Effect of *S. macrosiphon* and *L. perfoliatum* seed gums on rheological characterization of bitter orange (*Citrus aurantium* L.) and pomegranate (*Punica granatum* L.) paste blends

Maryam Asnaashari¹ · Ali Motamedzadegan¹ · Reza Farahmandfar¹ ·
Tandis Khosravi Rad²

Revised: 27 August 2015 / Accepted: 21 October 2015 / Published online: 7 November 2015
© Association of Food Scientists & Technologists (India) 2015

Abstract The steady shear flow properties of bitter orange and pomegranate pastes and blend of two pastes including 0.5% *Salvia macrosiphon* (SMG) and *L. perfoliatum* (LPG) seed gums, two traditional Iranian hydrocolloids, were determined. All treatments exhibited shear-thinning behaviour. LPG added sample showed stronger shear thinning behaviour than the other due to its high molecular weight and intermolecular through hydrogen bonds and polymer entanglement. Ostwald model was found the best model to describe steady shear flow behaviour among different time-independent rheological model applied. Treatments including 0.5% these two seed gums indicated a flow behaviour index less than 0.6 and consistency coefficient raised by increasing concentration from 60 °Bx to 76 °Bx in bitter orange paste (from 0.55 Pa sⁿ to 32.58 Pa sⁿ), pomegranate paste (from 0.55 Pa sⁿ to 84.87 Pa sⁿ) and mix of these two pastes (from 0.64 Pa sⁿ to 56.9 Pa sⁿ). Oscillatory shear data showed weak gel-like behaviour of bitter orange and pomegranate pastes treatments including seed gums with the elastic modulus predominating over the viscous one at lower frequency. However, after weak

gel formation, G'' was higher than G' in the frequency range of 0.01 to 10 Hz. An Ostwald model was used to describe the changes of viscose modulus with frequency. The results indicate that the elastic properties of bitter orange/ pomegranate paste and bitter orange paste may be increased by the presence of LPG and SMG due to associations of ordered chain segments of these gums, resulting in a weak three-dimensional network.

Keywords Bitter orange paste · LPG (*L. perfoliatum*) · Rheology · (SMG) *Salvia macrosiphon* · Pomegranate paste

Introduction

Hydrocolloids which are high molecular weight hydrophilic biopolymer are broadly used in food systems due to thickening, gelling, texture modifying and stabilization properties. They improve functional properties like viscosity, water binding capacity and emulsion stability and also can be used to diverse physical, mechanical and sensorial functions of food. The demand for food hydrocolloids with specific functionality increased in last decade. Among commercial available gums, the hydrocolloids from seeds are of much importance due to their low price, easy extraction and availability (Razavi et al. 2009).

Salvia macrosiphon had a great potential to produce mucilage, when small seeds soaked in water. Razavi et al. (2012) studied gum extraction from *S. macrosiphon*. The optimum condition was observed at pH 5.5, water to seed ratio 51:1 and 25°C. At the optimum condition, the *S. macrosiphon* powder contained 79.75% carbohydrate, 8.17% ash, 6.72% moisture, 2.84% protein, 1.67% crude fiber, 0.85% lipid. *S. macrosiphon* dispersion (1% w/v) indicated shear-thinning behaviour, the consistency and flow indices ranged

Highlights

- Non-Newtonian shear thinning behaviour of LPG and SMG in bitter orange and pomegranate and mix of bitter orange/pomegranate pastes
- Stronger shear thinning behaviour of LPG than SMG due to its high molecular weight and polymer entanglement
- The best model described the samples' rheological behaviour was Ostwald

✉ Maryam Asnaashari
m.asnaashari@yahoo.com

¹ Department of Food Science and Technology, Sari Agricultural Sciences & Natural Resources University (SANRU), Sari, Iran

² Tabarestan Technology Incubator Center (related to Sari Agriculture Sciences & Natural Resources), Sari P. O. Box 48156-64985, Iran

from 4.5 to 9.4 Pa.s and 0.32 to 0.37, respectively (Bostan et al. 2010). *L. perfoliatum* is cultivated in some countries including Egypt, Arabia, Iraq, Iran and Pakistan (Koocheki et al. 2009b). It is locally called Qodume shahri. Qodume shahri as herbal medicine in Iran, are widely used in the dry coughs, asthma, lung infection and demulcent treatments after soaking in water and extracting mucilage. The *L. perfoliatum* seed gum powder includes 88.23 % carbohydrate, 6% moisture, 4.6 % protein and 0.18 % ash. The hydrated *L. perfoliatum* seed gum exhibits non-Newtonian pseudoplastic behaviour and has thickening agent property in food industry (Koocheki et al. 2013). However, there is no research in literature about the rheological properties of this gum in bitter orange and pomegranate pastes to date.

Understanding the rheological properties of food products influences on process equipment design such as pumps, heat exchangers, mixers, piping and evaporators (Mandalari et al. 2007). The rheological properties of fruits and vegetables are important not only for human diet formulation, but also for studying their rheological changes during harvesting and physiological changes after harvest and processing. A large amounts of fruit paste are produced commercially for direct consumption and as ingredient, e.g. fruit leathers (Hosseini-Parvar et al. 2010). The rheological properties of many fruits such as kiwi juice concentrate (Ibarz et al. 1995), banana puree (Guerrero and Alzamora 1997), cashew juice (Morley et al. 2007), and apricot-peach pulps (Houska et al. 1998) have been investigated. In general, pastes of fruits and vegetables mostly indicate pseudoplastic behaviour. Moreover, the various factors affecting rheological behaviour of fruits paste such as temperature (Oomah et al. 1999), total soluble solids (Ilicali 1985), particle size (Pelegrine et al. 2002) and pH (Dik and Özilgen 1994) are literature in various studies.

The current research, studies the impact of 0.5% of *S. macrosiphon* and *L. perfoliatum* seed gums on flow behaviour and rheological properties of each bitter orange (*C. aurantium*) and pomegranate pastes and the mixture of both pastes. Moreover, the dynamic rheological behaviour of these blends at two different concentrations (60 and 76°Bx) as a function of those seed gums were assessed.

Materials and methods

Materials

Pomegranate (*Punica granatum* L.) and bitter orange (*C. aurantium* L.) were purchased from a local market, Mashhad, Iran. The pomegranates did cut and pressed using fruit extractor (Bosch, MES3000GB, Germany) to extract the juice. Then, the extract (17.5°Bx) heated by stove (DE91GW109L, DeLonghi, Australia) to make a specific consistency (60 and 76°Bx) of thick paste, then cooled with

tap water to 25 °C in 30min. Moreover, the bitter oranges cut and extracted using a citrus juicer (MCP 3500, Bosch, Germany) and concentrated in direct heat at 96 °C using a stove (DE91GW109L, DeLonghi, Australia) to reach from 13.5°Bx to 60 and 76°Bx. The bitter orange paste was removed from the heat and allowed to cool to 25 °C for 30 min.

Gums extraction

S. macrosiphon seeds were provided from a local market of Sari, Iran. After manually cleaning the seeds from all foreign matter, the gum was extracted at optimum conditions as described by Bostan et al. (2010). The dispersion was dehydrated overnight in forced convection oven (Model Memert UFB 400, Germany) at 50°C, then milled and sieved by a mesh 18 sifter. *L. perfoliatum* seed gum was dispersed in deionised water (water/seed ratio 30:1) under pH 8 and 48°C conditions. The seed-water mixture was mixed (1.5h) and dried in a conventional oven (45°C), then milled and sieved using a mesh 18 sifter (Koocheki et al. 2009b).

Sample preparation

S. macrosiphon and *L. perfoliatum* seed gums solution were prepared by adding appropriate amounts of the LPG and SMG powder to a portion of deionised water. The bitter orange and pomegranate pastes samples were prepared by mixing 60 g of the pastes with 0.5% of LPG and SMG seed gums for 20min in laboratory PW overhead stirrer (Velp, Italy). These samples were kept in a refrigerator at 4°C for 24 h before further experiments.

Rheological measurement

For steady flow measurements, the rheometer was programmed at 25°C and equilibrated for 10 min following with a two-cycle programmed shear changing from 0.1 to 10 sec⁻¹ in 5min (upward) and from 10 to 0.1 sec⁻¹ in next 5 min (downward). Rheological parameters (shear stress, shear rate, shear viscosity, and other parameters) were obtained from the Rheoplus software (version 3.40; Anton Paar GmbH, Germany). Various rheological flow models based on shear stress-shear rate were tested. Among them, Hershel-Bulkley's and Ostwald-Waele's (Eqs. 2 and 3) were given better fitted.

The hysteresis loop was obtained from the area between the upward, and downward data. This area was obtained by the difference between integrating the area for forward and backward measurements from γ_1 (initial shear rate) to γ_2 (final shear rate):

$$\text{Hysteresis loop area} = \int_{\gamma_1}^{\gamma_2} k \cdot \dot{\gamma}^n - \int_{\gamma_1}^{\gamma_2} k' \cdot \dot{\gamma}'^n \quad (1)$$

Fig. 1 Comparison the apparent viscosity of 0.5 % *S. macrosiphon* (SMG) and 0.5 % *L. perfoliatum* (LPG) seed gums in bitter orange and pomegranate pastes blend. $\square$ - Bitter orange (76 °Bx), $\blacksquare$ - Pomegranate (76°Bx), $\blacklozenge$ - Mix (76°Bx), $\triangle$ - Bitter orange (60°Bx), $+$ - Pomegranate (60°Bx), $\diamond$ - Mix (60°Bx), $\blacktriangledown$ - Bitter orange (60°Bx) +0.5 LPG, ∇ -Bitter orange (60°Bx) + 0.5 SMG, $\ast$ - Mix (60°Bx) + 0.5 LPG, $\blacktriangle$ - Mix (60°Bx) + 0.5 SMG

where k , k' and n , n' are the consistency coefficient and flow index behaviour for forward and backward measurements, respectively.

All rheological measurements were carried out using an advanced stress/strain controlled rheometer (Anton Paar physica MCR301, Austria), equipped with parallel plate geometry (diameter 50 mm, gap 1 mm) was applied to measure small-deformation oscillatory changes. For all the rheological tests, the temperature was fixed at desired temperature (25°C). Amplitude sweep tests in controlled shear stress (CSS) and controlled shear rate (CSR) modes were carried out for determining linear viscoelastic region (LVE) at 25°C and 1 Hz. Deformation was elevated from 0.1% to 100% in amplitude sweep. Frequency sweep tests were then performed, within the LVE (strain of 0.1%), in the range of 0.01 to 100 Hz, to characterize the mechanical spectrum of bitter orange and pomegranate paste blends. The storage modulus (G'), loss

modulus (G''), complex viscosity (η^*), and other parameters were recorded. Various rheological models based on steady flow behaviour and loss modulus-frequency were tested (Newtonian, Bingham, Casson, Ostwald and Herschel Bulkley). The best fitted models were Herschel Bulkley and Ostwald-Waele's based on Rheoplus software (version 3.40; Anton Paar GmbH). Those model were calculated as following:

Herschel-Bulkley's model:

where τ_0 is the yield stress (Pa), k is the consistency coefficient (Pa.s^n), and n is flow behaviour index for this model.

$$\tau = \tau_0 + K(\dot{\gamma})^n \quad (2)$$

Ostwald-Waele's (Power law) model:

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

Table 1 Hysteresis loop area of *S. macrosiphon* (SMG) and *L. perfoliatum* (LPG) seed gums in bitter orange and pomegranate pastes blend

	Integrating area for up curve	Integrating area for down curve	Hysteresis loop area (Pa.s^{-1})
Bitter orange (76°Bx)	35.18	35.07	0.11
Pomegranate (76°Bx)	161.66	132.18	29.48
Mix (76°Bx)	88.56	74.62	13.29
Bitter orange (60°Bx)	0.99	0.96	0.03
Pomegranate (60°Bx)	1.94	4.68	1.94
Mix (60°Bx)	1.75	2.01	0.26
Bitter orange (60°Bx) + 0.5LPG	24.74	14.72	10.02
Bitter orange (60°Bx) + 0.5 SMG	10.36	6.23	4.31
Mix (60°Bx) + 0.5 LPG	20.21	11.6	8.61
Mix (60°Bx) + 0.5 SMG	17.21	8.12	9.09

where k is the power law consistency coefficient ($\text{Pa}\cdot\text{s}^n$) and n is the power law flow behaviour index.

Statistical analysis

All the experiments were carried out at least in triplicates. Rheological data and graphs were analyzed and data fitting by models was carried out by using Rheoplus software (version 3.40; Anton Paar GmbH) and statistical analysis by SPSS (version 16.0, Chicago, SPSS Inc).

Results and discussion

Flow behaviour determination

The apparent viscosity (η) versus shear rate ($\dot{\gamma}$) was applied to study the rheological behaviour of all treatments. Figure 1 shows that the variation is exponential and therefore they are non-newtonian fluids. Apparent viscosity of all the treatments decreased with increasing shear rate. The decrease in apparent viscosity with increasing shear rate can be explained by the pastes' structural breakdown because of hydrodynamic forces generated and enhanced alignment of the constituent molecules (Behrouzian et al. 2014). Reduction in apparent viscosity facilitates high shear processing operations such as pumping and filling. Considering thixotropic properties of pomegranate paste mixed with bitter orange, the time dependency of pomegranate reduced. Thus, the observed shear thinning behaviour of the bitter orange/pomegranate pastes appears to be an intermediate behaviour between these two distinct flow properties. Samples containing LPG showed stronger shear thinning behaviour rather than those having SSG. This could be explained based on its high molecular weight, intermolecular hydrogen bonds and intramolecular interactions of biopolymers (Lee and Coates 2003). Indeed, the concentration of polysaccharide in solution is known to affect directly the viscosity and the degree of pseudoplasticity. This is due to the higher solid contents which mostly cause an increase in the viscosity resulting from molecular movements (Maskan and Göğüş 2000). Koocheki and Kadkhodae (2011) compared the apparent viscosity of LPG seed gum with other commercial gums. They reported that the viscosity of this gum was lower than guar, almost similar to xanthan and higher than that for locust bean. Steady shear flow properties at different temperatures and concentrations indicated higher viscosity, yield stress and strong shear thinning characteristics for SMG compared to commercial gums such as guar, xanthan and locust bean (Razavi et al. 2011). Moreover, Razavi et al. (2014) determined the physico-chemical characteristic of SMG. Their results under steady shear rate demonstrated that strong shear- thinning behaviour and a typical a weak gel characteristic.

Table 2 Effect of *S. macrospira* (SMG) and *L. perfoliatum* (LPG) seed gums in rheological properties of bitter orange and pomegranate pastes blend

	Shear rate = 0.1			Shear rate = 0.4			Shear rate = 1			Shear rate = 4			Shear rate = 8		
	Shear Stress (Pa)	Viscosity (Pa.s)	Deflection Angle (mrad)	Shear Stress (Pa)	Viscosity (Pa.s)	Deflection Angle (mrad)	Shear Stress (Pa)	Viscosity (Pa.s)	Deflection Angle (mrad)	Shear Stress (Pa)	Viscosity (Pa.s)	Deflection Angle (mrad)	Shear Stress (Pa)	Viscosity (Pa.s)	Deflection Angle (mrad)
Bitter orange (76°Bx)	0.61	6.1	239	2.4	5.99	644	5.91	5.91	1180	23.3	5.82	2820	46.1	5.76	4330
Pomegranate (76°Bx)	3.06	30.6	239	7.99	20	644	16.4	16.4	1180	49.5	12.4	2820	85.2	10.6	4330
Mix (76°Bx)	2.27	22.7	239	4.78	11.9	644	9.53	9.53	1180	34.1	8.52	2820	60.7	7.59	4330
Bitter orange (60°Bx)	0.013	0.013	234	0.041	0.103	640	0.107	0.107	1170	0.387	0.0969	2820	0.778	0.0973	4330
Pomegranate (60°Bx)	0.269	2.69	239	0.431	1.08	644	0.684	0.684	1180	1.49	0.372	2820	2.48	0.311	4340
Mix (60°Bx)	0.04	0.04	239	0.104	0.261	645	0.236	0.236	1180	0.797	0.199	2820	0.778	0.0973	4330
Bitter orange(60°Bx) +0.5LPG	2.9	29	239	3.48	8.69	644	3.99	3.99	1180	5.5	1.38	2820	6.8	0.85	4340
Bitter orange(60°Bx) + 0.5 SMG	0.897	8.97	239	1.25	3.14	645	1.65	1.65	1180	2.72	0.68	2820	3.63	0.453	4340
Mix (60°Bx) + 0.5 LPG	1.95	19.5	239	2.52	6.29	645	3.23	3.23	1180	4.74	1.19	2820	4.94	0.742	4340
Mix (60°Bx) + 0.5 SMG	1.6	16	239	2	5	645	2.56	2.56	1180	3.96	0.99	2820	5.17	0.646	4340

Table 3 Flow behaviour Parameters obtained by different models for *S. macrosiphon* (SMG) and *L. perfoliatum* (LPG) seed gums in bitter orange and pomegranate pastes blend

	Herschel Bulkley Model				Ostwald Model		
	τ_0	k	n	R ²	K	n	R ²
Bitter orange (76 °Bx)	−0.0004	5.9049	0.9902	0.99	5.9032	0.9907	0.99
Pomegranate (76°Bx)	1.49	19.61	0.72	0.98	16.86	0.74	0.99
Mix (76°Bx)	−0.0524	9.803	0.8018	0.98	10.297	0.71896	0.94
Bitter orange (60°Bx)	−0.0024	0.0835	0.8868	0.93	0.095	0.97	0.99
Pomegranate (60°Bx)	0.0024	0.3662	0.8624	0.94	0.495	0.6766	0.93
Mix (60°Bx)	−0.0061	0.2512	0.8868	0.99	0.2384	0.9439	0.98
Bitter orange (60°Bx) +0.5 LPG	0.0786	2.8165	0.31459	0.75	3.2452	0.2818	0.79
Bitter orange (60°Bx) + 0.5 SMG	0.015	1.1353	0.5091	0.88	1.3331	0.4105	0.9
Mix (60°Bx) + 0.5 LPG	0.2873	1.9448	0.4138	0.76	2.5901	0.2854	0.79
Mix (60°Bx) + 0.5 SMG	0.03654	1.5159	0.48886	0.63	1.9499	0.3314	0.7

The hysteresis area is an index of the energy per unit of time and per unit of volume needed to eliminate the influence of time in flow behaviour. It could be concluded that the calculated hysteresis area of pomegranate paste (76°Bx) with 29.48 Pa.s^{−1} had the biggest hysteresis loop, followed by bitter orange/pomegranate (50:50) (76°Bx), bitter orange (76°Bx), bitter orange containing LPG (60°Bx), bitter orange/pomegranate (50:50) (60°Bx) containing 0.5% LPG, bitter orange/pomegranate (50:50) (60°Bx) containing SMG, bitter

orange containing SMG (60°Bx), pomegranate (60°Bx), bitter orange/pomegranate (50:50) (60°Bx), and bitter orange (60°Bx) in that order (Table 1). According to Tárrega et al. (2004), a high viscosity thixotropic fluid might show a larger hysteresis area than a lower viscosity one. As shown in Table 2, a clear shear thinning behaviour was observed for all samples. As shear rate changed from 0.1 to 8, the viscosity decreased in bitter orange and pomegranate pastes samples. Such behaviour has been reported for many hydrocolloid in

Fig. 2 Comparison the Complex modulus of 0.5 % *S. macrosiphon* (SMG) and 0.5 % *L. perfoliatum* (LPG) seed gums in bitter orange and pomegranate pastes blend.

□- Bitter orange (76 °Bx), ■- Pomegranate (76°Bx), ◆- Mix (76°Bx), △- Bitter orange (60°Bx), + - Pomegranate (60°Bx), ◇- Mix (60°Bx), ▼- Bitter orange (60°Bx) +0.5 LPG, ▽- Bitter orange (60°Bx) + 0.5 SMG, * - Mix (60°Bx) + 0.5 LPG, ▲ - Mix (60°Bx) + 0.5 SMG

fruit paste systems (Maceiras et al. 2007). The decrease in viscosity with increase in shear rate is mainly related to the disentanglement of macromolecular chains under shear field and breaking of possible structure in solution. Moreover, in specific shear rate, pomegranate paste (76°Bx) showed the highest shear stress, followed by blend of bitter orange and pomegranate pastes (76°Bx), bitter orange paste (76°Bx), samples with 0.5% LPG and those containing SMG.

In order to determine the presence of apparent yield stress and find out the rheological flow behaviour, plotting the obtained shear stress-shear rate data are required. On comparison of different models of flow behaviour of bitter orange, pomegranate and bitter orange/pomegranate (50:50) pastes, the two models (Ostwald and Herschel-Bulkley models) which have been extensively used in theoretical analysis and in practical engineering calculation, give a very good fit. Indeed, low values of R^2 show that the model is inadequate in describing the shear stress-shear rate relationship. Moreover, based on the physical criteria, estimated parameters of a model should not be negative. The most appropriate models for rheological behaviour of pomegranate and bitter orange pastes, with and without LPG and SMG seed gums along with their regression parameters are shown in Table 3. Although Hershel-Bulkley model with yield stress indicated high R^2 in most of the

samples, the extrapolated yield stress was negative; the results were near to zero. As mentioned above, the estimated parameters should not be negative, thus this model is not appropriate for prediction of their flow properties. Ostwald model showed a better fit for these samples. So that, n values for most of the samples are less than one which indicates pseudoplastic flow behaviour. The shear-thinning behaviour of LPG and SMG seed gums added in pomegranate and bitter orange pastes, related to the modifications in macromolecular organization, represents an irreversible structural alignment that occur within such substance (Rha 1975). Treatments including 0.5% these two seed gums indicated a flow behaviour index less than 0.6 which is an important factor in sensorial properties and food formulation. Hydrocolloids with low n value provide high viscosity, demonstrate pleasant mouthfeel (Szczesniak and Farkas 1962). Moreover, K as a function of the dispersing medium and consistency coefficient raised by increasing concentration from 60°Bx to 76°Bx in bitter orange paste (from 0.55 Pa.sⁿ to 32.58 Pa.sⁿ), pomegranate paste (from 0.55 Pa.sⁿ to 84.87 Pa.sⁿ) and mix of these two pastes (from 0.64 Pa.sⁿ to 56.9 Pa.sⁿ). Many other studies indicated that Ostwald model is the best model for describing the flow behaviour of the food hydrocolloids such as Qodume shirazi mucilage (Koocheki et al. 2009a), salep (Farhoosh and Riazi 2007) and brown seaweeds

Fig. 3 Mechanical spectrum of complex viscosity (η^*) with frequency for 0.5 % *S. macrosiphon* (SMG) and 0.5 % *L. perfoliatum* (LPG) seed gums in bitter orange and pomegranate pastes blend. -□- Bitter orange (76 °Bx), -■- Pomegranate (76°Bx), -◆- Mix (76°Bx), -Δ- Bitter orange

(60°Bx), - + - Pomegranate (60°Bx), -◇- Mix (60°Bx), -▼- Bitter orange (60°Bx) + 0.5 LPG, -□- Bitter orange (60°Bx) + 0.5 SMG, -*- Mix (60°Bx) + 0.5 LPG, -▲- Mix (60°Bx) + 0.5 SMG

Table 5 The effect of *S. macrosiphon* (SMG) and *L. perfoliatum* (LPG) seed gums added to bitter orange and pomegranate pastes blend on frequency dependency of storage modulus by two models

	Herschel-Bulkley Model				Ostwald Model		
	τ_0	k	n	R ²	K	n	R ²
Bitter orange (76°Bx)	0.09	32.35	0.99	0.99	32.58	0.98	0.99
Pomegranate (76°Bx)	9.77	71.93	0.84	0.99	84.87	0.72	0.99
Mix (76°Bx)	3.13	51.61	0.8	0.99	56.90	0.7	0.99
Bitter orange (60°Bx)	0.08	0.55	5.14	0.92	0.55	1.04	0.95
Pomegranate (60°Bx)	0.11	0.89	1.22	0.92	0.55	1.04	0.95
Mix (60°Bx)	0.05	0.63	1.06	0.98	0.64	1.01	0.95
Bitter orange (60°Bx) + 0.5 LPG	0.64	2.32	0.85	0.99	3.32	0.55	0.95
Bitter orange (60°Bx) + 0.5 SMG	0.29	3.00	0.71	0.99	3.45	0.6	0.99
Mix (60°Bx) + 0.5 LPG	0.8	2.38	0.85	0.99	3.6	0.52	0.94
Mix (60°Bx) + 0.5 SMG	0.43	3.43	0.68	0.99	4.05	0.55	0.99

(60°Bx) with 0.135 Pa.s in that order. Moreover, dynamic rheological properties of SMG obtained by frequency sweep tests indicated that the SMG exhibited weak gel behaviour at all concentrations (0.5–2%) (w/w) like psyllium and xanthan (Razavi et al. 2014). The tangent of phase angle (δ) (a ratio of viscous to elastic modulus) measures energy lost relatively to the energy stored in a cyclic deformation. A phase angle of 90° indicates that the material is fully viscous and a fully elastic material is characterized by phase angle value of 0°. For all samples phase angle values were in the range of 88.73–20.98 for lower frequency (0.1 Hz) and in the range of 89.59–65.71 at higher frequency (10 Hz), indicating that the treatments exhibited lower phase angle at low frequencies, but it increased slightly at higher frequencies, showing a higher contribution of the viscous component at higher frequencies. The phase angle values of the treatments including the two seed gums were lower than those treatments without LPG and SMG, meaning that they are more structured and more elastic gel-like compared to the gum free samples. From these results, it was found that those samples containing LPG, and SMG showed more solid-like behaviour than the control, indicating

that they can reinforce the network structure of the bitter orange and blend of these pastes (Razavi et al. 2012).

The dynamic rheological moduli were fitted to Ostwald and Herschel Bulkley models. Linear regression of G'' vs. frequency was carried out for all treatment and magnitudes of slopes and intercept were computed. Regression parameters obtained are reported in Table 6. It is evident from the table that viscous modulus-frequency data fitted the both models adequately. The magnitudes of k increased in treatment including LPG and SMG. So that, the highest k value in Ostwald model was attributed to pomegranate paste (76°Bx) with 84.87 pa.s. There was a substantial difference between the k value of the pomegranate and bitter orange pastes with and without LPG and SMG. The n value of the treatments was mostly lower than 1. The observed results indicate that the elastic properties of bitter orange/ pomegranate paste and bitter orange paste may be increased by the presence of LPG and SMG. Such elastic properties of samples containing LPG and SMG can merely be related to the associations of ordered chain segments of these gums, resulting in a weak three-dimensional network (Razavi and Karazhiyan 2009).

Table 6 The effect of *S. macrosiphon* (SMG) and *L. perfoliatum* (LPG) seed gums on Crossover of storage modulus and viscose modulus in frequency sweep mode

	Frequency (Hz)	Storage Modulus (Pa)	Complex Modulus (Pa)	Complex Viscosity (Pa.s)
Bitter orange(76°Bx)	No Crossover			
Pomegranate(76°Bx)	No Crossover			
Mix (76°Bx)	0.075	9.66	13.66	28.96
Bitter orange(60°Bx)	No Crossover			
Pomegranate(60°Bx)	0.01	0.072	0.1	1.3
Mix (60°Bx)	0.305	0.257	0.36	0.19
Bitter orange(60°Bx) + 0.5 LPG	1.91	4.64	6.57	0.55
Bitter orange(60°Bx) + 0.5 SMG	0.39	1.84	2.61	1.07
Mix (60°Bx) + 0.5 LPG	1.43	3.86	5.45	0.61
Mix (60°Bx) + 0.5 SMG	0.79	3.43	4.86	0.97

Conclusion

It is well acknowledged that high viscosity of food hydrocolloid is one of the most important requests for food products. In this study, LPG and SMG behaved as non-Newtonian shear thinning fluid in bitter orange and pomegranate and combination of bitter orange/pomegranate pastes. The Ostwald model described the rheological behaviour of all samples as well. Because of their shear thinning nature, LPG and SMG seed gums could be suitable for applications as thickening agents, and further study should be done in order to thoroughly understand the potential of these gums in different foods and drinks which are our further objectives.

References

- Behrouzian F, Razavi SMA, Phillips GO (2014) Cress seed (*L. sativum*) mucilage, an overview. *Bioact Carbohydr Dietary Fibre* 3:17–28. doi:10.1016/j.bcdf.2014.01.001
- Bostan A, Razavi SMA, Farhoosh R (2010) Optimization of hydrocolloid extraction from wild sage seed (*Salvia macrosiphon*) using response surface. *Int J Food Prop* 13:1380–1392. doi:10.1080/10942910903079242
- Dik T, Özilgen M (1994) Rheological Behaviour of Bentonite—Apple Juice Dispersions. *LWT - Food Science and Technology* 27:55–58. doi:10.1006/fstl.1994.1012
- Farhoosh R, Razi A (2007) A compositional study on two current types of salep in Iran and their rheological properties as a function of concentration and temperature. *Food Hydrocoll* 21:660–666. doi:10.1016/j.foodhyd.2006.07.021
- Guerrero SN, Alzamora SM (1997) Effect of pH, temperature and glucose addition on flow behaviour of fruit purées I. Banana purée. *J Food Eng* 33:239–256. doi:10.1016/S0260-8774(97)00032-0
- Hosseini-Parvar SH, Matia-Merino L, Goh KKT, Razavi SMA, Mortazavi SA (2010) Steady shear flow behaviour of gum extracted from *Ocimum basilicum* L. seed: Effect of concentration and temperature. *Journal of Food Engineering* 101:236–243. doi:10.1016/j.jfoodeng.2010.06.025
- Houska M, Kyhos K, Gree R, Strolham J, Landfeld A, Nobotna P (1998) Rheological properties of fruit pulp during concentration. *Czech J Food Sci* 16:189–194
- Ibarz A, Giner J, Pagan J, Gimeno V, Garza S (1995) Rheological behaviour of kiwi fruit juice concentrates. *J Texture Stud* 26:137–145. doi:10.1111/j.1745-4603.1995.tb00789.x
- Illici C (1985) Correlations for the consistency coefficients of apricot and pear purees. *J Food Process Eng* 8:47–51. doi:10.1111/j.1745-4530.1985.tb00098.x
- Koocheki A, Kadhodaee R (2011) Effect of *Alyssum homolocarpum* seed gum, Tween 80 and NaCl on droplets characteristics, flow properties and physical stability of ultrasonically prepared corn oil-in-water emulsions. *Food Hydrocolloids* 25:1149–1157. doi:10.1016/j.foodhyd.2010.10.012
- Koocheki A, Mortazavi SA, Shahidi F, Razavi SMA, Taherian AR (2009a) Rheological properties of mucilage extracted from *alysum homolocarpum* seed as a new source of thickening agent. *J Food Eng* 91:490–496. doi:10.1016/j.jfoodeng.2008.09.028
- Koocheki A, Taherian AR, Razavi SMA, Bostan A (2009b) Response surface methodology for optimization of extraction yield, viscosity, hue and emulsion stability of mucilage extracted from *L. perfoliatum* seeds. *Food Hydrocolloids* 23:2369–2379. doi:10.1016/j.foodhyd.2009.06.014
- Koocheki A, Taherian AR, Bostan A (2013) Studies on the steady shear flow behaviour and functional properties of *L. perfoliatum* seed gum. *Food Research International* 50:446–456. doi:10.1016/j.foodres.2011.05.002
- Lee HS, Coates GA (2003) Effect of thermal pasteurization on Valencia orange juice color and pigments. *LWT - Food Sci Technol* 36:153–156. doi:10.1016/S0023-6438(02)00087-7
- Maceiras R, Álvarez E, Cancela MA (2007) Rheological properties of fruit purees: Effect of cooking. *J Food Eng* 80:763–769. doi:10.1016/j.jfoodeng.2006.06.028
- Mandalari G et al. (2007) Antimicrobial activity of flavonoids extracted from bergamot (*Citrus bergamia* Risso) peel, a byproduct of the essential oil industry. *J Appl Microbiol* 103:2056–2064. doi:10.1111/j.1365-2672.2007.03456.x
- Maskan M, Göğüş F (2000) Effect of sugar on the rheological properties of sunflower oil–water emulsions. *J Food Eng* 43:173–177. doi:10.1016/S0260-8774(99)00147-8
- Morley KL, Ferguson PJ, Koropatnick J (2007) Tangeretin and nobiletin induce G1 cell cycle arrest but not apoptosis in human breast and colon cancer cells. *Cancer Lett* 251:168–178. doi:10.1016/j.canlet.2006.11.016
- Oomah BD, Séry G, Godfrey DV, Beveridge THJ (1999) Rheology of Sea Buckthorn (*Hippophae rhamnoides* L.) juice. *J Agric Food Chem* 47:3546–3550. doi:10.1021/jf981312c
- Pelegri DH, Silva FC, Gasparetto CA (2002) Rheological behaviour of pineapple and mango pulps. *LWT - Food Sci Technol* 35:645–648. doi:10.1006/fstl.2002.0920
- Razavi SMA, Karazhiyan H (2009) Flow properties and thixotropy of selected hydrocolloids: Experimental and modeling studies. *Food Hydrocoll* 23:908–912. doi:10.1016/j.foodhyd.2008.05.010
- Razavi SMA, Mortazavi SA, Matia-Merino L, Hosseini-Parvar SH, Motamedzadegan A, Khanipour E (2009) Optimisation study of gum extraction from Basil seeds (*Ocimum basilicum* L.). *Int J Food Sci Technol* 44:1755–1762. doi:10.1111/j.1365-2621.2009.01993.x
- Razavi SMA, Taheri H, Quinchia LA (2011) Steady shear flow properties of wild sage (*Salvia macrosiphon*) seed gum as a function of concentration and temperature. *Food Hydrocoll* 25:451–458. doi:10.1016/j.foodhyd.2010.07.017
- Razavi SMA, Moghaddam TM, Emadzadeh B, Salehi F (2012) Dilute solution properties of wild sage (*Salvia macrosiphon*) seed gum. *Food Hydrocoll* 29:205–210. doi:10.1016/j.foodhyd.2012.02.020
- Razavi SMA, Cui SW, Guo Q, Ding H (2014) Some physicochemical properties of sage (*Salvia macrosiphon*) seed gum. *Food Hydrocoll* 35:453–462. doi:10.1016/j.foodhyd.2013.06.022
- Rha C (1975) Theories and principles of viscosity. Theory, determination and control of physical properties of food materials. Springer, In, pp. 7–24
- Rioux L-E, Turgeon SL, Beaulieu M (2007) Rheological characterisation of polysaccharides extracted from brown seaweeds. *J Sci Food Agric* 87:1630–1638. doi:10.1002/jsfa.2829
- Robinson G, Manning CE, Morris ER (1991) Conformation and physical properties of the bacterial polysaccharides Gellan, Welan and Rhamsan. *Food Polymers, Gels and Colloids* 22–33
- Ross-Murphy SB, Todd S (1983) Ultimate tensile measurements of filled gelatin gels. *Polymer* 24:481–486. doi:10.1016/0032-3861(83)90039-3
- Szczesniak AS, Farkas E (1962) Objective characterization of the mouth-feel of gum solutions. *J Food Sci* 27:381–385. doi:10.1111/j.1365-2621.1962.tb00112.x
- Tárrega A, Durán L, Costell E (2004) Flow behaviour of semi-solid dairy desserts. Effect of temperature. *Int Dairy J* 14:345–353. doi:10.1016/j.idairyj.2003.12.004