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Rheological and functional properties of asafoetida gum

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Abstract

The asaofetida gum was extracted and purified from oleo-gum-resin of *Ferula assa foetida* root and characterized by high pressure anions exchange chromatography after acidic hydrolysis. It was composed of Gal: Ara: Rha: GlcA with the ratio 11.5: 5.0: 2.1: 1.0. This monosaccharide composition was found similar to that of a commercial Arabic gum which exhibited a Gal: Ara: Rha: GlcA ratio of 11.7: 5.4: 3.2: 1.0. As the Arabic gum is currently used for its emulsifying properties, the two gums were evaluated for their functional and rheological behaviors. Surface and interfacial tensions values were lower for asafoetida gum compared to Arabic gum. Critical micelle concentration was achieved at concentrations of 0.5 %w/w and 1 %w/w for asafoetida and Arabic gums, respectively. Values of Emulsion capacity, emulsion stability and foaming properties were considerably higher for asafoetida gum in contrast to emulsion activity index that was lower than that of Arabic gum. As those of Arabic gum, solutions of asafoetida gum (2-30 %w/w) exhibited Newtonian flow behavior at shear rates between 1 and 500 s^{-1}. Apparent viscosities of Arabic and asaofetida gums were close and logically decreased by increasing temperature (10-80 °C). Higher viscosities were achieved at higher pH and $CaCl_2$ concentrations.

Key words: *Ferula assa foetida* L., asafoetida gum, viscosity, emulsion, foam, polysaccharide

1. Introduction

Asafoetida is an exudate gum obtains from the roots of *Ferula assa foetida* L. The freshly milky oleo-gum-resin changes to yellowish-brown gum when exposing to the sun. The plant grows extensively in Iran and Afghanistan and is frequently used as herbal medicine [1]. Oleo-gum-resin consists of three main fractions. The first one is the resin (40-64 % w/w of the dried matter (DM)) and is composed of terpenoids, coumarin derivatives, ferulic acid and its esters. The second fraction known as a gum (40-64 % w/w of the dried matter (DM)) includes a mix of protein and arabinogalactan called arabinogalactan-protein (AGP). The last fraction, the volatile oil (10-17 % of the DM), contains sulfur compounds and monoterpenes [2]. The resin and volatile compounds of asafoetida are traditionally used as a treatment for asthma, intestinal parasites and influenza [3]. AGP remaining from ethanolic extraction of resins and volatile oil is generally considered as a by-product. In our previous research, the chemical structure of asafoetida gum was uncovered. Polysaccharide of asafoetida contained units of (1→3)-*β*-D-galactan as the main chain and terminal-*α*-L-Ara*f*, terminal-*α*-L-Rha*p*, (1→3)-*α*-L-Ara*f*, (1→5)-*α*-L-Ara*f*, terminal-*β*-D-Gal*p*, *β*-D-GlcA and (1→4)-*β*-D-GlcA in the side chains. Arabic gum is composed of galactopyranose in form of (1→3)-*β*-D units as the core of polysaccharide and five other monosaccharides including arabinopyranose, arabinofuranose, rhamnopyranose, glucuropyranosyl uronic acid and *4-0* methyl glucuropyranosyl uronic acid commonly in the side residues. The polysaccharide is attached to protein from hydroxyproline-rich domains. Several investigations have been carried out on rheological, physicochemical and/or functional properties of Arabic gum [4-6]. Arabic gum is been using as a reference product for comparison with new structurally characterized and possible substitute gums [7, 8]. Although the chemical nature of the asafoetida gum and the therapeutic effect of oleo-gum-resin has been well characterized [9-13], few data are available regarding its physico-chemical and functional properties considering its structural similarities with Arabic gum.

The main aim of this study was then to investigate asafoetida gum as a potential industrial product potentially competitive to commercial Arabic gum from several techno-functional aspects such as surface and interfacial tension, emulsion and foaming properties.

2. Materials and methods

2.1. Materials

Oleo gum resins of *Ferula assa-foetida* L. were collected in September 2015, from Tabas city, South Khorasan province, Iran. The roots were scraped in the summer to collect the gum exudates. Then the exudates were stored at -18 °C freezer until the assays. The commercial Arabic gum (Instant gum IRX 40693) was supplied by C.N.I.- Colloïdes Naturels International, Rouen, France.

2.2. Gum extraction and purification

Extraction of gum was performed according to a method adapted to Saeidy et al. [11]. The yellowish-brown crude asafoetida gum was milled in a blender to obtain powder. Extraction was conducted in a reactor system at 75°C, during 5 hours and under stirring (200 rpm) using ethanol (ethanol to crude gum ratio was 35:1 w/w) as solvent of resins and volatile oil for oleo gum resin. The ethanol insoluble gum was collected after precipitation using a glass filter (100-160 µm). The precipitate was then dissolved at x $g.L^{-1}$ in ultra pure water during 30 min at 45 °C and then 2 h at room temperature under stirring. The gum solution was then filtered (cloth filter), centrifuged (1500 g, 15 min and 20 °C) and precipitated with 3 volumes of ethanol at 4 °C, overnight. The precipitate was collected, air dried, dissolved with 10 fold of water and precipitated again with 3 volumes of ethanol to increase the degree of purity. Finally, the precipitate was collected as described above, resolved in 5 fold of ultra pure water and freeze dried.

2.4. Chemical composition

Dry matter content was measured using an oven at 110 °C for 24 h. Total sugar was calculated according to phenol-sulfuric method provided by DuBois et al [14]. Total protein was determined based on total nitrogen obtained by an elemental analyzer (TNM-1, Shimadzu) and water soluble protein was estimated respect to microBradford method [15] using Bovine Serum Albumin as standard.

2.5. Monosaccharide composition

Monosaccharide composition of gum asafoetida and Arabic gum were determined according to a method adapted to Goncalves et al [16]. Ten mg of gums were mixed with 1 mL of 2M trifluoroacetic acid (TFA) solution in a glass tube and heated at 120 °C for 90 min. The samples were stirred time to time during the hydrolysis. After hydrolysis, pH was adjusted to 7 by addition of ammonium hydroxide (35 %w/v) and the solutions were centrifuged at 14000 g for 15 min at room temperature. Supernatant was filtered through 0.2 µm membrane filter and analyzed by High Pressure Anion Exchange Chromatography (HPAEC) with an ICS 3000 (Dionex Corporation, Sunnyvale (CA), USA) equipped with pulsed amperometric detection (PAD) and AS 50 autosampler. Twenty five µL of samples were injected in the system and eluted into a pre-column CarboPac PA1-column (4×50 mm) and an analytical CarboPac PA1-column (4×250 mm) equilibrated 15 min with 18 mM NaOH. Samples (25 µL) were eluted isocratically with 18 mM NaOH for 25 min, followed by a linear gradient between 0 to 0.5 M sodium acetate in 200 mM NaOH for 20 min to elute acidic monosaccharides. Run was followed by 15 min washing with 200 mM NaOH. The eluent flow rate was kept constant at 1 $mL.min^{-1}$. Columns were thermostated at 25°C. Data were collected and analyzed with Dionex Chromeleon 6.80 software (Sunnyvale, USA). L-Rha, D-Rib, L-Fuc, L-Ara, D-Xyl, D-Man, D-Gal, D-Glc, D- GlcA, and D-GalA were used as standards.

2.6. Surface and interfacial tension

Surface and interfacial tensions of gums were evaluated with a tensiometer (KRÜSS GmbH, Hamburg, Germany) using a plate as probe. Gums solutions at concentrations of 0.2, 0.3, 0.4, 0.5, 1 and 1.5 % (w/w) were prepared 24 h prior to experiments. For surface tension, 50 mL of solution was poured into a glass

cell and the temperature was kept around 20 °C. The measurements were recorded each 30 s until the standard deviation reached a minor value of 0.01. For interfacial tension measurements, the system was first calibrate with 90 mL of rapeseed oil then the probe was fitted at the interfacial of 50 mL of gum solution and 42 mL of rapeseed oil. The measurements were done in duplicate.

2.7. Emulsion properties

Emulsions were prepared using an Ultra-turrax (T25 device IKA-WERKE GmbH, Germany) homogenizer. All the measurements were performed in triplicates.

2.7.1. Emulsifying activity

Emulsifying activity was determined with method reported by Pearce and Kinsella [17] and modified by Moure [18]. Twenty mL of 0.1 % (w/v) gum solutions (pH 7.0) were homogenized with 6.6 mL of rapeseed oil at 9500 rpm during 1 min. Aliquots of 50 µL of emulsion was diluted with 5 mL of 0.1 % (w/v) sodium dodecyl sulfate (SDS). The absorba,nce at 500 nm ($A_{500\ nm}$) of diluted samples was measured using a Shimadzu UV-1700 spectrophotometer. Emulsion activity index was calculated following the equation 1:

$$EAI\ (m^2/g) = [(2.303 \times A_0)/L] \times [(2 \times D)/(10^6 \times C \times \varphi)] \quad (1)$$

where A_0 is $A_{500\ nm}$ observed immediately after dilution. L refers to 0.01 m (optical path), C the concentration of gum (10^{-3} g.mL^{-1}), φ the oil ratio (φ = 0.25) and D the dilution factor (d = 100).

Emulsion stability index (ESI) was estimated using the equation 2:

$$ESI\ (min) = 10 \times [A_0/(A_0-A_{10})] \quad (2)$$

where A_{10} is $A_{500\ nm}$ of diluted emulsion after 10 min.

2.7.2. Emulsion capacity

The emulsion capacity (EC) was measured as reported previously [19]. Gum solutions at 0.5 and 1 % (w/v) and at pH 7 were prepared 24 h before the test. Emulsion was obtained adding gradually rapeseed oil (density of 0.9 g/cm^3) to 50 mL of gum solution under vigorous stirring. The conductivity was measured by a CDM210 conductimeter (Radiometer Analytical, France) and the temperature was kept in the range of 19-22 ˚C. The final point was the emulsion broke into two phases where conductivity decreased suddenly. EC was reported as the amount of oil that can be emulsified by a defined quantity of gum as expressed by equation 3:

$$EC\ (mL\ oil/g\ powder) = V/W \quad (3)$$

V refers to maximum volume of oil stable in the emulsion (mL) and W represents the amount of gum (g).

2.7.3. Emulsion stability

Emulsion stability (ES) was analyzed following the method published by Yasumatsu et al. [20] and modified by Ursu et al. [19]. Equal volumes of gum solutions (2 % w/v) were homogenized with rapeseed oil at 9500 rpm during 1 min at room temperature. The emulsion samples were divided into four glass tubes and sealed with caps. After that the tubes were put in two conditions: (A) keeping at 20 °C; (B) heating at 80 °C for 30 min in a water bath and then cooling to 20 °C. Emulsion stability (ES) was calculated as the ratio of stable emulsion height (H_1) to total mixture height (H_0) 24 h after the experiments according to equation 4.

$$ES\ (\%) = (H_1/H_0) \times 100 \quad (4)$$

2.8. Foaming properties

Foaming ability (FA) and foaming stability (FS) of 2 % (w/w) gum solutions were carried out using an Ultra turrax at 13500 rpm during 2 min at room temperature. Experiments were done in triplicate. FA the volume ratio of foam volume compared to initial volume of gum solution (equation 5). FS is defined as the time required for foam to reach the half of its volume [21, 22]:

$$FA\ (\%) = [(V-V_0)/V_0] \times 100 \quad (5)$$

where V_0 is the initial volume of gum solutions (mL). V refers to the volume of foam after homogenizing (mL).

2.9. Viscosity measurements

Rheological measurements were performed on an AR-G2 rheometer (TA Instruments, USA). A standard double concentric cylinder geometry (rotor outer radius/ rotor inner radius = 1.09, stator inner radius = 15.1 mm) with gap of 2 mm was used for all measurements. The shear rate was studied in the rage of 0.1-500 s^{-1}.

Effect of gum concentration on steady shear flow and viscosity was evaluated using solutions of gums at 2, 5, 10, 15, 20, 25 and 30 % (w/w) at pH 6 and 20 °C. Gums were dissolved during 72h at 4°C under stirring before each experiment. Effect of $CaCl_2$ was assessed measuring the viscosity of 5 % (w/w) gum solutions with different molarities of this salt (between 0 and 1 M) at 20 °C. The influence of pH (3, 6 and 9) on viscosity of gum solutions (5 % w/w) was observed at 20 °C. Finally the effect of temperature increment (10-80 °C) on steady shear flow and viscosity of gum solutions (10 % w/w) was studied at pH 6. A steel cover was used to prevent the evaporation of solutions during the measurements. Data were collected and analyzed by Rheology Advantage Instrument V 5.7.1.

3. Results and discussion

3.1. Chemical composition

Chemical compositions of asafoetida and Arabic gums are summarized in **Table 1**. The measurements of total sugar contents gums showed a higher purity for Arabic gum compared to asafoetida one. However the protein content is higher in asafoetida gum considering both total and soluble proteinaceous compounds. **Table 2** gives the monosaccharide composition of gums. Gal: Ara: Rha: GlcA ratio for asfoetida gum was 11.5: 5.0: 2.1: 1.0. It was slightly higher than that of Arabic gum (11.7: 5.4: 3.2: 1.0).

Islam et al. [23] reported the monosaccharides composition of several acacia species. They calculated the amount of uronic acid in the range 6.5-14.5 % that was higher in comparison with Arabic gum used in this study (4.7 % w/w).

3.2. Surface and interfacial tensions

Fig. 1 shows the data obtained for surface and interfacial tensions of 0.2-1.5 %w/w solutions of gums. Asafoetida gum reduced the surface tension from 60.3 ± 0.2 mN/m at concentration of 0.2 % (w/w) to 54.5 ± 1.5 mN/m at concentration of 1.5 % (w/w) solutions. According to **Fig.1A**, different concentrations of the asafoetida gum did not alter the surface tension in a large range and no significant reductions in surface tension were observed with solutions of gums having concentrations equal or higher than 0.5 % (w/w). In contrast, reduction of surface tension by Arabic gum occurred in a larger range of concentrations, following a sharper decrease (from 72.4 ± 0.0 to 56.7 ± 0.2 mN/m) up to concentration of 1 % (w/w). It can be inferred that critical micelle concentration obtained in lower concentrations for asafoetida (0.5, %w/w) gum compared to Arabic gum (1, %w/w). As at all the concentrations, asafoetida gum exhibited lower surface tension comparing to Arabic gum. Similar results were achieved for interfacial tension as it is displayed in **Fig. 1B**. The higher protein content and protein to polysaccharide ratio of asafoetida gum could explain this result. The minimum interfacial tension observed for asafoetida and Arabic gums were 17.6 ± 0.2 mN/m and 17.9 ± 0.4 mN/m, respectively. Huang et al. reported a lower surface tension (46.9 mN/m) and interfacial tension (9.9 mN/m) for Arabic gum at 0.5 % (w/w) [24]. They discussed about surface activity of several gums and polysaccharides and declared that carrageenan and galactommanan from fenugreek had respectively the lowest and the highest surface activities. Surface tension of the ghatti gum was previously evaluated to be 40.7 mN/m [25]. Almond gum expressed lower interfacial tension but a slower kinetic to adsorb at interface of n-hexadecane-water compared to Arabic gum [26]. Jahanbin et al. studied the surface and interfacial tension of a new polysaccharidic gum from *Acanthophyllum bracteatum* roots (a glucoarabinogalactan) and compared them to those of to Arabic gum [27]. They reported lower surface activity for this new gum.

3.3. Emulsifying properties

Table 3 gives the emulsifying properties of the asafoetida and Arabic gums and compared them to reference proteins including sodium caseinate, whey protein isolate (WPI) and soy protein isolate (SPI) used in food formulations.

Emulsion activity relating to the turbidity of emulsion after adsorbing of surface active agents to the interfacial of oil-water, was analyzed using spectrophotometric method. EAI of emulsion made with asafoetida gum was considerably lower than emulsions made using the other biopolymers. This result was not in agreement with that of interfacial tension that revealed a better ability to adsorb on oil-water interface for asafoetida rather than Arabic gum. On the other hand, asafoetida gum demonstrated higher ESI. Therefore, it can be inferred that the use of Arabic gum leads to more opaque (turbid) but less stable emulsions.

Maximum emulsion capacity was investigated using a method based on conductivity measurement. EC of gums were higher at 0.5 % (w/v) compared to 1 % meaning the lower the emulsifying agent concentration is, the higher is its ability to cover the interface of oil droplets in an aqueous medium (**table 3**). This phenomenon is attributed to depletion flocculation in the presence of non-adsorbing polysaccharides [28]. In other words, when hydrocolloid concentration reaches the saturation state, unabsorbed biopolymers accelerate the destabilization of an emulsion. Since oil was adding during the EC measurement, the oil droplets accumulated until the distance between oil droplets decreased to less than mean diameter of free hydrocolloids. At this time biopolymers may start to departure the intervening gap with force due to depletion tendency of aqueous medium as a consequence of osmotic pressure [29]. The result would be phase separation of the emulsion. According to this explanation, it is interesting to notice that even with a higher protein content (**Table 1**), asafoetida gum had a higher EC (477.5 ± 10.7 mg oil/g powder) compared with Arabic one. The EC of asafoetida gum was also higher than those of commercial ingredients while the oil fraction was very high in all cases.

As described in methods, emulsion stability was surveyed at 20 °C with and without preheating emulsions at 80 °C for 30 min 24 h before the experiment. The results showed that asafoetida gum was more stable compared to Arabic gum and Na-caseinate but less stable than SPI when keeping the emulsions at 20 °C without any heat pretreatment. However, asafoetida gum displayed the highest ES (76.2 ± 0.3 %) among the emulsions that undergo the heating treatment (**Table 3**). Therefore, the emulsion made by asafoetida gum was not affected by heat treatment in a large extent and in both cases stability is higher than emulsions generated by Arabic gum.

3.4. Foaming properties

While agitating a surface active solution, air entraps in the system as bubbles. These bubbles have a tendency to approach and join together (coalescence). The result will be larger bubbles which are thermodynamically unstable and cause the foam system to collapse. In order to prevent the coalescence of the air bubbles, a surface active agent is required to create surface tension gradient. Proteins are introduced as a specific surface active agent since they are capable to slow down the motion of air bubbles dispersing in foam [30]. Most of the polysaccharides have the ability to prevent the coalescence of air bubbles by increasing the thickness and viscosity of the layers coating the air bubbles.

Values of FA and FS of the gums, WPI and SPI are given in **Table 4**. Asafoetida gum exhibited a low FA in comparison with reference proteins *i.e.* WPI and SPI. However, Arabic gum did not make foam. Contrary to lower ability of asafoetida gum to establish high volumes of foam by whipping, the resultant foam was more stable (more than one day) compared to those obtained with WPI and SPI. It was a notable outcome in comparison with other hydrocolloids studied by the same method.

3.5. Rheology of gum

Fig. 2 shows the effect of gum concentration (2-30 % w/w) on apparent viscosity of solutions at 20 °C in a range of shear rate between 1 and 500 s^{-1}. Apparent viscosity of solutions of asafoetida gum was low and quite close to those of Arabic gum in all concentrations and shear rates. Viscosity values obtained for

Arabic gum in this study were lower than that was published by Li et al. [4] but more similar to data reported by Sanchez et al. [31]. Asafoetida and Arabic gums demonstrated Newtonian flow behaviors as denoted by linear relationship between shear stress/shear rate. Note that some arabinogalactan gum exudates exhibited different rheological behaviors. For example ghatti, tragacanth and *Prunus cerasus* gums displayed shear thinning pseudoplastic characteristics [32-34]. On the other hand, *Albizia zygia* gum was found to be a shear thickening dilatant [35]. Muñuz et al. [36] declared that gum from *Acacia tortuosa* showed non-Newtonian shear thinning behavior at 15-40 % w/v.

Fig. 3A shows the influence of Ca^{2+} cations on viscosity of 5 % (w/w) solutions of asafoetida gum at 20 °C. The viscosity decreased slightly at 0.01 M $CaCl_2$ followed by increasing at 0.1 M and 1 M of $CaCl_2$. The effect of $CaCl_2$ on viscosity of *Anacardium occidentale* gum was studied [37]. They discussed that at concentration below 2.5×10^{-4} M, divalent cation (Ca^{2+}) interacted with polyanionic domain of the gum leading to a reduction in viscosity of the gum solution. This phenomenon is known as shielding effect. At higher ion strength the viscosity increased as a result of cross linking effect. The same phenomenon was reported previously for Arabic gum [38]. The shielding effect of the asafoatida gum occurred at $CaCl_2$ concentrations lower than 0.01 M. It was clearer at higher shear rates (80-500 s^{-1}) because the steady state flow became more stable and the recorded viscosity fluctuations were diminished. The cross linking effect was dominant upper 1 M $CaCl_2$.

Fig. 3B shows the effect of different pH on apparent viscosity of 5 % (w/w) solutions of asafoetida gum at 20 °C. The natural pH of asafoetida gum was 6, consequently pH 3, 6 and 9 were observed as acidic, neutral and basic conditions. Basic condition does not have any effect on the rheological behavior of the solution whereas acidic pH tended to alter the rheology by adding shear-thinning behavior. The apparent viscosity increased with increasing of pH at high shear rates. This phenomenon was explained by the increasing in ionization degree of carboxylate groups of the gum. Similar discussions were reported by other researchers [39, 40]. Generally speaking, raising pH and ion concentration did not influence the

apparent viscosity of asafoetida gum in a large extent. It should be taken into account for applications of this gum in foods, drugs and/or cosmetics.

The effect of temperature on apparent viscosity of solutions of asafoetida and Arabic gums was investigated (**Fig. 4A**). Generally, the apparent viscosity of gum solutions decreased by increasing of temperature as described for the other gums and polysaccharides [27, 41-43]. The way that viscosity is affected by temperature basically depends on the hydrocolloid nature. For example, the temperature enhancement leads to little changes in viscosity of xanthan and the temperature dependency of this gum decreases with increasing concentration [44]. It has been mentioned for *Ocimum basilicum* seed gum that increasing temperature up to 60 °C caused the apparent viscosity to decrease, while at 85 °C the viscosity inceased as a result of polysaccharide interactions [45]. Above 40 °C, either asafoetida or Arabic gums demonstrated a limited shear thinning behavior especially at low shear rates. However, when the shear rate increased the solution flow became more similar to Newtonian behavior. No gelling effect was observed for both gums by increasing the temperature.

4. Conclusion

In this investigation the chemical composition, surface and interfacial tension, emulsifying and foaming properties and viscosity of asafoetida gum were compared with those of Arabic gum. Total sugar of the asafoetida gum was lower and protein content was higher than that of Arabic gum. Higher amount of protein caused asafoetida to exhibit lower surface and interfacial tensions. As a result, some of emulsifying factors of asafoetida gum such as ESI, EC and ES of non-treated and heat treated emulsions surpassed those of Arabic gum. The asafoetida gum demonstrated low foaming ability but long lasting foams. Rheological characteristic of the gum solutions were similar to those of Arabic gum in a large extent. These results showed a high potential of application range for gum asafetida extracted as a by-product of oleo-gum-resin refining process.

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Table 1. Chemical composition of asafoetida and Arabic gums

Parameter (% w/w)	asafoetida gum	Arabic gum
Dry matter content	98.6 ± 0	89.7 ± 0.1
Total sugar	67.1 ± 1.1	84.8 ± 0.3
Total protein[a]	6.8 ± 0	2.1 ± 0
Water soluble protein	4.9 ± 0.1	1.0 ± 0

[a] calculation was based on N × 6.25

Table 2. Monosaccharides composition of the asafoetida and Arabic gums

Monosaccharides (%w/w)	asafoetida gum	Arabic gum
Rhamnose	10.8	14.9
Arabinose	25.3	25.6
Galactose	58.8	54.8
Glucuronic acid	5.1	4.7

Table 3. Emulsifying properties (EAI, ESI, EC and ES) of gums in comparison with reference ingredients.

Emulsion parameters	Asafoetida gum	Arabic gum	Na-caseinate[a]	WPI[a]	SPI[a]
EAI (m^2/g)	38.6 ± 0.1	88.0 ± 4.0	160.0 ± 10.0	164.0 ± 3.0	113.0 ± 7.0
ESI (min)	149.6 ± 0.5	33.0 ± 5.0	57.4 ± 0.4	45.0 ± 7.0	18.0 ± 2.0
EC (mL oil/g powder) (0.5 % w/v)	881.0 ± 2.0	773.0 ± 7.8	-	-	-
EC (mL oil/g powder) (1 % w/v)	477.5 ± 7.7	334.3 ± 12.7	410.0 ± 20.0	356.0 ± 4.0	380.0 ± 20.0
ES (%)[b] Treatment A	75.0 ± 0.7	66.1 ± 0.4	61.5 ± 0.6	-	82.0 ± 3.0
ES (%)[c] Treatment B	76.2 ± 0.3	66.7 ± 0.9	63.0 ± 0.3	-	61.0 ± 2.0

[a][19], Ursu, Marcati, Michaud and Djelveh [46]; WPI and SPI stand for whey protein isolate and soy protein isolate, respectively.

[b] Keeping emulsion at 20 °C, 24 h

[c] Emulsion pretreatment (80 °C, 30 min) then keeping at 20 °C, 24 h

Table 4. Foam ability (FA) and Foam stability (FS) of hydrocolloids

Sample	asafoetida gum	Arabic gum	Na-caseinate[a]	WPI[b]
FA (%)	53.0 ± 2.7	0	238.3 ± 2.4	216.7 ± 7
FS (min)	1440 ± 60	0	10.3 ± 1.1	28.5 ± 2.1

[a] Ursu, Marcati, Michaud and Djelveh [46];

[b] Whey protein isolate

Figure captions

Fig. 1. Surface tension (A) and interfacial tension (B) of asafoetida and Arabic gums regarding the concentration.

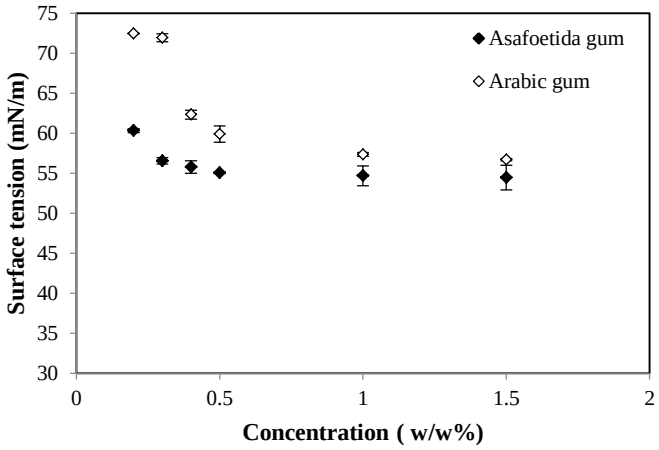
Fig. 2. Viscosity versus shear rate of different gum concentrations (2-30 %w/w): (A) asafoetida gum, (B) Arabic gum at 20 °C.

Fig. 3. Effect of Ca^{2+} ($CaCl_2$) molarities (blank = 0, 0.01 M, 0.1 M, 1 M) (A) and pH (3, 6, 9) (B) on apparent viscosity of 5 % (w/w) asafoetida gum solution at 20 °C.

Fig. 4. Effect of temperature on apparent viscosity of 10 % (w/w) asafoetida (A) and Arabic (B) gums.

International journal of biological macromolecules, Saeidy *et al.*, Fig. 1.

(A)



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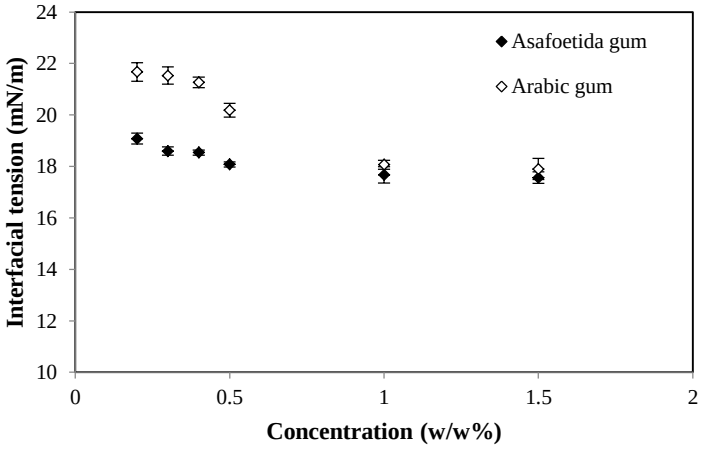
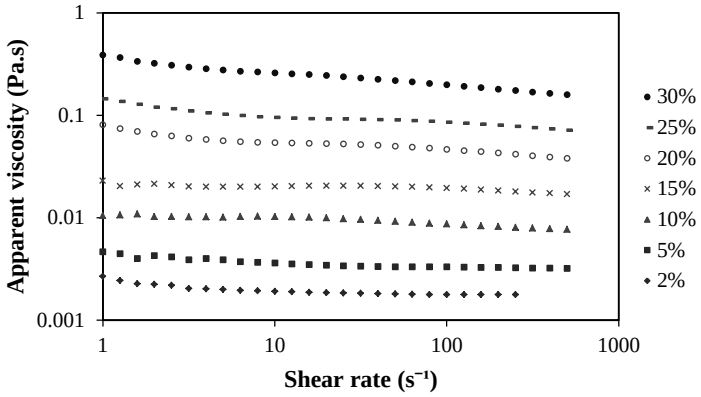


International journal of biological macromolecules, Saeidy *et al.*, Fig. 2.

(A)



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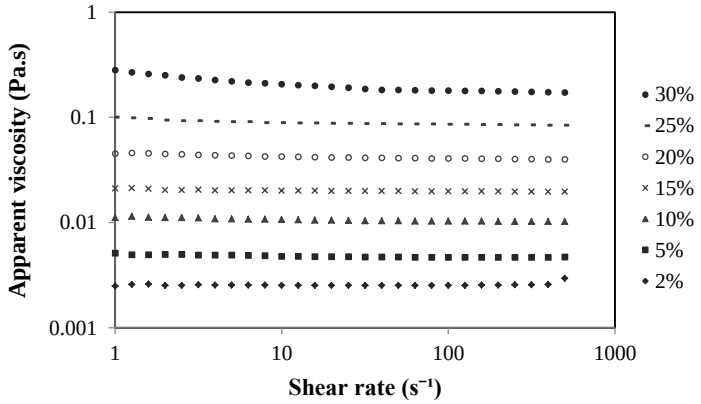
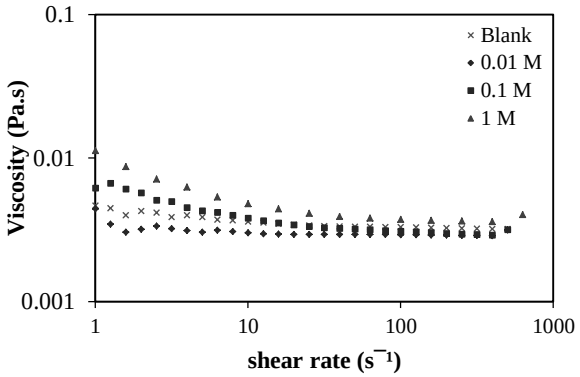


International journal of biological macromolecules, Saeidy *et al.*, Fig. 3.

(A)



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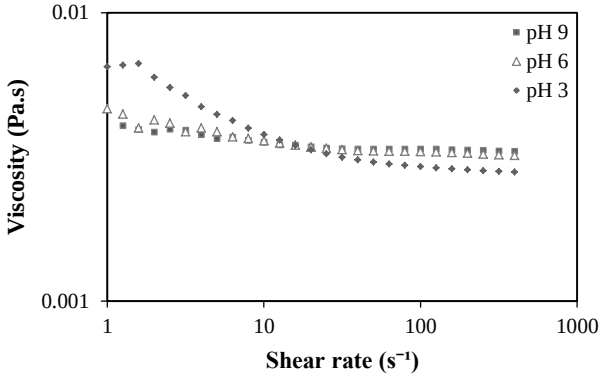
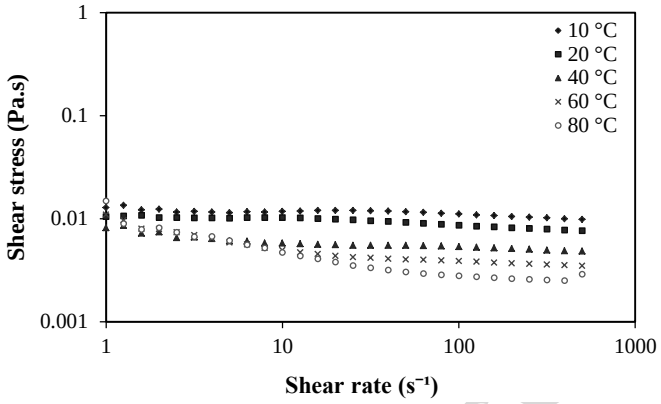


International journal of biological macromolecules, Saeidy *et al.*, Fig. 4.

(A)



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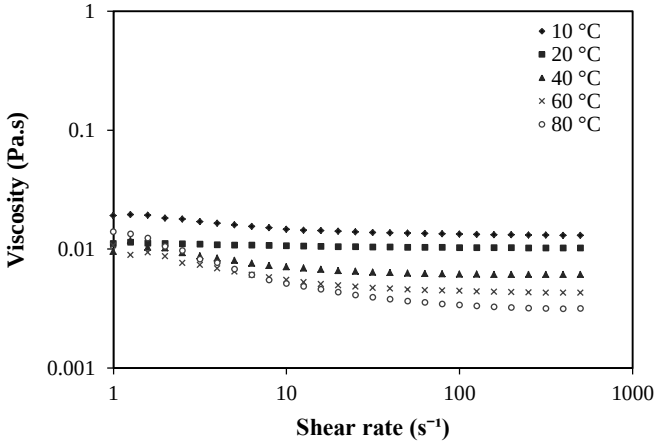

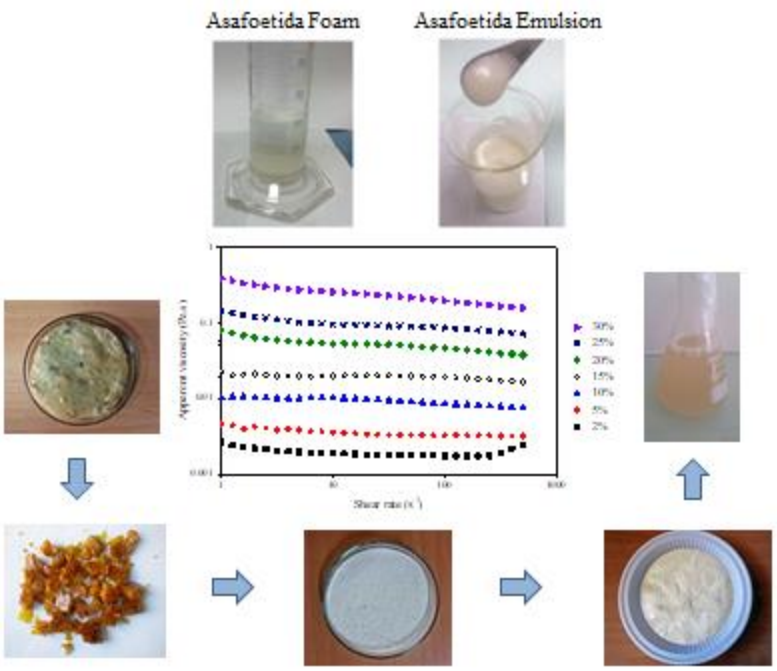

Graphical abstract

Highlights

- Asafoetida gum contained less carbohydrate and protein than Arabic gum.
- Asafoetida gum exhibited higher emulsion capacity and stability than Arabic gum.
- Rheological behavior of asafoetida gum solutions was similar to Arabic gum.