Tropical Journal of Pharmaceutical Research August 2011; 10 (4): 385-392

Available online at http://www.tjpr.org
http://dx.doi.org/10.4314/tjpr.v10i4.3

Research Article

Grewia Gum 1: Some Mechanical and Swelling Properties of Compact and Film

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Abstract

Purpose: *To study the mechanical and dynamic swelling properties of grewia gum, evaluate its compression behaviour and determine the effect of drying methods on its properties.*

Methods: *Compacts (500 mg) of both freeze-dried and air-dried grewia gum were separately prepared by compression on a potassium bromide (KBr) press at different pressures and subjected to Heckel analysis. Swelling studies were performed using 200 mg compacts of the gum (freeze-dried or air-dried) compressed on a KBr press. The mechanical properties of the films of the gum prepared by casting 1 % dispersions of the gum were evaluated using Hounsfield tensiometer. The mechanical properties of grewia gum films were compared with films of pullulan and guar gum which were similarly prepared. The effect of temperature on the water uptake of the compacts was studied and the data subjected to Schott's analysis.*

Results: *Drying conditions had no effect on the yield pressure of the gum compacts as both air-dried and freeze-dried fractions had a yield pressure of 322.6 MPa. The plots based on Schott's equation for the grewia gum samples showed that both samples (freeze-dried and air-dried) exhibited long swelling times. Grewia gum film had a tensile strength of 19.22±3.61 MPa which was similar to that of pullulan films ($p > 0.05$). It had an elastic modulus of 2.13±0.12 N/mm^2 which was significantly lower ($p < 0.05$) than those of pullulan and guar gum with elastic moduli of 3.33±0.00 and 2.86±0.00 N/mm^2, respectively.*

Conclusion*: The type of drying method used does not have any effect on the degree of plasticity of grewia gum compacts. Grewia gum obtained by either drying method exhibited extended swelling duration. Matrix tablet formulations of the gum will likely swell slowly and promote sustained release of drug.*

Keywords: *Grewia gum compact, Films, Heckel analysis, Swelling behaviour*

Received: 30 October 2010 *Revised accepted: 8 June 2011*

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INTRODUCTION

There is a renewed interest in films made from natural polymers [1]. This is because they are renewable resources and are environmentally friendly. Edible or biodegradable films from natural polysaccharides have the potential to replace their synthetic counterparts as packaging materials and also as coatings for solid dosage forms [2].

Like proteins, natural polysaccharides are formed by various sugar units or monosaccharides which are capable of promoting intra- and inter-molecular bonds. They therefore exhibit large variation in their functional properties [3]. Intermolecular interactions between polysaccharide chains based on hydrogen bonding, hydrophobic interactions and electrostatic forces can result in brittle films [4]. Consequently, plasticisers must be added to modify the mechanical properties of the films. These compounds decrease inter- and intra-molecular attractive forces and increase chain mobility thereby improving flexibility [5].

In the literature, polyols such as glycerol, sorbitol, polyethylene glycol and ethylene glycol have been used as plasticisers for films derived from carbohydrate sources [6]. Incorporation of these additives may however cause significant changes in the properties of the films. The choice of a plasticizer is based on compatibility between plasticizer and polysaccharide, permanence in the formed film, and its efficiency [4]. It has also been reported that the extent and degree of modification of film properties is dependent on the type of plasticizer used [5].

Natural polymers have found wide use in oral prolonged release matrix tablets. For these natural polymers to effectively function as matrix systems, they must possess good degrees of compactibility and compressibility in their dry powder form. A number of relationships based on transformation of classical stress-strain or force-displacement relationships where either the compaction pressure or the volume is transformed, have been used to describe the compressibility of powders [7]. Most of these equations are however of limited practical value [8]. In the development and formulation of tablets, the characterization of the compressibility of a material powder should achieve the goal of predicting the strength of the resultant compact from force-displacement curves and derived parameters.

When relating the relative density, *D,* of a powder bed during compression to the applied pressure, *P*, the Heckel equation (Eq 1) is often used.

$$\frac{\ln 1}{1-D} = A + KP \quad \text{..... (1)}$$

where *A* is a constant related to the die filling and particle rearrangement before deformation and bonding of the discrete particles, and *K* is the slope of the straight-line portion of the Heckel plot and is the reciprocal of the yield pressure P_y, of the material. This material constant (*K*) is reported to be influenced by process conditions thus resulting in different yield pressures being reported for the same material [9]. Despite the fact that its practical application has been questioned, Heckel analysis (determination of the P_y value) remains one of the most widely used techniques for the study of the compaction behaviour of pharmaceutical compacts [10].

An important functional property of polysaccharide gums is their ability to hydrate and swell to form highly viscous solutions or dispersions. This physical property governs their use as viscosity imparting or suspending agents and their use as matrix formers in prolonged release solid dosage forms. The hydration rate and degree of swelling is therefore critical to their successful application and is dependent on a number of factors such as pH and temperature. The water absorption characteristics of polysaccharide gums can have a significant influence on the transport of medicaments across the gel layers [11].

Grewia polysaccharide gum is obtained by extraction from the inner stem bark of the edible plant *Grewia mollis,* Juss (Tiliaceae). In Nigeria, grewia polysaccharide gum tree grows abundantly (wild or cultivated) in the middle belt region of the country where the gum is used as a delicacy by the local people. The polysaccharide is isolated from the cell wall of the plant and has been reported to consist of glucose and rhamnose as the main monosaccharide components [12]. Although the compression, mechanical and release properties of paracetamol tablet containing acid treated grewia gum has been reported [13], the effect of drying method on the compression of the gum has not been investigated.

The purpose of this study was to evaluate the compactibility and swelling of grewia gum in order to determine the suitability of the polysaccharide as a polymer matrix in controlled release tablets.

EXPERIMENTAL

Materials

All the materials used for this study were procured from Sigma-Aldrich, UK, unless otherwise stated. Grewia gum was extracted in our laboratory. All items of equipment used are indicated in the text.

Extraction and purification of grewia gum

Grewia polysaccharide gum was extracted as detailed previously [12]. Briefly, the dried and pulverized inner stem bark of *Grewia mollis* shrub (2000 g) was dispersed in 0.1 %w/v sodium metabisulphite and allowed to hydrate for 48 h. The mixture was then stirred for 2 h and passed through muslin to remove extraneous solid matter. The filtrate was treated with 20 mL of 0.1M NaOH to precipitate and isolate alkali insoluble impurities, and centrifuged at 3,000 rpm for 10 min. The supernatant was then treated with acidified ethanol, (containing 10 mL of 0.1M HCl) to isolate acid insoluble impurities, and centrifuged again as described above. The supernatant was treated with absolute ethanol and the resultant precipitate washed several times until only clear absolute ethanol was recovered. The precipitate was wet-milled and then passed through muslin before air-drying the product, or the precipitate was redispersed in water and thereupon freeze dried. The air-dried product was dry-milled before further drying at 50 ^{o}C in an oven for 24 h.

Freeze-drying was carried out using an Edwards Modulyo freeze-dryer (Thermo Fisher Scientific Inc, UK) at -40 ^{o}C for 72 h. The freeze-dried and air-dried products were dry-milled, passed through a 1.0 mm sieve, weighed and stored in air-tight containers until use.

Evaluation of tensile properties of grewia gum films

An aqueous dispersion of grewia gum (1%w/v) was prepared from the powder and allowed to hydrate overnight in order to rid the dispersion of trapped air. Similar dispersions were made using pullulan and guar gums. Pullulan dispersion was prepared by heating the powder in distilled water at 60 ^{o}C while stirring continuously before allowing it to stand overnight to exclude trapped air. The solutions/dispersions so prepared (10 mL) were cast on plastic Petri dishes (150 mm in diameter) and allowed to dry in an oven at 37 ^{o}C. The films were conditioned for 48 h at 55 % relative humidity prior to analysis. Grewia gum films, containing the plasticizer, polyethylene glycol (PEG 200), in the ratios 5:1, 2:1 and 1:1 (w/v), were similarly prepared, cast and conditioned. All the films were cut into rectangular pieces (10 x 30 mm) and their mechanical properties, including tensile strength and elastic modulus, determined using a Hounsfield tensiometer (Tinius Olsen, UK) which incorporated a QMAT Professional software (Tinius Olsen, UK) with settings adjusted to an extension range of 2000 mm, gauge length of 20 mm, and speed of withdrawal and approach of the upper arm of 20 mm/min

and 2 mm/min, respectively. The load was 5000 N.

Water uptake and swelling behaviour of gum compacts

Discs (diameter = 13 mm) of air-dried or freeze-dried grewia gum (200 mg) were compressed using a KBr press (Specac 15.011, Germany) at 5 KgF/cm^2 for 2 min. Each accurately weighed disc was placed in a glass vial containing 10 mL of distilled water maintained at 10, 30 or 50 ^{o}C in a water bath. The water uptake, *W*, was measured at 15 min intervals by draining and removing excess water from the surface of the swollen gels using a laboratory tissue and accurately determining the weight gained. The vial was replenished with fresh distilled water after each weighing. Water uptake (*W*) was calculated as in Eq 2.

$$W = \frac{M - M_o}{M_o} \quad \text{..... (2)}$$

where, M_o is the weight of the dry disc and *M* is that of the swollen sample at time, *t*.

Heckel analysis of grewia gum compacts

Grewia gum (500 mg) was compressed at 3, 4, 5, 6 or 7 KgF/cm^2, maintaining for 60 seconds, using a KBr press (Specac 15.011, Germany). Thereafter, the thickness and diameter of the compacts were measured in triplicate using a digital slide calliper (The Starett Co, MA). The apparent density of the discs was determined by geometric calculation while true density of the gum powder was determined using a multipycnometer (MVP- D160-E, Quantachrome Instruments U.S.A.).

Statistical analysis

The data were subjected to one-way ANOVA at 95 % confidence interval using Instat software (GraphPad, San Diego, CA).

RESULTS

Mechanical properties of grewia gum films

The mechanical properties of films containing 1% grewia gum (including those plasticized with PEG 200), pullulan or guar gum are shown in Table 1.

Table 1: Mechanical properties of 1% w/v polysaccharide films (n=5, mean ± s.d.)

	Tensile strength (MPa)	Maximum force (N)	Elastic modulus (N/mm^2)
Grewia	19.2±3.6	9.1±2.2	2.13±0.12
Pullulan	22.3±8.0	6.7±2.4	3.33±0.00
Guar	35.8±2.5	12.5±0.9	2.86±0.00
Grewia/PEG (5:1)	13.5±0.9	6.9±0.5	1.97±0.02
Grewia/PEG (2:1)	12.0±0.7	7.2±0.4	1.67±0.00
Grewia/PEG (1:1)	8.8±0.4	5.5±0.6	1.62±0.11

Heckel analysis of grewia gum compacts

A plot of *ln 1/1-D* against compression pressure *P* gives the Heckel plot for grewia gum compacts (Figure 1). Heckel [14] showed the existence of a linear portion of the curve in which the slope (*K*) was inversely related to the hardness of metal powders. To explain the deformation characteristic of grewia gum, Heckel constants were derived from the straight line portion of the plots. The mean yield pressure, P_y, values were calculated from the slope of the linear portion over the compression pressure range. Grewia gum samples (air-dried and freeze-dried) both gave a P_y value of 322.58 MPa and slope (*K*) of 3.1x10^{-3}. The linear correlation (r^2) was 0.9142 and 0.7929 for the air-dried and freeze-dried grewia gum, respectively.

Effect of temperature on water uptake of grewia gum

The swelling profile of grewia gum at different temperatures is shown in Figure 2*a-c*. At any

given time and temperature, the air-dried grewia gum swelled and absorbed more water than the freeze-dried one.

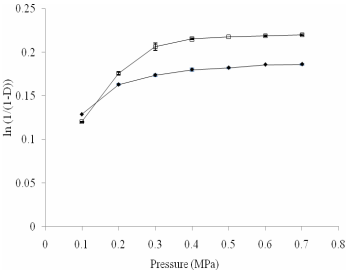

Figure 1: Heckel plot for freeze-dried (□) and air-dried (♦) grewia gum compacts (n=3, mean ± s.d.).

Water uptake was plotted against square root of time ($t^{1/2}$) to explore the mechanism of drug release [15] and the plots are shown in Figure 3*a-c*. For polymers with a long swelling time, Schott [16] proposed Eq 3:

$$\frac{t}{W} = A + Bt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Eq 3 was applied to the data plotted in Figure 3*a-c* where W is water uptake at time t, $B = 1/W_\infty$ (W_∞ is water uptake at infinite time, which in this case was 180 min), and $A=1/(dW/dt)_0$, the reciprocal of the initial swelling rate. The plots according to Schott's equation are shown in Figure 4*a-c.*

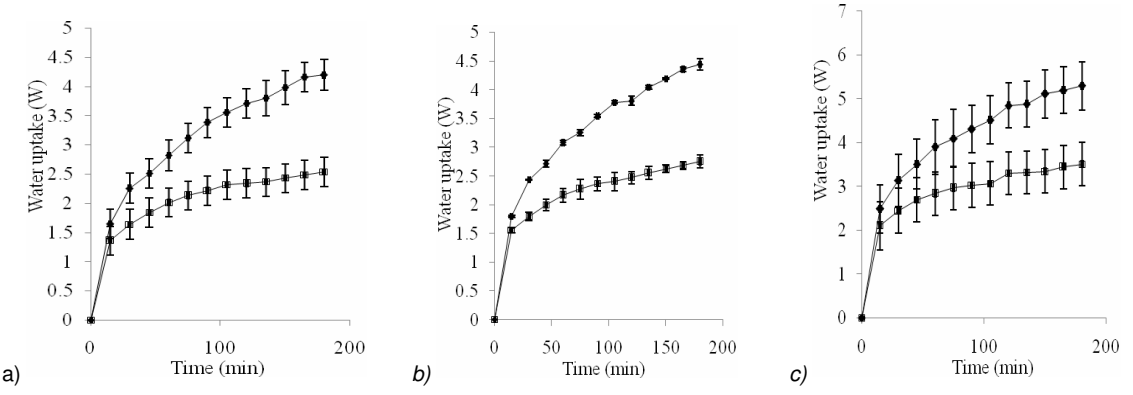

Figure 2: Water sorption profile of freeze-dried (□) and air-dried (♦) grewia gum in distilled water at (*a*) 10 °C, (*b*) 30 °C and (*c*) 50 °C (mean ± s.d., n=3).

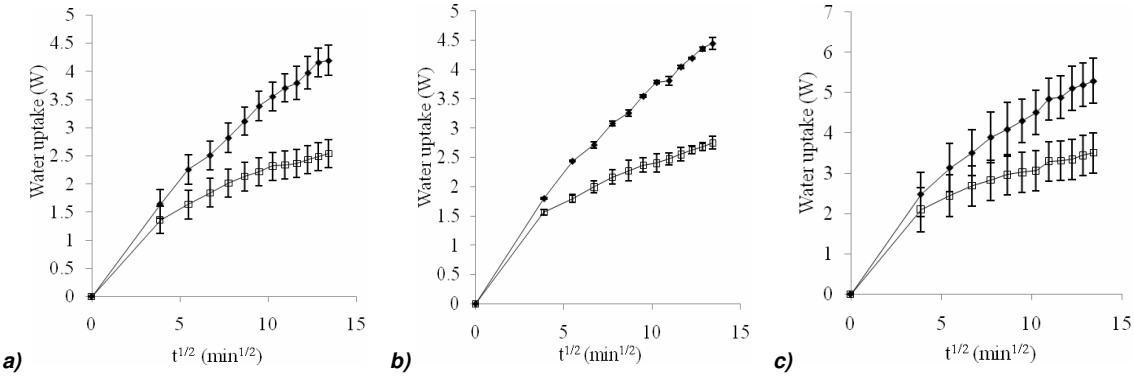

Figure 3: Plots of water uptake of freeze-dried (□) and air-dried (♦) grewia gum against time$^{1/2}$ in distilled water at (*a*) 10 °C (*b*) 30 °C and (*c*) 50 °C (mean ± s.d., n=3).

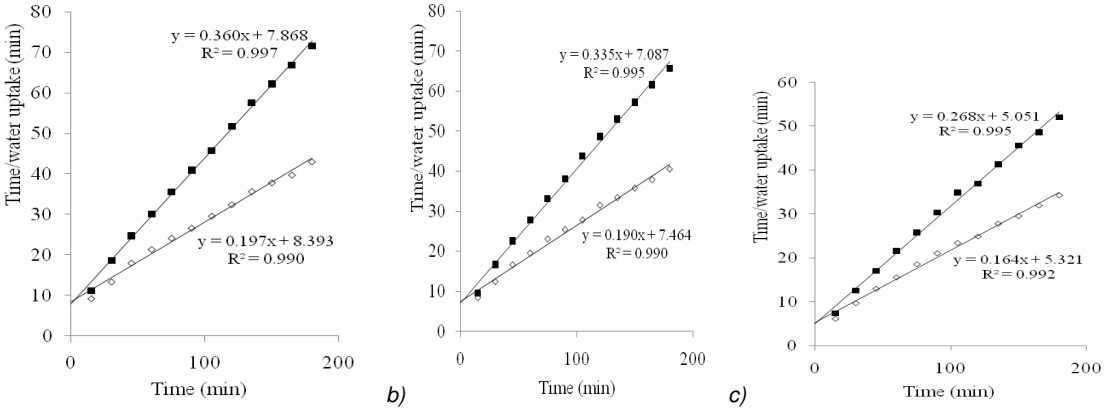

Figure 4: Schott's plots for freeze-dried (■) and air-dried (◊) grewia gum gels at (*a*) 10 °C, (*b*) 30 °C and (*c*) 50 °C in distilled water (± s.d., n=3).

DISCUSSION

Mechanical properties of grewia gum films

Without plasticizer, grewia gum and guar gum films were brittle and difficult to handle; in contrast, pullulan films were highly flexible. Although the tensile strength of grewia gum film was similar to that of pullulan films ($p > 0.05$), it showed a lower elastic modulus than the films of pullulan and guar gums ($p < 0.05$). The tensile strength of grewia gum films decreased with increasing concentration of polyethylene glycol, and becoming less brittle with a more translucent appearance. The tensile strength of grewia gum film containing the PEG 200 in a ratio of 5:1 (i.e., 20 % by weight of grewia gum) decreased by about 30 %. Elastic modulus also showed a decrease with increase plasticizer concentration. These results agree with those of other studies on the effects of plasticizer on the mechanical properties of films [17]. Thus, PEG is capable of plasticising grewia gum films and the effect is concentration-dependent. The present study shows that at a grewia/PEG 200 ratio of 1:1, the plasticizer exceeded its solubility limit in the gum, hence the transluscent appearance of the films. PEG 200 should not be used as plasticizer in grewia gum films in as high a ratio as 1:1.

Heckel analysis of grewia gum

Powder compaction is a volume reduction process, and Heckel equation is also based on volume change of a powder column during compression. Heckel plot gives a general impression of the densification process of the powder column.

The Heckel plots of the air-dried and freeze-dried gum were similar. The *K* value indicates that during compression or compaction, grewia gum underwent plastic deformation. Greater plasticity in a material is indicated by an increase in the value of *K* of the Heckel plot [18]. The constant, *K*, for the polysaccharide gum was unaffected by the drying technique employed

The yield pressure P_y is inversely related to the ability of a material to deform plastically under pressure and was the same for both air-dried and freeze-dried grewia gum. This implies that the onset of plastic deformation in the two samples of grewia gum occurred at the same pressure and yield pressure was independent of experimental conditions [9]. This also implies that drying conditions have no effect on the yield pressure and consequently both the air-dried and freeze-dried gums have the same onset of plastic deformation.

It has been reported [19] that lower values of P_y (i.e., larger K value) can be correlated with tablet crushing strength of tablets with lower P_y values usually indicating harder tablets. The implication here is that in designing tablet formulations, freeze-dried grewia gum may not have any advantage over the air-dried one as a binder or release retardant. Correlation with the Heckel analysis was lower for the freeze-dried form, suggesting that it might undergo greater fragmentation on compaction [19]. For air-dried form, which had a larger r^2 value, it is probable that plastic deformation of the predominant primary particles contributed overwhelmingly to the formation of compacts compared to a combination of fragmentation and plastic deformation of the primary particles for the freeze-dried form.

Effect of temperature on water uptake of grewia gum

Water uptake increased with increasing temperature. This is in contrast to "thermo-shrinking" gels that swell at low temperatures and de-swell at higher temperatures [15]. The plots show an initially rapid uptake of water over the first 20 min following contact with the aqueous environment. Subsequently, the air-dried compacts swelled to a greater extent than the freeze-dried ones.

Schott's plot show linearity with high correlation coefficients for all the swelling experiments irrespective of temperature, indicating that both air-dried and freeze-dried grewia gum compacts are capable of swelling over an extended period. The good water absorption property of grewia gum may have a significant influence on the transport of medicaments across its gel layers [11]. The implication of a long swelling time is that release of medicaments from polymer matrix tablets of the gum will be relatively slow. Since drug release from matrix tablets is controlled by transport across the gel layer of the swollen polymer, polymers with a long swelling time will tend to take longer to hydrate and form gels across which diffusion of the drug occurs. Consequently, it is expected that grewia gum will have a strong release retardant property when used in matrix tablets.

CONCLUSION

Although grewia gum films were brittle, suitable plasticization with PEG 200 yielded films, which though were of lower strength, were nonetheless, flexible. The data obtained also indicate the method of drying did not influence the mechanical properties of grewia gum compacts and therefore, it would not be necessary to use the more costly freeze-drying method. The swelling and water absorption characteristics of the compacts suggest that matrix tablet formulations of grewia gum may have release retardant properties that would make it suitable for the preparation of controlled oral drug delivery systems.

ACKNOWLEDGEMENT

Financial support for this work was provided by the Commonwealth Scholarship Commission, UK and Aston University, Birmingham, UK.

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