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Original research

The physical and rheological properties of egg albumin emulsions are influenced by basil seed gum as the stabilizer

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A B S T R A C T

In this study, the effect of basil seed gum (BSG) on the stability and rheological properties of egg white albumin (EWA) emulsions was investigated. A constant amount of EWA (0.5% w/v) and different concentrations of BSG (0-0.3% w/v) were used for the manufacture and stabilization of oil-in-water emulsions (30% w/w). The results showed that by increasing BSG concentration, the storage (21 days) stability of the emulsions was significantly ($p < 0.05$) improved. The highest creaming index was obtained in the case of the control emulsion (containing no BSG). Negative zeta potential was observed for all emulsion samples, with the emulsion containing 0.3% BSG showing the most negative surface charge, indicating the improvement in the stability of the manufactured emulsions in the presence of BSG. All of the emulsions showed shear-thinning flow behavior. The apparent viscosity increased with the increase in BSG concentration. Hysteresis area increased due to the increase in BSG concentration. The results of the frequency sweep test showed that storage and loss moduli increased by increasing the frequency and both of these moduli increased due to the increase in BSG concentration. Fitting frequency sweep data with power-law model confirmed a gel-like behavior for the emulsions containing a higher concentration of BSG. Overall, the findings of this study demonstrated that basil seed gum at an optimum concentration (0.3%) could be used as a natural stabilizer in the food emulsions containing egg albumin.

Keywords: Basil seed gum, Emulsion stability, Flocculation, Particle size, Rheological properties

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1. Introduction

Emulsion systems are thermodynamically unstable, because they consist of two immiscible liquid phases. Polysaccharides are one of the most important compounds, which can improve the stability of food emulsions via two different mechanisms. Basil seed gum (BSG) is a novel, but yet natural, a polysaccharide extracted from an herbaceous plant named *Ocimum basilicum* L. This polysaccharide (i.e. BSG) contains two parts; major fraction and minor fraction. The major fraction of this gum consists of glucomannan and (1-4)-linked xylan, which constitutes about 43% and 24% of BSG, respectively. The minor part is mostly comprised of glucan (about 2.3%) (Anjaneyalu & Gowda, 1979). BSG contains some substantial thickening and surface-active properties so it is considered as an emulsifying hydrocolloid, which can be used as a stabilizer in various food products (Naji-Tabasi & Razavi, 2017).

Biopolymers like proteins with emulsifying properties and the ability to increase the viscosity of the emulsion systems are the essential ingredients in the formation of a stable emulsion. Importantly, the interactions between proteins and polysaccharides at the interface can change some of the emulsion properties such as storage stability, texture, mouthfeel, and physicochemical stability (Sun et al., 2007). Protein-polysaccharide complexes have extended usage in the food industry, because of their specific structure, size, and composition (Xiong et al., 2016).

Egg white albumin (EWA) is one of the best choices among proteins for the fabrication of food emulsions with desirable properties, owing to its great functional possessions (Xiong et al., 2016). As a stabilizing agent, EWA has been chosen as a strong model for investigation of the effects of protein-polysaccharide

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complexes on the emulsion properties (Kudryashova et al., 2007). The complexes of proteins and polysaccharides have been used in food emulsions not only for stabilization of such emulsions but also for their effect on the rheological properties of such food systems (Neirynck et al., 2007; Tuinier et al., 2000). In addition to the stability, the rheological properties of food emulsions are important properties, which have significant effects on the other properties (e.g. sensorial properties) of the food emulsions (Kontogiorgos et al., 2004; Paraskevopoulou et al., 2005). Previously, we studied the effect of different concentrations of BSG on the physical and rheological properties of heat-induced EWA gels (75°C) and found that the addition of BSG substantially improved such properties of EWA gels (Razi et al., 2018). Therefore, to follow up that study, the objective of the current work was to investigate the effects of BSG on the stability and rheological properties (dynamic oscillatory and steady-shear) of the food emulsions emulsified by EWA. While EWA has surface-active properties, which with the possible adsorption on the surface of the droplets can prevent aggregation, BSG can improve emulsion stability by increasing the viscosity.

2. Material and Methods

2.1. Materials

Basil seeds were purchased from a local market in Neka, Iran and the gum was extracted at optimum conditions as reported by Hosseini-Parvar et al. (2010). Egg white albumin powder (> 80% ovalbumin) was purchased from Applichem (Darmstadt, Germany). Sunflower oil was obtained from a local supermarket in Sari, Iran. All other chemicals were of analytical grade.

2.2. Emulsion fabrication

The BSG stock solution (1% w/v) was prepared by mixing BSG powder in distilled water and stirring (300 rpm) overnight (25°C) using a magnet stirrer (300 rpm). The EWA stock solution (4% w/v) was also prepared in distilled water by stirring at 25°C for 2 h using a magnet stirrer (300 rpm). The experimental mixtures of EWA (0.5% w/v) and BSG (0%, 0.05%, 0.1%, 0.2%, and 0.3% w/v) were obtained by mixing the appropriate amount of each biopolymer in the presence of 0.02% (w/v) sodium azide as an antimicrobial agent, followed by stirring (300 rpm) at room temperature for 1 h (Niu et al., 2015). We chose a wide range of BSG concentrations to see the effect of different behaviors of biopolymers on the properties of the emulsion. The oil-in-water (O/W) emulsions were prepared by dispersing 30% (w/v) sunflower oil in the EWA-BSG mixture solution. Primary emulsions were prepared using an Ultra-Turrax blender (IKA T25 Basic, Germany) at 11,000 rpm for 2 min (Niu et al., 2015). Fine emulsions were then prepared by homogenization of the primary emulsions using an ultrasonic apparatus (20 kHz, 100 W; UP400A, Ultrasonic Tech Development Co, Tehran, Iran) for 2 min and pH was adjusted to 7.0. During the sonification, the primary emulsions were kept in a mixture of ice and water to prevent the possible temperature rise.

2.3. Creaming measurement (phase stability)

15 mL of each emulsion was transferred into a cylindrical tube and then sealed with a plastic cap to prevent evaporation. The emulsion samples were stored at ambient temperature for 21 days. Some of the emulsions were separated into different phases. The extent of creaming was characterized by creaming index (*CI*, %) as presented below:

$$\mathrm{CI}\ (\%) = \frac{\mathrm{H_S}}{\mathrm{H_E}} \times 100 \tag{1}$$

where $\mathrm{H_S}$ is the height of the serum layer, and $\mathrm{H_E}$ indicates the total height of the emulsion (Niu et al., 2016).

2.4. Zeta potential and particle size

Fresh emulsion samples were diluted with distiller water (1: 25) and then zeta potential and particle size were determined using a Zeta plus analyzer (ZEN3600, Malvern, United Kingdom), which measures the direction and velocity of the droplet movement in the applied electric field (Rashidinejad et al., 2014).

2.5. Rheological properties

The rheological properties of the oil-in-water emulsions were measured at 20°C using an Anton Paar Physica Rheometer (Physica, MCR 301, Anton Paar GmbH, Germany) with a double-gap geometry (internal and external gaps were 27.59, 24.66, and 23.82 mm, respectively). Apparent viscosity was measured with increasing the shear rate from 0.1 to 300 s^{-1}. The thixotropic behaviors of the emulsions were determined by using hysteresis experiments, which is inducing a two-step process (upward and downward) with an increase in the shear rate from 0.1 to 100 s^{-1} followed by a decrease from 300 to 0.1 s^{-1}. The flow behavior data of the emulsions were described with different predicting models (based on upward curve), including Power law (Eq. 2), Herschel–Bulkley (Eq. 3), Bingham (Eq. 4), Cross (Eq. 5), and *Carreau* (Eq. 6), to find the best relationship between shear rate (γ) and shear stress (τ), as presented below:

$$\tau = k\gamma^{n} \tag{2}$$

$$\tau = k\gamma^{n} + \tau_0 \tag{3}$$

$$\tau = \tau_0 + \eta_p\gamma \tag{4}$$

$$\eta_a = \eta_\infty + \frac{\eta_0 - \eta_\infty}{1 + (\alpha_c\gamma)^m} \tag{5}$$

$$\eta_a = \eta_\infty + \frac{\eta_0 - \eta_\infty}{(1 + (\lambda_c\gamma)^2)^N} \tag{6}$$

where τ: shear stress (Pa), γ: shear rate (s^{-1}), k: consistency coefficient ($Pa.s^n$), τ_0: yield stress (Pa), n: flow behavior index (dimensionless), η_p: Bingham plastic viscosity, η_0: zero shear viscosity (Pa.s), η_∞: infinitive shear viscosity (Pa.s), α_c and λ_c: time constants related to the relaxation times of the polymer in solution, and finally, m and N: dimensionless exponents (Niknam et al., 2018; Razi et al., 2018).

2.6. Frequency sweep measurements

The storage modulus (G'), loss modulus (G''), and complex viscosity (η^*) in frequency sweep test were recorded from 0.1 to 10 Hz at γ 0.2% and at 20 °C. The frequency dependencies of storage modulus (Eq. 7) and loss modulus (Eq. 8) were approximated by a Power law model as follows:

$$G^{/} = a.\omega^{b} \quad (7)$$

$$G^{//} = c.\omega^{d} \quad (8)$$

where ω is the angular frequency (Rad/s), *a* (Pa.s^n) and *c* (Pa.s^n) intercept, and *b* and *d* indicate the slopes of log moduli-log frequency curves (Razi et al., 2019; Razi et al., 2020).

2.7. Statistical analysis

The experimental data were analyzed using SPSS statistical software (Version 16, IBM, Armonk, NY, USA). All of the experiments were carried out at least in duplicate. The rheological data fitting was done using Rheoplus software (Version 3.4, Ostfildern, Germany). Significant differences between the means of different treatments were determined by Duncan's multiple range tests ($p < 0.05$).

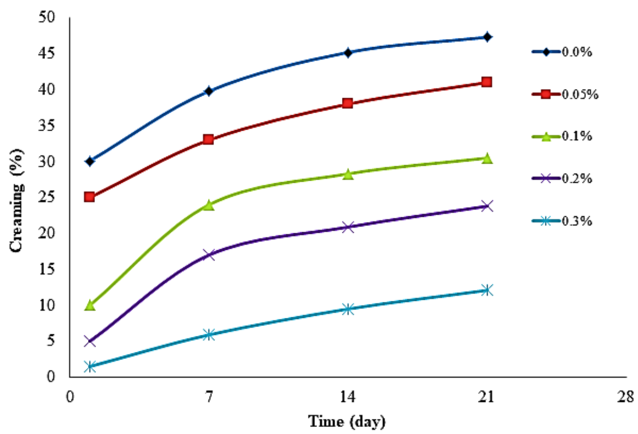

Fig. 1. The effect of different concentrations of basil seed gum on the creaming of egg white albumin emulsions during 21 day of storage.

3. Results and Discussion

3.1. The effect of BSG on creaming behavior of the emulsions

The creaming behavior of the fabricated emulsions as a function of BSG concentration during 21 days of storage at ambient temperature is shown in Fig. 1. According to this data, the emulsion stability improved as a result of the increase in BSG concentration. This is likely related to the higher viscosity of the continuous phase at higher BSG concentration. The creaming index of the emulsions containing 0% and 0.3% of BSG were 30.1% and 1.5%, respectively, after one day of storage, while these values increased to 47.3% and 12.1 %, respectively, after 21 days of storage The viscosity of the aqueous phase is one of the most important parameters that has a substantial effect on emulsion creaming. Based on Stokes law, which expresses settling velocities of small particles in a fluid medium, the increase in BSG concentration can cause an increase in emulsion's viscosity and a decrease in droplet's movement that in turns can result in a lower creaming of the emulsions (Niu et al., 2015).

Another parameter that has some effect on the creaming behavior of the emulsions is surface tension. As it was explained in the previous section, BSG is a polysaccharide with some extensive surface-active properties (Naji-Tabasi & Razavi, 2017). Correspondingly, this polysaccharide can improve the emulsion stability with the reduction of surface tension at the oil-water interface. The surface activity of other galactomannans (such as gums of fenugreek, guar, tara, and locust bean), sugar beet pectin, soybean soluble polysaccharides, and the gum extracted from *Portulaca Oleracea* L. and *Opuntia Ficus* L. has been previously reported (Akhtar et al., 2002; Funami et al., 2007; Garti & Leser, 2001; Li et al., 2013; Nakauma et al., 2008; Wu et al., 2009). Thus, these polysaccharides have the ability of the adsorption at the oil-water interface and making stable O/W emulsions (Dickinson, 2003; Huang et al., 2001). In the current experiment, the creaming behavior of all samples increased during storage, which can be related to gravity force and Brownian motion. Oil droplets in the emulsion system are weakly flocculated and Brownian motion of the droplets can affect the restructuring of such droplets during the storage. In addition, gravity force has a direct effect on the creaming of emulsions during the storage. Both of these factors (i.e. gravity force and Brownian motion) can reduce the number of the linkages between the oil droplets and cause a reduction in yield stress, and so the destruction of the emulsion network (Hemar et al., 2001; Krstonošić et al., 2009).

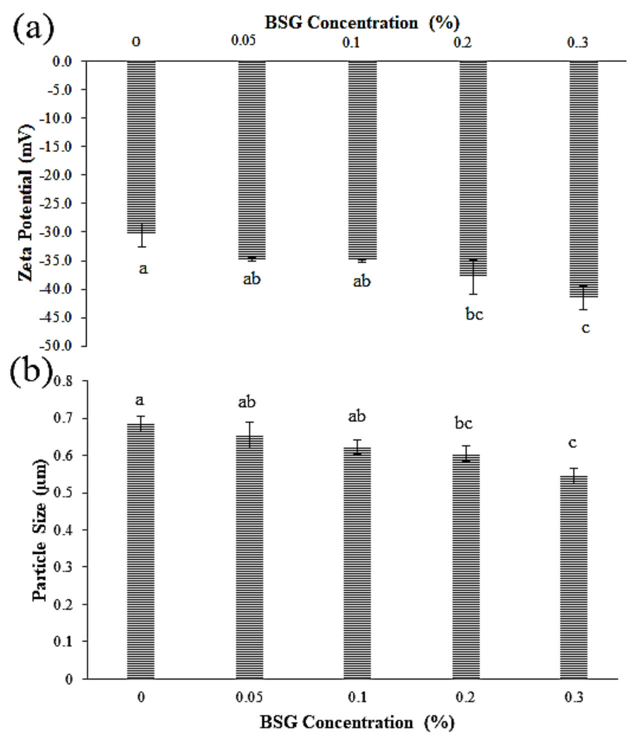

Fig. 2. The effect of different concentrations of basil seed gum on zeta potential (a) and particle size of egg white albumin emulsions (b). BSG: basil seed gum.

3.2. Zeta potential and particle size

The effect of different concentrations of BSG on zeta potential and particle size of EWA emulsion are shown in Fig. 2a and Fig. 2b, respectively. The lowest negative values of Zeta potential were observed for the control emulsion (0% BSG). The values were -30.5 and -41.5 mV for the control emulsion and the emulsion containing 0.3% BSG, respectively. The negative amount of zeta potential indicates that the protein-polysaccharide complex has a negative charge when pH is more than the pI of egg albumin (~ 4.8). BSG contains acidic functional groups such as uronic acid that can cause a negative amount of zeta potential in the emulsion systems. The findings of this study confirm that BSG and egg albumin repulsed each other as both of them have a negative charge in pH > pI (Najafi et al., 2016). In brief, the zeta potential of all samples was less than -30 mV, indicating a great condition for protecting the oil droplets against coalescence and creating the stable emulsions (Najafi et al., 2016).

The effect of BSG on the particle size of the emulsions is shown in Fig. 2b. The emulsion that contained 0.3% BSG had the smallest particle size (0.545 µm), while the emulsions containing lower amounts of BSG (i.e. 0-0.1%) showed bigger particle sizes ($p < 0.05$). The size of particle was 0.685 ± 0.021, 0.655 ± 0.035, and 0.622 ± 0.017 µm in the emulsions containing 0%, 0.05%, and 0.1% BSG, respectively. A possible explanation to this is that at the low concentrations of BSG, there is not enough amount of polysaccharide to cover all of the particles in the system and accordingly, the large oil droplets flocculate. It is well-known that the insufficient amount of the protein and/or polysaccharide for covering oil droplets in an emulsion system after homogenization can result in macromolecular bridging and bigger particle size (Osano et al., 2014).

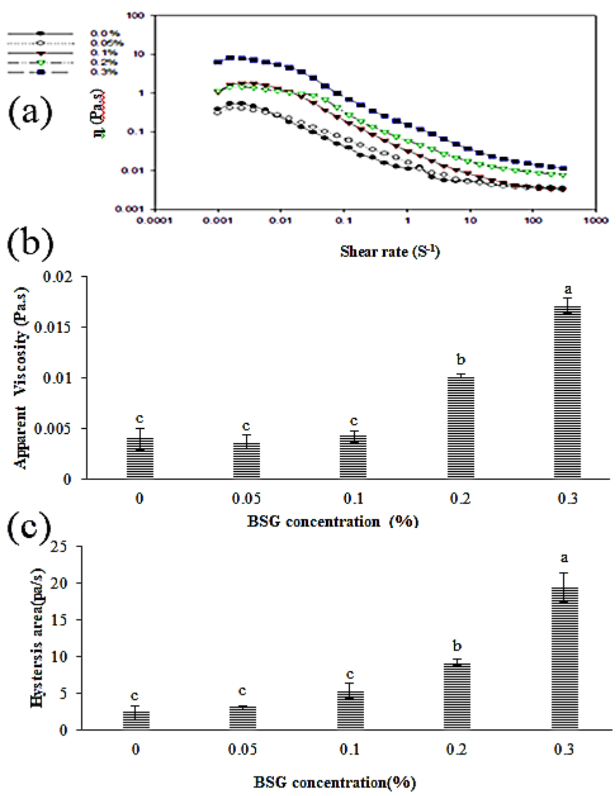

Fig. 3. The effect of different concentrations of basil seed gum on the flow behavior properties (a), apparent viscosity (b), and hysteresis area (c) of egg white albumin emulsions. BSG: basil seed gum.

3.3. Steady-state measurements

Fig. 3a presents the effect of BSG concentration on the flow behavior of EWA emulsions. Based on this data, all emulsion samples presented a shear-thinning flow behavior and their apparent viscosity gradually dropped with the increase in shear rate. As can be seen from Fig. 3a, apparent viscosity was higher in the case of the emulsions containing higher concentrations of BSG. These behaviors can be explained with the ordering of emulsion droplets along the flow direction due to overcoming Brownian motion with increasing shear rate, which causes a decrease in resistance to flow and thus, decreases the viscosity (Erçelebi & Ibanoğlu, 2009). The shear-thinning behavior of the emulsion samples at low BSG concentrations could be a result of bridged-droplets disruption that causes a Newtonian profile at high shear rates. An increase in the viscosity and shear thinning behavior was observed in the case of the emulsions with a higher amount of BSG. This behavior could be related to the effect of non-adsorbed BSG on the rheological properties of the corresponding emulsions and a more thinning behavior under shear rate. These findings are in agreement with the results reported by Hosseini-Parvar et al. (2010), who studied the rheological properties of BSG in a solution system and indicated that BSG solution (0.1-2.0% w/w) showed a pseudoplastic flow behavior. Hosseini-Parvar (2009) reported that the shear-thinning behavior of BSG was related to a change in the molecular realignment of BSG polymer chain in the shear rate direction, as well as a decrease in polymers interaction with increasing shear rate. Vardhanabhuti and Ikeda (2006) reported that permeability of the food liquids was better in the samples with higher shear-thinning behavior and this resulted in a better swallowing property due to the thinner consistency of the food in the mouth. The pseudo-plasticity of the emulsions in the present study increased as a result of an increase in BSG concentration, which is related to the existence of BSG in the aqueous phase. It is possible that the bridging of the droplets/particles can form the aggregation of the droplets in a low amount of BSG, while in the high amount of BSG, non-adsorbed polysaccharides increase the emulsion viscosity and cause a more shear-thinning behavior (McClements, 2005).

The effect of BSG concentration on the apparent viscosity of EWA emulsions at a constant shear rate of 50 s^{-1} is shown in Fig. 3b. The apparent viscosity of the emulsion containing 0.5% EWA and 0.3% BSG was higher than the other emulsions ($p < 0.05$). There was no significant difference between the viscosities of the emulsions made with 0 to 0.1% BSG ($p > 0.05$). The apparent viscosity was 0.01 ± 0.0002 and 0.0171 ± 0.0007 Pa.s for the emulsions containing 0.2 and 0.3% BSG, respectively, while this parameter was in the range of 0.0039 ± 0.0011 to 0.0042 ± 0.0006 Pa.s in the case of the emulsions made with the low concentrations of BSG (0-0.1%). BSG solutions are vicious, and so BSG can improve the apparent viscosity of the emulsion even in low concentration. The aggregation of the emulsion droplets at low concentrations of BSG can happen, because there is no sufficient BSG to cover the particles in the emulsion system, while a high concentration of BSG can change the liquid phase properties and cause a wider hydrodynamic volume (McClements, 2005). Hosseini-Parvar et al. (2010) and Hosseini-Parvar et al. (2014) reported that the viscosity of the BSG solution increased with the increase in BSG concentration.

The results of fitting flow behavior data by different equations are presented in Table 1. In the current study, the results of fitting flow behavior data by the *Carreau* model showed η_0 of the emulsions increased as BSG concentration increased. The highest value of η_0 belonged to the emulsion samples containing 0.3% BSG. The previous studies of flow behavior data in galactomannans and other polysaccharides with random coils structure and non-gelling characteristics indicated two Newtonian plateaus at very low shear rates (zero shear rate viscosity (η_0) and at very high shear rates (infinite viscosity) (Morris, 1989). Carreau and Cross are the best models for describing flow curve data of polysaccharides such as BSG (Carreau, 1972; Cross, 1965; Doublier & Launay, 1981; Morris, 1989). Hosseini-Parvar et al. (2010) reported the Newtonian plateau at low shear rates (> 0.01 s^{-1}) for konjac and guar gum but not for BSG and xanthan gum. They reported that BSG had a high zero-shear viscosity, which was not detected by the rheometer used in their study. Najafi et al. (2016) reported that the emulsion viscosity increased by an increase in BSG concentration, which was related to the water absorbance ability of BSG. Also, the amount of flow behavior index (n) decreased as BSG concentration increased. As the droplet size increases (presented in the previous section), the number of the droplets per unit volume of the emulsion decreases, and the average distance of separation between the droplets increases as well. Therefore, the droplets become more mobile by showing less resistance to the flow, due to the decrease in hydrodynamic interaction (Hayati et al., 2009).

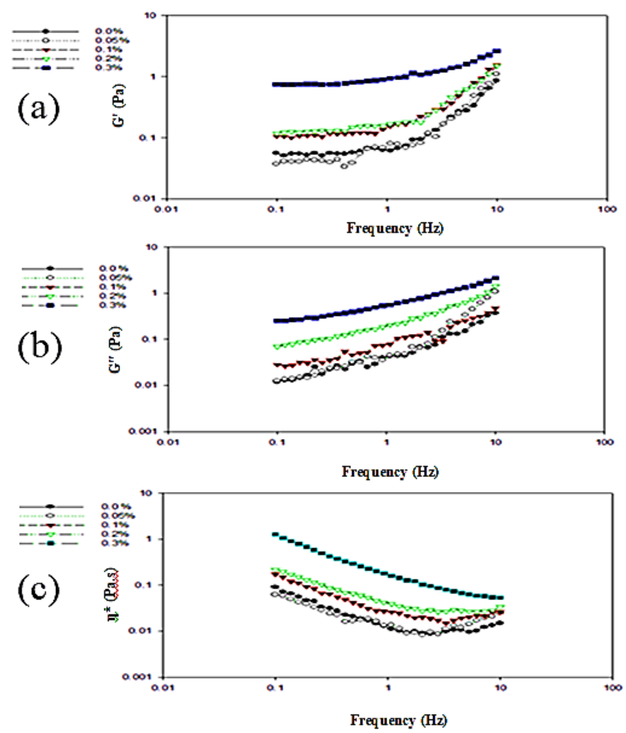

Fig. 4. The effect of different concentrations of basil seed gum on storage modulus (a), loss modulus (b), and complex viscosity (c) of egg white albumin emulsions in frequency sweep test.

In this experiment, the hysteresis area, which is the area between upward and downward flow behavior curves, was determined by Rheoplus software (Niknam et al., 2018). Hysteresis loop tests should be considered as quality control tests since they depend on the rate of increasing/decreasing shear rate and on the maximum shear rate reached (Niknam et al., 2018). The amount of hysteresis area of the emulsions containing different concentrations of BSG is shown in Fig. 3c. All of the emulsion samples showed a thixotropic behavior and the amount of hysteresis area was dependent on BSG concentration. Hysteresis areas of BSG emulsion varied from 2.33 to 19.35 pa/s. While there was no significant hysteresis difference among the emulsions containing 0-0.1% BSG ($p < 0.05$), the hysteresis was significantly higher in the case of the emulsions containing the higher concentration of BSG ($p < 0.05$). These results indicated that an increase in BSG concentration increased the amount of hysteresis area. This effect can be related to the irreversible breakdown of the emulsion structure under the effect of shear rate. Similar results were obtained by Niknam et al. (2018) who studied the effect of Plantago major seed gum on emulsion hysteresis, where it was found that with an increase in the concentration of Plantago major seed gum, hysteresis area of emulsions increased.

3.4. *Oscillatory measurements*

The frequency sweep test was done in LVE region (a strain of 0.2%, 20°C) to determine the effect of frequency on G' and G'' value. The effect of BSG supplementation on G' and G'' in the frequency sweep test is shown in Fig. 4a and Fig. 4b, respectively. According to this data, the amount of G' and G'' increased as BSG concentration increased and the samples containing 0.5% EWA-0.3% BSG showed the highest amount of G' and G''. The measurement of G' and G'' in the oscillatory rheological test can be used for the determination of flocculation in the emulsion systems (Erçelebi & Ibanoğlu, 2009). The results showed that both moduli (i.e. G' and G'') depended on the frequency and both increased as a result of the increase in frequency. The amount of G' was higher than G'' (except for the sample containing 0.2% BSG in the range of 1-4 Hz). This domination of G' over G'' indicates a gel structure, especially at a higher concentration of BSG (Razi et al., 2018; Razi et al., 2019). The strong structure of such emulsions is related to the presence of BSG, which can be explained with two mechanisms; EWA-BSG complex that causes a viscoelastic behavior, which is related to the highly flocculated droplet network, and/or formation of a gel-like structure in the continuous phase by the polysaccharide itself (Erçelebi & Ibanoğlu, 2009).

Some of the rheological parameters obtained by the frequency sweep test were compared at the constant frequency of 1 Hz and are shown in Table 2. According to these results, the G' value was greater than G'' in all samples (except for the sample containing 0.2% BSG). Both moduli raised by increasing the BSG concentration. Increase in BSG concentration from 0% to 0.3% resulted in an increase in G' and G'' from 0.045 and 0.066 to 0.547 and 0.92 Pa, respectively. The increase in BSG concentration led to an improvement in the viscoelasticity of the fabricated emulsions (Table 2). The stronger elastic behavior shows that the elasticity of BSG could significantly contribute to the stability of the emulsions by providing more of a solid-like structure ($G' > G''$) which can restrict the droplet movement. The solid-like structure of BSG solutions has also been reported by Hosseini-Parvar (2009). This may also indicate that the non-adsorbed BSG is likely to dominate the rheological properties of the corresponding emulsions (Hosseini-Parvar, 2009).

The effect of different concentrations of BSG on the complex viscosity of the emulsions is shown in Fig. 4c. According to these results, the increase in BSG concentration caused an increase in the complex viscosity of the emulsion samples, in agreement with the results reported by Hosseini-Parvar et al. (2010) who reported that the viscosity of BSG solution increased with an increase in BSG concentration. Previously, we also reported that the increase in BSG concentration increased the complex viscosity of EWA solutions before gelation (Razi et al., 2018). This increase in viscosities caused by the increase in BSG concentration confirms the creaming data reported in Section 3.1, because the higher viscosity can prevent the movement of the droplets and their connections, and therefore, leads to a more stable emulsion system (Hosseini-Parvar et al., 2014). As can be seen in Fig 4c, complex viscosities of all samples decreased as the frequency increased, indicating a shear-thinning behavior of the emulsions in frequency sweep test. This behavior is a result of the disruption of the bridged-droplets with increasing the frequency. The amount of complex viscosity in the constant frequency of 1 Hz is shown in Table 2, where it can be found that the complex viscosity of the emulsions containing 0.5% EWA and 0.3% BSG was higher than other samples ($p < 0.05$). The higher amount of complex viscosity can be related to the increasing of the non-adsorbed polysaccharide (BSG) in the aqueous phase of the emulsion (Vélez et al., 2003).

Power law model indicates the frequency dependency of G' in a liquid-like fluid, based on polymer dynamic theory (Ferry & Ferry, 1980). Frequency dependency of storage modulus and loss modulus can be demonstrated by Eq. (7) and (8), respectively. The amount of b and d is closer to zero when the frequency dependency is low, the higher amount of b represents the elastic characteristic of the samples, it is more than zero for physical gels, and zero for the covalent gels (Hesarinejad et al., 2014). The result of fitting frequency sweep data by using Power law model is also shown in Table 2. Power low model described the frequency sweep data properly (except for G'' in the presence of 0% BSG). The amount of b value was in the range of 0.326 to 1.55 (Table 2). This parameter was lower in the case of the emulsions with a higher concentration of BSG, especially the emulsion containing 0.5% EWA-0.3% BSG. These results represent a higher tendency of EWA-BSG emulsions to aggregate and form a more stable gel at a higher amount of BSG. A similar trend was also seen for c, which was in the range of 0.55 to 1.7. The lower amount was observed for the emulsion containing 0.5% EWA and 0.3% BSG, confirming a gel-like behavior of this system at higher concentrations of BSG (Behrouzian et al., 2017). BSG chains can create a web network inside the EWA matrix and improve the stability and structure of the manufactured emulsion (Hosseini-Parvar et al., 2015).

Table 1. The flow behavior data obtained for egg albumin emulsions using different rheological models (Herschel Bulkley, Ostwald, Carreau, Cross, and Bingham), as well as the effect of different concentrations of basil seed gum on Carreau parameters of these emulsions.

BSG Concentration (%)	Herschel Bulkley	Ostwald	Carreau	Cross	Bingham	Carreau parameter	
						η_0	P
0	0.816	0.715	0.965	0.855	0.875	0.375±0.14	0.410±0.005
0.05	0.535	0.760	0.969	0.952	0.852	0.930±0.10	0.388±0.009
0.1	0.425	0.749	0.960	0.870	0.815	0.897±0.07	0.400±0.007
0.2	0.555	0.820	0.980	0.947	0.795	1.250±0.09	0.371±0.006
0.3	0.605	0.795	0.980	0.922	0.760	7.910±1.90	0.387±0.009

Table 2. The effect of different concentrations of basil seed gum on storage modulus, loss modulus, and complex viscosity of egg albumin emulsions at constant frequency of 1 Hz. The rheological parameters were obtained after fitting frequency sweep data by power law model.

BSG Concentration (%)	1 Hz			$G'=a.\omega^b$			$G''=c.\omega^d$		
	Storage modulus (Pa)	Loss modulus (Pa)	Complex viscosity (Pa.s)	A	b	R^2	c	d	R^2
0	0.066±0.01^b	0.045±0.01^c	0.081±0.00^b	0.003±0.00	1.32±0.12	0.830	-	-	-
0.05	0.076±0.00^b	0.049±0.02^c	0.092±0.02^b	0.001±0.00	1.55±0.13	0.977	0.0007±0.00	1.7±0.11	0.994
0.10	0.159±0.04^b	0.077±0.02^c	0.177±0.06^b	0.008±0.00	1.20±0.10	0.957	0.0146±0.00	0.82±0.07	0.953
0.20	0.171±0.01^b	0.201±0.00^b	0.265±0.01^b	0.015±0.00	1.09±0.09	0.936	0.032±0.00	0.88±0.08	0.965
0.30	0.920±0.24^a	0.548±0.07^a	1.070±0.25^a	0.551±0.08	0.33±0.03	0.870	0.202±0.04	0.55±0.07	0.988

4. Conclusion

Taken together, the results of the current study showed that the addition of BSG, as the natural stabilizer, up to 0.3% could improve the stability of the egg albumin emulsions, due to the emulsifying properties of BSG that result from its ability to increase the viscosity of the emulsion systems. Creaming index of the control sample (0% BSG) was higher than other samples during the 21 days of storage and the creaming index of all samples increased during the storage. The values of zeta potential were -30.5 and -41.5 mV for the control emulsion and the emulsion containing 0.3% BSG, respectively, which indicates the stability of the droplets. Particle size decreased as BSG concentration increased. All of the samples showed a shear-thinning behavior and their viscosity gradually decreased by the increase in shear rate. Carreau was chosen as the best model for describing the flow behavior data of the emulsion systems (R^2 = 0.96-0.98). The highest value of η_0 belonged to the emulsion samples containing 0.3% BSG. G' was dominated over G'' in frequency sweep test. The domination of elastic modulus over viscous modulus indicates the existence of a gel-like structure in the emulsion systems. The strongest flocculation was observed in the emulsions containing lower concentrations of BSG or in particular, the control emulsion (0% BSG). This can be explained in terms of depletion flocculation caused by the presence of the non-adsorbing added biopolymer (i.e. BSG). Therefore, BSG can be used as a stabilizer and thickener for the fabrication of the stable food emulsions containing egg albumin (or similar proteins) as the emulsifier, owing to the viscoelastic properties of BSG as well as the surface-active properties of egg albumin. Proteins such as egg albumin can decrease the surface tension of the emulsion droplets by adsorbing to the droplet surfaces and preventing the droplets from joining each other. Polysaccharides such as BSG are able to increase the viscosity of the continuous phase and improve the emulsion stability by retarding of droplets movements. These include improvement in various rheological properties, physicochemical stability, storage stability, texture, and mouthfeel. Further research is required to EWA emulsions and -the microstructure of the BSG investigate eractions between BSG andunderstanding the int egg albumin, which can be studied as a function of pH, ionic strength, and heat treatment. The combination of BSG and EWA, the way that was experimented for this study, can provide a range of beneficial properties for food-based emulsion systems.

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Conflict of interest

The authors declare that there is no conflict of interest.

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