JFBE 5(1): 34-42, 2022

Journal of Food and Bioprocess Engineering

Journal homepage: https://jfabe.ut.ac.ir

Original research

Physico-chemical and rheological properties of sage seed gum extracted by dry method in comparison with the conventional method

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A B S T R A C T

This paper aimed to evaluate the chemical compositions, water absorption capacity (WAC), solubility, extraction yield, and steady shear rheological properties of sage seed gum (SSG) extracted by the dry method (DEM) in comparison with the SSG extracted by the conventional wet method (WEM). The chemical compositions (w.b.%) including moisture, ash, protein, fat, and carbohydrate of the gum extracted by DEM were 7.64, 4.11, 7.02, 10.41, and 68.74%, respectively, while the values using WEM were 7.51, 8.69, 3.21, 0.97 and 77.21%, respectively. The solubility and WAC were 41% and 72% in DEM, and 13.73%, and 18.32% in WEM, respectively. Rheological results showed that the best model to fit the time-dependent rheological data was the first-order stress decay model with a non-zero equilibrium stress value. Based on this model, the extent and rate of thixotropy were obtained as 0.042 and 0.0038 s^{-1} for the DEM-SSG sample and 0.048 and 0.0082 s^{-1} for the WEM-SSG sample, respectively. The time-independent shear-thinning behavior was described by the Herschel-Bulkley model with excellent correlation. Based on this model, the yield stress, consistency coefficient, and flow behavior index for the WEM-SSG were 3.82 Pa, 3.22 $Pa.s^{n,}$ and 0.41 while the relevant values for DEM-SSG were 1.07 Pa, 0.47 $Pa.s^{n,}$ and 0.56, respectively. According to the findings of this research, the dry extraction method can be used as a fast, single-stage, low energy consumption, cost-effective and environment-friendly process.

Keywords: Extraction; Friction; Green technology; Mucilaginous seeds; Rheology

Received 22 January 2022; Revised 30 April 2022; Accepted 3 May 2022

1. Introduction

Hydrocolloids or hydrophilic colloids are long-chain polymeric systems that have wide applications in changing the rheological properties of materials. Natural hydrocolloids such as some food polysaccharides and proteins are utilized as stabilizing, thickening, fat replacing, encapsulating (aroma, flavor, and bioactive compounds), edible coating, emulsifying, and gel-forming agents (Razavi, 2019). Natural hydrocolloids may originate from herbal plants, animals, seaweeds, and microbial sources. The herbal plants-based hydrocolloids are classified into three categories: secretive, seed-based, and structural, such as tragacanth, guar, and pectin, respectively (Imeson, 2010). Widespread sources of herbal hydrocolloids are mucilaginous seeds which have become a useful source for extraction of the natural hydrocolloids. Various studies were so far conducted on the optimization of extraction method, and physicochemical characterization of the hydrocolloids from mucilaginous seeds, including *Lepidium sativum* (Karazhiyan et al., 2011), *Ocimum basilicum* (Razavi et al., 2009), *Lepidium perfoliatum* (Koocheki et al., 2009a), *Plantago Ovata* (Farahnaky et al., 2010), *Alyssum homolocarpum* (Koocheki et al., 2009b), *Lallemantia royleana* (Razavi et al., 2016), *Plantago major* L. (Zahedi et al., 2017) and *Salvia macrosiphon* (Bostan et al., 2010).

Sage (*Salvia macrosiphon*) seeds have a small and spherical shape and rapidly swell in the aquatic environment due to the presence of mucilage substances within the seed hull. The aqueous extraction of sage seed gum (SSG) was optimized in terms of water to seed ratio, temperature, and pH using response surface methodology. The SSG dispersions (1%) exhibited non-Newtonian shear thinning behavior and the apparent viscosity of the SSG was reported to be 312 mPa.s at 46.16 s^{-1} and 25°C (Bostan et al., 2010). It has also been found that SSG revealed high zero-shear viscosity, yield stress, and pseudoplasticity (Razavi et al., 2011). The mechanical spectrum obtained from the frequency sweep test showed that similar to some commercial gums (guar gum, xanthan,

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https://doi.org/10.22059/jfabe.2022.337828.1107

locust bean gum), SSG presented a weak gel behavior at 0.5 to 2% (w/w) concentrations (Razavi et al., 2013a). The literature shows that the SSG possesses excellent functional properties such as stabilizing, thickening, bonding, and gelation for application in food and pharmaceutical products (Razavi, 2019).

Various methods are applied for gum extraction, most of them are solvent-based extraction known as wet or conventional extraction method (WEM). The efficiency of the conventional extraction was improved by some treatments such as ultrasonic-assisted extraction (Latufa et al., 2017; Rafiquzzaman et al., 2016; Farahnaky et al., 2013a), microwave-assisted extraction (Keisandokht et al., 2018; Vazquez-Delfin et al., 2014; Francavilla et al., 2013; Sousa et al., 2012), and enzyme-assisted extraction (Blanco-Pascual et al., 2014; Varadarajam et al., 2009). Each of the aforementioned methods has limitations for industrial scale, and in most cases, they are not environment-friendly (Hosseini et al., 2021). Also, all of these methods require a lot of solvent and chemical agents for extraction, fractionation, and purification. The dry extraction method (DEM) is a novel physical method based on the abrasive (friction) force that was developed to separate the mucilaginous layer of seeds without the solvent and chemicals (Hosseini et al., 2021). Such a technique can be recognized as green technology and poses fewer hazards to the environment compared to conventional methods. In optimization conditions of SSG extraction, rotor speed, abrasion angle and gap size were 900 rpm, 6.9°, and 2.2 mm. The highest extraction yield (10.61%), apparent viscosity (112 mPas), and the lowest amount of protein (7.02%) in the optimized conditions were obtained (Hosseini et al., 2021). As an extension to the previous work that comprised designing and constructing dry extraction equipment based on an abrasive mechanism from mucilaginous seeds and optimization of the dry extraction conditions of sage seed gum by response surface methodology, an investigation was conducted to evaluate the properties of SSG extracted by dry extraction method and to compare it with the conventional wet method. For this purpose, chemical compositions, extraction yield, water absorption capacity, and time-dependent and time-independent rheological properties were analyzed.

2. Material and Methods

2.1. Sample preparation

The sage seeds (*Salvia macrosiphon*) were supplied from a medicinal herb store located in Mashhad, Iran. The seeds underwent a blowing process using a blowing device to remove foreign matters such as soil, rubble, and wood. The cleaned seeds were placed in plastic packages and were kept in a dry and cool environment.

2.2. Sage seed gum extraction

2.2.1. Wet extraction method (WEM)

Aqueous extraction of sage seed gum in optimized conditions (water to seed ratio of 51:1; T = 25°C; pH = 5.53) was conducted according to Bostan et al. (2010). In this method, pH was adjusted using a 0.1 molar solution of hydrochloric acid and sodium hydroxide. The temperature was regulated by a water bath system. To achieve the intended ratio, 40g of seed was mixed with 1000 ml of water and stirred in a water bath (20 minutes) for full water absorption. Then, swollen seeds were passed through a laboratory extractor device (Pars Khazar Company, Iran) for gum extraction. Following that, the crude extract was collected and passed through a vacuum filter to remove unwanted materials and was dried in an oven at 70°C. Next, the dried SSG was powdered by a ball mill and screened through 80-micron sieves.

2.2.2. Dry extraction method (DEM)

This method was performed based on the work patented by Razavi and Hosseini (2020). In brief, the seeds have entered the chamber between the two metal abrasive surfaces from entry (Fig. 1). The upper level (C) is capable of rotation and the lower level (G) is stationary. The gap between the two abrasion surfaces, as an influential variable, is controlled by an adjustment screw. The other controlling variable was the angle between the abrasion surfaces and horizon which regulates the rate of seed output of the device. By adjusting the mentioned variables, the abrasion between the seed and the surfaces leads to the dehulling of seeds. Based on the optimized conditions of dry method (Hosseini et al., 2021), rotor speed of 900 rpm, abrasion angel of 6.9° and gap size of 2.2 mm were applied to achieve the highest extraction yield, lowest protein level, and highest apparent viscosity (in an aqueous solution):. Next, the gum powder was obtained using a blower to screen the ground material. The obtained gum was then powdered using a ball mill and screened using a sieve with an 80-micron mesh size.

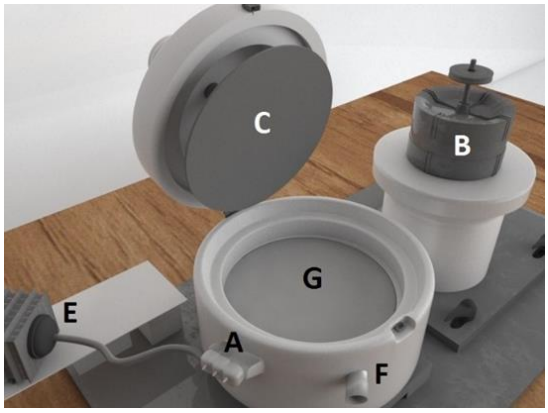

Fig. 1. Dry-based extractor designed for separation of the mucilage from the mucilaginous seeds: (A) Feed inlet, (B) Rotor, (C) Mobile abrasion surface, (E) Air compressor, (F) Outlet, (G) Stationary abrasion surface.

2.3. Chemical compositions analysis

The amounts of moisture, protein, fat, and ash of the SSG powders derived by both DEM and WEM were determined by the oven-dry method (at 105°C for 5 hours), the Kjeldahl method (with a conversion factor of 6.25), the Soxhlet method (using diethyl ether and hexane as solvents), dry ashing technique with a furnace (at 550°C for 3 hours), respectively (AOAC, 2005). Total carbohydrates content in both samples was measured using the phenol-sulfuric acid method (DuBois et al., 1956).

2.4. Extraction yield determination

To determine the extraction yield, the weight of the extracted gum powder was divided by the weight of the seeds used for the extraction process:

$$\text{Yield} = \frac{\text{Gum powder}}{\text{Weight of seeds}} \times 100 \quad (1)$$

2.5. Water absorption capacity (WAC) measurement

0.5 g of each SSG powder was first dissolved into 40 ml of distilled water and centrifuged at 3000 g for 10 minutes. Then, the supernatant was decanted and the remaining hydrated sample was weighted. The WAC was calculated by dividing the weight of the swollen sample by the initial dry sample (AACC, 1995).

2.6. Solubility determination

For this test, 20 ml of 0.5% (w/v) SSG dispersion was stirred at 25°C for 30 minutes using a 150-rpm shaker. Next, the dispersions were further centrifuged at 800 rpm for 15 minutes and 10 ml of suspension, from the upper part of the centrifuged dispersion (supernatant), was transferred into a plate using a pipette. The plate was then dried in an oven at 100°C till reaching a constant dry weight. The solubility was consequently determined as follows (Lopez Franco et al., 2013):

$$\text{Solubility} = \frac{(w_f \times 20)}{(w_i \times 10)} \times 100 \quad (2)$$

Where w_f is the dry weight of the supernatant and w_i is the weight of the dry sample used for the suspension preparation.

2.7. Steady shear rheological measurements

To study the rheological properties of the SSG dispersions (1%, w/w) at 25 ± 0.5°C, a rotational viscometer (Visco 88, Bohlin Instruments, UK) equipped with a thermal circulator (F12-MC, Julabo Labortechnik, Germany) and a cup and bob (C25) geometry was used. The time-dependent behavior of the SSG samples (DEM and WEM) was investigated to determine the association between shear stress and the duration of the applied shear force at a constant steady shear rate. So, the samples were prepared at identical conditions and tested for 300 s at 52 s^{-1}. To model the time-dependent behavior of the DEM and WEM dispersions, the following three rheological models were utilized.

First-order stress decay, with non-zero equilibrium stress value:

$$\tau = \tau_e + (\tau_0 - \tau_e)e^{-kt} \quad (3)$$

In which, τ is shear stress (Pa), τ_0 is shear stress (Pa), k is destruction rate constant (l/s), τ_e is equilibrium shear stress (Pa) and t is the duration of the shearing (s).

Weltman model:

$$\tau = A + B\ln(t) \quad (4)$$

In which, A is initial shear stress and B is a time-dependent parameter.

The flow behavior of the SSG samples was characterized at the shear rate range of 14-600 s^{-1} and the shear stress-shear rate data were fitted by the following time-independent rheological models:

Power-law model:

$$\tau = k_p\dot{\gamma}^{n_p} \quad (5)$$

In which, n_p is the power-law flow behavior index (dimensionless) and k_p is the power-law consistency coefficient ($Pa.s^n$).

Herschel-Bulkley model:

$$\tau = \tau_{0H} + k_H\dot{\gamma}^n \quad (6)$$

In this model, τ_{0H} is the Herschel-Bulkley yield stress (Pa), k_H is the Herschel-Bulkley consistency coefficient ($Pa.s^n$) and n is the Herschel-Bulkley fluid behavior index.

Bingham model:

$$\tau = \tau_{0B} + \eta_B\dot{\gamma} \quad (7)$$

In which, η_B is known as Bingham plastic viscosity (Pa.s) and τ_{0B} is Bingham yield stress (Pa).

2.8. Validation of the fitted models

To select the best model for describing the time-dependent and time-independent behaviors of the SSG dispersions, R^2 and RMSE statistical parameters were used. The R^2, coefficient of determination, takes a value between 0 and 1, from which a value closer to 1 indicates a higher correlation between the model's predicted values and numerical values derived from the experiment. RMSE values less than 10 represent optimal fitting and values in the range of 10-20 are considered as good while values from 20 to 30 are counted as moderate, and >30 as weak fitting quality (Myers & Montgomery, 1995).

2.9. Statistical analysis

One-way ANOVA and Duncan test (at a 5% significance level) were used to analyze and compare the means by SPSS statistical software (v24), respectively. Also, an independent t-test ($p < 0.05$) was used to compare each pair of means. It should be noted that all experiments were performed in triplicates and all results were presented as the mean ± standard deviation.

Table 1. Chemical compositions (%, w.b.) and extraction yield (%) of sage seed gum derived by wet extraction (WEM-SSG) and dry extraction (DEM-SSG) methods.

Composition	WEM-SSG	DEM-SSG
Moisture	7.61±0.11[a]	7.64±0.23[a]
Ash	8.69±0.25[a]	4.11±0.16[c]
Protein	3.21±0.09[c]	7.02±0.43[b]
Fat	0.97±0.03[c]	10.41±0.59[a]
Carbohydrate	77.21±1.89[a]	68.74±2.30[b]
Extraction yield	9.52±0.41[b]	10.61±0.56[a]

3. Results and Discussion

3.1. Chemical compositions and extraction yield

The results of chemical analysis (%, wet-basis) for the SSG samples in optimal conditions are summarized in Table 1. It can be found that the gum extracted with wet and dry methods contained 8.69 and 4.11% ash, respectively. In comparison, the total ash content of flaxseed gum (7.4-8.4%), locust bean gum (0.7-1.5%), cress seed gum (11.5%), basil seed gum (5.89%), guar gum (11.9%), xanthan gum (9.35%) and purified guar gum (0.89%) were reported by Cui and Mazza (1996), Dakia et al. (2008), Karazhiyan et al. (2009b), Razavi et al. (2009), and Wu et al. (2009), respectively. The amounts of fat and protein in the DEM-SSG sample (10.41 and 7.02%) were significantly higher than in the WEM-SSG sample (0.97 and 3.21%), respectively ($p < 0.05$). It was due to the lack of conducting a purification process (using ethanol) for DEM, which is commonly used for the wet extraction of sage seed gum. The protein content of DEM-SSG was lower than that reported for locust bean gum (4.57-14.5%) and *Gleditsia triacanthos* gum (11.54%), but higher than flaxseed gum (1.50-2.95%), basil seed gum (2.01%), cress seed gum (2.45%), and guar gum (4.92%) (Dakia et al., 2008; Jiang et al., 2011; Cui & Mazza, 1996; Razavi et al., 2009; Karazhiyan et al., 2009b; Sciarini et al., 2009). In a similar work done by Razavi et al. (2013b), the reported levels of moisture, ash, protein and carbohydrate of SSG extracted by wet method were 11.24% (w.b), 9.20% (d.b), 2.08% (d.b) and 69.01% (d.b) respectively. They stated that the chemical composition of gums depends on the variety, plant growth conditions, extraction, and purification processes used.

Sage seed contains, on average, 22.69% protein and 58.94% carbohydrates (Farahnaky et al., 2013b). In case of poor performance of abrasion process, the seeds probably get pulverized, it is expected that the protein and carbohydrate levels of the SSG approximate to their corresponding levels in the seeds. However, the decrease in protein value (7.02%) and increase in carbohydrate content (68.74%) of the SSG obtained by DEM in comparison with the corresponding levels in the sage seeds can be a benchmark to evaluate the DEM. Therefore, it can be stated that the seeds were not pulverized and the total carbohydrates extracted by DEM and WEM were comparable. The carbohydrate content of SSG extracted by WEM was 77.21% (w.b) which had the same approximately level compared to guar gum (74.6%), fenugreek gum (73.6%), basil seed gum (74.19%), but lower than that reported for cress seed gum (87.4%), locust bean gum (85.1-88.7%), and *Gleditsia triacanthos* gum (85.19%) (Dakia et al., 2008; Razavi et al., 2009; Karazhiyan et al., 2009b; Sciarini et al., 2009; Jiang et al., 2011).

The extraction yields for dry and wet methods (in optimal conditions) were 10.61% and 9.52%, respectively, which confirms the higher performance of DEM compared with WEM. Farahnaky et al. (2013b) studied the effects of hydration time and temperature on sage seed mucilage extraction. They reported that increasing the temperature from 25 to 65°C at a constant time (15 min) increases the extraction yield from 9 to 9.25% and increasing soaking time from 15 to 120 min (at 25°C) increases the extraction yield from 9 to 12%. Bostan et al. (2010) reported that the variables that had the most impact on yield were water to seed ratio (W/S) and temperature because these parameters caused to increase in the mass transfer rate. In the mentioned study, the minimum extraction yield (7.04%) was obtained at the lowest W/S ratio (25:1) at 52.5°C, and the maximum extraction yield (12.2%) was obtained at the highest temperature (80°C), with (W/S) 55:1. Hydration at low temperatures such as room temperature reduces the efficiency of hydrocolloid extraction because it reduces the dissolution rate (Cerqueira et al., 2009). Therefore, not applying temperature in the dry extraction method can affect the efficiency of extraction yield.

3.2. Water absorption capacity

The functional properties of hydrocolloids led to their widespread applications in food products. Such wide-ranging characteristics, from adhesion to flow ability, are due to their primary feature of viscosity and increased thickness. The stabilizing capacity in emulsions, suspensions and dispersions, foam and film generation potential, encapsulation, and preventing crystal-formation are other major functional properties of gums (Glicksman, 1982).

Water absorbing capacity (WAC) is one of the essential contributing factors in the extensive industrial application of gums. It contributes to the generation of gels or highly viscous solvents (Simas Tosin et al., 2010). Table 2 demonstrates the WAC values of both SSG samples in comparison with some hydrocolloids extracted by the wet method. The WAC value of SSG derived by DEM was 13.73 g/g, which was significantly ($p < 0.05$) lower than that of WEM (18.32 g/g). Guar gum, Mesquite gum, and higher than *Gleditsia Triacantos* gum compared to the WEM samples ($p < 0.05$). As seen in Table 2, SSG by the dry method displayed higher WAC compared to Persian gum and *Eruca sativa* seed mucilage ($p < 0.05$). Differences between WAC values can be related to differences in the amount of carbohydrates in DEM-SSG (68.24%) and WEM-SSG (77.21%) samples. In addition, higher water absorption of the hydrocolloids is due to differences in extraction methods and conditions, which could cause the unfolding of the constituent polysaccharides and their higher ramification proportion (Sciarini et al., 2009).

Table 2. Comparison of water absorption capacity (WAC) of sage seed gum with some selected gums.

Gum	WAC (g/g)	Reference
WEM-SSG*	18.32 ± 0.39^{a}	Present work
DEM-SSG*	13.73 ± 0.24^{e}	Present work
Persian gum	12.65 ± 1.09^{f}	Abbasi et al. (2015)
Mesquite gum	15.84 ± 0.10^{c}	López-Franco et al. (2013)
Guar gum	16.84 ± 0.48^{b}	López-Franco et al. (2013)
Gleditsia Triacantos gum	15.20 ± 0.09^{d}	Sciarini et al. (2009)
Eruca sativa seed mucilage	9.3 ± 0.00^{G}	Koocheki et al. (2012)

*WEM-SSG: wet extraction method; DEM-SSG: dry extraction method.

3.3. Solubility

Some hydrocolloids express their maximum functional properties after being fully dissolved into the water (Laaman, 2011). Nonetheless, the temperature increase is required to boost their solubility, which limits their application in thermal-sensitive industries. The gum solubility at a given temperature (in this study: 25°C) is an important parameter among the functional properties and gel formation of the gums. According to the data presented in Table 3, the solubility of the DEM-SSG (41%) was lower than the WEM-SSG (72%) and mesquite gum (69%), approximately equal

to the solubility of locust bean gum with 45%, and higher than the values reported for flaxseed seed gum (15-40%) and *Eruca sativa* seed gum (28.5%). The difference in gum solubility may originate from the difference in the levels of mannose to galactose as gums with higher galactose levels usually show higher solubility (Srivastava et al., 2005; Cerqueira et al., 2009; Wu et al., 2009). The lower solubility in DEM-SSG (41%) than in WEM-SSG (72%) is probably due to a lack of purification. The purification process reduced the content of main impurities (such as trace elements, tannin, natural pigments, and protein), which improved the solubility of the WEM-SSG (Naji-Tabasi & Razavi., 2017). Also, the broad-range solubility of the samples may be due to the different molecular weights of the gums. Structure and molecular weight are two influential determining factors in the solubility of polysaccharides. In identical samples, molecular weight decrease often results in increased dissolution (Cui et al., 2005). This might be due to the prolonged duration of separation and dispersion of particles with higher molecular weights in the solvent compared to their less-weighted counterparts. Wang et al. (2003) observed that the dissolution rate of guar gum was negatively correlated with the molecular weight of galactomannans.

Table 3. Comparison of solubility of sage seed gum with other selected gums.

Gum	Solubility (%)	Reference
WEM-SSG*	72±2.97	Present work
DEM-SSG*	41±1.79	Present work
Locust bean gum	45	Dakia et al. (2008)
Mesquite gum	69	López-Franco et al. (2013)
Flaxseed gum	15-40	Kaewmanee et al. (2014)
Eruca sativa seed mucilage	28.5	Koocheki et al. (2012)

*WEM-SSG: wet extraction method; DEM-SSG: dry extraction method.

3.4. Time-dependent rheological properties

3.4.1. First-order stress decay with a non-zero equilibrium stress value

First-order stress decay with a non-zero equilibrium stress value (Eqn. 4) was used to fit the data obtained from the shear stress-time of shearing data. According to Table 4, this model revealed the highest R^2 and RMSE values in optimized conditions for both WEM and DEM samples and was more capable than the Weltman model. In other studies, such as Karazhiyan et al. (2009a) on Saleb and Balangu seed gums, and Karazhiyan et al. (2009b) on *Lepidium sativum* seed extract, the stress-decay model with a non-zero equilibrium stress was also chosen as the best model for describing time-dependent behavior.

In this model, τ_0 is an indicator of initial shear stress required for a structural breakdown during the shearing process. The calculated value for τ_0 was 5.06 Pa for DEM, which was significantly ($p < 0.05$) lower than that of WEM (20.64 Pa).

The equilibrium shear stress (τ_e) values acquired in optimized conditions for DEM and WEM samples were 5.23 and 19.64 Pa, respectively. In Karazhian et al. (2009b) study, the τ_e values for *Lepidium sativum* extract solution (6% w/w) at 5, 25, 45, 65 °C and the same shear rate (100 s^{-1}) were 90.4, 80.7, 50.3, and 18.3 Pa, respectively. Also, the τ_e values of this extract solution in different shear rates of 200, 400, 600, 800 s^{-1} and the same temperature (25°C) were 81.5, 60.6, 30.2, and 42.2 Pa, respectively. Therefore, by applying shear and temperature changes, the values of the parameters also change.

It might be possible for DEM to exhibit higher initial and equilibrium shear stresses if used in manufacturing processes that deal with high moisture and temperature levels such as canning and dairy-based desserts. According to the results presented in Table 4, the extent of thixotropy ($\tau_0 - \tau_e / \tau_0$) for the samples treated with wet and dry extraction methods were 0.048 and 0.042, respectively, indicating a similar thixotropy extent.

The *k* parameter is the breakdown rate constant and denotes the rate of time-dependency (Razavi, 2019). As shown in Table 4, the *k* value of the SSG dispersions obtained by WEM and DEM were 0.0082 and 0.0038 s^{-1}, respectively, indicating a lower thixotropy breakdown of the DEM sample than the WEM sample at 52 s^{-1}.

The difference between the time-independent rheological properties of purified (WEM-SSG) and crude (DEM-SSG) gums could be explained by their different chemical structures, i.e., monosaccharide composition, molecular weight, and protein content (Razmkhah et al., 2016). SSG-DEM had lower carbohydrate content and higher impurities (protein and fat) than SSG-WEM, which weakened the thixotropy extent and rate. The varying temperature during the extraction process also affects the SSG rheological behavior (Razavi et al., 2011).

3.4.2. Weltman model

According to Table 4, the Weltman model exhibited the adequate potential to describe time-dependent behavior in both samples. In this model, parameter A indicates the initial shear stress required for initiating the breakdown (Taghizadeh et al., 2010). In this study, the value of A for the DEM sample was 5.387 Pa, which was significantly ($p < 0.05$) lower than the WEM sample (21.490 Pa). The time coefficient of thixotropy (B) of the SSG sample obtained by WEM (0.314 Pa) was greater than that of the DEM (0.102 Pa) as well ($p < 0.05$), indicating more sensitivity of the viscosity of the WEM sample to the time of shearing. The negative value of this parameter is an indicator of the thixotropy behavior of the gums' dispersion (Javidi et al., 2014).

3.5. Time-independent rheological properties

3.5.1. Power-law model

According to Table 5, the flow behavior index obtained from the power-law model suggests a shear-thinning behavior ($n < 1$) upon shearing the SSG dispersion of wet and dry methods. According to the studies conducted by Bostan et al. (2010) and Alghooneh et al. (2017), the power-law model also adequately described the flow behavior of the SSG dispersions. It should be noted that most hydrocolloids showed shear-thinning behavior (Towle & Christensen, 1992; Song et al., 2006; Hosseini-Parvar et al., 2009; Karazhiyan et al., 2009b). The n_p value of the WEM sample was lower than that of the DEM (0.35 compared with 0.48), indicating higher pseudoplasticity of the SSG extracted by the wet method. Farahnaky et al. (2013b) reported that flow behavior index of SSG solution at the concentrations of 0.1% and 0.5% (w/v) was 0.45 and 0.37, respectively. In Bostan et al. (2010) study, SSG

hydrocolloid solutions (1% w/v, 25°C) displayed shear thinning behavior, and the flow behavior index was varied between 0.317 and 0.374 in different extraction conditions. Karazhian et al. (2009b) reported that the flow behavior index of *L. sativum* seed extract (2% w/w) in different temperatures (10 to 70°C) ranged from 0.327 to 0.261. The flow behavior index of SSG extracted by the wet method (Razavi et al., 2013b) was lower than basil seed gum (Hosseini-Parvar et al., 2010) and cress seed gum (Karazhiyan et al., 2009b). They stated that increasing the concentration of SSG from 0.5 to 2.0% decreases the n_p from 0.243 to 0.232.

The consistency coefficient (k_p) for DEM and WEM dispersions were 0.832 and 5.006 Pa.s^n, respectively. The consistency coefficient for SSG dispersions in Bostan et al. (2010) study was varied from 4.455 to 9.435 (Pa.s^n), for Razavi et al. (2013b) study was 8.441 (Pa.s^n), and in Karazhian et al. (2009b) study for *L. sativum* seed extract (2% w/w) in 25 and 70°C were 9.9 and 4.4 (Pa.s^n) respectively. This can be due to different extraction processes carried out in wet and dry methods such as the exclusion of temperature in the dry method (Razavi et al., 2011), lack of purification (Razmkhah et al., 2016), and lack of need for sample drying. Given the high R^2 and RSMD values, it can be stated that the power-law model can adequately describe the time-dependent behavior of the SSG extracted in dry-based optimal conditions.

3.5.2. *Herschel-Bulkley model*

Given the values obtained for the statistical parameters (Table 5), it can be observed that the Herschel-Bulkley model excellently described the time-independent behavior of the SSG dispersions. Various models such as power-law, Herschel-Bulkley, Bingham, Vocadlo, and Sisco models were utilized for modeling the time-independent behavior of this gum, from which the Herschel-Bulkley model was the most prominent (Razavi et al., 2011). The WEM-SSG had stronger shear thinning behavior (n_H=0.41) at 1% concentration than the DEM-SSG (n_H=0.56) significantly ($p < 0.05$). Razavi et al. (2011) reported the n_H values for the SSG dispersion (1%) at 20, and 30°C were 0.42 and 0.38, respectively. In another study, Razavi et al. (2016) reported the n_H value of 1% aqueous solution of BSG (at 20°C, shear rate range of 0.01–1000 s^{-1}) as 0.35.

As observed in Table 5, changing the extraction method altered the value of yield stress (τ_{0H}) correspondingly as in the WEM, it increased 2.57 times the amount of DEM under the optimal conditions. In addition, the consistency coefficient (k_H) of the WEM-SSG was much higher than the DEM-SSG ($p < 0.05$). According to the studies conducted by Razavi et al. (2011) on a similar concentration (1%) at 20°C and 30°C, the yield stress values were 4.03 Pa and 3.44 Pa. Also, the Herschel-Bulkley consistency coefficients reported 3.14 and 3.06 Pa.s^n for WEM-SSG dispersions at 20 and 30°C, respectively, which were similar to the k_H and τ_{0H} values obtained in this study. Applying purification methods increases pseudoplasticity (n), thickening (k), and stabilizing (τ_0) properties of the cress seed gum (Naji-Tabasi & Razavi, 2017). In general, the sage seed gum produced by the WEM contained higher carbohydrate levels and lower impurities (proteins, lipids) compared to the DEM. Therefore, it was predictable that the values of consistency coefficient and yield stress might increase in WEM-SSG due to the presence of more hydrophilic carbohydrates which in turn enhances the flow resistance (Emadzadeh et al., 2011; BahramParvar et al., 2010).

3.5.3. *Bingham model*

As seen in Table 5, similar to the power-law and Herschel-Bulkley models, the Bingham model was able to describe adequately the time-independent behavior of the SSG dispersions under the optimal conditions. However, it showed a lower R^2 and a higher RSME compared to the other two models. In comparison, the Bingham plastic viscosity (η_B) value of WEM-SSG (0.065 Pa.s) was higher than the DEM one (0.034 Pa.s) ($p < 0.05$). Also, the Bingham yield stress (τ_{0B}) of the WEM-SSG and DEM-SSG dispersions were 17.05 and 3.48 Pa, respectively. Razavi et al. (2016) reported the values of 0.044 Pa.s and 5.66 Pa for the η_B and τ_{0B} of Balangu seed gum dispersion (1%) at 20°C, respectively. The different viscosities and rheological properties of the purified gums and crude gums could be related to their different chemical structures, molecular weight & conformation, extraction conditions, etc. (Naji-Tabasi & Razavi, 2017).

Table 4. Time-dependent rheological properties of sage seed gum dispersions (1% w/w) derived by dry (DEM) and wet (WEM) extraction methods (25°C, 52 s^{-1} and 300 s).

Model	Parameter	WEM-SSG	DEM-SSG
First-order stress decay with a non-zero equilibrium stress value	τ_0 (Pa)	20.64±0.19^a	5.47±0.4^b
	τ_e (Pa)	19.64±0.14^a	5.23±0.04^b
	$\frac{\tau_0-\tau_e}{\tau_0}$ (Pa)	0.048^a	0.042^b
	k (s^{-1})	0.008±0.000^a	0.004±0.000^b
	R^2	0.908	0.886
	RMSE	2.071	3.283
Weltman	A (Pa)	21.49±0.17^a	5.39±0.05^b
	-B (Pa)	0.31±0.01^a	0.10±0.00^b
	R^2	0.906	0.879
	RMSE	2.393	3.134

Table 5. Steady shear rheological properties of sage seed gum dispersions (1% w/w) derived by dry (DEM-SSG) and wet (WEM-SSG) extraction methods (25°C and 14-600 s^{-1}).

Model	Parameter	WEM-SSG	DEM-SSG
Power-law	k_p (Pa.s^n)	5.01±0.02[a]	0.83±0.01[b]
	n_p	0.35±0.01[b]	0.48±0.01[a]
	R^2	0.998	0.999
	RMSE	0.304	0.059
Herschel-Bulkley	τ_{0H} (Pa)	3.82±0.02[a]	1.07±0.01[b]
	k_H (Pa.s^n)	3.22±0.02[a]	0.47±0.00[b]
	n_H	0.41±0.01[b]	0.56±0.00[a]
	R^2	0.999	0.998
	RMSE	0.273	0.119
Bingham	η_B (Pa.s)	0.065±0.002[a]	0.034±0.004[b]
	τ_{0B} (Pa)	17.05±0.15[a]	3.48±0.09[b]
	R^2	0.942	0.976
	RMSE	2.631	1.869

4. Conclusion

At optimal conditions, the sage seed gum derived by the dry extraction method (DEM) contained higher protein and fat levels and lower ash and carbohydrate values compared to the wet extraction method (WEM), underlining the higher impurities amount in the DEM. However, the moisture content and extraction yield were the same. The water absorption capacity and solubility of the DEM-derived gum were lower than that of the WEM one. Under the optimal conditions, both DEM-SSG and WEM-SSG dispersions showed thixotropy behavior from which, the WEM sample showed higher thixotropic extent. The first-order stress decay, with a non-zero equilibrium stress value model, was the best model to describe the time-dependent behavior of both SSG dispersions. The gums derived from both methods exhibited shear thinning behavior, which were adequately described by the power-law and Herschel-Bulkley models. Given that no solvent is used in the dry method, the cost per batch of tests will become lesser than in the wet method. Another edge of this method is that it can be carried out constantly. In the dry method, the entire extraction duration is several minutes which, compared to other methods that, by taking the drying step into account, might take several hours is significantly shorter. Additionally, this method is a potential alternative to other extraction procedures as it faces fewer operational and economical limitations and can be considered an environment-friendly method. The dry extraction method is a fast, single-stage, low energy consumption, and cost-effective process, which is suggested to apply to other mucilaginous seeds. Also, further studies are needed to improve the DEM-SSG characteristics and to develop its potential application.

Acknowledgment

This project was funded by the Iran National Science Foundation (INSF) (Grant No., 96015540) and the Ferdowsi University of Mashhad (Grant No. 47962), Iran. The financial support is gratefully acknowledged.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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