negative; and increasing in the fat percentage caused a reduction in $L^*$. The model coefficients have been listed in Table 4.

By comparing the mean values, and in consideration of Fig. 8, it can be concluded that yogurt L* increased with increasing in the temperature and storage period. According to Fig. 8, at the 4ºC and 25ºC temperature, with the increasing in storage period from 1st to 21st, the amount of low-fat yogurt L* increased by 22.5% and 16.6%, respectively. According to Fig. 8, at the 4ºC and 25ºC temperature, with the increasing in storage period of from 1st to 21st, the amount of high-fat yogurt L* increased by 19.75% and 8.21%, respectively. As well as L* decreased with the increasing in the fat percentage (Fig. 8). L* Index indicates the brightness of food samples. The brightness of milk is due to the presence of colloidal particles such as fat corpuscles and Casein micelles and it has a favorable effect on consumer acceptance (Garcia et al., 2005). Then as previously was mentioned, the increasing of fat content reduced the L* index in yogurt samples. Similar results have also been presented by Garcia et al. (2005), which showed that by adding hydrocolloids to yogurt samples, the L* index has decreased. Staffolo et al. (2004) have reported a dropping in the brightness index with the addition of fiber to the samples, too.

## 4.Conclusions

In this research, the parameters of L* and yogurt viscosity were investigated. Also, the effects of two temperature levels (4 and 25 ºC), three pressing speeds of the probe (40, 60 and 80 mm/min), two types of yogurts (low-fat and high-fat) and the storage duration (21 days) on L* and yogurt viscosity were evaluated. Some of the main and mutual parameters had a significant effect on L* and yogurt viscosity at a probability level of 1%.

The results of the parameters effects on L* and yogurt viscosity (η) can be summarized as follows:

The increasing of probe speed was leads to the reduction of yogurt viscosity.

Yogurt viscosity generally was increased by the reduction of temperature from 25 to 4 ºC.

The storage duration did not have a significant influence on yogurt viscosity.

At both temperatures (4 and 25 ºC), the low-fat yogurt viscosity was less than the high-fat yogurt viscosity.

The high-fat yogurt had a smaller L* index compared to the low-fat yogurt.

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