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Rheological properties of the gum fractions from psyllium (*Plantago psyllium* L.)

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ABSTRACT

Background & Aim: Psyllium (*Plantago psyllium* L.) is a native plant that grows widely in India and Iran. Different cases of using psyllium gum for its suitable rheological properties in a wide range of food products exist in nature.

Experimental: In this study, different fractions of psyllium gum were extracted by water and alkali treatments. Rheological properties of these fractions were measured by Brookfield rheometer (RV DVIII). The obtained data was fitted by Herschel-bulkly model in three temperatures 30, 60 and 80°C.

Results & Discussion: Results indicated that fractions show different behaviours during heating treatment.

Recommended applications/industries: According to results of present study, the largest variations were observed in $AEG_{0.5}$ fraction.

1. Introduction

Psyllium gum (*Plantago psyllium* L.) is known as psyllium gum in Iran. *Plantago psyllium* is an annual herb which belongs to the family Plantaginaceace (Ghasemi Pirbalouti, 2010). Though it is found all around the world, its abundance can be seen generally in India, Pinjab, Pakistan, Iran and Canary islands. India, selling 39000 tons annually, is one of the most prominent exporters of the seed. The plant is diversely outspread in different provinces of Iran due to the different climate. It has also been long used in Iranians traditional medicine (Guo, 2009).

The term "Psyllium" is used for the crust, seed and the whole plant (Theuissen, 2008). It is considered as a good source for soluble and insoluble fiber. Its soluble content is almost eight times more than that of oat's bran. The diet fibers extracted from the plant possess pharmaceutical properties and can be used in producing low calorie food (Theuissen, 2008). The studies have revealed the beneficial uses of psyllium such as its reducing effect on blood fat and sugar that are considered as the main risk factor of cardiovascular diseases (Yu , 2003; Theuissen , 2008).

Psyllium can also be used as a laxative and its crust as an dietetic fiber can augment the healthy environment of the colons (Singh, 2007). Some of the impacts can be due to its bioactive components, namely phenolic compounds such as Acetoside and Isoacetoside. Antidotal and antioxidant activities beside being painkillers are among their biological functions (Li, 2005). The so called properties have made psyllium a suitable functional dietetic fiber to use in some food products. It can be used as a bioactive oligosaccharide with probiotic properties (Askari, 2008). Investigating the chemical properties of seed, crust and the psyllium produced -mucilage shows that, they contain 6.05, 6.24, and 6.13% moisture respectively. The total protein content of the seed exceeds the one of the crust and the mucilage and the crust and the mucilage output is 28%. About 90% of the seed, crust and mucilage are made of the carbohydrates and xylose and arabinose are the most important of all.

The suitable gelling properties of the psyllium polysaccharides make it a suitable choice in many fields (Ghasemi Pirbalouti, 2010). For instance, it can be used as a binding agent in pharmaceutical industry or lubricating agent for soil in petroleum usages. It can also be a good alternative in sewage separation. As data on gelling properties of the psyllium gum is scarce and the mechanism of gel construction is not completely known yet, the possibility of performing more research in this field to reach a suitable understanding of how to use it efficiently in food industry still exists (Guo, 2009). The usage of the psyllium fiber has been noticed in several studies. In a research done in 1988, the use of psyllium and mucilage was studied. Some of these usages such as instant drinks, pies, dietetic bakery products, soft gel puddings, sauces and in particular meat sauces, soups and confectionary products have been pointed to.

Frust et al. (1989) proposed psyllium to produce a water dispersible component that can be used as a dietetic bulking agent. Due to the findings of a study which was carried out in 1998, psyllium mucilage is a natural dietetic fiber which can be used to decrease the caloric value of the puffed cereal products. This component may modify the dough texture while cutting, drying and puffing (Frust, 1989).

The products obtained from psyllium crust can be used to prevent ice crystal formation. They can substitute mono and disaccharides in ice cream (Nikoozadeh 2008). Park et al. (1997) used a mixture of wheat fiber and psyllium crust (7:3). Their study showed a loaf of bread containing fiber and antioxidant, in a single portion (268 g) would provide 1.2 g or 8% of the daily requirement of the dietetic fiber which exists in 30% soluble form and its calorie value is 16% less than white bread (Park, 1997).

The hydrophobicity of the psyllium seed hydrocolloid was also investigated. All the solutions showed non Newtonian shear thinning behaviour in different concentrations and pH. The viscosity of the psyllium crust solution is temperature, pH, concentration and shear rate dependent (Farahnaki, 2010). About 90% of the whole seed, crust and mucilage are made of carbohydrates and specially, xylose and arabinose are among the 3 major components of the polysaccharides extracted from psyllium crust namely, WE, $AEG_{0.5}$, $AES_{0.5}$. The arabinose / xylose ratio the 3 major parts of the psyllium crust are WE = 1:4.2, $AES_{0.5}$ = 1:3.1 and $AEG_{0.5}$ = 1:2.3 (Fischer, 2004). Studies have revealed that xylose existing in psyllium gum is extensively in the form Pyranosyl ring, while the only structure of arabinose is furanosyl. The output of these 3 polysaccharide parts is about 99% and among them the major part with 60% of the whole output belongs to $AEG_{0.5}$.

Significant amounts of Uronic acid (around 15%) exists in $AES_{0.5}$, WE, while $AEG_{0.5}$ lacks Uronic acid. Investigating the 3 polysaccharide component shows WE has the simplest side branches and the highest stability in alkali condition is related to $AEG_{0.5}$ (Guo, 2008). The so called components also differ in water solubility. As WE is water soluble, $AES_{0.5}$ can also be solved in water, and can be extracted with alkali solution. $AEG_{0.5}$ is also extractable with alkalis (Guo, 2008).

2. Materials and Methods

In this work, to study the effect of psyllium gum fractions on its rheological properties, at first 5 grams of psyllium crust powder (purchased from Rose Darvak corporations) was mixed with 1000 ml distilled water and the obtained gel was heated while mixing at 80 °C. The extraction operation was carried out with some modifications based on Guo et al. (2008) (Fig 1).

This gel was named ‘gel-1’ and contained all main (WE, $AES_{0.5}$, and $AEG_{0.5}$) and sub fractions ($AES_{1.2}$, and $AES_{2.0}$). Rheological properties of gel-1 were determined using a Brookfield Rheometer, RV DVIII and small sample adapter at 30, 60 and 80 °C. In the next stage, gel-1 was centrifuged for 1 h at 21000*g*. During this stage, gel-2 and its supernatant were formed. The supernatant contained a main fraction called WE. Then, gel-2 lacks the water soluble WE fraction. The rheological properties of gel-2 were studied likewise.

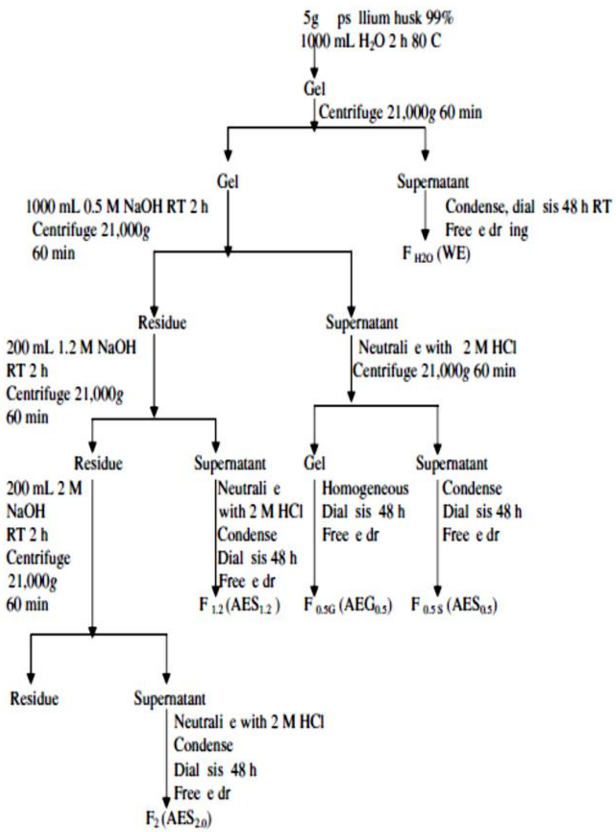

Fig1. Extraction path for psyllium gum (Guo, 2008)

The psyllium crusts present in gel-2 was precipitated using 1000 ml of sodium hydroxide (0.5 M). The resulted sediment contained $AES_{1.2}$, $AES_{2.0}$, and psyllium crusts. The sediment was separated and then centrifuged for 1 h at 21000*g* and then was neutralized using a 2 M hydrochloric acid and then the supernatant was again neutralized using 2 M hydrochloric acid and was centrifuged again at 21000*g*, thus gel-3 with its supernatant was obtained. This stage's supernatant contained the soluble fraction of $AES_{0.5}$, which is another main fraction. It is clear then, that it lacks the main fractions $AES_{0.5}$, WE and sub fractions $AES_{1.2}$, AES_2 and only contains $AEG_{0.5}$ (the extraction path is shown in Fig 1.). The rheological properties of gel-3 were also determined using the rheometer and then was fitted with a Hercshel- Bulky model using a Rheocalc $_{(version\ 3.2)}$ software (Eq. 1).

Eq.1

$$\sigma = k\gamma^n + \sigma_0$$

Where:

σ: shear rate(D/cm^2)

γ: shear rate(1/s)

σ_0: yield stress (D/cm^2)

k: consistency index (Poise)

n: flow constant (Steffe, 1996)

Smaller than one amounts for n, indicate a shear thinning behaviour while when it exceeds 1, the flow is shear thickening.

3. Results and discussion

Considering the explanation above, and Fig. 1, the extracted gels contain components as below:

Gel-1: ($WE+AES_{0.5}+AEG_{0.5}$) + ($AES_{2.0}+AES_{1.2}$)

Gel-2: ($AES_{0.5}+AEG_{0.5}$) + ($AES_{2.0}+AES_{1.2}$)

Gel-3: $AEG_{0.5}$

WE: is one of the main fractions, which is completely water soluble and has the highest stability in alkali condition.

$AES_{0.5}$: one of the main fractions, completely water soluble and extractable by alkali solution.

$AEG_{0.5}$: completely soluble in alkali solution- this fraction is extractable through using alkali solutions- among all fraction this is the only one that can form a gel and exists in all the gels 1, 2 and 3. This fraction lacks Uronic acid while WE and $AES_{0.5}$ contain Uronic acid. After analyzing the obtained graphs, the rheological properties were reported in Table 1 using Rheocalc 3.2 software. As it can be seen in Table 1, the yield stress for all treatments and all temperatures is zero; it means that, no fraction needs an initial stress for starting to flow. Thus all the graphs originate in zero and can be interpreted by the power law model. (Eq. 2)

Eq. 2
$$\sigma = k\gamma^n$$

Gel-1 indicates a shear thickening behavior in all temperatures. In this gel the flow index decreases by increasing the temperature and approximates a Newtonian behavior, while consistency index, which is an indicator of the apparent viscosity, shows an increase with temperatures.

Table 1. Rheological properties of the extracted gels from psyllium

temperature		Gel1	Gel2	Gel3
	K	0.109	0.930	5.125
30	n	1.400	1.257	0.946
	σ_0	0.000	0.000	0.000
60	K	0.290	0.094	10.900
	n	1.294	1.143	0.599
	σ_0	0.000	0.000	0.000
80	K	0.463	0.062	2.270
	n	1.198	1.140	0.599
	σ_0	0.000	0.000	0.000

As it was mentioned before, this fraction has large amounts of WE, and $AES_{0.5}$ that both are among the main fractions of psyllium and are high in Uronic acid. In lower temperatures, the ionization constant of the acid agent is low and therefore its molecular elongation and hydrodynamic radius are smaller. This shows how with increase in temperature, the amount of ionization and gel consistency raises. Some other probable reasons may be the intermolecular interactions which happens because of the electric charge of the carboxyl groups in the fractions and weakens the effect of temperature in decreasing the consistency and viscosity.

In gel-2, WE is one of the main gel forming Uronic acid containing component- exits, decreasing consistency with temperature would follow a reasonable behaviour. Considering the partition of WE from the other fraction, the hypothesis of the charged carboxyl group and intermolecular interaction intensifies. This gel also shows a shear thickening behaviour.

As it was mentioned before gel-3 lacks Uronic acid and it's the only fraction that is able to form a firm gel. It can be seen in Table 3 that this gel shows a shear thinning behaviour (n<1) in all temperatures, and as temperature raises n shows a decreasing procedure. This gel has got a large consistency index in compare with the other 2 gels. This amount increases at 60 °C and decreases again at 80 °C. To understand the real cause of this phenomenon, it is required to measure the molecular radius precisely in future studies. The changes in rheological properties (shear stress, shear rate) have been depicted in figures 1, 2, and 3. As it can be seen, Fig 2 verifies the information done in Table 2. It can be seen that rheological properties of this gels are completely different from each other and they show different behaviour toward temperature changes.

Regarding to Fig 2, it can be perceived that, to provide desirable consistency at lower temperatures, gels 2 and 3 are more suitable while in higher temperatures gel 1 is the better choice. Thus the presence of the fraction WE which is high in Uronic acid effects the temperature behavior of the psyllium gum dramatically. Due to the works of Askari et al. (2008) who described the psyllium gel as shear thinning and the results shown in Table 1 and Fig 2, it seems that the properties of gel-3, is more effective on the gel which is resulted from the whole fractions, and can affect the overall properties of the gel. The fraction 1 and 2 of the gel that are shear thinning, are less effective than fraction 3.

4. Conclusion

A large number of researches have been performed on rheological properties of psyllium gel have been performed, but due to the manifold of its fractions and because of the different properties of the food products, only one fraction may be effective on rheological attributes of the final product, thus to gain a better perception of functions the psyllium gel, separating its fractions is inevitable. Therefore, the necessity of the future studies on its technological properties seems quite clear.

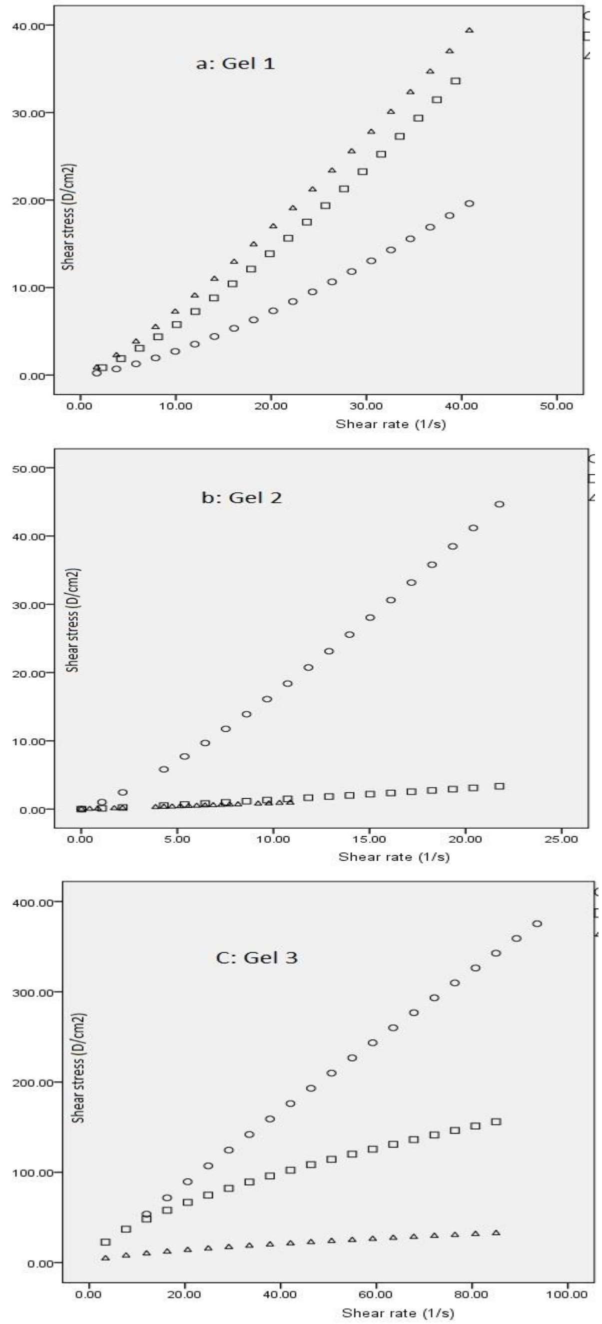

Fig 2. Shear-Stress- Shear rate charts of different components of Psyllium gel in the various temperatures. a: Gel-1, b: Gel-2, c: Gel-3. **O**:30 °C, **□**: 60 °C, **△**: 80 °C.

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