Turkish Journal of Agriculture and Forestry

Volume 38 | Number 3 Article 11

1-1-2014

Microbiological, steady, and dynamic rheological characterization of boza samples: temperature sweep tests and applicability of the Cox-Merz rule

MUHAMMET ARICI

NEVRUZ BERNA ERSÖZ

ÖMER SAİD TOKER

MUSTAFA TAHSİN YILMAZ

HASAN CANKURT

See next page for additional authors

Recommended Citation

ARICI, MUHAMMET; ERSÖZ, NEVRUZ BERNA; TOKER, ÖMER SAİD; YILMAZ, MUSTAFA TAHSİN; CANKURT, HASAN; DURAK, MUHAMMED ZEKİ; and SAĞDIÇ, OSMAN (2014) "Microbiological, steady, and dynamic rheological characterization of boza samples: temperature sweep tests and applicability of the Cox-Merz rule," *Turkish Journal of Agriculture and Forestry*: Vol. 38: No. 3, Article 11. https://doi.org/10.3906/tar-1304-38
Available at: https://journals.tubitak.gov.tr/agriculture/vol38/iss3/11

Microbiological, steady, and dynamic rheological characterization of boza samples: temperature sweep tests and applicability of the Cox-Merz rule

Authors

MUHAMMET ARICI, NEVRUZ BERNA ERSÖZ, ÖMER SAİD TOKER, MUSTAFA TAHSİN YILMAZ, HASAN CANKURT, MUHAMMED ZEKİ DURAK, and OSMAN SAĞDIÇ

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2014) 38: 377-387
© TÜBİTAK
doi:10.3906/tar-1304-38

Microbiological, steady, and dynamic rheological characterization of boza samples: temperature sweep tests and applicability of the Cox–Merz rule

Muhammet ARICI[1,*], Nevruz Berna ERSÖZ TATLISU[1], Ömer Said TOKER[1,2], Mustafa Tahsin YILMAZ[1], Hasan CANKURT[3], M. Zeki DURAK[1], Osman SAĞDIÇ[1]

[1]Department of Food Engineering, Faculty of Chemical and Metallurgical Engineering, Yıldız Technical University, İstanbul, Turkey
[2]Department of Food Engineering, Faculty of Engineering, Iğdır University, Iğdır, Turkey
[3]Department of Food Technology, Safiye Çıkrıkçıoğlu Vocational College, Erciyes University, Kayseri, Turkey

Received: 10.04.2013 • **Accepted:** 02.09.2013 • **Published Online:** 14.03.2014 • **Printed:** 11.04.2014

Abstract: Boza is a beverage produced by lactic acid bacteria (LAB) and yeast, which affects rheological properties. In the present study, boza samples collected from a local market were characterized with reference to microbiological and rheological approaches. The boza samples were characterized with respect to their microbiological population, i.e. the numbers of LAB and yeast. The numbers of LAB and yeast were found to range from 2.88×10^6 to 2.06×10^{10} CFU/mL and from 3.71×10^3 to 9.40×10^5 CFU/mL, respectively. Their steady and dynamic rheological properties were investigated within the temperature range of 0–50 °C. Apparent viscosity values (η) of the boza samples decreased with shear rate, indicating that the samples behaved as a pseudoplastic fluid. The Ostwald–de Waele model satisfactorily described ($R^2 > 0.99$) the flow behavior of the samples at 5 and 20 °C. Storage modulus (G') values were higher than loss modulus (G''), indicating that boza samples had a solid-like structure. Temperature had a remarkable effect on the steady and dynamic properties of the samples; therefore, temperature sweep tests were also conducted to determine temperature dependency of the samples. The η_{50}, G', and G'' values decreased with increase in temperature. The Arrhenius equation could be satisfactorily used to describe changes in these parameters depending on temperature. A modified Cox–Merz rule with shift factors ranging from 1.0 to 2.2 was successfully applied to put forward a relationship between steady shear and dynamic shear viscosity data.

Key words: Arrhenius, boza, Cox–Merz rule, dynamic and steady shear, temperature sweep

1. Introduction

Boza is a traditional fermented cereal (millet, maize, wheat, or rice flours) Turkish beverage produced by lactic acid bacteria (LAB) and yeast (Arici and Daglioglu, 2002) that is widely consumed in Turkey, Bulgaria, Albania, and Romania (Gotcheva et al., 2000). There are also boza-like products such as Kenyan busaa, South African kaffir beer, and Turkmen krimbusa (Hayta et al., 2001). Boza is a low acid and highly viscous beverage, usually consumed in winter months and generally served with white chickpeas and cinnamon. This beverage is usually stored at 4 °C; however, its shelf life is very short (10 days). When this drink is not consumed in due time, the product spoils and becomes undrinkable (Sanni, 1993; Blandino et al., 2003; Botes et al., 2007). On the other hand, it is a nourishing beverage because of its LAB microflora and protein, carbohydrate, mineral, fiber, and vitamin contents (Morcos et al., 1973). LAB have very important benefits for human health (Todorov et al., 2006) and elongate the shelf life of the product by producing antimicrobial compounds and bacteriocins (Deegan et al., 2006). LAB also improve the consistency and flavor of the product (De Vuyst and Vandamme, 1994; Ivanova et al., 2000). Moreover, LAB and several yeasts produce some compounds, such as vitamins, that improve the nutritional value of the product (Leroy and De Vuyst, 2004). In addition to the nutritional properties of boza, sensory and rheological properties are also crucial factors affecting consumer acceptability of product.

Rheology is important for determining a relationship between consumer preferences and stability of the product (Fischer and Windhab, 2011). It is also very important for the selection of proper design and process equipment, such as heat exchangers, pumps, and evaporators (Bourne, 1982; Ibanoglu and Ibanoglu, 1998). Moreover, rheological properties of foods are used in quality control of the product, including optimization of the formulation. The rheological characteristics of products are determined by

---

* Correspondence: muarici@yildiz.edu.tr

several techniques, such as dynamic and steady rheological measurements. The steady shear measurements are performed to determine flow behavior of a sample while the dynamic shear oscillatory measurements are conducted to provide information about the viscoelastic properties of the samples. In order to determine the storage modulus (G'), loss modulus (G''), complex modulus (G^*), and complex viscosity (η^*), a sinusoidal strain cycle was used in a dynamic test. It was indicated by previous studies that there was a correlation between steady shear and dynamic shear properties of macromolecular dispersions (Chun and Yoo, 2004). The Cox–Merz superposition rule is used to relate the complex dynamic shear viscosity (η^*) as a function of angular frequency (ω) to the steady shear flow viscosity (η) as a function of shear rate (γ), which has been experimentally confirmed for several macromolecular dispersions (Chun and Yoo, 2004). The hypothesis that steady shear viscosity might be predicted using a Cox–Merz rule or vice versa is also valid.

There are a couple of studies available on the rheological characteristics of several beverages and traditional products (Dogan et al., 2012; Goksel et al., 2012; Toker et al., 2012a). Furthermore, a very limited number of studies have been reported so far on the rheological properties of boza samples in the literature (Genc et al., 2001; Hayta et al., 2001). However, in these studies, only apparent viscosity values were tested by using a rotational viscosity; in order to perform a full rheological characterization of this product, viscoelastic properties in addition to steady shear properties should also be reported. Temperature is a very important parameter affecting rheological properties. Therefore, it is also important to determine how significantly steady and dynamic shear properties would be affected by temperature.

As mentioned above, boza is a beverage produced by the activity of LAB and yeast; the rheological properties are considerably affected by the activity of these organisms. Therefore, the aims of the present study were: 1) to determine microbiological populations, 2) to test steady and dynamic rheological properties, 3) to evaluate the effect of temperature on the steady and dynamic shear properties, and 4) to apply a modified Cox–Merz rule to correlate steady shear properties with dynamic shear viscosities of boza samples.

2. Materials and methods

2.1. Materials

In this study, various boza samples were randomly collected from local markets and bazaars in the cities of İstanbul and Tekirdağ in Turkey.

2.2. Microbiological analyses

Approximately 5 mL of each boza sample was taken under aseptic conditions and placed in 45 mL of peptone water solution (0.1%). After preparation of appropriate dilutions, 200 µL of each dilution was plated on specific media for viable cell counts. LAB were counted on De Man, Rogosa, and Sharpe Agar (Oxoid CM 361) after the plates were incubated at 30 °C for 72 h (Sharpe et al., 1966). Yeasts were enumerated after incubation at 25 °C for 5 days on Dichloran Rose Bengal Chloramphenicol Agar (Oxoid CM 727) (Kocabaş and Karapınar, 1993). All analyses were carried out in triplicate with 2 replications.

2.3. Rheological analyses

2.3.1. Steady shear properties

A stress- and strain-controlled rheometer (Anton Paar, MCR 302, Austria) equipped with a Peltier heating system was used for the determination of rheological properties of the boza samples. The samples were sheared using a plate-plate configuration (diameter 50 mm, gap 0.5 mm). The measurements were carried out in the shear rate range of 1–100 s^{-1} at 2 temperature levels, 5 and 20 °C. After placing 2.25 mL of sample on the plate, the measurement started immediately. Each measurement was replicated with 3 repetitions. The apparent viscosity was determined as a function of shear rate. The relation between shear rate and shear stress was explained by the Ostwald–de Waele model; therefore, the consistency coefficient (K) and flow behavior index values (n) were calculated according to the following equation:

$$\sigma = K\gamma^{\eta}, \tag{1}$$

where σ is the shear stress (Pa), K is the consistency coefficient (Pa s^n), γ is the shear rate (s^{-1}), and n is the flow behavior index (dimensionless).

2.3.2. Dynamic shear properties

Stress and frequency sweep tests were conducted using a dynamic oscillatory shear rheometer (Anton Paar, MCR 302). Dynamic rheological properties were measured by using a plate-plate configuration (plate diameter 50 mm, gap 0.5 mm). The amplitude sweep test was performed at 1 Hz between 0.1% and 10% strain to determine linear viscoelastic region. The frequency sweep test was performed at a 1% strain, as determined by the amplitude sweep test, over a frequency range of 0.1–10 Hz at 5 and 20 °C. The equations of complex modulus G^* (Gunasekaran and Ak, 2000) and complex viscosity η^* were used to characterize the overall response of the sample to the sinusoidal strain.

$$G^* = [(G')^2 + (G'')^2]^{1/2} \tag{2}$$

$$\eta^* = G^*/\omega \tag{3}$$

A nonlinear regression was applied to the plots of ω versus G' and G'' dynamic rheological data to calculate magnitudes of intercepts (K', K'', and K^*), slopes (n', n'', and n^*), and R^2 according to the following equations (Rao and Cooley, 1992; Yoo and Rao, 1996):

$$G' = K'(\omega)^{n'}, \tag{4}$$

$$G'' = K''(\omega)^{n''}, \tag{5}$$

$$\eta^* = K^*(\omega)^{n^*-1} \ . \tag{6}$$

2.3.3. Effect of temperature and applicability of Cox–Merz rule

In order to observe the variation in the steady and dynamic shear parameters depending on temperature, a temperature sweep test was also conducted at a shear rate of 50 s^{-1} and 1 Hz, respectively, at temperature levels ranging between 0 and 50 °C. The variations in the η_{50}, G', and G'' values with temperature were determined using the Arrhenius equation, as follows (Rao, 1999):

$$\eta_{50} = \eta_0 \exp\left(E_\alpha / RT\right), \tag{7}$$

$$G' = G_0 \exp\left(E_\alpha / RT\right), \tag{8}$$

$$G'' = G_1 \exp\left(E_\alpha / RT\right), \tag{9}$$

where η, G_0, and G_1 values are the constant parameters of η_{50}, G', and G''; E_a is the activation energy; R is the gas constant; and T is the temperature (in Kelvin).

The Cox–Merz rule was used to correlate the values of oscillatory shear parameters [complex viscosity (η^*) and angular frequency (ω)] and steady shear parameters [apparent viscosity (η) and shear rate (γ)] (Rao and Tattiyakul, 1999; Gunasekaran and Ak, 2000; Juszczak et al., 2004). The Cox–Merz rule can also be used to estimate steady shear viscosity from complex shear viscosity and vice versa (Steffe, 1996).

$$\eta^*(\omega) = \eta(\gamma)\big|_{\omega=\gamma} \tag{10}$$

In the present study, a modified Cox–Merz rule was performed as the following equation (Augosto et al., 2012).

$$\eta^*(\alpha * \omega) = \eta(\gamma)\big|_{\omega=\gamma} \ \eta^*(a * \omega) = \eta(\gamma)\big|_{\omega=\gamma} \tag{11}$$

3. Results

3.1. LAB and yeast populations in boza samples

Table 1 indicates the pH values, LAB, and yeast populations of 9 boza samples. As can be seen here, pH values of the boza samples ranged between 3.19 and 3.99. As can also be seen from Table 1, LAB and yeast numbers ranged from 2.88×10^6 to 2.06×10^{10} CFU/mL and from 3.71×10^3 to 9.40×10^5 CFU/mL, respectively.

Table 1. pH, LAB, and yeast count value of the boza samples.

Boza samples	pH	LAB number (CFU/mL)	Yeast number (CFU/mL)
S1	3.63	2.88×10^6	4.42×10^5
S2	3.99	0.51×10^8	1.23×10^4
S3	3.83	0.71×10^7	4.21×10^4
S4	3.68	0.56×10^9	2.86×10^4
S5	3.90	0.71×10^9	3.71×10^3
S6	3.81	1.27×10^9	9.40×10^5
S7	3.71	2.06×10^{10}	6.09×10^3
S8	3.19	0.54×10^{10}	4.02×10^3
S9	3.72	3.31×10^8	2.43×10^4

3.2. Rheological properties

3.2.1. Steady shear properties

Figure 1 shows the shear rate versus shear stress data for boza samples at 5 and 20 °C. As can be seen, shear stress values of the boza samples increased with an increase in shear rate, indicating that all the boza samples showed shear thinning behavior (Steffe, 1996; Rao, 1999; Sikora et al., 2007) at both temperature levels. The obtained data were described by an Ostwald–de Waele model with R^2 values higher than 0.99, which was in accordance with the previous studies (Genc et al., 2002; Zorba et al., 2003; Öztürk et al., 2013). The model parameters [namely, consistency coefficient (K) and flow behavior index (n)] of the boza samples at 5 and 20 °C are presented in Table 2. The n values were observed to range from 0.142 to 0.473 and from 0.132 to 0.465 at 5 and 20 °C, respectively. Regarding K values, they were determined to range from 10.64 to 40.92 Pa s^n and from 7.49 to 32.29 Pa s^n, respectively. Apparent viscosity (η_{50}) values of the boza samples measured at 50 s^{-1} (considered as shear rate in mouth; Bourne, 2002) are also shown in Table 2. The η_{50} values of 9 boza samples were in the range of 0.571–2.550 Pa s and 0.425–1.713 Pa s at 5 and 20 °C, respectively.

In addition to steady rheological properties, temperature sweep tests were also performed. Changes in η_{50} values as a function of temperature are seen in Figure 2, indicating that increase in temperature levels caused a decrease in η_{50} values. Similar behavior was revealed for different food materials in previous studies (Yilmaz et al., 2011; Toker et al., 2012b; Goksel et al., 2013). The Arrhenius equation was applied to determine the temperature dependency of η_{50} values. The constants of the models (η_0, E_a, and R^2 values) are presented in Table 3. The R^2 value of the established models ranged from 0.9637 to 0.9998, which

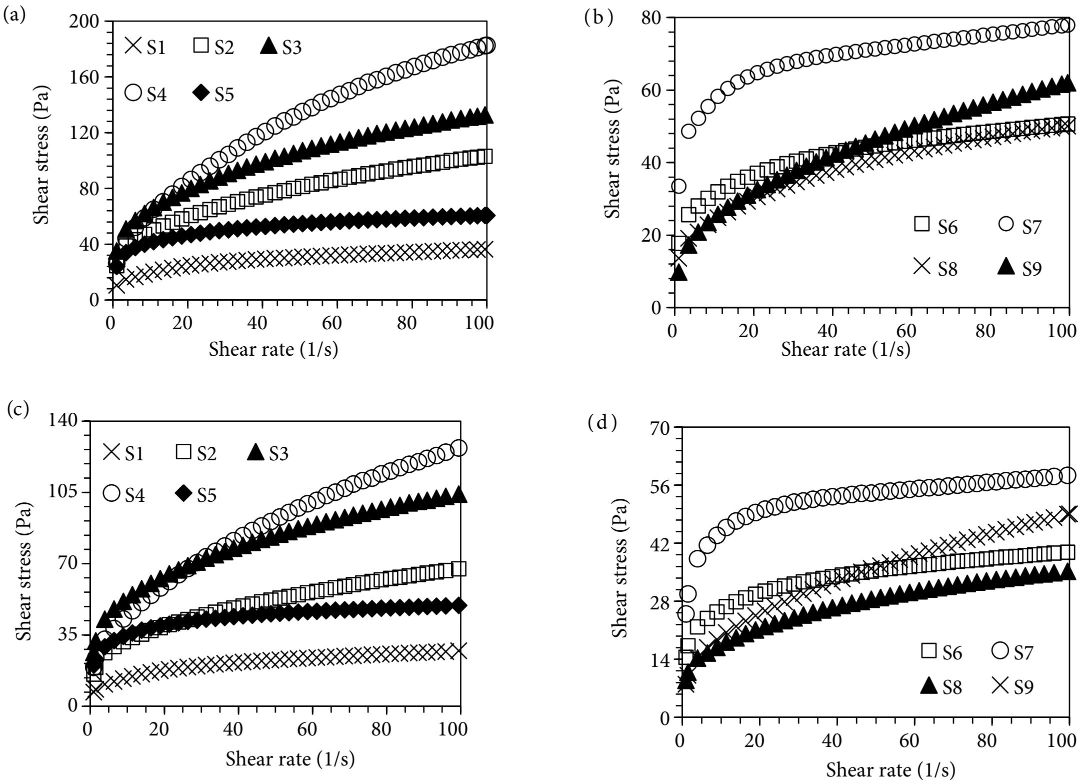

Figure 1. Shear rate versus shear stress plot of boza samples (S1–S9) at 5 °C (a, b) and 20 °C (c, d).

Table 2. Ostwald–de Waele parameters and η_{50} (apparent viscosity at shear rate 50 s^{-1}).

Temperature levels	Boza samples	Ostwald–de Waele parameters			η_{50} (Pa s)
		K (Pa s^n)	n	R^2	
5 °C	S1	10.64 ± 0.10	0.269 ± 0.000	0.9954	0.571 ± 0.004
	S2	19.87 ± 0.66	0.286 ± 0.005	0.9903	1.267 ± 0.012
	S3	33.03 ± 0.96	0.299 ± 0.002	0.9962	2.003 ± 0.031
	S4	16.18 ± 0.43	0.470 ± 0.004	0.9994	2.550 ± 0.040
	S5	23.32 ± 0.42	0.445 ± 0.004	0.9962	1.040 ± 0.061
	S6	31.65 ± 2.60	0.149 ± 0.005	0.9957	0.821 ± 0.017
	S7	19.46 ± 0.56	0.473 ± 0.006	0.9938	1.300 ± 0.010
	S8	40.92 ± 1.26	0.142 ± 0.009	0.9793	0.760 ± 0.005
	S9	13.17 ± 1.09	0.294 ± 0.009	0.9903	0.871 ± 0.049
20 °C	S1	7.46 ± 0.34	0.286 ± 0.005	0.9966	0.425 ± 0.013
	S2	16.25 ± 0.21	0.303 ± 0.003	0.9937	0.987 ± 0.023
	S3	27.47 ± 0.44	0.286 ± 0.007	0.9971	1.567 ± 0.023
	S4	13.66 ± 0.30	0.465 ± 0.002	0.9992	1.713 ± 0.047
	S5	17.08 ± 0.08	0.431 ± 0.002	0.9956	0.833 ± 0.017
	S6	23.63 ± 0.97	0.166 ± 0.005	0.9938	0.652 ± 0.009
	S7	16.69 ± 0.23	0.191 ± 0.004	0.9961	0.992 ± 0.059
	S8	32.29 ± 1.70	0.132 ± 0.003	0.9903	0.535 ± 0.003
	S9	9.01 ± 0.15	0.295 ± 0.003	0.9978	0.683 ± 0.005

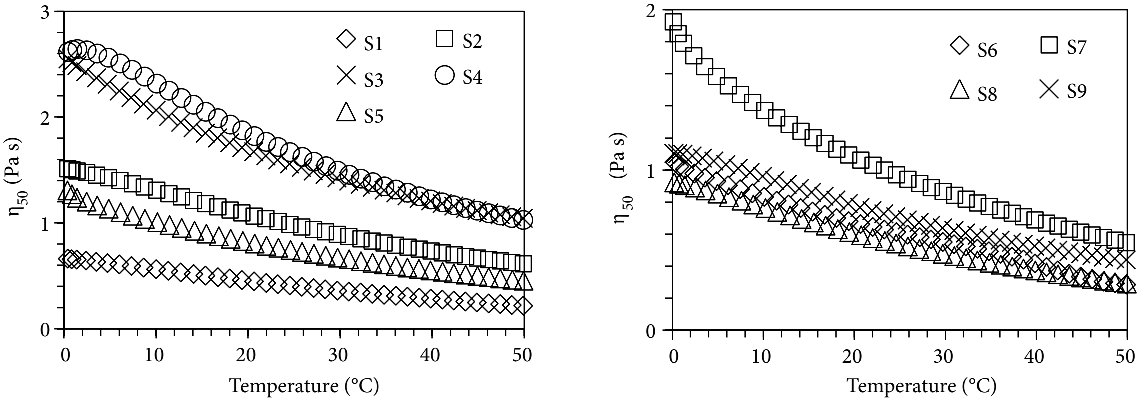

Figure 2. Temperature sweep tests indicating the effect of temperature on apparent viscosity value of boza samples (S1–S9) at shear rate 50 s^{-1} (η_{50}).

Table 3. Temperature dependency parameters of the steady and dynamic rheological parameters.

Boza samples	$\eta_{50} = \eta_0 \exp(E_a/RT)$			$G' = G_0 \exp(E_a/RT)$			$G'' = G_1 \exp(E_a/RT)$		
	η_0	E_a (kJ/mol)	R^2	G_0	E_a (kJ/mol)	R^2	G_1	E_a (kJ/mol)	R^2
S1	0.0056	10869	0.9980	5.65	4017	0.9515	0.20	9329	0.9925
S2	0.0206	9775	0.9965	26.08	3760	0.9573	1.13	8513	0.9788
S3	0.0052	14063	0.9998	64.61	1790	0.9122	4.83	5302	0.9941
S4	0.0490	9099	0.9637	8.86	5885	0.9835	1.91	7894	0.9891
S5	0.0010	16156	0.9946	86.03	1393	0.8017	0.24	10806	0.9895
S6	0.0018	14481	0.9979	19.96	3723	0.9307	1.89	6032	0.8710
S7	0.0007	17766	0.9988	42.40	2945	0.9334	0.80	9162	0.9900
S8	0.0040	12397	0.9970	8.09	5009	0.9764	0.11	12129	0.9885
S9	0.0159	9650	0.9902	2.32	6762	0.9893	0.40	9426	0.9870

indicated that these models might be satisfactorily used for prediction of η_{50} values as a function of temperature. As is seen, η_0 and E_a values were in the range of 0.0007–0.0490 and 9099–17,766 kJ/mol, respectively.

3.2.2. Viscoelastic properties of the boza samples

In order to determine the viscoelastic characteristics of the boza samples, frequency sweep tests were carried out at 1% strain (within the linear viscoelastic region). The G' and G'' values of the boza samples at 5 and 20 °C are presented in Figure 3. As can be seen, both G' and G'' values increased with frequency. G' values of the boza samples were found to be higher than the G'' values. Along the whole frequency range studied, no cross-point of G' and G'' was observed, meaning that magnitudes of G' values of the samples were higher than those of G'' values over the whole frequency range.

G' and G'' values were subjected to nonlinear regression as a function of frequency [Eqs. (4) and (5)] to calculate the magnitudes of intercepts, K' and K'' and slopes, and η' and η'', along with their R^2 values. From the values R^2 ($R^2 > 0.91$; Table 4), it can be stated here that viscoelastic characteristics of the boza samples could be successfully described by the power law model. From dynamic oscillatory test data, it was also found that the boza samples exhibited weak gel-like behavior because the slopes were positive ($n' = 0.07$–0.17; $n'' = 0.16$–0.22; Table 4) (Ross-Murphy, 1984).

Another parameter measured by frequency sweep test was complex viscosity (η^*). Total resistance of material to flow is represented by the η^* value (Dimitreli and Thomareis, 2008). η^* values were observed to decrease with frequency. The obtained η^* versus frequency data were fitted to Eq. (6) and the calculated K^* and η^* values of the

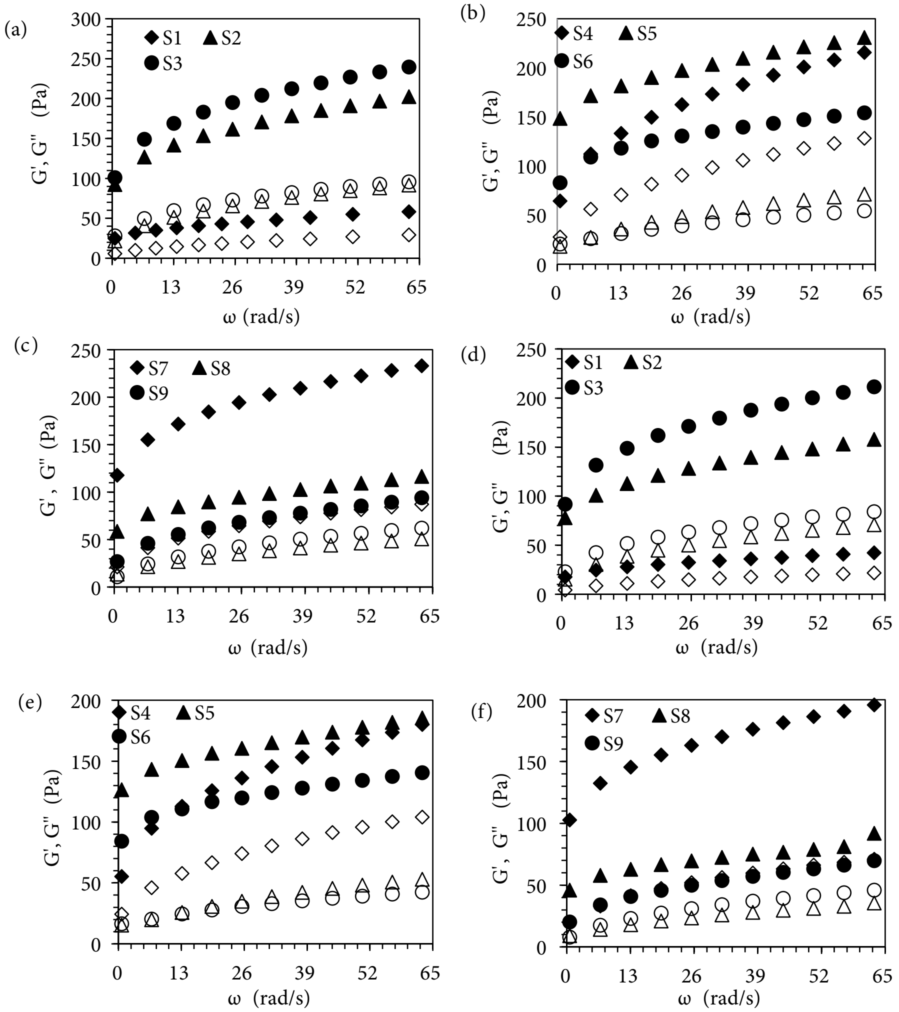

Figure 3. *G′* (storage modulus) and *G″* (loss modulus) values of boza samples (S1–S9) as a function of angular frequency (ω) at 5 °C (a, b, c) and 20 °C (d, e, f). Filled symbols: *G′*, open symbols: *G″*.

boza samples at 5 and 20 °C are presented in Table 4. It can be seen that R^2 values were very close to unity, indicating that η^* values could be satisfactorily predicted versus ω values. Temperature sweep tests were also conducted to determine changes in the parameters obtained from dynamic measurements. Figure 4 shows the effect of temperature changes from 0 to 50 °C on the *G′* and *G″* values. As can be seen, *G′* and *G″* values showed a general trend to decrease with temperature due to reduction in intermolecular forces. The Arrhenius equation was applied to reveal temperature dependency of *G′* and *G″* values of the boza samples. The calculated G_0, G_1, E_a, and R^2 values are shown in Table 3. Generally, R^2 values were higher than 0.90, indicating that temperature dependency of the *G′* and *G″* values of the boza samples followed the Arrhenius equation. E_a values for *G′* and *G″* ranged from 1393 to 6762 kJ/mol and 5302 to 12,129 kJ/mol.

3.3. Applicability of the Cox–Merz rule

The prediction of dynamic shear data using steady shear data or vice versa is possible by means of the Cox–Merz rule (Rao and Cooley, 1992). As frequency is equal to the shear rate, apparent viscosity of the sample is very close to complex viscosity; under this circumstance, the empirical Cox–Merz rule can be used (Cox and Merz, 1958). Accordingly, the Cox–Merz rule has been applied for polymer solutions and food systems in previous studies (Da Silva and Rao, 1992; Tiziani and Vodovotz, 2005; Yasar et al., 2009; Yilmaz et al., 2011; Dogan et al., 2012; Goksel et al., 2012; Toker et al., 2012b). On the other hand, the application of the empirical Cox–Merz rule to food products is difficult due to their complex structure; therefore, a modified Cox–Merz rule was applied in this study, by calculating a shift factor (Rao, 2005). Figure 5 illustrates the applicability of the modified Cox–Merz rule on steady and dynamic shear data from

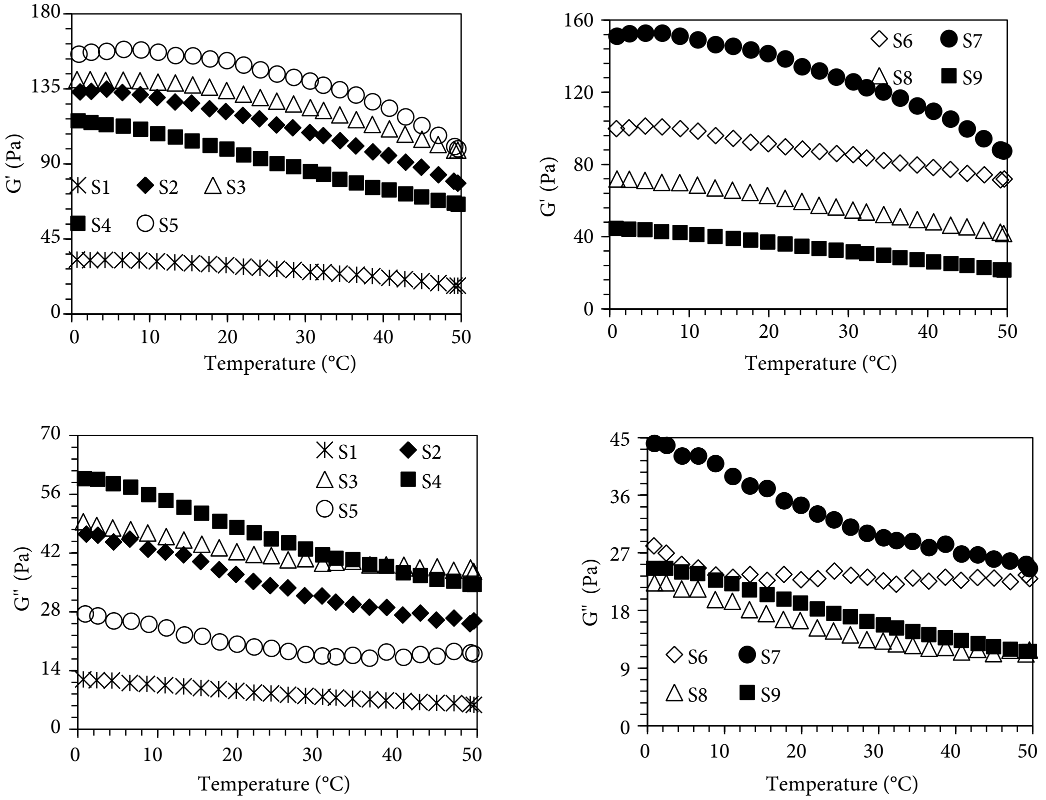

Figure 4. Effect of temperature on G' and G'' values of boza samples (S1–S9).

Table 4. Parameters of power-law functions describing storage and loss moduli and complex viscosity.

Temperature levels	Boza samples	$G' = K'(\omega)^{n'}$			$G'' = K''(\omega)^{n''}$			$\eta^* = K^*(\omega)^{n^*-1}$		
		K' (Pa)	n'	R^2	K'' (Pa)	n''	R^2	K^* (Pa s)	n^*	R^2
5 °C	S1	31.23	0.16	0.9609	13.18	0.21	0.9532	29.37	0.339	0.9958
	S2	128.5	0.12	0.9350	44.79	0.19	0.9273	96.82	0.057	0.9995
	S3	151.5	0.12	0.9147	52.21	0.16	0.9155	108.2	0.083	0.9997
	S4	117.5	0.16	0.9226	61.72	0.20	0.9258	75.70	0.175	0.9994
	S5	171.5	0.08	0.9611	32.56	0.21	0.9478	146.6	0.004	0.9998
	S6	108.5	0.10	0.9210	28.72	0.17	0.9595	85.70	0.014	0.9993
	S7	157.6	0.11	0.9269	45.06	0.18	0.9147	121.3	0.031	0.9997
	S8	77.15	0.11	0.9421	24.24	0.20	0.9438	60.79	0.026	0.9997
	S9	48.80	0.17	0.9335	27.99	0.21	0.9276	31.44	0.187	0.9992
20 °C	S1	24.99	0.14	0.9499	9.73	0.21	0.9350	18.73	0.070	0.9995
	S2	103.1	0.11	0.9327	33.85	0.20	0.9258	80.26	0.033	0.9996
	S3	134.2	0.12	0.9207	45.16	0.17	0.9135	97.55	0.073	0.9697
	S4	99.29	0.16	0.9210	50.93	0.19	0.9289	64.97	0.163	0.9994
	S5	142.7	0.07	0.9641	23.87	0.21	0.9613	123.9	0.005	0.9995
	S6	103.1	0.08	0.9349	22.57	0.17	0.9618	85.04	0.001	0.9998
	S7	134.0	0.10	0.9326	36.65	0.18	0.9275	105.2	0.018	0.9997
	S8	57.26	0.11	0.9456	16.10	0.20	0.9543	46.86	0.005	0.9997
	S9	35.86	0.17	0.9393	20.30	0.22	0.9301	23.45	0.179	0.9991

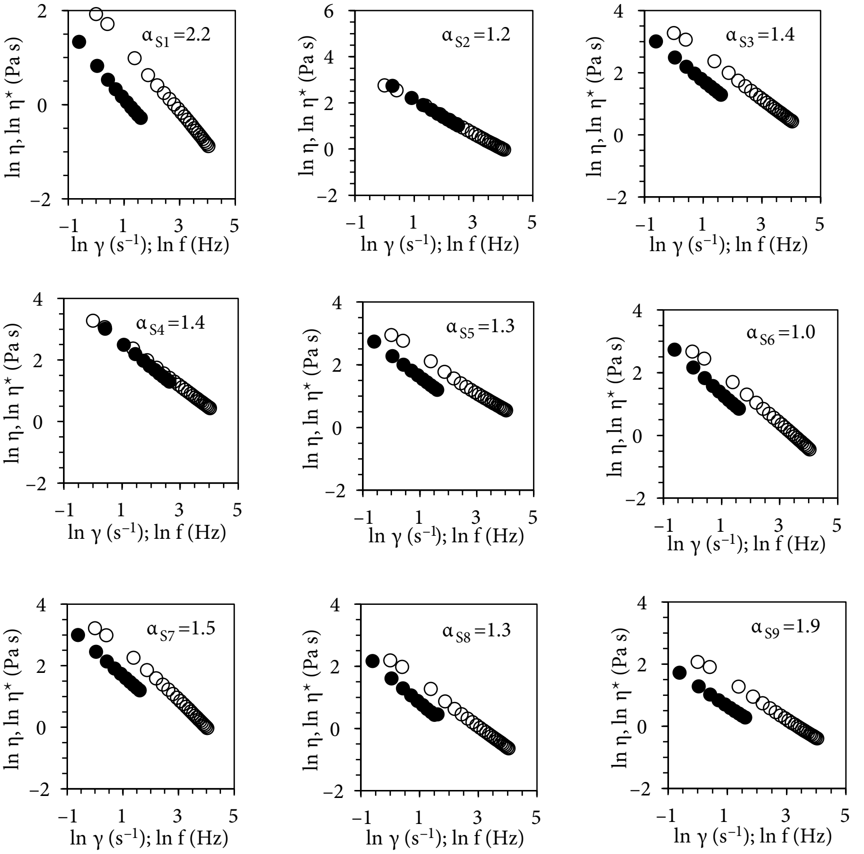

Figure 5. Comparison of oscillatory and continuous shear viscosities (a modified Cox–Merz rule along with shift factors) of boza samples (S1–S9) at 20 °C. Open symbols: shear viscosity, filled symbols: complex viscosity.

different boza samples. As revealed here, the Cox–Merz rule could be successfully applied to the data from the boza samples, indicating that the dynamic shear viscosity might be predicted from steady shear viscosity using the calculated shift factors, as shown in Figure 5.

4. Discussion

The pH values of the boza samples analyzed in the present study were consistent with those of previous studies (Gotcheva et al., 2000; Todorov, 2010). Uysal et al. (2009) reported that the pH value of the different boza samples changed between 3.94 and 4.63, which was slightly higher than our findings. A previous study on the microbial population of boza samples prepared in Turkey reported that LAB and yeasts counts were found to be 4.6×10^8 and 8.1×10^6 CFU/mL, respectively (Hancioglu, 1997). Uysal et al. (2009) reported that the LAB and yeast numbers in different boza samples ranged from 3.70×10^5 to 5.60×10^7 CFU/mL and from 1.03×10^2 to 2.88×10^5 CFU/mL, respectively. In another study, Gotcheva et al. (2000) determined that LAB and yeast numbers of different boza samples ranged from 6.0×10^7 to 8.8×10^7 CFU/mL and 2.6×10^7 to 3.9×10^7 CFU/mL, respectively. As can be seen, the LAB and yeast populations may significantly differ from one sample to another. The variation might result from type of starter culture, fermentation conditions (time and temperature), total acidity, and type of the substrate converted to organic acid during fermentation of boza samples.

Differences could also be attributed to the differences between the boza production types and microflora ecotypes (Todorov, 2006). In addition, differences in the storage temperatures and times were thought to remarkably affect microflora of boza samples (Uysal et al., 2009). Furthermore, the raw material (millet, maize, wheat, or rice flours) from which boza is produced could also be another factor contributing to differences in the microbial population of boza samples from different origins. It should also be noted here that the number of LAB was higher than that of the yeast colonies, indicating that LAB forms a dominant microflora in boza. Similar results were reported in previous studies (Hancioglu and

Karapinar, 1997; Gotcheva et al., 2000; Zorba et al., 2003; Uysal et al., 2009).

Shear thinning behavior resulted from the hydrodynamic forces that generated a break in structural units in the product during shear (Bahnassey and Breene, 1994). The variation between K and n values of the boza samples might be due to cereal flour type, fermentation conditions (temperature and time), or use of different bacteria and yeast. In recent years, exopolysaccharide (EPS)-producing strains have received great attention from some researchers since EPS has been proven to improve the textural properties of foods (Altay et al., 2013). EPS is important due to its stabilizing, viscosity-modifying, and gelling effects (Ahmed et al., 2013). Therefore, rheological properties of the boza samples were thought to be strongly related to the number and type of microorganisms present in the samples as well as to their EPS-producing capability. The temperature dependency of the η_{50} values of the boza samples can be explained by the increase in the thermal energy of the molecules and intermolecular distances, which caused reduction in intermolecular forces (Holdsworth, 1971; Hassan and Hobani, 1998; Arslan et al., 2005). When considering E_a values calculated for η_{50} values among the boza samples analyzed in the present study, S7 appeared to be the most temperature-dependent sample with respect to η_{50} values. According to the results of the dynamic rheological measurements, it can be seen that magnitudes of the G' value of each boza sample was higher than those of the G'' values, implying that boza samples had an elastic rather than viscous nature. K' and K'' values at 5 °C were found to be higher than those at 20 °C, which might have resulted from a decrease in the intermolecular forces with an increase in temperature. Similar results were reported in previous studies (Karaman et al., 2011; Yilmaz et al., 2011; Karaman et al., 2012; Toker et al., 2012c; Goksel et al., 2013). K' values were higher than K'' values, indicating that the boza samples were more elastic than viscous at both temperature levels, as revealed above. Moreover, an increase in temperature levels caused a decrease in the η^* values, indicating that resistance of the material to flow also decreased. At both temperature values, S5 had the highest K^* values among those of the rest of the boza samples, implying that this sample was the most resistant to flow. For all the boza samples analyzed in the present study, E_a values for G'' were higher than those for G', indicating that G'' was more affected by temperature changes. At any rate, it can be said that the viscoelastic characteristics of the boza samples were remarkably affected by temperature; therefore, serving and storage temperatures are important for consumer preference of the product. After determination of both the steady and dynamic rheological properties of the boza samples, a modified Cox–Merz rule was applied to correlate them. The shift factor (α) values of the boza samples were found to range between 1.0 and 2.2. The Cox–Merz rule was satisfactorily applied to different food systems to correlate apparent viscosity and complex viscosity of the samples in many studies. The α values for tomato juice and tomato paste were found to be 0.12 and between 0.0029 and 0.029, respectively (Rao and Cooley, 1992; Augusto et al., 2013). In addition, the magnitude of α was determined to be in the range of 0.008–0.021 and 0.307–0.478 for potato puree and rice starch–xanthan gum mixtures, respectively (Kim and Yoo, 2006; Alvarez et al., 2011). As can be seen from the results, α values were smaller than unity, indicating that the magnitude of the η^* (complex viscosity) was higher than η_a (apparent viscosity) values (Augusto et al., 2013). On the contrary, in the present study, α values of the boza samples were higher than unity, meaning that the η_a value was higher than η^*.

As a conclusion, the rheological characteristics of boza are one of the most important quality indicators affecting preference regarding the product. Therefore, primary factors affecting the rheological properties should also be important for controlling the quality of the product. In the present study, steady and dynamic rheological properties of different boza samples collected from local markets were tested. The rheological properties of the beverages varied from one sample to another to a remarkable extent, indicating that formulation and production steps are important factors affecting these rheological changes. The Arrhenius equation was applied to estimate the parameters as a function of temperature. A modified Cox–Merz rule was successfully applied to correlate steady shear properties with dynamic shear viscosities using the calculated shift factors.

References

Ahmed Z, Wang Y, Anjum N, Ahmad A, Khan ST (2013). Characterization of exopolysaccharide produced by *Lactobacillus kefiranofaciens* ZW3 isolated from Tibet kefir-Part II. Food Hydrocolloid 30: 343–350.

Altay F, Karbancıoglu-Güler F, Daskaya-Dikmen C, Heperkan D (2013). A review on traditional Turkish fermented non-alcoholic beverages: microbiota, fermentation process and quality characteristics. Int J Food Microbiol 167: 44–56.

Alvarez MD, Fernández C, Canet W (2011). Effect of cryoprotectant mixtures on rheological properties of fresh and frozen/thawed mashed potatoes. J Food Process Eng 34: 224–250.

Arici M, Daglioglu O (2002). Boza: a lactic acid fermented cereal beverage as a traditional Turkish food. Food Res Int 18: 39–48.

Arslan E, Yener ME, Esin A (2005). Rheological characterization of tahin/pekmez (sesame paste/concentrated grape juice) blends. J Food Eng 69: 167–172.

Augusto PED, Falguera V, Cristianini M, Ibarz A (2013). Viscoelastic properties of tomato juice: applicability of the Cox–Merz rule. Food Bioprocess Tech 6: 839–843.

Bahnassey YA, Breene WM (1994). Rapid visco-analyzer (RVA) pasting profiles wheat, corn, waxy corn, tapioca and amaranth starches (*A. hypochondriacs* and *A. cruentus*) in the presence of konjac flour, gellan, guar, xanthan and locust bean gum. Starch 46: 134–141.

Blandino A, Al-Aseeri ME, Pandiella SS, Cantero D, Webb C (2003). Cereal based fermented foods and beverages. Food Res Int 36: 527–543.

Botes A, Todorov SD, von Mollendorff JW, Botha A, Dicks LMT (2007). Identification of lactic acid bacteria and yeast from boza. Process Biochem 42: 267–270.

Bourne MC (1982) Food Texture and Viscosity: Concept and Measurement. New York, NY, USA: Academic Press.

Bourne MC (2002). Physics and texture. In: Bourne MC, editor. Food Texture and Viscosity. London, UK: Academic Press, pp. 59–106.

Chun SY, Yoo B (2004). Rheological behavior of cooked rice flour dispersions in steady and dynamic shear. J Food Eng 65: 363–370.

Cox W, Merz E (1958). Correlation of dynamic and steady flow viscosities. J Polym Sci 28: 619–622.

Da Silva JAL, Rao M (1992). Viscoelastic properties of food hydrocolloid dispersions. In: Rao MA, Steffe JF, editors. Viscoelastic Properties of Foods. London, UK: Elsevier, pp. 285–315.

Deegan LH, Cotter PD, Hill C, Ross P (2006). Bacteriocins: biological tools for bio-preservation and shelf-life extension. Int Dairy J 16: 1058–1071.

De Vuyst L, Vandamme EJ (1994). Bacteriocins of Lactic Acid Bacteria: Microbiology, Genetics and Applications. London, UK: Blackie Academic and Professional.

Dimitreli G, Thomareis AS (2008). Effect of chemical composition on the linear viscoelastic properties of spreadable-type processed cheese. J Food Eng 84: 368–374.

Dogan M, Kayacier A, Toker OS, Yilmaz MT, Karaman S (2012). Steady, dynamic, creep and recovery analysis of ice-cream mixes added with different concentrations of xanthan gum. Food Bioprocess Tech 6: 1420–1433.

Dogan M, Toker OS, Aktar T, Goksel M (2012). Optimization of gum combination in prebiotic instant hot chocolate beverage model system in terms of rheological aspect: Mixture design approach. Food Bioprocess Tech 6: 783–794.

Dogan M, Toker OS, Goksel M (2011). Rheological behaviour of instant hot chocolate beverage: Part 1. Optimization of the effect of different starches and gums. Food Biophys 6: 512–518.

Fischer P, Windham EJ (2011). Rheology of food materials. Curr Opin Colloid In 16: 36–40.

Genc M, Zorba M, Ova G (2002). Determination of rheological properties of boza by using physical and sensory analysis. J Food Eng 52: 95–98.

Goksel M, Dogan M, Toker OS, Ozgen S, Sarioglu K, Oral RA (2012). The effect of starch concentration and temperature on grape molasses: rheological and textural properties. Food Bioprocess Tech 6: 259–271.

Gotcheva V, Pandiella SS, Angelov A, RoshkovaZG, Webb C (2000). Microflora identification of the Bulgarian cereal-based fermented beverage boza. Process Biochem 36: 127–130.

Gunasekaran S, Ak MM (2000). Dynamic oscillatory shear testing of foods selected applications. Trends Food Sci Tech 11: 115–127.

Hancioglu O, Karapinar M (1997). Microflora of boza, a traditional fermented Turkish beverage. Int J Food Microbiol 35: 271–274.

Hassan BH, Hobani AI (1998). Flow properties of roselle (*Hibiscus sabdariffa* L.) extract. J Food Eng 35: 459–470.

Hayta M, Alpaslan M, Kose E (2001). The effect of fermentation on viscosity and protein solubility of boza a traditional cereal based fermented Turkish beverage. Eur Food Res Technol 213: 335–337.

Holdsworth SD (1971). Applicability of rheological models to the interpretation of flow and processing behaviour of fluid food products. J Texture Stud 2: 393–418.

Ibanoglu S, Ibanoglu E (1998). Rheological characterization of some traditional Turkish soups. J Food Eng 35: 251–256.

Ivanova I, Kabadjova P, Pantev A, Danova S, Dousset X (2000). Detection, purification and partial characterization of a novel bacteriocin substance produced by *Lactococcus lactis* subsp. *lactis* B14 isolated from boza – Bulgarian traditional cereal beverage. Biocatalysis 41: 47–53.

Juszczak L, Witczak M, Fortuna T, Banys A (2004). Rheological properties of commercial mustards. J Food Eng 63: 209–217.

Karaman S, Yilmaz MT, Cankurt H, Kayacier A, Sagdic O (2012). Linear creep and recovery analysis of ketchup-processed cheese mixtures using mechanical simulation models as a function of temperature and concentration. Food Res Int 48: 507–519.

Karaman S, Yilmaz MT, Dogan M, Yetim H, Kayacier A (2011). Dynamic oscillatory shear properties of O/W model system meat emulsions: linear viscoelastic analysis for effect of temperature and oil concentration on protein network formation. J Food Eng 107: 241–252.

Kim C, Yoo B (2006). Rheological properties of rice starch–xanthan gum mixtures. J Food Eng 72:120–128.

Kocabaş N, Karapınar M (1993). Kuru incir fungal florasının saptanmasında farklı besiyeri ve besiyeri dökme sıcaklığının etkisi. Doğa-Türk Tarım Ormancılık Dergisi 17: 205–211 (article in Turkish).

Leroy F, De Vuyst L (2004). Lactic acid bacteria as functional starter cultures for the food fermentation industry. Trends Food Sci Tech 15: 67–78.

Morcos SR, Hegazi SM, El-Damhoughy ST (1973). Fermented foods in common use in Egypt. II. The chemical composition of Bouza and its ingredients. J Sci Food Agric 24: 1151–1561.

Öztürk İ, Karaman S, Törnük F, Sağdıç O (2013). Physicochemical and rheological characteristics of alcohol free probiotic boza produced using *Lactobacillus casei* Shirota: estimation of apparent viscosity of boza using non-linear modeling techniques. Turk J Agric For 37: 475–487.

Rao MA (1999). Rheology of Fluid and Semisolid Foods: Principles and Application. New York, NY, USA: Springer.

Rao MA (2005). Rheological properties of fluid foods. In: Rao MA, Rizvi SSH, Datta AK, editors. Engineering Properties of Foods. 3rd ed. Boca Raton, FL, USA: CRC Press.

Rao MA, Cooley HJ (1992). Rheological behaviour of tomato pastes in steady and dynamic shear. J Texture Stud 23: 415–425.

Rao MA, Tattiyakul J (1999). Granule size and rheological behavior of heated tapioca starch dispersions. Carbohyd Polym 38: 123–132.

Ross-Murphy S (1984). Rheological methods. In: Chan HWS, editor. Biophysical Methods in Food Research. London, UK: Blackwell, pp. 138–199.

Sanni AI (1993). The need for process optimization of African fermented foods and beverages. Int J Food Microbiol 18: 85–95.

Sharpe ME, Fryer E, Smith DG (1966). Identification of lactic acid bacteria. In: Gibbs BM, Skinner FA, editors. Identification Method for Microbiologists, Part A. London, UK: Academic Press, pp. 65–79.

Sikora M, Kowalski S, Tomasik P, Sady M (2007). Rheological and sensory properties of dessert sauces thickened by starch–xanthan gum combinations. J Food Eng 79: 1144–1151.

Steffe JM (1996). Rheological Methods in Food Process Engineering. 2nd ed. East Lansing, MI, USA: Freeman Press.

Tiziani S, Vodovotz Y (2005). Rheological effects of soy protein addition to tomato juice. Food Hydrocolloid 19: 45–52.

Todorov SD (2010). Diversity of bacteriocinogenic lactic acid bacteria isolated from boza, a cereal-based fermented beverage from Bulgaria. Food Control 21: 1011–1021.

Todorov SD, Dicks LMT (2006). Screening for bacteriocin-producing lactic acid bacteria from boza, a traditional cereal beverage from Bulgaria. Comparison of the bacteriocins. Process Biochem 41: 11–19.

Toker OS, Dogan M, Canyilmaz E, Ersoz NB, Kaya Y (2012c). The effects of the different gums and their interactions on the rheological properties of a dairy dessert: a mixture design approach. Food Bioprocess Tech 6: 896–908.

Toker OS, Dogan M, Goksel M (2012a). Prediction of rheological parameters of model instant hot chocolate beverage by adaptive neuro fuzzy inference system. Milchwissenchaft 67: 22–25.

Toker OS, Karaman S, Yuksel F, Dogan M, Kayacier A, Yilmaz MT (2012b). Temperature dependency of steady, dynamic, and creep-recovery rheological properties of ice cream mix. Food Bioprocess Tech 6: 2974–2985.

Uysal UD, Oncu EM, Berikten DI, Yilmaz N, Tuncel NB, Kivanc M, Tuncel M (2009). Time and temperature dependent microbiological and mycotoxin (ochratoxin-A) levels in boza. Int J Food Microbiol 130: 43–48.

Yasar K, Kahyaoglu T, Sahan N (2009). Dynamic rheological characterization of salep glucomannan/galactomannan-based milk beverages. Food Hydrocolloid 23: 1305–1311.

Yilmaz MT, Karaman S, Cankurt H, Kayacier A, Sagdic O (2011). Steady and dynamic oscillatory shear rheological properties of ketchup-processed cheese mixtures: effect of temperature and concentration. J Food Eng 103: 197–210.

Yoo B, Rao MA (1996). A creep and dynamic rheological behavior of tomato concentrates: effect of concentration and finisher screen size. J Texture Stud 27: 451–459.