



## The impact of concentration, temperature and pH on dynamic rheology of psyllium gels

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### ABSTRACT

Structural aspects of the psyllium gum prepared from the seed husk of the plant of *Plantago ovata* Forsk was characterized by dynamic rheology and microscopy. Dynamic rheological properties of psyllium gel in the linear viscoelastic region, as a function of concentration (2, 2.5 and 3% w/w), temperature (5–95 °C) and pH (2.5–10) were investigated. Mechanical spectra of the psyllium gels were obtained by frequency sweep measurement classified into that of weak gels because  $G'$  was larger than  $G''$  throughout the tested frequency range and the separation of the two moduli ( $\tan \delta$ ) was greater than 0.1. The phase angle increased with temperature and a peak associated with gel melting appeared at about 40 °C. All gels at different pH presented a typical weak gel spectrum. Scanning electron microscopy showed porous structures with different pore-size distribution for psyllium gels under different conditions in terms of concentration, pH and temperature.

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### 1. Introduction

Psyllium, a mucilaginous material prepared from the seed husk of the plants of *Plantago* genus, is an excellent source of both soluble and insoluble fibres (Yu et al., 2001). Recently, psyllium has been recognized for its cholesterol-lowering effects, effective laxative activity, and insulin sensitivity improvement capacity (Anderson et al., 2000a,b; Song et al., 2000). A few food products have been developed using psyllium as a bioactive component and marketed for cholesterol-reducing effects (Childs, 1999; Aygustin and Dwyer, 1999; Jensen et al., 1993).

A factor in physiological fibre behavior of psyllium gum is its high viscosity and gel-like character in water (Al-Assaf et al., 2003). Gel-forming fraction of the alkali extractable polysaccharides of psyllium is composed of arabinose, xylose and traces of other sugars (Fischer et al., 2004). The seeds have been used for hundreds of years in traditional Iranian medicinal prescriptions. Because of its pharmacological effects, foods fortified with *Plantago ovata* mucilage gum may have a superior consumer acceptance. Rheology of food products has a significant role in product development, quality control, sensory evaluation and design and evaluation of the process equipment (Marcotte et al., 2001a,b).

Oscillatory rheology measurements are often employed to investigate the gelling or viscoelastic behavior of a system as it is well recognized that one can differentiate a solid from a liquid

based on the frequency dependence of the storage and loss modulus of the system (Ross-Murphy, 1994). Because gels are viscoelastic materials, dynamic rheological tests to evaluate properties of gel systems are well suited for studying the characteristics of gels as well as gelation and melting. From dynamic rheological tests in the linear viscoelastic range, the storage modulus,  $G'$ , the loss modulus,  $G''$ , and  $\tan \delta = (G''/G')$ , the loss factor, can be obtained.  $G'$  value is a measure of the deformation energy stored in the sample during the shear process, representing the elastic behavior of a sample. In contrary,  $G''$  value is a measure of the deformation energy used up in the sample during the shear and lost to the sample afterwards (Mezger, 2002). If  $G'$  is much greater than  $G''$ , the material will behave more like a solid; that is, the deformations will be essentially elastic or recoverable. However, if  $G''$  is much greater than  $G'$ , the energy used to deform the material is dissipated viscously and the material behavior is liquid-like (Rao, 1999). Dynamic rheological properties can be used along with steady shear rheological properties to provide insight on the structure of the sample. Gel systems can be divided into two classes: “true gels” and “weak gels”, depending upon the macroscopic behavior. A weak gel exhibits flow properties when submitted to high enough stress, in which, there is a higher dependence on frequency for the dynamic moduli, suggesting the existence of relaxation processes even at a short time scale, and a less difference between moduli values indicating the lower percentage recovery of the stored energy (Clark and Ross-Murphy, 1987).

The rheological properties of gels depends on many factors such as concentration, temperature, degree of dispersion, dissolution

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and electrical charge (Marcotte et al., 2001a,b; Rao and Anantheswaran, 1982). Guo et al. (2008) studied microstructural and rheological properties of alkaline extracted fraction of psyllium polysaccharide as affected by calcium. However, the weak gel-like properties of psyllium gum have not been reported in details. The aim of the present work was to study the gel formation, the effects of different factors on the gel properties and microstructure of psyllium gum extracted from *P. ovata* Forsk.

## 2. Materials and methods

### 2.1. Materials

The Espharze (*P. ovata* Forsk) seeds were obtained from the local market for medical herbs, Tehran, Iran. They had been collected from the Khorasan province of Iran located between 55°, 28'–61°, 20' longitude and 30°, 21'–38°, 17' latitude. The seeds were manually cleaned to remove all foreign matters such as dust, dirt, stones, chaff and immature seeds. All chemicals used in this study were of analytical grade and purchased from Merck Company (Darmstadt, Germany).

#### 2.1.1. Gum extraction and purification

Husks of *P. ovata* seeds were separated from the seed coats by mechanical milling of the outer layer of the seeds using a blade type grinder (Mammonlex, Taiwan) for 1 min at low speed, and for further 3 min at high speed. The seeds were then sieved using a mesh number 18 sifter and the husk was separated from seeds. Husks of seeds were dispersed in distilled water at a water/husk ratio of 20:1. The husk–water slurry was stirred continuously with a mechanical mixing paddle throughout the entire extraction period (1 h). The residual of seeds was discarded, and the rest of the supernatant was subjected to ethanol precipitation (97% ethanol/mixture ratio of 3:1). The precipitate was then kept in the solvent for approximately 20 min with occasional gentle stirring. Later, the precipitate was removed using centrifugation at 10,000g for 20 min at 25 °C. The gum then was dried in a conventional oven (overnight at 40 °C) and milled to a particle size range between 53 and 125 µm. The powder was stored in an air-tight test tube at room temperature for further experiments.

#### 2.1.2. Analysis of chemical composition

Moisture, protein, fat and ash content of the mucilage were determined using the AOAC approved method. The quantity of total sugar was estimated as the remainders of the samples after substances (protein, fat, ash, and moisture) were accounted for AOAC (1984).

#### 2.1.3. Fourier transform infrared spectroscopy (FT-IR)

FT-IR spectrum of purified psyllium gum was obtained at a resolution of 1 cm<sup>-1</sup>. The sample was incorporated into KBr (spectroscopic grade) and pressed into a 2 mm pellet. IR spectra were recorded in the transmittance mode from 4000 to 400 cm<sup>-1</sup>, using a BRUCKER spectrometer (EQUINOX 55, Germany).

## 2.2. Dynamic rheological measurements

### 2.2.1. Gel preparation

Gels were prepared at different concentrations (2, 2.5 and 3% w/w) in distilled water, and heated up to 85 °C in a thermally controlled water bath and kept at this temperature for 5 min. After thermal treatment, the samples were cooled down rapidly using water (15 °C) and kept for 24 h at 4 °C.

### 2.2.2. Frequency sweep

Oscillatory measurements were performed in a controlled stress rheometer (Physica, MCR300, Germany). Parallel plate geometry (25 mm diameter) with a gap of 1 mm was used for oscillatory measurements and the exposed edges of the samples were covered with low viscosity paraffin oil to prevent evaporation of water during measurement. Strain sweeps were performed at 25 °C and a frequency of 10 Hz for all gels to determine the linear viscoelasticity zone. Frequency sweeps tests, at 1% strain and 25 °C were performed from 0.1 to 100 Hz at least in duplicates. The oscillatory rheological parameters used to compare the viscoelastic properties of all gel systems were: storage modulus ( $G'$ ), loss modulus ( $G''$ ), loss angle ( $\tan \delta$ ) and complex viscosity ( $\eta^*$ ).

### 2.2.3. Temperature sweep

Rheological behavior of the sol–gel transition of the psyllium gel (2.5% w/w) was measured by performing a temperature sweep. The sample gel of psyllium was loaded onto the pre-cooled peltier plate (5 °C) of the rheometer and allowed to equilibrate for 5 min. The periphery of the sample was coated with paraffin oil, in order to minimize water evaporation. Temperature dependence of storage ( $G'$ ) and loss ( $G''$ ) moduli as well as loss tangent ( $\tan \delta$ ) were measured by heating the systems from 5 to 95 °C. The temperature gradient was 2 °C/min on heating scan, while the frequency was fixed at 1.0 Hz. Parallel plate geometry (25 mm diameter and 1 mm gap) was used for the measurement. The measurements were performed at 1%, which was well within the linear viscoelastic region. Prior to temperature sweep, dynamic torque sweeps were conducted to choose common linear viscoelastic region for all samples. The melting temperature was taken as the point at which phase angle,  $\delta$ , peaks immediately after a sharp increase (Sarabia et al., 2000).

### 2.2.4. Scanning electron microscopy (SEM)

After preparation of psyllium gels under different conditions, they were freeze dried (SPEEDIVAC, UK). Thin layers were prepared from the unground freeze-dried samples and coated with gold using an ion sputter coater (Fisons Instruments, UK). The coated samples were viewed and photographed using a scanning electron microscope (model 5526, Cambridge, UK) at 20 kv.

## 3. Results and discussions

### 3.1. Chemical composition

The chemical compositions of the whole seed, seed coats (husk), and the purified mucilage from *P. ovata* seeds are shown in Table 1. The moisture content of whole seed, seed coats (husk), and the purified mucilage was similar, 6.05%, 6.24% and 6.13%, respectively. The protein content of the whole seed was greater than that of seed coats (husk) and mucilage and the majority (i.e. about 90%) of

**Table 1**

The chemical compositions of the whole seed, seed coats (husk), and the purified mucilage from *P. ovata* seeds.

Composition	Compositional distribution of total material (%)		
	Whole seed	Husk	Mucilage
Moisture	6.05 ± 0.06	6.24 ± 0.02	6.13 ± 0.02
Protein	2.93 ± 0.20	0.25 ± 0.02	0.11 ± 0.00
Fat	0.30 ± 0.06	0.50 ± 0.05	0.36 ± 0.03
Ash	2.98 ± 0.23	3.59 ± 0.17	1.51 ± 0.06
Fibre	24.32 ± 0.21	2.63 ± 0.07	3.19 ± 0.13
Total carbohydrate <sup>a</sup>	87.74 ± 0.55	89.25 ± 0.14	91.81 ± 0.06

<sup>a</sup> Calculated from total (moisture, protein, fat and ash).

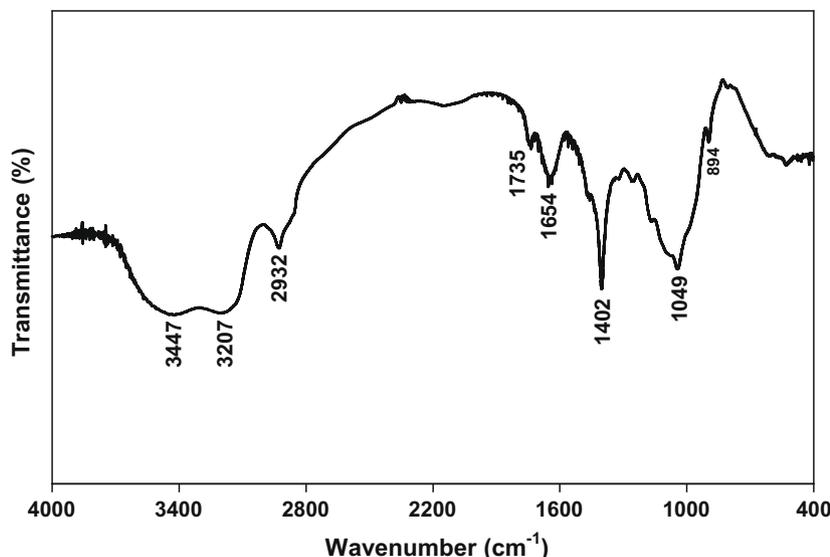


Fig. 1. FT-IR spectrum of psyllium powder.

whole seed, seed coats (husk), and the mucilage was carbohydrates. The production yield of purified mucilage from the seeds was 28.5% (w/w). This was in agreement with Fischer et al. (2004), who reported an approximate yield of 25% for *P. ovata* Forsk.

### 3.2. FT-IR spectroscopy

Fig. 1 shows the FT-IR spectrum of dry powder of purified psyllium gum. The spectrum is dominated by a broad band at about 3447 and 3207  $\text{cm}^{-1}$ , which is assigned to the stretching vibration modes of –OH groups and –OH of alcohols, respectively. The peak at 1654  $\text{cm}^{-1}$  is due to the asymmetrical –COO<sup>−</sup> stretching vibration, whereas the band at 1402  $\text{cm}^{-1}$  is due to the symmetrical –COO<sup>−</sup> stretching vibration. A detailed band assignment is not presented in this work, but the main absorption peaks and their tentative assignments are shown in Table 2.

### 3.3. Rheological measurement

#### 3.3.1. Steady oscillatory flow measurement

The difference between strong and weak gels or entangled solutions can be assessed by means of oscillatory dynamic experiments using parallel or cone and plate geometries (Shoemaker et al., 1992). Strain/stress sensitivity and determination of critical strain/stress can be appropriately considered for the characterization of the heterogeneity level within the gel structure (Lapasin and Pricl, 1995). The strain/stress dependence of  $G'$  and  $G''$ , and consequently the critical stress/strain of  $G'$  and  $G''$ , and the critical

stress/strain values can be useful to study the structure of different samples (Clark and Ross-Murphy, 1987; Gue et al., 2009).

In the strain test,  $G'$  remained constant until the strain reached a critical point at which  $G'$  started to decrease sharply, as demonstrated in Fig. 2. The strain at which  $G'$  decreased sharply is defined as the critical strain. At the critical strain, gel structure begins to collapse. Therefore, critical strain reflects the deformability of a gel. As shown in Fig. 2,  $G'$  and  $G''$  did not show any strain dependence until the strain reached around 34%. Thus, the strain of 1% used in the entire experiments was well within the linear viscoelastic region, where the weak gel network was not damaged by the strain imposed during the measurements.

#### 3.4. Effect of concentration and frequency

Frequency sweep information can be used to characterize or classify a dispersion. The four most common and traditional classifications are that of a dilute solution, an entanglement network systems (or a concentrated solution), a weak gel and a strong gel (Clark and Ross-Murphy, 1987; Steffe, 1996). Typical oscillatory flow curves as a function of psyllium concentration at 25 °C are shown in Fig. 3. As can be observed, both the dynamic storage modulus,  $G'$ , and the viscous modulus,  $G''$ , show a dependency on the frequency. The spectra showed that for the concentrations tested  $G'$  was always higher than  $G''$  and it was not dependent on concentration and as expected an increase in both  $G'$  and  $G''$  was observed when concentration is increased (Medina-Torres and Brito-De La Fuente, 2000). At 3% concentration a stronger frequency dependency was observed for both  $G'$  and  $G''$ . The mechanical spectra of the gels at different concentrations can be considered as typical of three-dimensional networks (Fig. 7), indicating true gel formation, according to Clark and Ross-Murphy (1987). This type of behavior is indicative of a weak gel according to the classification mentioned above. It has been reported that an entanglement network system shows  $G''$  and  $G'$  curves intersecting at the middle of the frequency range, indicating a clear tendency for more solid-like behavior at higher frequencies (Ross-Murphy, 1984). Weak gels have  $G'$  higher than  $G''$  with moduli almost parallel to each other (Clark and Ross-Murphy, 1987). A slight increase in  $G''$  with frequency was observed at low concentrations but maintaining the predominantly elastic character. This type of behavior has been reported by other authors for  $\kappa$ -carrageenan gels (Fernandes et al.,

Table 2

The main absorption peaks and their tentative assignments of FT-IR spectrum of dry powder of purified psyllium gum.

Wavenumber ( $\text{cm}^{-1}$ )	Fragment
3447	–OH stretching
2932	–CH stretching of $\text{CH}_2$ and $\text{CH}_3$ groups
1735	C=O stretching of ester
1654	COO <sup>−</sup> asymmetrical stretching of the hydrogen-bonded carboxylic groups
1402	COO <sup>−</sup> symmetrical stretching of carboxylic groups
1049	C–C or C–O stretching vibration

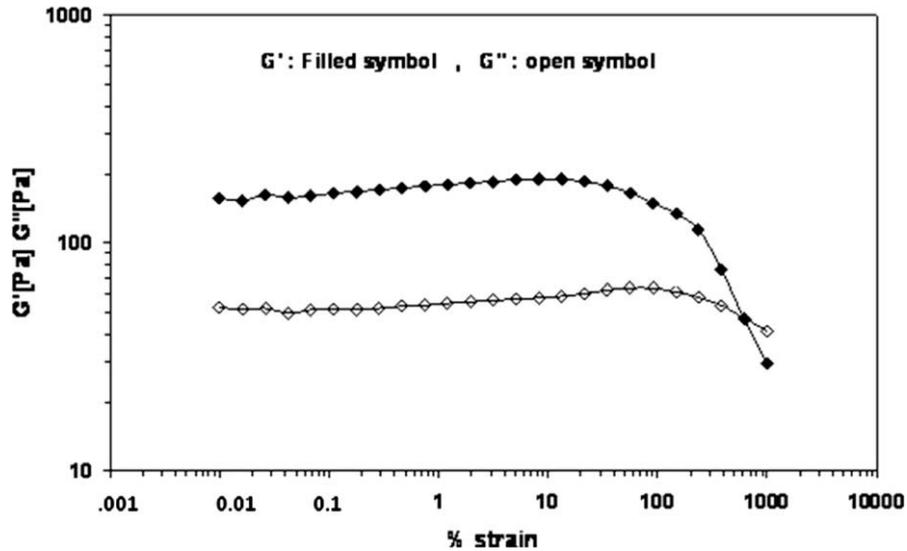


Fig. 2. Spectra of yield stress of psyllium gum by dynamic stress sweep test method for 2.5% gum solution at 25 °C.

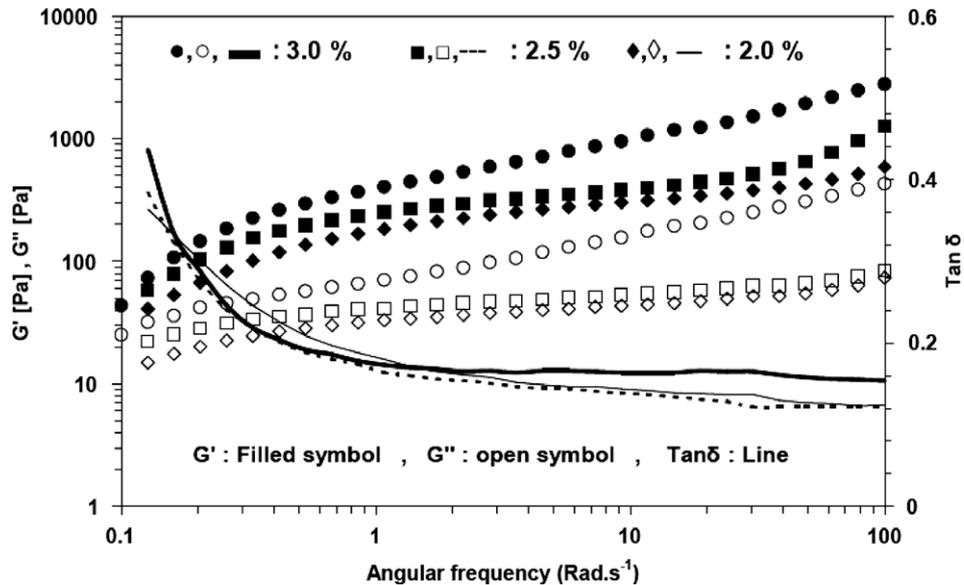


Fig. 3. Effect of psyllium concentration on (a) storage ( $G'$ ), loss ( $G''$ ) moduli and  $\tan \delta$  as functions of frequency at 25 °C.

1991; Ikeda and Nishinari, 2001), gellan gum gels (Miyoshi et al., 1994; Rodríguez-Hernández et al., 2003) and  $\kappa$ -carrageenan/LBG gels (Chronakis et al., 1999; Andrade et al., 2000). The tendency of the dilute solution and the concentrated solution to exhibit more fluid or solid-like behavior with increasing frequency can be examined in more detail by considering the frequency dependence of the phase lag.  $\tan \delta$  is directly related to the energy lost per cycle divided by the energy stored per cycle. The maximum phase lag which can be observed is  $\pi/2$  found with a Newtonian fluid and the minimum value is zero found with a Hookean solid. Since  $0 < \delta < \pi/2$ ,  $\tan \delta$  can vary from zero to infinity. Observations of polymer system give the following numerical ranges for  $\tan \delta$ : very high for dilute solutions, 0.2–0.3 for amorphous polymers, low (near 0.01) for glassy crystalline polymers and gels. High values of  $\delta$  at low frequencies indicate a tendency toward more fluid-like behavior for both the dilute and concentrated solutions at low deformation rates (Steffe, 1996). More solid-like behavior is observed for these solutions at high deformation rates associated

with high frequencies. Fig. 3 shows the change of  $\tan \delta$  versus frequency for different concentrations of psyllium gum. Increasing of frequency resulted in a decrease in  $\tan \delta$ .  $\tan \delta$  was 0.4 on low frequency and reached to a constant amount of 0.2 at high frequencies.

Psyllium gels showed a shear dependent flow behavior as the complex dynamic viscosity ( $\eta^*$ ) decreased with increasing frequency on double logarithmic scale by a slope of  $\sim -0.77$  (for 2.5% w/w) which is close to  $-0.76$  described by Morris (1990) (Fig 4). He proposed this value to for “weak gel” property of a polysaccharide gel formed by overlapped and entangled flexible random coil chains. The weak gel structure of psyllium is similar to xanthan weak gel, which was formed by tenuous association of rigid, ordered polysaccharide chains (Morris, 1990). In a previous study, Guo et al. (2008) found the alkaline extractable gel fraction of psyllium (AEG) was an arabinoxylan with (1  $\rightarrow$  4) linkages presenting in the xylan backbone, which was heavily substituted by short arabinose branches (Guo et al., 2008). This structure could

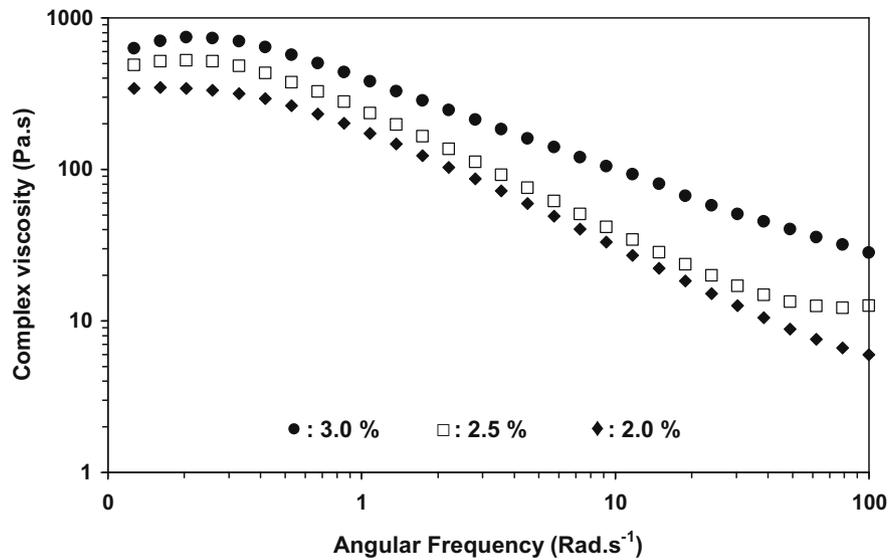


Fig. 4. Effect of psyllium concentration on complex viscosity of psyllium solutions as functions of frequency at 25 °C.

form a rigid, ordered polysaccharide chain conformation; however, the presence of branches could prevent molecules from associating with each other to form a stronger gel. In the same study, it was found that AEG had a very large average hydrodynamic diameter ( $\sim 120$  nm), which provided evidence that AEG behaved as a rigid chain.

### 3.5. Effect of temperature

The process of gelation involves transforming a liquid solution of macromolecules or particles into a well-shaped elastic solid (Djabourov et al., 1988). The mechanism of gelation is considerably more complicated for a food polymer than a synthetic polymer, because of the involvement of factors such as coil–helix transitions, disulfide bonds and hydrogen bonds (Kumagai et al., 1993). The temperature for a biopolymer to melt may be defined as the temperature where the dynamic shear storage modulus ( $G'$ ) equals the

shear loss modulus ( $G''$ ) (the gel–sol transition) (Djabourov et al., 1988). This can be easily measured using a controlled stress rheometer in oscillatory mode. It is important to recognize that viscoelastic moduli are frequency dependent and this dependence must be recognized when measuring the melting or gelling points (Djabourov et al., 1988).

Fig. 5 presents the changes of  $G'$  and  $G''$  with temperature for psyllium gel (2.5% w/v) between 2 and 95 °C. Up to about 40 °C,  $G'$  and  $G''$  increased gradually, whereas above that both  $G'$  and  $G''$  reached a plateau. Plot of phase angle as a function of temperature in Fig. 6 gives a peak with an onset of about 30 °C and an endset of about 40 °C. This might be related to the melting of gel structure, accompanying the breakage of some inter- or intra-molecular hydrogen bonds, similar to the behavior of starch gels. In a preliminary study, it was tried to find the melting point of psyllium gel by differential scanning calorimetry (DSC) but no obvious peak was observed between 5 and 110 °C, which means that no detect-

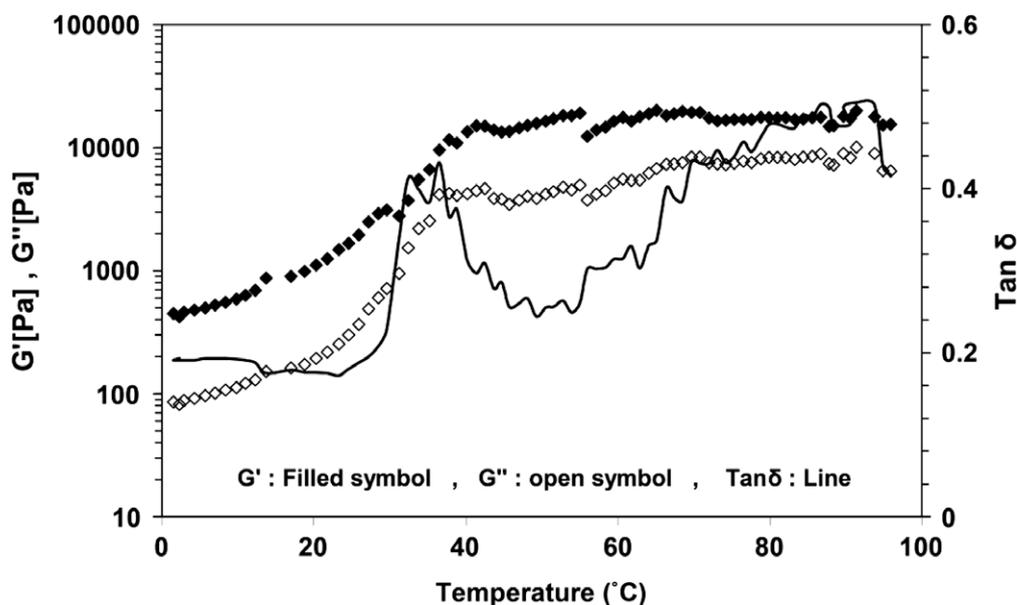


Fig. 5. Temperature dependence of storage modulus, loss modulus and  $\tan \delta$  for a 2.5% (w/w) psyllium gum solution during melting process.

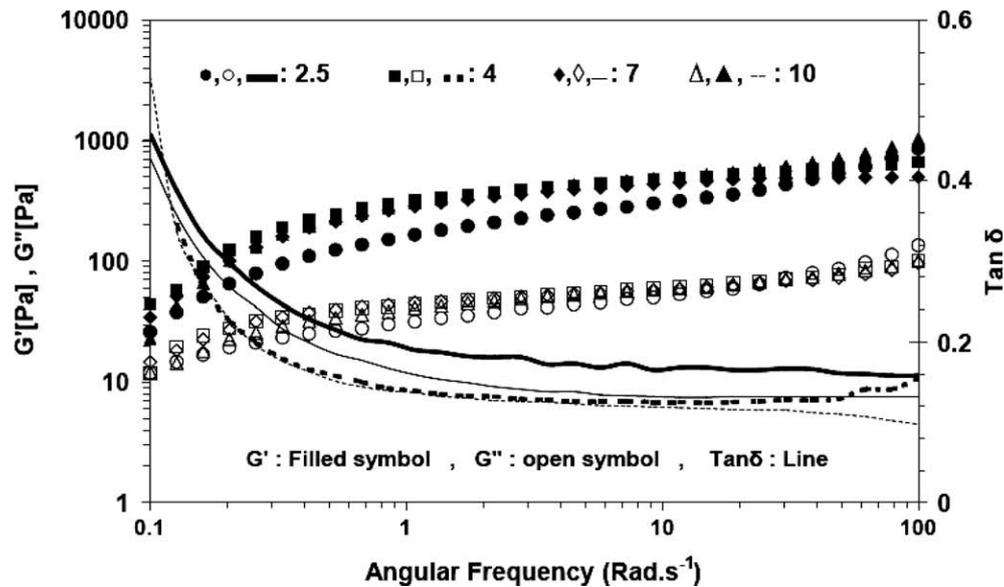


Fig. 6. Effect of pH on (a) storage ( $G'$ ), loss ( $G''$ ) moduli and  $\tan \delta$  as functions of frequency at 25 °C.

able change in enthalpy occurred. These results implied that the melting process of psyllium gel was a continuous and long procedure rather than a sharp melting point. This may suggest the general conclusion that the cross linking junctions of a psyllium gel are mainly intermolecular hydrogen bonds between polysaccharide chains. During the gel melting process, the mobility of the polymer chains is expected to be promoted at elevated temperatures because the chain mobility is tied to solvent viscosity, which drops with increasing temperature. This effect may soften the elastic response of the system. At the gel point it was frequently found, for chemical irreversible gels and also for physical gels of biopolymers, that  $G' < G''$  (Adolf et al., 1990; Hodgson and Amis, 1991; Lairez et al., 1992; Michon et al., 1993), while for physically reversible gels it has been observed that  $G' > G''$  (Clark and Ross-Murphy, 1987; Hossain et al., 2001; Nyström et al., 1995). In the present work, the psyllium gel showed a storage modulus higher than the loss modulus, in the whole range of investigated temperatures. The thermal profile revealed losses in the network strength (aggregates) and/or changes in structural (conformation) of the sequence segments involved in the bonding zones (Vaikousi et al., 2004). Conflicting results have been previously reported for low concentrated solutions of HPMC, high ester pectin and  $\beta$ -glucans where a drop of moduli with increasing temperature (melting) was measured (Hussian et al., 2002; Lazaridou et al., 2003; Tsoga et al., 2004; Vaikousi et al., 2004).

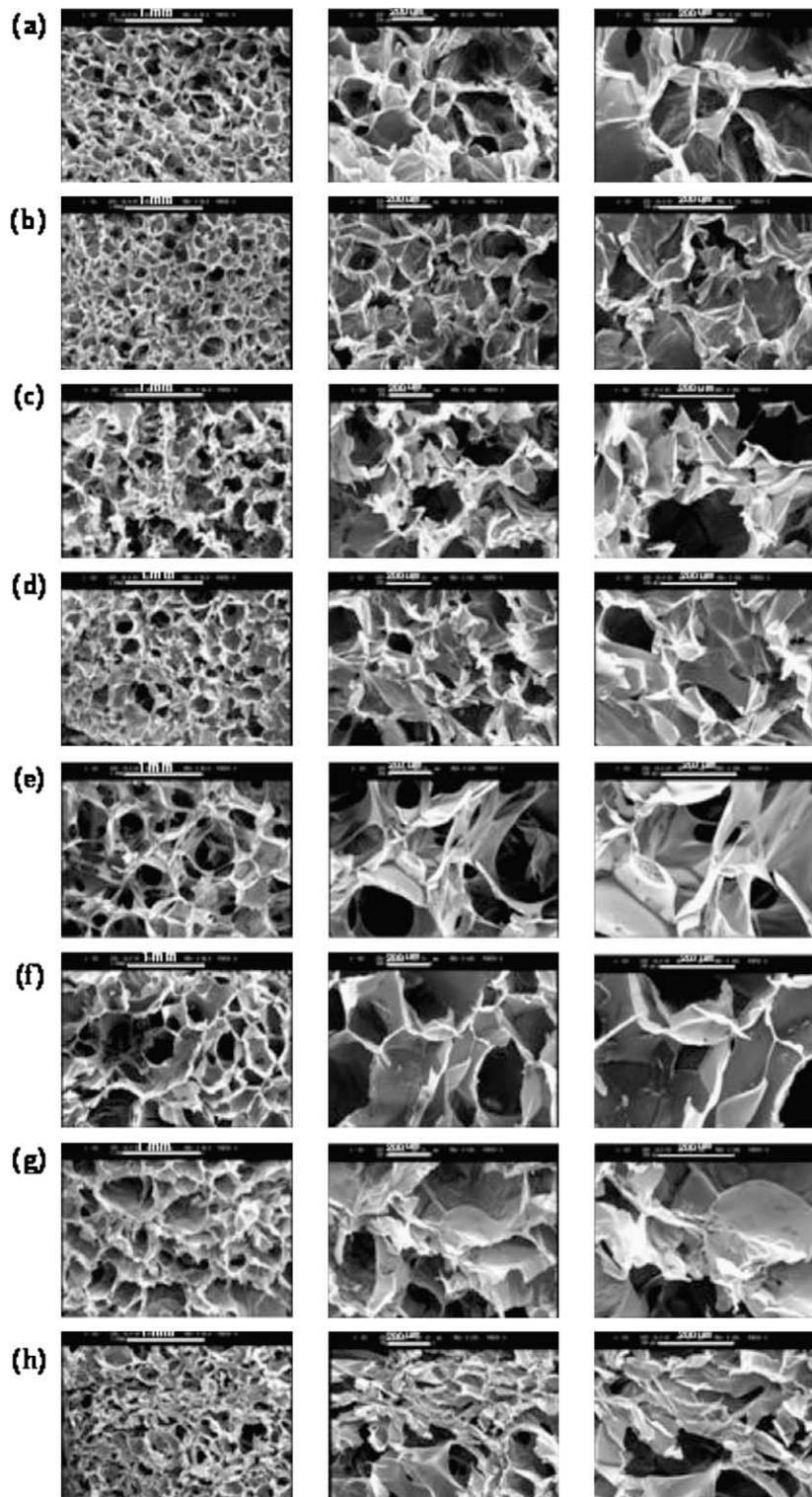
### 3.6. Effect of pH

Storage and loss moduli of psyllium gels (2.5% w/w) at different pH values as a function of frequency are shown in Fig. 6. The storage modulus ( $G'$ ) increased with frequency and reached a maximum value which is nearly two orders of magnitude greater than the initial value appeared for the system at different pH, whereas a modest rise of the loss modulus  $G''$  for all pH values. All psyllium gels presented a typical weak gel spectrum, i.e.  $G'$  was always higher than  $G''$ , at different pH (Haque et al., 1993). Psyllium gum is an anionic polysaccharide which bears a negative charge due to ionized carboxyl groups. Intermolecular electrostatic repulsions due to homo-charges make the molecular chains fully extended and interpenetrated with each other, to form intermolecular cross-linking which induced gelation. Since net electrostatic repulsion decreases at low pH values, the interaction of molecules also

decreases, leading to reduction in gel elasticity. At higher pH values, the decrease in gel elasticity might be attributed to alkaline depolymerization reaction, resulting in less junction zones (BeMiller, 1993; Fedeniuk and Biliaderis, 1994).  $\tan \delta$  was 0.4 at low frequencies and it reached a constant value of about 0.2 at high frequencies for all pH. However,  $\tan \delta$  value at pH 2.5 for all frequencies, were greater than other pH values showing the fact that this pH leads to a reduction in gel elasticity (Fig. 6).

### 3.7. Gel microstructure

Although rheology provided an important analytical tool for our understanding of the gelling property of psyllium polysaccharides, it did not provide the complete story. The microstructure of psyllium gels was also analyzed using the SEM technique for a better understanding of the properties of the psyllium gum gels. Gel preparation is a challenge for electron microscopy by conventional methods because they have high water contents. Improper freeze drying can result in unreal conclusions. Macro-porous hydrogels can be examined using scanning electron microscopy (SEM) after freeze drying, when the material has an adequate modulus to avoid the structural collapse during dehydration. In the current study, freeze-dried samples were used to remove the artifacts. During sample preparation, water in the gels was rapidly frozen at  $-70$  °C and then dried for 48 h in a freeze drier. Fig. 7a–d shows SEM images of a range of concentrations (2, 2.5 and 3% w/w) of dried psyllium gels. The electromicrographs of 2% gel shows the collapse of gel structure, confirming the formation of a weak gel at this concentration. However, some large flat sheets are present. A lath sheet-like structure was formed within the 2.5% sample and sheets were more numerous, larger with inclusions of macropores. There was almost no interconnection between laths and it is possible that the large sheets were torn. However, a significantly stronger gel was formed which did not collapse upon freeze drying when the concentration of psyllium was further increased to 3% (w/w). The SEM images showed a sheet-like or membrane structure with significant interactions forming a three-dimensional network. The micrographs in Fig. 7b and c showed the three-dimensional networks of psyllium gum gel that was heated to 85 °C for 3 min and psyllium gum gel swelled in distilled water at concentration of 2.5% w/w, respectively. The heated psyllium gel network showed a more ordered structure than of the swelled



**Fig. 7.** Scanning electron micrographs of psyllium gels. Concentration of 2% (w/w) (a), 2.5% (b), and 2.5% that only swelled in distilled water and not heated (c) and 3% (d). Concentration of 2.5% at (e) pH 2.5, (f) pH 4, (g) pH 7, and (h) pH 10. Left to right, magnification.

psyllium gel network (i.e. the unheated sample). From Fig 7d, it can be seen that the gel network was getting denser with increasing of concentration of psyllium in solution. Furthermore, the microstructure of psyllium gel investigated by SEM at different pH (2.5, 4, 7 and 10) is presented in Fig. 7e–h. The microstructure of psyllium gels at high pH showed that the polymer surface mor-

phology had a porous structure with a small pore-size distribution. This occurrence can be explained by the ionization of the mucilage carboxyl groups at alkaline condition. Types of interactions play an important role at this condition, namely the charge repulsions between carboxylic groups. In this case, the polymer expanded by electrostatic repulsions between chain segments.

#### 4. Conclusion

The results showed that psyllium gum contains carboxylic groups on the backbone of polymer. Mechanical spectra of the psyllium gels classified into that of weak gels because  $G'$  was larger than  $G''$  throughout the tested frequency range and the separation of the two moduli ( $\tan \delta = G''/G'$ ) is larger than 0. Both fluid-like ( $G''$ ) and solid-like ( $G'$ ) behavior were found to be dependent on concentration and frequency.

For all mucilage concentrations,  $G'$  was always superior to  $G''$ , i.e. psyllium solutions will show mainly elastic properties. The maximum functional properties were seen for pH of 4 and 7. These characteristics exhibited by psyllium make this functional dietary fibre a suitable ingredient for some food applications. Moreover, food industries are constantly looking for economic and innovative ways of generating food products with more desirable textural, nutraceutical and organoleptic properties to meet consumers requirements. Nevertheless, several sources of fibres such as cereals, sugar-beet,  $\beta$ -glucan, hazelnut, pea cell wall and pea hull are used to make fibre-enriched baked goods (Anil, 2007; Brennan and Cleary, 2007; Collar et al., 2006, 2007; Redgwell and Fisher, 2005). Particular attention would be paid to the technological potential effects of some bioactive oligosaccharides with prebiotic properties. Psyllium could play a major role in this respect.

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