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Influence of gum tragacanth on the physicochemical and rheological properties of kashk

Setareh Ghorban Shiroodi[1], Mohammad Amin Mohammadifar[2]*, Elham Ghorbani Gorji[1], Hamid Ezzatpanah[1] and Nilofar Zohouri[3]

[1] Department of Food Science and Technology, Faculty of Agriculture, Islamic Azad University, Science and Research Branch, Tehran, Iran
[2] Department of Food Science and Technology, National Nutrition and Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Shahid Beheshti University of Medical Sciences, P.O. Box 19395-4741, Tehran, Iran
[3] School of Food Science and Nutrition, University of Leeds, UK

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In this study, the physicochemical properties of a low-fat dried yogurt paste (kashk) were determined, and the effects of different concentrations (0, 0·1, 0·3 and 0·5% w/w) of gum tragacanth exudates from *Astragalus gossypinus* on the stability and texture of the samples were investigated by measuring amount of syneresis, turbidity, particle size distribution (PSD), flow behaviour and viscoelastic properties. The flow behaviour index was not very sensitive to the concentration of gum, while a remarkable concentration dependency of the power-law consistency coefficient and Herschel–Bulkley yield stress was observed. The initial increase in the gum concentration at 0·1 and 0·3% levels led to a higher degree of syneresis, which was related to the depletion flocculation mechanism. However, the reduced amount of syneresis in samples containing 0·5% gum tragacanth was attributed to the significant increase in viscosity of the continuous phase, which is also accompanied by trapping of the aggregated casein particles. The presence of 3% salt in the samples may have led to the neutralization of charges on the surface of gum tragacanth; consequently, the non-adsorbing behaviour of high-ionic-strength polysaccharides inhibited the formation of electrostatic protein–polysaccharide complexes. Furthermore, maximum values of polydispersity, syneresis and tan δ at high frequencies were found in samples containing 0·1% gum tragacanth.

Keywords: Dried yogurt, kashk, gum tragacanth, rheological properties, syneresis, particle size analysis.

The consumption of acid-fermented milk products, which are prepared by lactic acid fermentation, has increased tremendously in recent years due to their significant therapeutic and nutritional characteristics. Acidified dairy products, such as yogurt, labneh (concentrated yogurt), kefir, soy milk, butter-milk, whey drinks, and dried yogurt, such as kishk, exist all over the world (Toufeili et al. 1998; Abu-Jdayil et al. 2000; Roesch et al. 2004).

For thousands of years, humans have known that drying enables foodstuff to be preserved for extended periods of time. For example, the main objective of manufacturing yogurt in powder form is to store the product in a stable and readily utilizable state (Kurmann et al. 1992). In dried yogurt products, skim or buttermilk produced from churned fermented milk is concentrated, shaped into flat rolls and dried in the sun (Tamime & Robinson, 1999). The dried yogurt is normally utilized by desert dwellers in preparing food dishes or soups. These products are traditionally made throughout the region between the eastern Mediterranean and Indian subcontinent (Tamime et al. 2000). Depending on the ingredients and additives, and the region, many names are applied to dried fermented milk. For instance, products containing parboiled cracked wheat or flour in the Arab countries are called kishk; in Greece and Turkey, tarhana; in Nepal and Tibet, chura and in India, kadhi (Tamime & Robinson, 1999).

A low-fat dried yogurt including no cereal additives is called kashk in Iran and it is used in lots of Iranian traditional foods. It is available in a semi-liquid or dried form; in the latter form, it must be soaked and softened before it can be used.

There are two types of liquid kashk producing in the factories of Iran: Traditional liquid kashk and industrial liquid kashk. The production of traditional liquid kashk consists of

*For correspondence; e-mail: mohamdif@ut.ac.ir

two main steps; the first step is the production of dried kashk from yogurt, which is carried out by villagers in rural areas and the second step is the convesrion of dried kashk to liquid kashk, which is done in factories. On the other hand, industrial liquid kashk which is a byproduct of the dairy factories is produced by concentration of yogurt and other fermented milk products, by adding whey powder and salt (Iranian national standard No #6127). The traditional kashk is more popular among consumers due to its unique aroma and taste. It should be noted that our study was conducted on traditional liquid kashk.

Liquid Kashk is characterized by a pH less than 4·5, 20–25% nonfat solid, 1% fat, 3% salt, and at least 13% protein (Istitute of Standars and Industrial Research of Iran). A Previous study on the chemical composition determination showed a protein content of 39·6–67·8% for several dry kashk samples originating from various regions of Iran (Taleban & Renner, 1972).

Polysaccharides gums (stabilizers) are often added to dairy products and other foods containing milk proteins to enhance viscosity and alter textural characteristics (Thaiudom & Goff, 2003). Using hydrocolloids is one of the most powerful techniques to increase water-holding capacity and textural stability in acidified milk products .The physicochemical properties of acidified dairy products, including yogurt, kefir, doogh (fermented milk drink) and spray-dried yogurt with hydrocolloids, have been previously reported in numerous studies (Ramirez-Figueroa et al. 2002; Koksoy & Kilic, 2004; Tromp et al. 2004; Everett & McLeod, 2005; Janhøj et al. 2008). Everett & Mcleod (2005) carried out an extensive study on the stability of stirred yogurt influenced by a variety of polysaccharides. Their work has indicated that uncharged hydrocolloids (locust bean gum, alginate, xanthan, guar and κ-carrageenan) function as thickeners by increasing the viscosity of the continuous phase. They noted that use of the above-mentioned polysaccharides in low concentration, may lead to higher syneresis due to depletion flocculation. On the other hand, anionic hydrocolloids (λ-carrageenan, carboxymethyl cellulose, pectin and gum tragacanth) interact with the positive charges on the surface of casein micelles and reduce the syneresis via the formation of protein–polysaccharide complexes and strengthen the casein network through a bridging mechanism.

The mechanism of interaction between milk proteins and polysaccharides has been studied widely in model systems (Schmitt et al. 1999; Maroziene & De Kruif, 2000; Thaiudom & Goff, 2003; Spagnuolo et al. 2005; Picone & Da Cunha, 2010). Generally, interactions between proteins and polysaccharides in aqueous media can lead to one- or two-phase systems. From a thermodynamic point of view, proteins and polysaccharides can be compatible or incompatible in aqueous solutions. The nature of interactions, either repulsive or attractive, will lead to different behaviours such as co-solubility and, segregative or associative phase separation. Complex coacervation or associative phase separation phenomena give rise to the formation of soluble or insoluble complexes (Schmitt et al. 1998). The functional properties of the resulting complexes are generally different from those of the proteins and polysaccharides alone.

Internal and external factors such as pH, ionic strength, ratio of protein to polysaccharide, total concentration of biopolymers, the charge of the proteins and polysaccharides, quality of solvent and molecular weight affect the formation and stability of complexes (Glahn & Rolin, 1996; Weinbreck, 2004).

Gum tragacanth (GT) is a branched, heterogeneous, and anionic carbohydrate that consists of two major fractions: tragacanthin (water soluble) and bassorin (water swellable) (Mohammadifar et al. 2006). Tragacanth is one of the most acid-resistant gums containing D-galactronic acid, D-galactose, L-fucose, D-xylose and L-arabinose (Aspinall & Baillie, 1963; Anderson & Bridgeman, 1985). It has been shown that various types of GT exudates from different species of *Astragalus* have different uronic acid contents and, also, different neutral sugars contents. These differences result in specific functionalities for each type of GT (Balaghi et al. 2010).

The electrostatic interactions between GT and milk proteins have been studied in both real and model systems. The effect of pH and ionic strength on the formation of complexes between β-lactoglobulin and soluble part of GT (exudates form *A. gossypinus*) suggests an electrostatic nature of their interactions (Mohammadifar et al. 2007). Azarikia & Abbasi (2010) reported that bassorin is probably unable to interact with caseins, and its main effect on the stabilization of doogh is to increase the viscosity of the continuous phase.

Rheological data are required to predict and control the quality of products and their sensory attributes, process calculation and design of equipments. Although the effect of some hydrocolloids on rheological properties of a few acidified dairy products has been studied by several researchers, our knowledge of the role of polysaccharide functionality in stabilizing and texturizing acidic dairy products remains limited.

The aim of the present study was to investigate the steady shear and dynamic oscillatory rheological properties of kashk (a typical low-fat dried yogurt paste). Furthermore the effect of different concentrations (0, 0·1, 0·3 and 0·5% w/w) of GT exudates from *A. gossypinus* on rheological and textural properties of the product, in particular, reduction of syneresis, was the secondary aim of this research. We also determined the particle size distribution and turbidity of the samples to gain better insight into the mechanism of textural stability.

Materials and Methods

Sample preparation

The dried kashk was prepared from yogurt in the rural areas of Iran during the processes illustrated in Fig. 1. The yogurt

Table 1. Chemical characteristics of the kashk samples with different concentrations of GT

Gum tragacanth (%)	Protein (%)	Humidity (%)	Ash (%)	pH	Salt (%)
0	$13{\cdot}89 \pm 0{\cdot}62^a$	$74{\cdot}11 \pm 3{\cdot}34^a$	$2{\cdot}67 \pm 0{\cdot}08^a$	$4{\cdot}47 \pm 0{\cdot}13^a$	$2{\cdot}93 \pm 0{\cdot}08^a$
0·1	$14{\cdot}03 \pm 0{\cdot}21^a$	$74{\cdot}19 \pm 2{\cdot}23^a$	$2{\cdot}69 \pm 0{\cdot}13^a$	$4{\cdot}41 \pm 0{\cdot}18^a$	$2{\cdot}97 \pm 0{\cdot}10^a$
0·3	$13{\cdot}45 \pm 0{\cdot}40^a$	$74{\cdot}23 \pm 3{\cdot}31^a$	$2{\cdot}71 \pm 0{\cdot}07^a$	$4{\cdot}38 \pm 0{\cdot}22^a$	$2{\cdot}91 \pm 0{\cdot}05^a$
0·5	$14{\cdot}20 \pm 0{\cdot}53^a$	$74{\cdot}24 \pm 3{\cdot}70^a$	$2{\cdot}73 \pm 0{\cdot}09^a$	$4{\cdot}46 \pm 0{\cdot}11^a$	$3{\cdot}01 \pm 0{\cdot}12^a$

a Means with different letters with in the column differed significantly ($P < 0{\cdot}05$)

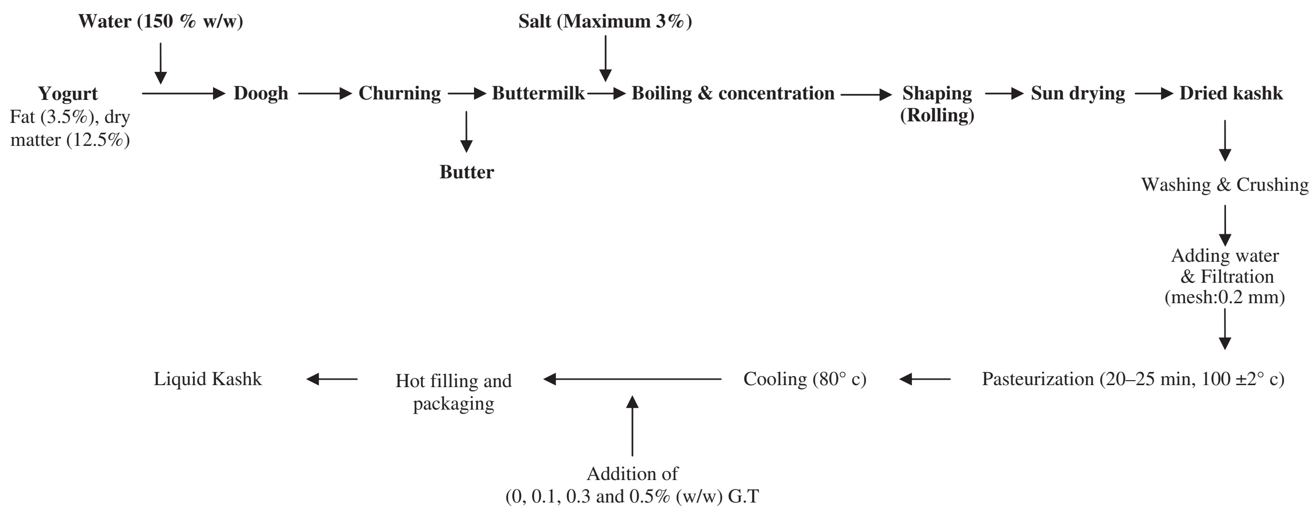

Fig. 1. Schematic production of the dried and liquid kashk (The production of dried kashk from yogurt is carried out in rural areas and the production of liquid kashk from dried kashk is carried out in factory).

was produced from whole cow's milk (3·5% fat and 12·5% dry matter) through a classical method (Heat treatment at 80 °C for 30 min, inoculation with starter and incubation at 42 °C for 3 h). The production of liquid kashk was carried out in the Somayeh Food Production Co. from the dried kashk. All samples were stored at 3 ± 1 °C. Some chemical characteristics of the product with different amounts of gum are illustrated in Table 1.

The Iranian GT used in this study was collected from plants growing in the central mountainous areas of the Isfahan province, Iran. The raw gum was ground and sieved. Powdered gum with a mesh size between 200 and 500 µm was used in the current experiment.

The physicochemical and rheological characterization of GT exudates from six species of Iranian *Astragalus* have been studied previously (Balaghi et al. 2010).

Syneresis

The determination of syneresis was performed using the method proposed by Keogh & O'Kennedy (1998). Ten grams of sample were placed in tubes and centrifuged at 8500 rpm for 2 min at 25 °C (Hettich Rotina 35 R centrifuge). The supernatant was removed, weighed and expressed as the percent weight relative to the original weight of sample. The measurements were carried out in triplicate.

Particle size analysis (PSA)

The PSD of the samples were determined at room temperature with a laser diffraction particle size analyzer equipped with an accessory Hydro2000S (A) (Malvern Mastersizer 2000 particle analyzer, Malvern Instruments Limited, UK). Size measurements are reported as the volume-weighted mean diameter ($D[4,3] = \sum n_i d_i^4 / \sum n_i d_i^3$) and surface-weighted mean diameter ($D[3,2] = \sum n_i d_i^3 / \sum n_i d_i^2$), where n_i is the number of particles with diameter d_i (McClements, 2005).

Span, as a measure of the distribution width of particles in dispersion, was calculated using the following equation:

$$\text{Span} = d(0{\cdot}9) - d(0{\cdot}1)/d(0{\cdot}5)$$

Span is the distribution width and has no relation to the middle particle diameter.

The absolute deviation from the median, which is indicative of the polydispersity, was also reported as uniformity (U), where v_i is the volume of the number of particles existing between the two consecutive diameters (Romero et al. 2009).

$$U = \frac{1}{d(0{\cdot}5)} \frac{\sum_i v_i |d(0{\cdot}5) - d_i|}{\sum_i v_i}$$

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Turbidity

Turbidity measurements were carried out with a UV–VIS Spectrophotometer (Optima SP-3000 plus) at a wavelength of 540 nm. The samples were put in a 10 mm path-length cuvette, and the turbidity (τ) was then measured as a function of time at 32 °C. The turbidity was defined as $\tau = -\ln(I/I_0)$.

In this formula, (I) is the light intensity that passes through a volume of solution in a 1 cm cube, and (I_0) is the incident light intensity. Each turbidity measurement was carried out in duplicate.

Rheological measurements

Steady and dynamic shear rheological data were obtained with a Physica MCR 301 rheometer (Anton paar GmbH, Graz, Austria) using a serrated parallel plate geometry (40 mm diameter; 1 mm gap). All measurements were performed at 25 °C. Each sample was transferred to the rheometer plate at the desired temperature, and left standing for 4 min to allow structure recovery and temperature equilibration. Then excess material was wiped off with a spatula. The dehydration of the samples was limited by using a solvent trap. The temperature control was carried out with a peltier system equipped with a fluid circulator. The rheological measurements were performed in triplicate.

Flow curves were obtained at shear rates of 0·1–900 s^{-1}. To calculate the amount of 'Herschel–Bulkley yield stress', the data were fitted to the Herschel–Bulkley model: ($\tau = m\dot{\gamma}^n + \tau_0$) at shear rates of 0·01–15 s^{-1}. To describe the variation in the rheological properties of samples under steady shear, the data were fitted to the power-law model ($\tau = m\dot{\gamma}^n$) over the shear rate range of 15–900 s^{-1}.

In amplitude sweep tests, the strain was increased from 0·01 to 2000% at a constant frequency of 1 Hz. Values for the storage modulus (G') and loss modulus (G'') were calculated inside the linear viscoelastic range (LVR) at 0·1% deformation as a measure of the structural strength and shape retention ability of the samples. Limiting values of LVR in terms of shear stress (τ_y), the flow point (τ_f) which is the stress in which the internal structure is ruptured to such an extent causing the material to flow ($G' = G''$), and the amount of complex modulus ($G^* = \sqrt{(G')^2 + (G'')^2}$) in the flow point was calculated. λ_L which is the limiting value of LVR in terms of strain, is used for the determination of cohesive energy density ($E_c = 1/2G' \times \lambda_L^2$).

To remain in the linear viscoelastic region of the samples in performing frequency sweep tests, a constant strain of 0·05% was adjusted, and the frequency was swept from 0·01 to 10 Hz. The complex modulus G^* and the damping factor ($\tan\delta = G''/G'$) of the samples at three different frequencies were determined.

Statistical analysis

The data reported in all of the tables are the means of double or triplicate observations. Analysis of variance (ANOVA) was used for data analysis (SPSS, 16). When F-values were significant ($P < 0{\cdot}05$) in ANOVA, Duncan's multiple range test was used to compare treatment means.

Experimental data were fitted to rheological models using the Anton Paar Rheoplus data analysis software (Rheoplu/32 V3.21).

Results and Discussions

Syneresis

Table 2 illustrates the synersis of samples without stabilizer and at three different concentrations of GT. As can be seen from the data, the addition of 0·5% gum decreased syneresis, whereas the addition of 0·1 and 0·3% gum increased the degree of syneresis. Syneresis is usually considered one of the instability parameters of gel polymer networks and can mostly be reduced by selecting an appropriate hydrocolloid at the proper concentration.

The functionality of hydrocolloids in dairy gel or gel-like systems is demonstrated by their ability to bind water, interact with the milk constituents (especially proteins), stabilize the protein network and prevent the free movement of water (Tamime & Robinson, 1999).

It seems that the presence of 3% salt in the samples led to the neutralization of charges on the surface of the gum; consequently, GT was incapable of interaction with the positive charges on the surface of the proteins and strengthening the protein network; therefore, it could not control the syneresis. In other words, the gum acted as a non-adsorbing gum, and we ascribed the phase separation to the so-called depletion interactions (Schmitt et al. 1999; Koksoy & Kilic, 2004).

As mentioned before, the addition of 0·5% gum decreased syneresis, which was probably due to the stabilization of the system, via the increase in viscosity of the continuous phase in the presence of high concentrations of GT. On the other hand, numerous studies have shown that salt addition in concentrated yogurt products increases protein–protein interactions and, hence, enhances syneresis during storage (Lucey et al. 1997; Abu-Jdayil & Mohameed, 2002).

Particle size measurements

Particle size analysis is widely used to monitor the formation and growth of electrostatic complexes between proteins and polysaccharides (Mohammadifar et al. 2007; Jensen et al. 2010). It can be seen from Table 2 that the addition of gum causes an increase in all particle size parameters. In general, the volume mean diameter $D[4, 3]$ indicates the presence of large particles, while the surface mean diameter $D[3, 2]$ is associated with smaller particles. When there is a large difference between $D[3, 2]$ and $D[4, 3]$, the size distribution is bimodal with two peaks, and when they are similar in value, there is only one peak. The median diameter of the aggregates in the samples containing no gum was about

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Table 2. Particle size, syneresis and turbidity of the samples with different concentrations of GT

Gum tragacanth (%)	*d* (0·1) (µm)	*d* (0·5) (µm)	*d* (0·9) (µm)	*D* [4,3] (µm)	*D* [3,2] (µm)	Uniformity	Span	Syneresis (%)	Turbidity (cm^{-1})
0	3·32 ± 0·06^{d}	9·62 ± 0·42^{d}	40·26 ± 1·98^{d}	16·86 ± 0·72^{d}	6·45 ± 0·17^{d}	1·18 ± 0·03^{c}	3·84 ± 0·09^{d}	14·73 ± 0·62^{c}	2·88 ± 0·12^{a}
0·1	3·84 ± 0·18^{c}	12·95 ± 0·51^{c}	281·24 ± 11·14^{c}	78·01 ± 2·85^{c}	8·22 ± 0·32^{c}	5·50 ± 0·22^{a}	21·42 ± 0·41^{a}	29·05 ± 0·73^{a}	2·42 ± 0·06^{b}
0·3	4·10 ± 0·15^{b}	16·4 ± 0·33^{b}	329·02 ± 6·47^{b}	98·12 ± 1·98^{b}	9·26 ± 0·21^{b}	5·51 ± 0·07^{a}	19·81 ± 0·70^{b}	17·87 ± 0·56^{b}	2·36 ± 0·04^{b}
0·5	4·79 ± 0·11^{a}	69·9 ± 0·9^{a}	406·44 ± 10·11^{a}	148·69 ± 2·40^{a}	12·48 ± 0·15^{a}	1·90 ± 0·09^{b}	5·75 ± 0·15^{c}	12·23 ± 0·50^{d}	2·19 ± 0·07^{c}

a–d Means with different letters with in the column differed significantly ($P < 0·05$)

9·62 µm, which reached a maximum of 69·9 µm with the addition of 0·5% gum: a sevenfold increase. According to previous studies, the median diameter of GT (exudates from *A. gossypinus*), the soluble part (tragacanthin) and the insoluble part (bassorin) are approximately 262 µm, 120 nm and 320 µm, respectively (Mohammadifar et al. 2007; Balaghi et al. 2010).

The presence of large particles in the samples containing GT can be attributed to bassorin, which increases the viscosity of the sample without the formation of any complexes with protein and remains intact in the sample (Balaghi et al. 2010).

As mentioned before, 3% salt causes the neutralization of GT and impedes the formation of complexes between gum and protein molecules. Similarly, in spray-dried yogurt in the presence of neutral hydrocolloids, such as carrageenan and guar gum, particle size increases (Ramirez-Figueroa et al. 2002). On the contrary, in the Iranian yogurt drink (doogh) in the presence of lower levels of salt (between 0·5–0·6%), GT was not completely neutralized; therefore, the formation of protein–polysaccharide complexes led to a decrease in particle size (Ghorbani Gorji et al. 2010).

Turbidity

Table 2 shows the optical density of samples, which is identified as the turbidity. According to the Pearson correlation coefficient, the level of turbidity has a negative correlation with gum concentration and *d*(0·9). It can be attributed to the high turbidity levels in samples containing no gum due to the presence of aggregated protein molecules. The addition of gum may have hindered the aggregation of proteins by increasing the viscosity of the continuous phase of the samples and, consequently, reduces the turbidity. Lower turbidity indicates fewer aggregated proteins (McClements, 2005).

Rheometery results

Steady shear flow. As shown in Table 3 as well as the flow curve of the samples in Fig. 2, increasing the concentration of GT caused an increase in both the apparent viscosity and the degree of pseudoplasticity of the samples. This behaviour is usually related to the high degree of internal network structure. A higher consistency index (*m*) and lower flow index (*n*) can be considered appropriate to achieve a high degree of viscosity and a clean mouthfeel.

The results were not consistent with previous reports on the study of adsorbing stabilizers (LM-pectin and λ carrageenan) and non-adsorbing stabilizers (locust bean gum, guar gum and xanthan) in stirred skim-milk yogurt (Everett & McLeod, 2005). For each sample stabilized with the mentioned hydrocolloids, by increasing the gum concentration, a minimum level of viscosity was reported. The concentration dependence of viscosity for the adsorbing stabilizer was related to the bridging of casein aggregates, which occurred at low concentrations of added gum

Table 3. Parameters related to Herschel–Bulkley and power-law models for the samples with different concentrations of GT

	†Herschel–Bulkley		‡Power-law		
Gum tragacanth (%)	Herschel–Bulkley Yield stress (Pa)	R^2	n	m (Pa.s^n)	R^2
0	4·31 ± 0·17[d]	0·99	0·23 ± 0·01[a]	40·52 ± 0·72[d]	0·99
0·1	14·44 ± 0·25[c]	0·99	0·20 ± 0·01[b]	62·29 ± 2·30[c]	0·99
0·3	31·08 ± 0·92[b]	0·99	0·20 ± 0·01[b]	96·82 ± 1·46[b]	0·99
0·5	76·49 ± 0·80[a]	0·98	0·20 ± 0·01[b]	154·39 ± 3·11[a]	0·99

a–d Means with different letters with in the column differed significantly ($P < 0·05$)
† Shear rate range: 0·01–15 (1/s)
‡ Shear rate range: 15–900 (1/s)

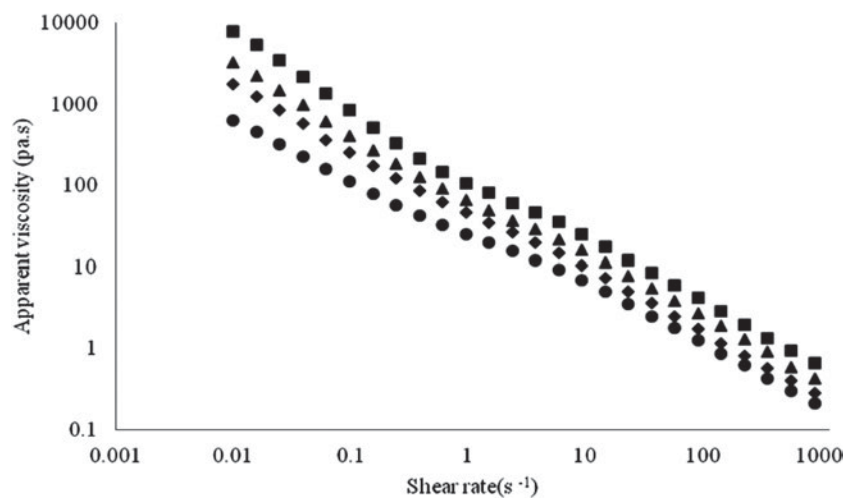

Fig. 2. The flow curve of the samples with different concentrations of GT at 25 °C: (●) 0%, (♦) 0·1%, (▲) 0·3%, (■) 0·5%.

(up to 0·1%) and resulted in reduction in the water-holding capacity with no change in volume fraction and constant viscosity. At higher gum concentrations, aggregates were partially sterically stabilized, which led to the reduction of the effective volume fraction and viscosity and an increase in water-holding capacity. By increasing the concentration of gum, depletion flocculation by unadsorbed polysaccharide became dominant. With the addition of higher quantities of gum to the sample, a gel-like structure was formed in the continuous phase; thus, colloidal aggregates could be trapped in a viscous polymer network. Previous studies revealed that, compared with the flow index (*n*), the consistency index (*m*) was affected to a greater extent by the addition of hydrocolloids (Keogh & O'kennedy, 1998; Ramirez-Santiago et al. 2010).

In contrast to the previously mentioned results, in the study of stirred yogurt containing several concentrations of different stabilizers, adding low amount of GT to the kashk samples resulted in both destabilizing) and stabilizing effects. Destabilization due to depletion flocculation phenomenon induced by low molecular and screened repulsive charged water soluble fraction of GTand stabilization due to the influence of water-swellable fraction of GT on increasing the apparent viscosity of the continuous phase in this high concentration protein system (presence of more intermolecular chain entanglement of biopolymers and therefore a higher order interaction between rheological units occurring) (Azarikia & Abbasi, 2010). It seems that adding 0·1% GT cannot increase the viscosity sufficiently to prevent the increase in syneresis.

Amplitude sweep. As shown in Table 4 the values of G', G'', λ_L and τ_y increased with gum concentration. Outside the LVR, irreversible elastic behaviour exists at the flow point in which the internal structure is ruptured to such an extent as to cause the material to flow, and the gel adopts a liquid character ($G' = G''$) (Mezger, 2006). Similar trends were observed for the stress (τ_f), flow point and G^* at flow point.

The cohesive energy density, E_c, which is an important parameter for the evaluation of structural strength in dispersions, can be obtained from the change in G' and λ_L using following equation: (Tadros, 2010)

$$E_c = \frac{1}{2} G' \times \lambda_L^2 (\text{unit of } E_c \text{ is Jm}^{-3})$$

where G' is storage modulus in the LVR, and λ_L is the strain limit of the LVR.

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Table 4. Amplitude sweep parameters of the samples at 25 °C

Gum tragacanth (%)	G' at(LVE) (Pa)	G'' (LVE) (Pa)	λ_L (%)	τ_y (Pa)	τ_f (Pa)	G^* at flow point (Pa)	Cohesive Energy (E_c) (J/m^3)
0	$51{\cdot}05 \pm 2{\cdot}31^d$	$22{\cdot}99 \pm 0{\cdot}64^d$	$0{\cdot}28 \pm 0{\cdot}01^d$	$0{\cdot}45 \pm 0{\cdot}01^d$	$2{\cdot}11 \pm 0{\cdot}07^d$	$14{\cdot}34 \pm 0{\cdot}57^d$	$2 \pm 0{\cdot}23^d$
0·1	$137{\cdot}56 \pm 2{\cdot}13^c$	$50{\cdot}11 \pm 2{\cdot}46^c$	$0{\cdot}36 \pm 0{\cdot}01^b$	$0{\cdot}50 \pm 0{\cdot}01^c$	$11{\cdot}76 \pm 0{\cdot}35^c$	$23{\cdot}27 \pm 0{\cdot}91^c$	$8{\cdot}91 \pm 0{\cdot}51^c$
0·3	$363{\cdot}16 \pm 3{\cdot}65^b$	$115{\cdot}71 \pm 3{\cdot}23^b$	$0{\cdot}33 \pm 0{\cdot}01^c$	$1{\cdot}09 \pm 0{\cdot}03^b$	$33{\cdot}03 \pm 0{\cdot}32^b$	$57{\cdot}28 \pm 0{\cdot}62^b$	$19{\cdot}77 \pm 1{\cdot}32^b$
0·5	$1224{\cdot}89 \pm 12{\cdot}32^a$	$318{\cdot}36 \pm 3{\cdot}18^a$	$0{\cdot}48 \pm 0{\cdot}01^a$	$5{\cdot}21 \pm 0{\cdot}02^a$	$88{\cdot}11 \pm 0{\cdot}88^a$	$133{\cdot}38 \pm 1{\cdot}33^a$	$141{\cdot}11 \pm 5{\cdot}32^a$

a–d Means with different letters with in the column differed significantly ($P < 0{\cdot}05$)

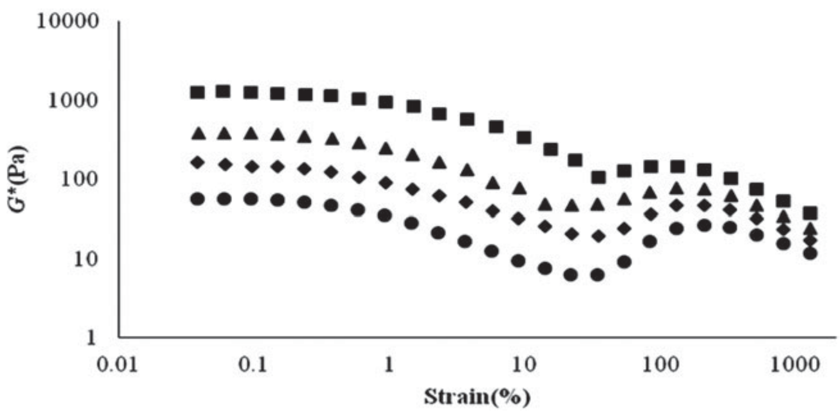

Fig. 3. Complex modulus versus strain for the samples with different concentrations of GT at 25 °C: (●) 0%, (♦) 0·1%, (▲) 0·3%, (■) 0·5%.

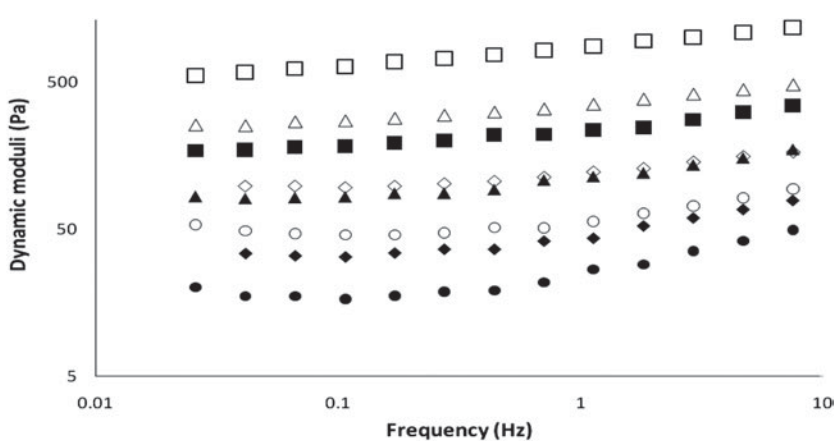

Fig. 4. G' and G'' versus frequency for the samples with different concentrations of GT at 25 °C: (○) 0% G′, (●) 0% G'', (◊) 0·1% G', (♦) 0·1% G'', (△) 0·3% G', (▲) 0·3% G'', (□) 0·5% G', (■) 0·5% G''.

E_c may be used in a quantitative manner as a measure of the extent and strength of the flocculated structures in dispersions. It should be noted that higher values of E_c, indicate more-flocculated structures. Not only does E_c depend on the volume fraction of the dispersion, but it also depends on the particle size distribution (which determines the number of contact points in a flocculation). Comparing the value of E_c in different samples (Table 4), revealed that increasing the amount of GT up to 0·3% did not significantly increase the values of E_c, whereas a drastic rise in the sample containing 0·5% GT was observed (the E_c of sample with 0·5% GT was 70 times more than the E_c of sample without GT).

Figure 3 illustrates an unusual increase in G^* outside the LVR after its initial decrease. The mentioned upward trend is described as being shear-induced and is less pronounced

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Table 5. Complex modulus and damping factor of the samples in 25 °C at three different frequencies

	G^* (Pa)			tan δ		
Gum tragacanth (%)	0·1 Hz	1 Hz	8 Hz	0·1 Hz	1 Hz	8 Hz
0	$48{\cdot}90 \pm 0{\cdot}96^{d}$	$62{\cdot}59 \pm 1{\cdot}23^{d}$	$106{\cdot}42 \pm 2{\cdot}15^{d}$	$0{\cdot}37 \pm 0{\cdot}01^{a}$	$0{\cdot}47 \pm 0{\cdot}01^{a}$	$0{\cdot}54 \pm 0{\cdot}02^{b}$
0·1	$101{\cdot}29 \pm 1{\cdot}85^{c}$	$130{\cdot}54 \pm 5{\cdot}21^{c}$	$185{\cdot}88 \pm 6{\cdot}25^{c}$	$0{\cdot}34 \pm 0{\cdot}01^{b}$	$0{\cdot}35 \pm 0{\cdot}02^{b}$	$0{\cdot}47 \pm 0{\cdot}01^{a}$
0·3	$285{\cdot}05 \pm 8{\cdot}43^{b}$	$371{\cdot}09 \pm 6{\cdot}67^{b}$	$509{\cdot}73 \pm 18{\cdot}30^{b}$	$0{\cdot}30 \pm 0{\cdot}02^{c}$	$0{\cdot}32 \pm 0{\cdot}01^{c}$	$0{\cdot}36 \pm 0{\cdot}02^{c}$
0·5	$660{\cdot}88 \pm 6{\cdot}57^{a}$	$907{\cdot}26 \pm 10{\cdot}12^{a}$	$1220{\cdot}88 \pm 27{\cdot}77^{a}$	$0{\cdot}29 \pm 0{\cdot}01^{c}$	$0{\cdot}27 \pm 0{\cdot}01^{d}$	$0{\cdot}29 \pm 0{\cdot}01^{d}$

a–d Means with different letters with in the column differed significantly ($P < 0{\cdot}05$)

in the presence of GT. This shear thickening behaviour has been reported for suspensions with high solid volume fractions and is usually observed after an initial shear thinning region.

It should be pointed that to control this strain-thickening behaviour, many parameters such as the particle size distributions, particle volume concentration, viscosity and viscoelasticity of the continuous phase and properties of the interfaces should be considered. It seems that changing the rheological behaviour of the continuous phase by adding GT affects the strain thickening of the whole system. (Raghavan & Khan, 1997).

According to Fig. 3, for all samples, the critical strain (the strain in which shear thinning behaviour changes into shear thickening behaviour) is approximately the same, and the addition of gum had no remarkable effect on the amount of critical shear in different samples. It should be considered that, unlike the yield stress calculated from the LVR (τ_y), the absolute values of the stress in flow points (τ_f) were in good agreement with the Herschel–Bulkley yield stresses (Table 3).

Frequency sweep. As illustrated in Fig. 4, for all samples, the elastic behaviour dominates the viscous one ($G' > G''$) across the entire frequency range. This indicates the formation of a three-dimensional network of forces and a certain degree of cross-linking between rheological units; however, both moduli are frequency-dependent and had higher values at high frequencies. Table 5 shows that G^* (which is indicative of structural strength) of the samples increases with gum concentration. On the other hand, at high levels of GT, the damping factor (tan δ) decreases, which indicates a more dominant elastic portion.

For the sample without added GT, a sparsely cross-linked structure is suggested, and this could be characterized as a soft food gel. The addition of 0·1% (w/w) GT to the samples caused a greater slope in the G'' values and resulted in the formation of a cross-over. Usually, this shape of the frequency sweep diagram is representative of a colloidal system composed of two distinct fractions. This result could be attributed to the instability effect in 0·1%-added gum on the system through the depletion flocculation mechanism. Therefore, an approximately twofold increase in syneresis and a sixfold increase in span (as a measure of polydispersity) was observed (Table 2). These results are also in accordance with the frequency sweep data. In other words, GT had a key role in the stability of the system via the alteration of the type of structure of the samples. At lower frequencies, longer molecules and aggregates are not capable of moving and gliding along each other, and consequently, their entanglements form a temporary network. Hence, the samples exhibit a slight solid viscoelastic behavior. By increasing the frequency (decrease in time period, over which the deformation is observed) the smaller and more movable molecules show more inflexibility; thus G' and G'' curves slope upward. When the gum concentration increased (more than 0·1%), the frequency dependence of G' and G'' declined. This behaviour was accompanied by reduced syneresis and polydispersity (Table 2). It could be assumed that higher concentrations of stabilizer entrapped the casein aggregates in an entangled viscous polysaccharide continuous phase.

Conclusion

Knowledge of the rheological properties of dispersed systems is a prerequisite for increasing the effectiveness of their production and function and also for their handling, shelf-life prediction, quality control and equipment design. The effect of adding GT on the stability, flow behaviour and structural properties of kashk, a heated, concentrated and acidified low-fat milk product, were determined. It was found that the addition of higher concentrations of GT resulted in higher structural strength and shape retention ability. Syneresis results showed that 0·5% (w/w) and 0·1% of GT were the most and the least effective in reducing the syneresis of the samples respectively. Unlike previous studies on the effect of polysaccharides on many model systems or real acidified dairy products, significant correlations were not observed between most of the rheological properties and the degree of syneresis. It appears that the addition of GT affected the stability of the samples by changing the type of structure, which is consistent with the results of the frequency sweep experiments.

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