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Rheological Properties of Iranian Yoghurt Drink, Doogh

Hossein Kiani, Seyed Mohammad Ali Mousavi and Zahra Emam-Djomeh
Department of Food Science, Technology and Engineering,
Faculty of Biosystem Engineering, University of Tehran, Iran

Abstract: In this research beside some conventional properties of Doogh, flow behavior of this product was investigated. Also particle size distribution and microstructure was measured. Finally the effect of homogenization on the rheological properties of Doogh was examined. Doogh exhibited Newtonian flow behavior and its viscosity was between 1 and 2 centipoises. Major particle size distribution was observed between 2-30 microns. Homogenization pressure did not affect the viscosity but particle size was increased by raising the pressure. Visualization of Doogh microstructure was performed by light microscopy.

Key words: Doogh, rheological properties, particle size distribution, microstructure

INTRODUCTION

Doogh is a native beverage in Iran and has an import share in beverage industry. It is an acidic dairy drink mainly consumed in plain type or with aromatic compounds. Nowadays Doogh is produced in large scales all over the country and its industrial production is increasing continuously. Though it is produced in large industrial scales, little data have been published introducing its practical properties. Also quality improvement is needed for this native industrialized product. Rheological behaviors in macro and micro scales are the most interesting properties affecting the quality of the food. Flow properties of foods are determined for a number of purposes, such as quality control, understanding the structure, process engineering applications and correlations with sensory evaluation (Rao, 2005). Also final properties of the product such as stability, texture and appearance are directly dependent on food microstructure (Norton and Foster, 2002). Similar products exist in other countries such as ayran (Akin and Rice, 1994; Koksoy and Kilic, 2003, 2004; Tamime and Robinson, 1999). This product is consumed as a refreshing drink and is a nutritionally potent drink.

Stirred or fluid/drinking yoghurt is considered as stirred yoghurt of low viscosity (Tamime and Robinson, 1999). Generally, acid dairy drinks can be described as acidified protein liquid systems with stability and viscosity similar to natural milk (Laurent and Boulenguer, 2003). There are several studies considering milk protein behavior in different conditions (Banon and Hardy, 1992; Ennis and Mulvihill, 2000; Everett and McLeod, 2005; Graveland-Bikker and Anema, 2003; Hemar *et al*., 2001; Koh *et al*., 2002; Lucey *et al*., 1997; O'Kennedy *et al*., 2006; Patocka *et al*., 2006; Sanchez *et al*., 2000; Sedlmeyer *et al*., 2004; Chan *et al*., 2007; Sourdet *et al*., 2003; Syrbe *et al*., 1998, Van Vliet *et al*., 2004; Vasbinder *et al*., 2001, 2003a, b). Rheological properties and stability of these drinks is of great interest arising from complex nature of these products. Drinking yoghurts are made by diluting a fermented yoghurt base with water (Janhoj *et al*., 2007; Tamime and Robinson, 1999). Three-dimensional network of casein strands in yoghurt can be broken apart by shearing and colloidal aggregates of milk proteins will be produced witch their size decreases as the rate of shearing increases

Corresponding Author: Hossein Kiani, Department of Food Science, Technology and Engineering, Faculty of Biosystem Engineering, University of Tehran, Iran

(Afonso and Joao, 1999; Everett and McLeod, 2005). Size, shape and volumetric percentage of these particles can influence the stability and rheological properties considerably (Koksoy and Kilic, 2003; Sedlmeyer *et al*., 2004).

Phase separation is a common phenomenon took place in acid dairy drinks. Several studies have been published considering phase separation and stabilizers have been used to prevent this phenomenon (Janhoj *et al*., 2007; Koksoy and Kilic, 2004; Laurent and Boulenguer, 2003).

Lack of any information about Iranian Doogh, in this article beside some conventional properties, rheological properties including flow behavior and microstructure of Iranian Doogh were investigated.

MATERIALS AND METHODS

Three samples (A, B and C) were randomly chosen from industrial products and provided from retail stores. Laboratory samples were also produced for examination. For laboratory samples, yoghurt was firstly produced in the pilot plant of the department of Food Engineering of University of Tehran and then diluted with pure water obtained by reverse osmosis filtration. NaCl (with 99.5% purity) was added in adequate amounts (1% w/w). Samples were standardized to 6% of total solids and stored in cooled temperature after preparation. Homogenization was done with a laboratory homogenizer (APV 1000, Denmark).

A rotational Brookfield RVTD viscometer was used to determine viscosities and flow behaviors. The RV2 spindle was chosen.

Particle size distribution was determined by light scattering using a Mastersizer 2000S (Malvern instruments Ltd., Malvern, UK). Analysis performed at least after 24 h for laboratory samples and was based on the principle of Fraunhofer.

Samples were stained by Rhodamine-B dye (MERCK, Germany) and microstructure was observed by light microscopy (Lieca Galen III, Germany) by contrast phase equipped with a digital camera. Observations were done immediately after preparation.

Phase separation and sedimentation was examined in tubes and the volume of the separated serum was measured.

Density, pH and Total Solids (TS) were obtained. Density was measured by hydrometer and pH was determined using a digital pH meter. For determination of total solids evaporation of water by using a boiling bath followed by drying of samples in 102°C with oven to reach to the constant weight was handled.

This study was conducted in autumn 2006.

RESULTS AND DISCUSSION

Density, pH and TS

Some general properties of Doogh samples were determined to depict the state of examined samples (Table 1). Statistical analysis performed to determine significant differences. TS was approximately in the range of 4.5-7 and density was about 1.06 to 1.021 g cm^{-3}. pH was between 3.3 and 4.

Viscosity and Flow Behavior

Flow curves and viscosity curves are shown in Fig. 1 and 2. Because of lower protein content in Doogh and diluted state of this product pseudo plastic behavior does not occur. Doogh is a diluted suspension of milk protein clusters. When comparing with milk, its TS is lower and is about half or third of the milk. Clusters are protein chains imparting caseins and whey proteins. They act as colloidal

Table 1: Some properties of doogh samples

Sample	Total solids (%)	Density (g cm^{-3})	pH
A	4.65±0.45[b]	1.0165±0.0070[c]	0.02±3.35[b]
B	6.55±0.38[a]	1.0210±0.0010[a]	0.04±3.89[a]
C	5.63±0.18[a,b]	1.0185±0.0007[b]	0.05±3.79[a]

a, b: Values with the same letter(s) are not significantly different

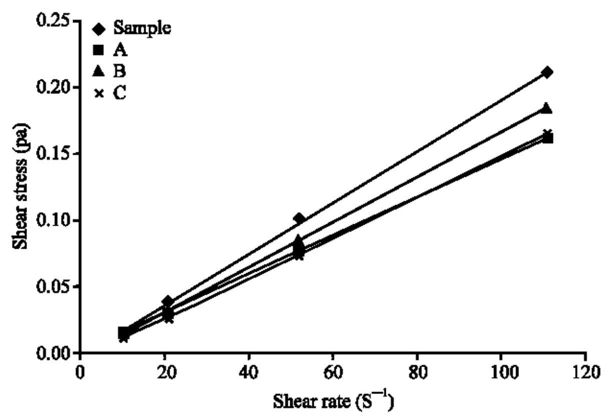

Fig. 1: Flow behavior of Doogh samples. Newtonian behavior observed for different samples

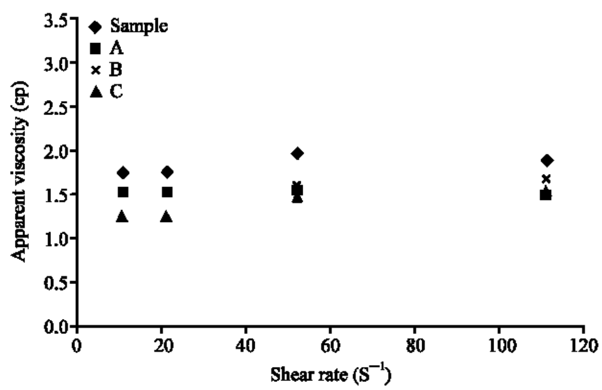

Fig. 2: Viscosity curve for Doogh samples. No changes observed in apparent viscosity as the result of increasing the shear rate

particles in Doogh. Functional properties of the proteins formed these clusters can influence the flow behavior. Inter molecular bonds and thermodynamic properties of proteins characterize the interaction of particles and so rheological behavior of the product. As Koksoy and Kilic (2003) showed for a similar Turkish product, in higher concentrations, particles can interact with each other and so the pseudo plastic behavior takes place. While when diluting the yoghurt to an adequate amount, particles do not close enough to associate and increase the viscosity in lower shear rates. Consequently as shown in flow curves Doogh exhibits Newtonian behavior and for an industrial plain Doogh, apparent viscosity is in the range of 1-2 cPs.

Particle Size Distribution

Table 2 shows the characteristics of Doogh particles for different samples. Distribution of the particles on the basis of the volumetric percentage is shown in Fig. 3. The lowest value for particle

Table 2: Particle size characteristics including particle range, area-volume mean diameter (D_{32}), volume-length diameter (D_{43}) and specific surface area (g m^{-2}) of Doogh samples

	Particle range (µm)				
Samples	Low	High	Specific surface area	D_{32} (µm)	D_{43}(µm)
A	0.39	42.76	0.888^{c}	6.70^{a}	12.54^{a}
B	0.45	35.27	1.215^{b}	4.93^{b,c}	8.50^{b}
C	0.48	40.77	1.039^{b,c}	5.90^{a,b}	11.34^{a}
Laboratory sample	0.45	40.00	1.445^{a}	4.14^{c}	8.63^{b}
Mean		--	1.147	5.42	10.25

a, b, c: Values with the same letter(s) are not significantly different

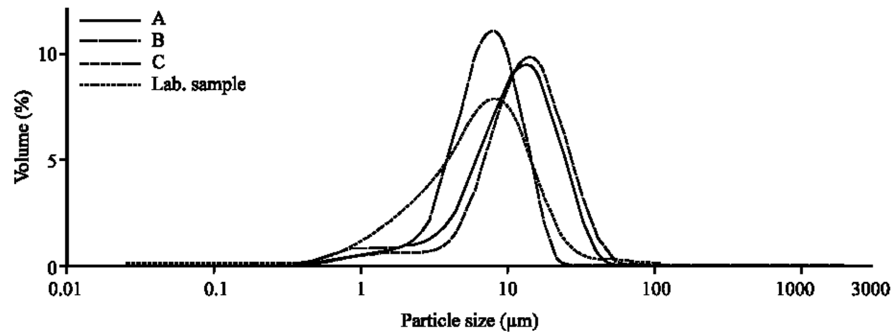

Fig. 3: Size distribution of protein aggregates in Doogh. Volumetric percentage of colloidal particles with different diameters is shown for different samples

size was 0.39 micron and the maximum was 40.77 microns. Particles in the range of 2-30 microns included the major part of the particle size distribution (Fig. 3). As discussed later, Doogh such as other acidic dairy drinks mainly contains clusters of milk proteins. They are particles made of milk proteins and are distributed in a continuous phase and include a range of particle diameter. Process conditions and raw materials influence the shape and size of these particles. If fat globules exist in Doogh, they may be covered by proteins or interact with them and their behavior will be similar to protein particles. Considering the distribution and size of the colloidal particles in milk, particles existing in Doogh are very large and by a simple numerical calculation a cluster may contain tens or hundreds of equal casein micelles (micelles′ average size is 120 nm and the range of distribution for them is 50-600 nm (Fox, 2003)). This can lead to the faster serum separation comparing to milk. In general, serum separation occurs in fermented milk products due to the aggregation of casein particles during fermentation process and storage time. A widely used method of expressing the mean particle size is the area-volume mean diameter (D_{32}), which is related to the average surface area of droplets exposed to the continuous phase per unit volume of suspension. Another commonly used method of expressing the mean particle size of a polydisperse suspension is the volume–length diameter (D_{43}), which is the sum of the volume ratio of droplets in each size-class multiplied by the mid-point diameter of the size-class (McClements, 2000). D_{32} and D_{43} for different samples (Table 2) and can indicate mean size of the colloidal particles.

Microstructure

In order to observe the shape and construction of the clusters, light microscopy was used. As it can be seen in (Fig. 4), particles are presented in different shapes and sizes, varying from very small particles to large ones. Also the internal structure of particles is similar to the yoghurt structure.

Acidification of milk results in dissociation of micellar casein structure. Lowering the pH reduces the repulsive forces and allows for hydrophobic interactions causing the casein micelles to coagulate

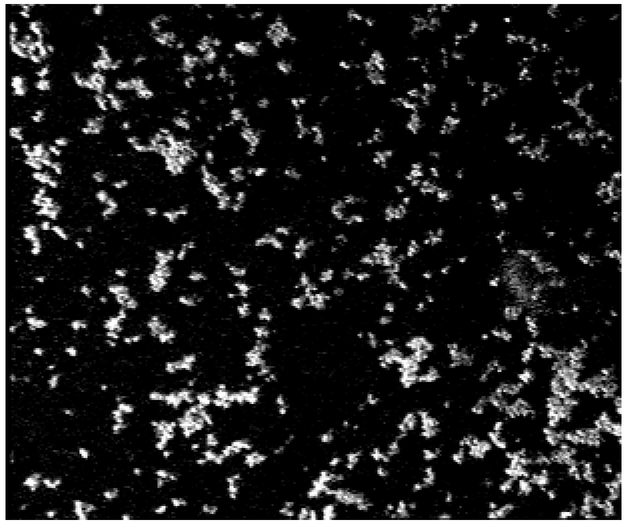

Fig. 4: Microstructure of Doogh. Observation was performed by light microscopy after staining the sample with rhodamin B. Bright zones are protein particles

(Van Hooydonk *et al*., 1986). During the production of acidic products from milk, whey proteins are completely denatured due to the pasteurization condition. They aggregate and also make complex compounds with caseins, so they have significant effect on formation of the clusters. Fat globules are also covered with proteins.

Yoghurt contains a network of three-dimensional casein strands aggregated through iso-electric precipitation brought about by the action of lactic acid bacteria (Janhoj *et al*., 2007). As mentioned earlier, after formation of the gel structure, mixing, diluting and homogenization are done to produce Doogh. These processes destroy the structure of the gel and cause to formation of the clusters. All mentioned interactions and processes can lead to formation of colloidal particles with a fractal surface due to aggregation of different constituents of milk and a complex structure will be formed inside the particles (Fig. 4). Microstructural characteristics of these particles can influence the rheological properties. Particle-particle interactions in plain Doogh and particle-hydrocolloid interactions in modified Doogh (for example stabilized), is of central important for improving the quality and stability of the product.

Effect of Homogenization

Homogenization of milk reduces the size of fat globules to a diameter of less than 1 μm and the surface area of the resultant fat globules is increased 4-10 fold (Keenan *et al*., 1983). But for acidic dairy drinks it is done to reduce the size of the clusters, make the particles homogenous and improve the organoleptic properties of the product. Industrial homogenization pressure is about 100 bars. It could be prospected that higher pressures may influence the stability, viscosity and particle characteristics. This hypothesis was examined and pressures more than 100 bars applied for homogenization of Doogh samples.

As it can be seen in (Table 3), no significant changes were observed in apparent viscosity of Doogh as the result of increasing the homogenization pressure and particle size was decreased a little by increasing the pressure (Table 4, Fig. 5).

Table 3: Effect of homogenization pressure on apparent viscosity of Doogh

Homogenization pressure (Bar)	Viscosity (cPs)
100	1.79[a]
150	1.72[a]
200	1.96[a]
250	1.80[a]
300	1.64[a]

a: Values with the same letter(s) are not significantly different

Table 4: Effect of homogenization pressure on specific surface area, area-volume mean diameter (D_{32}) and volume-length diameter (D_{43}) of Doogh particles

Homogenization pressure (Bar)	Specific surface area	D_{32}	D_{43}
100	1.75[a]	3.44[c]	7.33[b]
150	1.61[a,b]	3.75[c,b]	7.35[b]
200	1.71[a]	3.52[c]	7.20[b]
250	1.48[b]	4.07[b]	8.13[b]
300	1.29[c]	4.65[a]	9.45[a]

a, b, c: Values with the same letter(s) are not significantly different

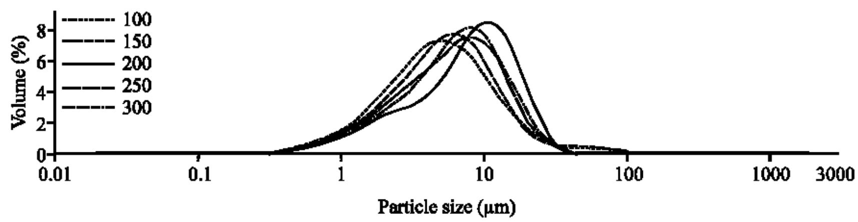

Fig. 5: Effect of homogenization pressure on particle distribution of Doogh. Different pressures in the range of 100-300 bars examined

The data obtained via volumetric measurements of phase separated samples indicated that homogenization did not have significant effects on the serum volume of Doogh. Volumetric percentage of separated serum was between 56 to 62%.

Finally it could be concluded that increasing the pressure of homogenization up to 100 bars do not have significant effect on the rheological properties of Doogh.

CONCLUSION

On the basis of this study the following conclusions can be drawn:

- Despite colloidal particles in a commercial Doogh are broken strands of casein aggregates and are capable to undergo particle-particle interactions, they are not close enough to interact with each other and exhibit Non-Newtonian behavior. So Doogh exhibits Newtonian behavior due to its diluted state.
- Colloidal particles of Doogh are distributed in a relatively large range and different shapes of particles with a complex structure of the particles can be observed.
- High pressure single stage valve homogenization of Doogh has no significant effect on the rheological properties and so quality improvement requires other strategies such as multi stage homogenization or ultrasound treatment.

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