Rheological characteristics of Arabic gum suspension and Plantago seeds mucilage

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Abstract: Rheological characteristics of different fluids are useful technologically to identify the most appropriate food system design as well as optimize operating conditions. This study was carried out to compare between chemical composition and rheological properties of Arabic Gum and Plantago seeds. Arabic Gum contained higher crude protein content, fat, total carbohydrates and ash (15.53, 2.13, 62.36 and 9.11, respectively) compared to Plantago seeds. Meanwhile, Plantago seeds had contained higher value of crude fiber (26.65).The higher mean sugar percentage was recorded to galactose in Arabic gum (40.3%) and glucuronic acid in Plantago seeds (15.3%).The shear rate-shear stress data of Arabic gum suspension and Plantago seeds mucilage at concentration 15, 20 and 25%w/v indicated behaved as non-Newtonian pseudo plastic fluid. Consistency index (k) and flow behavior index (n) increases as Arabic gum concentration increased while it decreases as Plantago concentration increased. The maximum apparent viscosity was dictated for Arabic gum at concentration 25% While, the maximum viscosity for Plantago dictated at concentration 15%. Moreover, only Arabic gum indicated thixotropic effect at concentration 15, 25%.

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Key words: Rheological - Arabic gum – Plantago seeds mucilage

1. Introduction:

Rheology is one of several important factors need to be taken into consideration in the design of food processing plants in order to assure the quality of the end products. Rheology also, concerns the flow behavior of the products. A main issue is also the measurement, adaptation and application of viscosity data, which concerns the design calculations of processing equipment **(Bolmstedt, 2000)**. Furthermore, rheology is used in food science to define the consistency of different products. Rheologically the consistency is described by two components, the viscosity ("thickness", lack of slipperiness) and the elasticity ("stickiness", structure). In practice, therefore, rheology stands for viscosity measurements, characterization of flow behavior and determination of material structure. Basic knowledge of these subjects is essential in process design and product quality evaluation.

Arabic gum (GA) or Acacia gum is an edible biopolymer obtained as exudates of mature trees of Acacia Senegal and Acacia seyal, which grow principally in the African region of Sahein Sudan. The exudate is a non-viscous liquid, rich in soluble fibers **(Williams & Phillips, 2000)**. Chemically, GA is a complex mixture of macromolecules of different size and composition (mainly carbohydrates and proteins). Today, the properties and features of GA have been widely explored and developed in food industry, it is used as a stabilizer, a thickener and/or an emulsifier agent (e.g., soft drink syrup, gummy candies and creams) **(Verbeken *et al.*, 2003)**.GA has high water solubility and a relatively low viscosity compared with other gums. Most gums cannot dissolve in water in concentrations above 5% due to their high viscosity. Instead, GA can get dissolved in water in a concentration of 50% w/v, forming a fluid solution with acidic properties (pH~4.5). The highly branched structure of the GA molecules leads to compact relatively small hydrodynamic volume and, consequently GA will only become a viscous solution at high concentrations. Solutions containing less than10% of GA have a low viscosity and respond to Newtonian behavior **(Williams *et al.*, 1990)**. However, steric interactions of the hydrated molecules increase viscosity in those solutions containing more than 30% of GA resulting in an increasingly pseudo plastic behavior. Psyllium is the common name used for the several members of the plant genus Plantago **Singh (2007).** The isapghula husk is derived from the dried ripe seeds of Plantago ovate Forsk. The seeds of psyllium are used commercially for the production of mucilage. The mucilage is obtained from the seed coat by mechanical milling of the outer layer of the seeds. It forms a mucilaginous gel by absorbing water. The gel nature composition of Psyllium polysaccharide (PPS) extracted from the seeds of Plantago ovata has been reported in the literature **(Kennedy, *et al.*, 1979)** and **(Sandhu, *et al.*, 1981)**. Psyllium has been reported as a medicinally active natural polysaccharide. It has been used for the treatment of constipation **[Bouchoucha, *et al.*, (2004), Ramkumar and Rao (2005)]** diarrhea **Washington, (1998)** inflammatory bowel disease **Fernandez-Banares, (2006)**, obesity in

children and adolescents **Pittler and Ernst (2004)**, high cholesterol **Moreyra (2005)** and diabetes **Anderson and Ward (1986)**. Studies have been conducted to fractionate the polysaccharide from the seed husk and evaluate its gelling ability. However no studies have been conducted to evaluate the properties of the polysaccharide present in the seeds. Thus, the aim of this study is to compare between the rheological properties of Arabic gum and Plantago seeds mucilage and to study the thixotropic effect to extend using these substances in food applications.

2. Materials and methods:

2.1. Materials

Commercial Arabic gum (*Acacia Senegal)* and plantago seeds (*Psyllium*) were obtained from local market, Cairo, Egypt.

2.2. Preparation of Arabic gum suspension and Plantago mucilage

Arabic gum and Plantago seeds from the local market were milled by high speed laboratory blender and then sieved to obtain the powders. The powdered at concentration of 15, 20 and 25% (W/V) were soaked in hot purified water (60°C) for 12 h. The solutions were stirred with low heat(40°C) for 60 min on a hot plate magnetic stirrer (Wiess Gallenkamp, Leicestershire, UK), then filtered to remove any un-dissolved impurities using cotton sheets **(Abdelgader and Ismail, 2011, Malviya, *et al.*, 2011 and Al-Juhaimi, *et al.*, 2012).**

2.3. Chemical analysis of Arabic gum and Plantago seeds

- Proximate Chemical analysis

Crude protein, crude fat, crude fiber, total carbohydrates and ash contents were determined by the standard procedures of the **A. O. A. C. (2005).** All analytical determinations were carried out in triplicate and the final data were expressed on a dry weight basis.

- Mean sugar analysis:

Free sugar profiles were determined by the method described by **Barreiraa, *et al.* (2009)** high performance with modification that liquid chromatography coupled to a refraction index detector (HPLC-RI). Soluble sugar determined at 35˚C. The HPLC system was equipped with a Hewlett Packard 1050 HP1047A RI detector and with a Eurospher 100-5 NH_2 column (4.6 × 250 mm, 5mm Hewlett). The mobile phase was acetonitrile/deionized water; 70:30 (v/v) at a flow rate of 1ml/min. the results are expressed in g/100gm of dried weight, calculated by internal normalization of the chromatographic peak area. Sugar identification was made by comparing the relative retention times of samples peaks with standards.

2.4. Rheological properties of Arabic gum suspension and Plantago musilage

Rheological parameters (shear stress, shear rate and viscosity) of Arabic gum and Plantago seeds prepared solutions were measured by using Brookfield Engineering labs DV-III Ultra Rheometer. The sample was placed in a small sample adapter and a constant temperature water bath was used to maintain the desired temperature. The viscometer was operated between 50 and 250 rpm, and shear stress, shear rate and viscosity data were obtained directly from the instrument, the SC4-21spindle was selected for the measurement. Rheological measurements were made at different soluble solid concentrations (15, 20 and 25%) and controlled at room temperature (25˚C± 1).

3. Results and Discussion:

3.1. Chemical analysis of Arabic gum and Plantago seeds.

- Proximate Chemical analysis.

Proximate chemical analysis of Arabic gum and Plantago seeds based on dry weight is shown in table (1). The results revealed that, Arabic gum contained higher crude protein content, fat, total carbohydrates and ash (15.53, 2.13, 62.36 and 9.11 respectively) compared to Plantago seeds. Meanwhile, Plantago seeds had contained higher value of crude fiber (26.65). **Islam, *et al.* (1997)** mentioned that chemical composition of Arabic gum is complex and consists of a group of macromolecules characterized by a high proportion of carbohydrates (97%), and a low proportion of proteins (<3%). The chemical composition of Arabic gum may vary slightly depending on its origin, climate, harvest season, tree age and processing conditions, such as spray dying **(Al-Assaf, *et al.*, 2005)**.

Hodgkinson, *et al.* (2007) reported that *P. lanceolata* (other species of Plantago major) leaves and seed contained crude protein (g kg^{-1}) 167± 4.1 and crude fiber (g kg^{-1}) 212±8.2. It is well known that protein content differs among cultivars due to differences in genotype and environmental conditions during developing and maturation of the grains **(Romero *et al.*, 2006)**

Table 1. Proximate chemical analysis of Arabic gum and Plantago seeds substances (% on d. wt).

Samples / Chemical analysis	Arabic gum	Plantago
Crude Protein	15.53±0.33	14.95±0.07
Crude Fiber	7.47±0.23	26.65±0.30
Crude Fat	2.13±0.05	1.34±0.02
Total Carbohydrates	62.36±0.52	45.73±0.36
Ash	9.11±0.13	7.09±0.06

Values are means ± SD of three measurements.
Means in the same row with different letters are significantly different ($p < 0.05$).

- Mean sugars compositions.

Mean sugars in Arabic gum and Plantago seeds are showed in table (2). The results in table (2) revealed that Arabic gum and Plantago seeds consisted of 26.5, 13.3% arabinose, 10.2, 2.2% rhamnose, 40.3, 2.4% galactose and9.6, 15.3%glucuronic acid for Arabic gum and Plantago, respectively. These results were in the same line with **Qi, *et al.* (1991) and Samuelsen, *et al.* (1999)** who studied the compositional analysis of Arabic gum and Plantago seeds they mentioned that percentage of mean sugars were 26.1, 13.1 arabinose, 9.9, 2.1rhamnose, 40.1, 2.5 galactose and 9.4,15.5 glucuronic, respectively.

Table 2. Mean sugars composition of Arabic gum and Plantago seeds.

Sugars	Arabic gum	Plantago
Arabinose	26.5	13.3
Rhamnose	10.2	2.2
Galactose	40.3	2.4
Glucouronic	9.6	15.3
Total % weight	86.6	33.2

3.2. Rheological properties of Arabic gum suspension and Plantago seedsmucilage.

***- Effect of different shear rate and concentration on apparent viscosity of Arabic gum suspension and Plantago seeds mucilage*:**

The effect of shear rate and concentration of Arabic gum and Plantago seeds solutions on apparent viscosity were presented in Figures (1, 2). The results revealed that apparent viscosity (η_0) of solutions was decreased as the shear rate (γ) was increased at different concentrations which indicating non-Newtonian pseudo plastic behavior similar results was reported for arabic gum at shear rate (γ) > 10 s^{-1} by **Mothe´ and Rao (1999)**. Also **Rao, *et al.* (2011)** mentioned that Plantago seeds mucilage of all strengths were found to have shear-thinning (pseudoplastic) properties as evident from the graphs of apparent viscosity vs. rate of shear indicating pseudoplastic behavior.

- Effect of shear rate on shear stress of Arabic gum suspension and Plantago seeds mucilage at different concentrations:

The effect of shear rate on shear stress was fitted well by the following constitutive equations which is also important for providing the coating parameters required by process control:

$$\tau = k\,\gamma^{n}$$

Where, τ is the shear stress, Pa, k is the consistency index, γ is the shear rate, S^{-1}, and n is the flow behavior index**. Paes, *et al* (2008).**

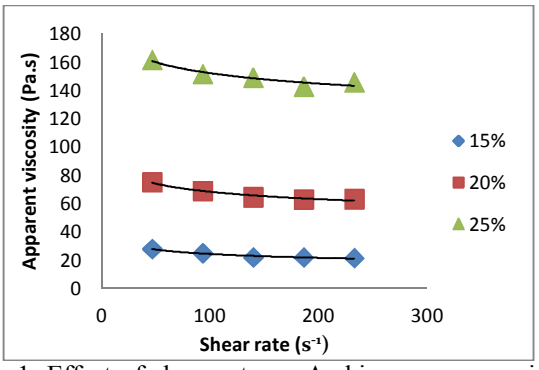

Fig.1. Effect of shear rate on Arabic gum suspension apparent viscosity at 15, 20 and 25%concentrations

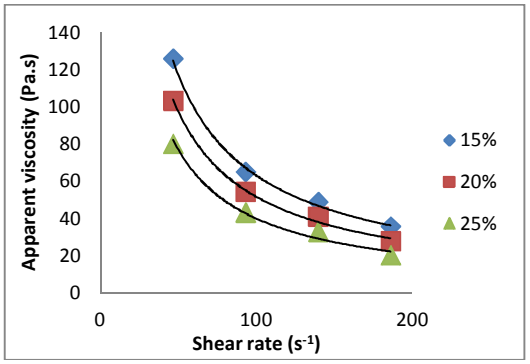

Fig.2. Effect of shear rate on Plantago seeds mucilage apparent viscosity at 15, 20 and 25% concentrations

Table (3) presents the parameters (k, n) which obtained by fitting to the power law model for Arabic gum suspension and Plantago seeds mucilage at different concentration. This table revealed that, consistency index (k) and flow behavior index (n) increases as concentration of Arabic gum increased, while it decreases as concentration of Plantago seeds mucilage increased. Since n values in both samples were less than one these results indicating that all samples showed a pseudo plastic behavior. **Coussot (2005)** approved that shear-thinning (pseudoplastic) behavior fluids are characterized by a value of n (power-law index) smaller than unity $0 < n < 1$. Many polymer melts and solutions exhibit the value of n in the range 0.3-0.7 depending upon the concentration and molecular weight of the polymer, etc. Naturally, smaller is the value of n, more shear-thinning is the material.

Relation between shear stress (τ) and shear rate (γ) are graphically presented in Figures (3, 4). The rheogram in Figures (3, 4) showed that relation between shear rate and shear stress was non-Newtonian pseudo plastic as the shear stress increased when increasing shear rate for both Arabic gum suspension and Plantago seeds mucilage samples at all studied concentrations. **(Verbeken, *et al.*, 2003)** found

that Arabic gum suspensions are characterized by a low viscosity, allowing the use of high gum concentrations in various applications. Furthermore, solutions exhibit pseudo plastic behavior at concentrations up to 40% and higher concentrations. Acacia gum (GA) dispersions at concentrations between 3 and 32 wt% showed shear–thinning flow behavior at shear rates <10s^{-1} **Sanchez *et al.* (2002). Rao, *et al.* (2011)** mentioned that polysaccharide extracted from psyllium seeds (Plantago) was found to have shear-thinning behavior.

Table 3. Flow constant (k, n) for Arabic Gum suspension and Plantago seeds mucilage at different concentrations:

concentration	Arabic gum suspension		Plantago seeds mucilage	
	k	n	k	n
15	53.661	0.829	3904.8	0.104
20	116.36	0.885	3557.7	0.08
25	212.1	0.928	3158.2	0.05

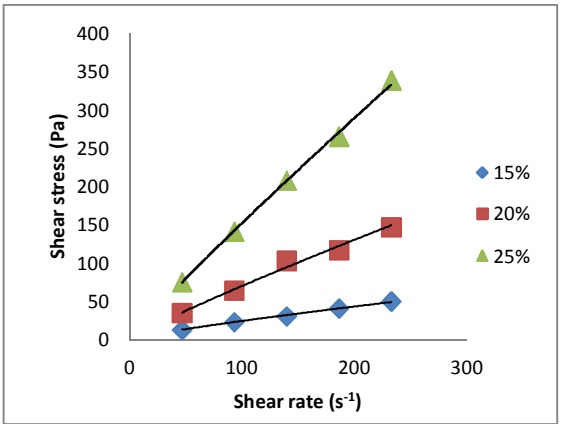

Fig.3. Relation between shear stress and shear rate for Arabic gum at different concentrations

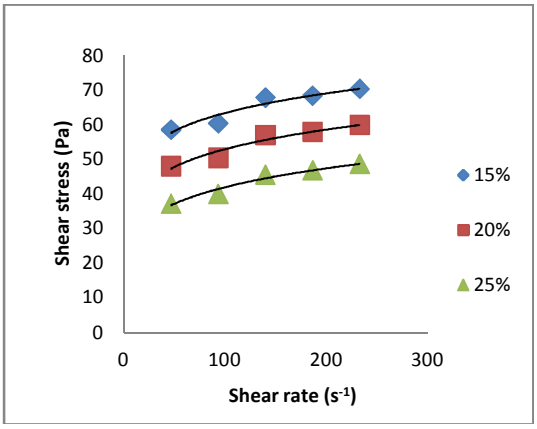

Fig.4. Relation between shear stress and shear rate for Plantago seeds mucilage at different concentrations

- Effect of concentration on the apparent viscosity of Arabic gum suspension and plantago seeds mucilage at different shear rate (γ).

The results in Figures (5, 6) obtained that apparent viscosity increased as concentration of in Arabic gum suspension increased. On the other hand, Plantago seeds mucilage showed a decrease in apparent viscosity as concentration increased this may be due to different structural of the two polysaccharides samples. Rheogram also reveal that maximum apparent viscosity was 162 CP for Arabic gum at concentration 25% and minimum apparent viscosity was 21.6 CP at concentration 15% in the range of shear rates studied. Meanwhile, the maximum and minimum viscosity for Plantago seeds mucilage were 126 and 80 CP at concentration 15 and 25%, respectively.

-Thixotropic effect of Arabic gum suspension and Plantago seeds mucilage.

A thixotropic fluid exhibits an increase in shear stress with increasing shear rate. If the shear rate is decreased, the material needs some time to rebuild its original structure, **(Rielly, 1997)**. The apparent viscosity of a pseudoplastic liquid decreases immediately when the rate of shear is increased. For some liquids the apparent viscosity continues to decrease further with the time for which the particular rate of shear is applied. These liquids are called thixotropic **Eirich, (1975).** The complication of thixotropy arises because its reversible, micro structural change itself takes time to come about due to local spatial rearrangement of the components. This frequently found time-response of a microstructure that changing with time makes thixotropic **Barnes, (1997).** Figure (7, 8) showed a hysteresis loop, such a loop is typical of a thixotropic material for a test in which the shear rate is ramped up then ramped down over the same period of time (30 sec) for Arabic gum solutions. Whereas, Plantago seeds mucilage at all studied concentration did not show any hysteresis loop figure (9, 10). The results indicated that Arabic gum suspension exhibited thixotropic effect at 15, 25% concentration. This result was in agree with **Li, *et al.*, (2011)** who studied

the influence of molecular association on the rheological behavior of Arabic gum solution. Using time-dependence of transient shear stress a reversible molecular association could be arrested and the thixotropy of Arabic gum solution was interpreted.

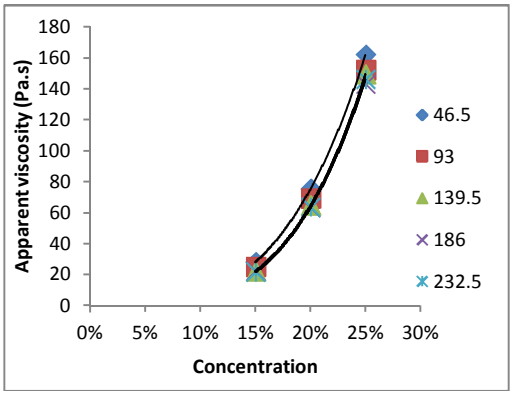

Fig.5. Effect of concentration on apparent viscosity of Arabic gum suspension at

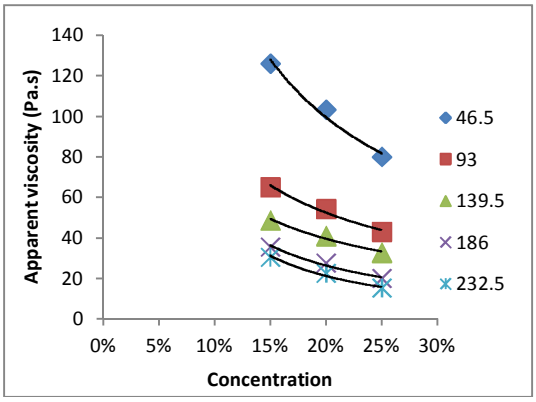

Fig.6. Effect of concentration on apparent viscosity of Plantago seeds mucilage at different shear rate

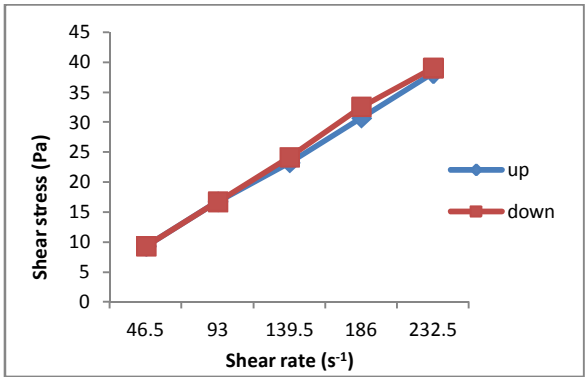

Fig.7. Thixotropic effect Arabic gum at 15% concentration

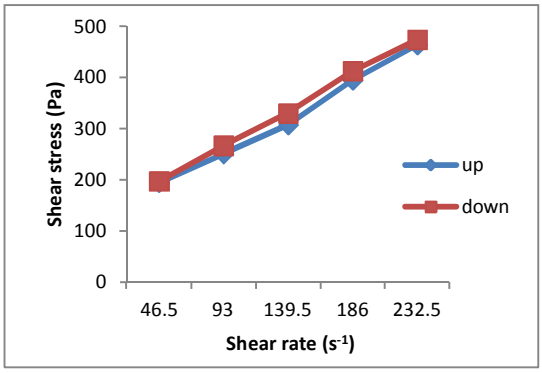

Fig.8. Thixotropic effect Arabic gum at 25% concentration

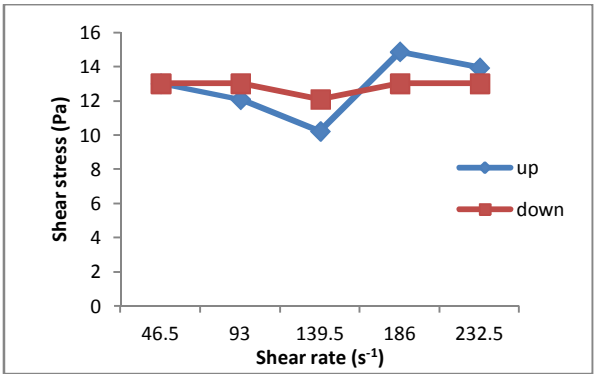

Fig.9. Thixotropic effect of Plantago seeds mucilage at 15% concentration

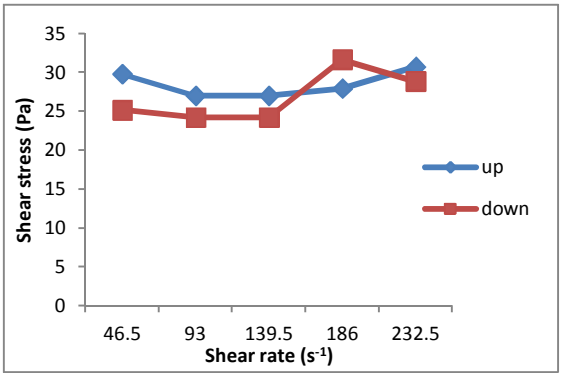

Fig.10. Thixotropic effect of Plantago seeds mucilage at 25% concentration

The structural breakdown, buildup and the effect of shear history due to molecular association. The contributions increased with rest time, indicating a buildup of molecular association. On the other hand, **Rao, *et al.* (2011)** conclude that polysaccharide extracted from psyllium seeds (Plantago) was found to have shear- thinning as well as thixotropic effect at concentrations (2, 2.5,3 and 10% w/v) compared with standard suspending agent sodium carboxymethyl cellulose (Na CMC).

Conclusion:

This investigation showed that Arabic gum preferred to use at concentration higher than 15% w/v meanwhile, Plantago seeds was preferred to use at concentration 15% or less to enhance rheological properties and thixotropic effect. This ensures different widely used in food industries and suggests more new innovate food application in further studies.

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