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Physicochemical and mechanical characterization of galactomannan from *Mimosa scabrella*: Effect of drying method

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ABSTRACT

The galactomannan from *Mimosa scabrella* Bentham was extracted on a pilot plant scale and dried either by vacuum oven (GVO) or by spray-drier (GSD) to evaluate the effect of the drying technique on the powder quality and its applicability as excipient in solid dosage forms. The analysis by high performance size exclusion chromatography (HPSEC) coupled to multiangle laser light scattering (MALLS) suggests that both products behave as semi-flexible polymers, although the GSD showed more aggregation at molecular level (~10%) and higher chain stiffness (Lp 9.1 nm). TG and DSC analysis showed weight loss event with peak at 299.7 and 311.9 °C to GVO and GSD, respectively, as well and higher ash content for GSD sample, in both inert and oxidant atmosphere. The X-ray diffraction confirmed the amorphous nature of both galactomannans although GVO showed high crystallinity. The GSD showed lower density (1.009 g/cm^3), higher cohesiveness (repose angle 35.5°, compressibility 32.2% and absence of flow), smaller and more spherical particles than GVO sample, both with high polydispersion. As vacuum oven-drying resulted in a like fibrous material, spray-drying appears as an alternative method easy to extrapolate in industry, requiring a glidant incorporation to improve the powder flowability.

1. Introduction

Natural polysaccharides and their derivatives represent a group of polymers widely used in pharmaceutical dosage forms due to their biocompatibility, low cost and free availability. The natural polymeric hydrogels are being increasingly studied for controlled-release applications (Kudela, 1987). In contact with water, tablets obtained from these polymers hydrate and form a gel before dissolving in the medium. If a drug is contained in the tablet, it is expected to be released through the gel layer, and sustained release may be achieved (Bhardwaj, Kanwar, Lal, & Gupta, 2000).

Galactomannans are found as reserve carbohydrates in the endosperm of numerous plants, particularly the Leguminosae. They are neutral water-soluble polysaccharides composed of β-(1-4) mannan (M) backbone with D-galactose (G) branches linked α-(1-6). According to the species, galactomannans differ in the mannose/galactose ratio (M/G), molecular weight and fine structure (Dea & Morrison, 1975), primary factors that control their functional characteristics. Commercially available galactomannans such as locust bean gum (*Ceratonia siliqua*, M/G 3.3/1), guar gum (*Cyamopsis tetragonolobus*, M/G 1.6/1) and tara gum (*Caesalpinea spinosa*, M/G 2.7/1) have found applicability as controlled-release agents (Baveja, Ranga Rao, Arora, Mathur, & Vinayah, 1991; Dürig & Fassihi, 2002; Khullar, Khar, & Agarwal, 1998; Krishnaiah, Karthikeyan, Gouri Sankar, & Satyanarayana, 2002; Nürnberg & Retting, 1974; Varshosaz, Tavakoli, & Eram, 2006).

However, galactomannans from sources in Latin America, especially from Brazil, have not been widely applied in pharmaceutical uses, in spite of the rich biodiversity of flora and the favorable climate for their production. Recently, Ughini, Andreazza, Ganter, and Bresolin (2004) and Vendruscolo, Andreazza, Ganter, Ferrero, and Bresolin (2005) showed the potential of a Brazilian galactomannan isolated from the seeds of *Mimosa scabrella* Bentham, known as bracatinga, as excipient for oral controlled drug release. These seeds provided a highly substituted galactomannan, with a M/G ratio close to 1 (Ganter, Milas, Corrêa, Reicher, & Rinaudo, 1992). Ganter, Cardoso, Kaminski, and Reicher (1997) processed the seeds of *M. scabrella* on a pilot plant scale and extracted the galactoman-

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nan in a 20% yield. The polysaccharide was subsequently dried in a vacuum oven (680 mm Hg) at room temperature and milled in a hammer mill to obtain the particle size required. Considering that the metropolitan region of Curitiba (PR), Brazil, can furnish 15,000 ton/year of *M. scabrella* seeds, the authors concluded that it should be possible to obtain 3000 ton/year of galactomannan by the scale-up process.

Ganter and Reicher (1999) also analyzed the galactomannans of Brazilian related species such as *M. scabrella* var. aspericarpa, *Mimosa flocculosa, Mimosa taimbensis* and *Mimosa bimucronata.* Considering the structure, rheological properties and seed availability, the authors observed that the galactomannan from *M. flocculosa* and *M. bimucronata* might be industrially applied as thickeners, as well as galactomannan from *M. scabrella* Bentham, since the latter produces seeds from November to March, *M. bimucronata* from April to July, and *M. flocculosa* from July to October. As a consequence, seeds would be available for galactomannan production all around the year.

Although some structural and rheological properties of galactomannan from *M. scabrella* Bentham have been previously investigated (Bresolin et al., 1997; Ganter et al., 1992), a full characterization of their physicochemical and mechanical properties is necessary to guarantee their behavior during the formulation and production phases of a drug product (Pifferi, Santoro, & Pedrani, 1999). So, the aim of this work is to further characterize the physicochemical and mechanical properties of native galactomannan from *M. scabrella* in order to elucidate its functionality as excipient for solid dosage forms. Since the drying process has a significant effect on the physical and solid-state properties of materials and subsequent formulation characteristics (York, 1983), the study is focused on the influence of two drying techniques (vacuum oven or spray-drying) on these parameters.

2. Materials and methods

2.1. Polysaccharide source

Seeds of *M. scabrella* Bentham, Argentina variety, were obtained from EMATER (Empresa Paranaense de Assistência Técnica e Extensão Rural, Bocaiúva do Sul-PR, Brazil). The seeds were milled in a hammer mill (Marconi®, Piracicaba-SP, Brazil) prior to extraction of galactomannan.

2.2. Scale-up process for galactomannan production

The conditions described for galactomannan extraction in a laboratory scale (Vendruscolo et al., 2005) were optimized for the scale-up process.

The milled seeds (1.25 kg) of *M. scabrella* were boiled in 10 L of water during 10 min for enzymatic inactivation using a stainless steel stirred tank reactor (Genial®, Piracicaba-SP, Brazil) of 30 L capacity. This dispersion was immediately cooled at 25 °C, with addition of 10 L of cold water and 5 kg of ice. The galactomannan was obtained by water extraction during 4 h under mechanical stirring at room temperature. The dispersion was filtered through phytoplancton cloth (nylon membrane with 25 μm pores) and the filtrate was precipitated with ethanol 50% v/v and washed in a gradient of ethanol (70–100% v/v). The product was subsequently dried either by vacuum oven (GVO) (Marconi® MA 030, Piracicaba-SP, Brazil) at 30 °C and 760 mm Hg or spray-drier (GSD) (Lab Plant SD 05, North Yorkshire, UK). The spray dryer system consists of an apparatus with an inlet temperature of 160 °C and an outlet temperature of 85 °C, pump speed of 600 mL/h, compression of 1.5 bar and air flow of 40 m^3/h. For this last method, the precipitated galactomannan was stirred and maintained in ethanol 96% in order to obtain a dispersion with 40% of solid material previous to drying.

2.3. Analysis of galactomannans

2.3.1. Mannose–galactose ratio (M/G) determination

The M/G ratio was determined by gas liquid chromatography (GLC), as described previously (Sloneker, 1972), using a 5890 SII HP gas chromatograph (California, USA) at 220 °C (free induction decay and injector temperature, 250 °C) with DB-225 capillary column (0.25 mm id × 30 m), film thickness 0.25 μm and nitrogen as carrier gas.

2.3.2. Protein content

The protein contaminant was determined by Bradford method (Kresze, 1983) and briefly described below. The Dye reagent was prepared according to Bradford method, using Coomassie brilliant blue G-250 (100 mg) dissolved in 50 mL 95% ethanol. A volume of 100 mL phosphoric acid (85% w/v) was added and the solution was diluted to 1 L with distilled water and immediately filtered twice. The dye reagent was stored at 4 °C, protected from light. The protein standard curve was prepared using 5 mg/mL of protein stock solution, freshly prepared and adjusted from 10 to 100 μg/mL. The absorbance of either samples or calibration standards was measured at 595 nm after 5 min of protein-reagent contact. In the assay 100 μL of BSA or sample solution was added to 3 mL of Bradford reagent.

2.3.3. Size exclusion chromatography – Multiangle laser light scattering

The weight–average molar mass (M_w) and radius of gyration (R_{gw}) were determined in duplicate using a high performance size exclusion chromatography (HPSEC) apparatus (Wyatt Technology, CA, USA) equipped with four Waters ultrahydrogel columns (2000, 500, 250 and 120) connected in series and coupled to a refractive index (RI) and a multiangle laser light scattering (Wyatt Technology Dawn MALLS) detectors. A 0.1 M $NaNO_2$ solution with 0.02% NaN_3 was used as eluent, with a flow rate of 0.6 mL/min. The samples (1.0 g/L) were prepared by stirring for 2 h and filtered through a 0.2 μm nitrocellulose membrane (GSWP, Millipore). A refractive index increment (dn/dc) of 0.135 mL/g was used (Bresolin et al., 1997).

M_w and R_{gw} values were obtained from the Zimm plot (K_c/R_θ *vs* $\sin^2(\theta/2)$) linear extrapolation at different bands of elution volumes (20–22, 22–24, 24–26, 26–28, 28–30 mL). From these values, chain flexibility parameters such as the characteristic ratio (C_∞) and persistence length (L_p) were obtained according to Roger, Axelos, and Colonna (2000) and Freitas et al. (2005). For a random coil molecule, Roger et al. (2000) proposed to obtain graphically the C_∞ value using the following relation:

$$\frac{R_{gw}^2}{M_w} = \frac{C_\infty l^2}{6M_0}\left(1 + c' M_w^{\frac{1}{2}}\right)$$

The linear fit of the ${R_{gw}}^2/M_w$ variation as a function of ${M_w}^{1/2}$ gives the linear coefficient $C_\infty l^2/6M_0$. The value of C_∞ was determined using a monomeric length (l) of 0.54 nm and a molar mass of the monomer unit (M_0) of 318.5 g mol^{-1} for the oven-dried galactomannan (GVO) and 330.1 g mol^{-1} for the spray-dried galactomannan (GSD). From the C_∞ value, it was possible to estimate the persistence length (L_p) using the equation:

$$C_\infty = 2\left(\frac{L_p}{l}\right) - 1$$

2.3.4. Loss on drying

The loss on drying was determined in triplicate using an infrared moisture analyzer (Mettler LJ16, Greifensee, Switzerland) at 105 °C, until constant weight.

2.3.5. Total ash

The total ash was determined in triplicate following the requirements of guar gum monograph (US Pharmacopeia, 2007).

2.3.6. pH determination

The pH of galactomannan aqueous solution at 1% (w/v) was determined using a pH-meter (Digimed®, Campo Grande-SP, Brazil).

2.3.7. Thermal analysis

Thermogravimetric analysis (TGA) of galactomannan was carried out using a thermogravimetric analyser (Shimadzu 50 H, Tokio, Japan) and samples of 10 ± 0.1 mg in platinum sample pans. Experiments were conducted, under a nitrogen atmosphere (50 mL min^{-1}), at a heating rate of 10 °C min^{-1} over a temperature range of 25–1000 °C. The differential scanning calorimetry (DSC) studies were performed using a SHIMADZU DSC-50 equipment (Tokio, Japan), with thermal software TASYS. Accurately weighed (10 ± 0.1 mg) material was placed into platinum cup and sealed, and the analysis was carried out in nitrogen atmosphere (50 mL min^{-1}) or synthetic air atmosphere (50 mL min^{-1}) at a heating rate of 10 °C min^{-1} over a temperature range of 25–500 °C.

2.3.8. X-ray diffraction studies

X-ray diffraction patterns were obtained using a Siemens Kristalloflex D-5000 (Haan, Germany) diffractometer with the following operating conditions: Ni-filtered Cu K_α radiation, 36 kV and 26 mA. The measurements were carried out at a goniometer speed of 1° (2θ)/min.

2.3.9. Particle size analysis

Particle size analysis was carried out on a vibratory sieve shaker (Retsch Vibro, Haan, Germany) during 30 min, using 500, 355, 250, 180, 125, 90, 63, 45, 38 μm calibrated sieves (Cisa, Barcelona, Spain). From plots of powder weight (%) *vs* size (μm), typical parameters from a particle size distribution were determined: mean particle diameter, standard deviation (SD) and kurtosis and skewness coefficients (Gutiérrez-Cabria, 1978).

2.3.10. Scanning electron microscopy (SEM)

Scanning electron microphotographs of the particulate samples were taken using a scanning electron microscope (Philips XL-30, Eindhoven, Holland), after coating the samples with gold on an Edwards AUTO-306 sputter coater. The microphotographs were obtained at both lower (59×) and higher (945×) magnifications in order to obtain information about the powder characteristics (i.e. particle size and shape) and the particle surface (i.e. texture).

2.3.11. Apparent particle density

The apparent particle densities of galactomannan powders were determined, in triplicate, by means of an air comparison pycnometer (Ultrapycnometer 1000, Quantachrome, Boyton Beach, FL, USA), using helium as an inert gas (European Pharmacopeia, 2006). A sample cell with nominal volume of 48.1 cm^3 was used for the measurements.

2.3.12. Flow properties

The flow behavior of the different samples was estimated by direct and indirect methods.

The angle of repose α (indirect method) was measured according to the fixed funnel and free standing cone method (Train, 1958). The funnel was secured with its tip at a height (H) of 2 cm above graph paper placed on a flat horizontal surface. Powder was carefully poured through the funnel until the apex of the conical pile so formed just reaches the tip of the funnel. The mean diameter ($2R$) of the base of the powder cone was determined and the tangent of the angle of repose was obtained as $\tan \alpha = H/R$. The results are shown as the mean value of six determinations.

Tap density measurements (indirect method) were carried out on a Vol-I SBS powder tester (Barcelona, Spain) under normalized conditions as described in the US Pharmacopeia (2007). The sample (40 g) was placed into a 250 mL glass graduated cylinder and the unsettled apparent volume (V_0) was measured giving access to bulk powder density d_0. After tapping the cylinder 10, 500 and 1250 times, tapped volumes (V_{10}, V_{500} and V_{1250}, respectively) were determined and the final tapped density d_{1250} was obtained. The data given are the means of three measurements. From these data, the compressibility index (%C) and Hausner ratio (HR) were calculated (US Pharmacopeia, 2007).

An automated flowmeter system (direct method) developed by Muñoz-Ruiz and Jiménez-Castellanos (1993) was used to estimate the flow rate of the different samples. Standard funnels as described in European Pharmacopeia (2006) were selected as vessels: a glass funnel with an internal diameter of 10 mm and an angle of 30° with respect to the vertical and a stainless steel funnel with a semi-angle of 20° and hole sizes of 5, 10, 15 and 20 mm. Weight data were acquired by means of a balance (Mettler LJ16, Greifensee, Switzerland) connected to a personal computer, using adequate software. The results are shown as the mean value (g/s) of three replicates.

3. Results and discussion

3.1. Physicochemical properties of galactomannans

The physicochemical characteristics of galactomannans, dried by vacuum oven (GVO) or spray-dried (GSD) are shown in Table 1. Both GSD and GVO present M/G of about 1.2, similar to the one reported for other galactomannans from the same specie (*M. scabrella*) (Bresolin et al., 1997; Ganter & Reicher, 1999; Ganter et al., 1997). Both samples showed also a similar protein content (4–6%), lower than the 10% specified in US Pharmacopeia (2007).

A light scattering technique was used to characterize the galactomannans dried by the two different methods. This tool is one of the few absolute methods available for measuring the size and shape of high molecular weight polymers due to its high sensitivity for detecting large molecules. However, when neutral polysaccharides, such as galactomannans, are dissolved in water, macromolecular aggregates are inevitably present via intermolecular hydrogen bonding between hydroxyl groups (Ganter, Sabbi, & Reed, 2001; Li, Wang, Cui, Huang, & Kakuda, 2006; Reed, 1995; Wang, Huang, Nakamura, Burchard, & Hallet, 2005), which could

Table 1
Physicochemical characteristics of galactomannans dried by vacuum oven (GVO) and spray-dried (GSD).

Sample	M/G ratio	Molecular weight (g/mol)*	Loss on drying (%)*	Total ash (%)*	pH*	Protein (%)*
GVO	1.3/1	8.48×10^5 (0.51×10^5)	13.0 (0.6)	2.3 (0.1)	7.3 (0.1)	5.4 (0.3)
GSD	1.2/1	9.20×10^5 (0.73×10^5)	12.5 (0.8)	5.5 (0.1)	7.1 (0.1)	4.3 (0.4)

* Average (standard deviation).

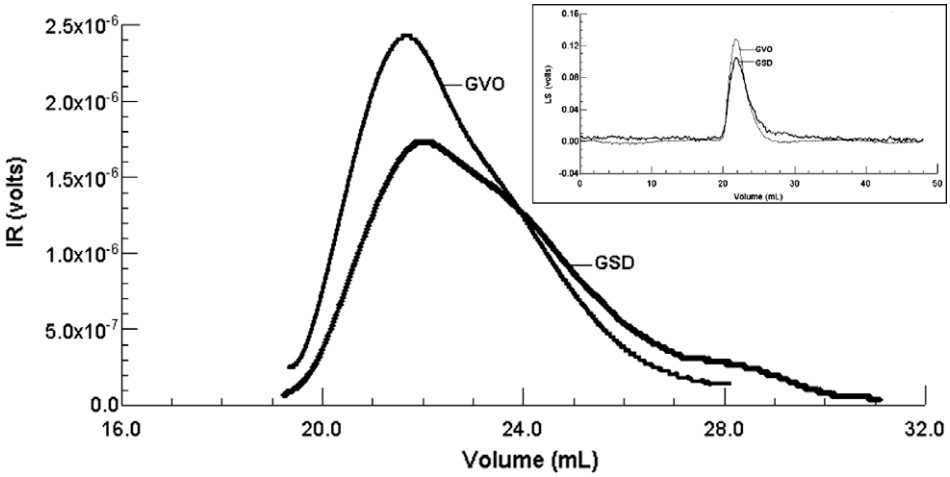

Fig. 1. HPSEC elution profiles of GSD and GVO using RI detector at 90°. Inset shows elution profile by LS (MALLS) detector at 90°.

lead to inaccurate measurements. The quantity and size of these aggregates depend largely on the preparation method of the dry powder.

The GSD and GVO elution profile obtained by HPSEC–MALLS at 90° are in Fig. 1. The refractive index (RI) detector gives a signal proportional to concentration whereas the multiangle laser light scattering (MALLS) response depends on both concentration and molar mass. Fig. 1 shows homogeneous and polydispersed elution profiles for both samples, being the polydispersity index (M_w/M_n) 1.3 (0.2) and 1.2 (0.1) for GSD and GVO, respectively.

The GSD sample shows a slightly higher M_w than GVO (Table 1). However, the analysis of the root-mean-square radius of gyration as a function of the molecular mass indicates the same Gaussian chain conformational relation for both GVO and GSD products in diluted solutions (data not shown). This means that the drying method do not alter significantly the molecular conformation of galactomannan in solution.

To confirm the structure and the absence of the drying effect on the behavior of the molecule in solution, the characteristic ratio (C_∞) and persistence length (L_p) were estimated from plots of R_{gw}^2/M_w *vs* $M_w^{1/2}$. Linear coefficients of 4.8×10^{-3} and 4.2×10^{-3} nm^2 mol g^{-1}, C_∞ values of 32.6 and 27.5 and L_p values of 9.1 and 7.7 nm were obtained for GSD and GVO products, respectively. Robinson, Ross-Murphy, and Morris (1982) and Cheng, Brown, and Prud'homme (2002) reported C_∞ values of ~12 for guar gum (M/G molar ratio ~ 2/1). On the other hand, Picout and Ross-Murphy (2002) described a L_p value for guar gum of 3.3 nm while Ganter and Reicher (1999) and Petkowicz et al. (1999) reported L_p values of 9–10 nm for galactomannans from the *Mimosaceae* family (M/G molar ratio ~ 1/1), closer to our results.

The disparity in C_∞ and L_p values reported for the galactomannans in the literature could be due to the different mathematical models used for determination of these parameters, the galactomannan substitution degree (a higher substitution degree is associated to a more stiff molecule), and the presence of molecular aggregates (increase the chain stiffness), as the samples were not treated by sonication, heating and/or pressure to reduce aggregates (Freitas et al., 2005; Picout, Ross-Murphy, Errington, & Harding, 2003). Anyway, the values obtained indicate that both galactomannans behave as semi-flexible polymers (Dervilly-Pinel, Thibault, & Saulnier, 2001), being the spray-dried derivative less flexible than the oven-dried one.

Fig. 2 shows the cumulative weight fraction *vs* molar mass profiles for GSD and GVO products. A non-homogeneous increment of molar mass can be observed at molecular mass values higher than

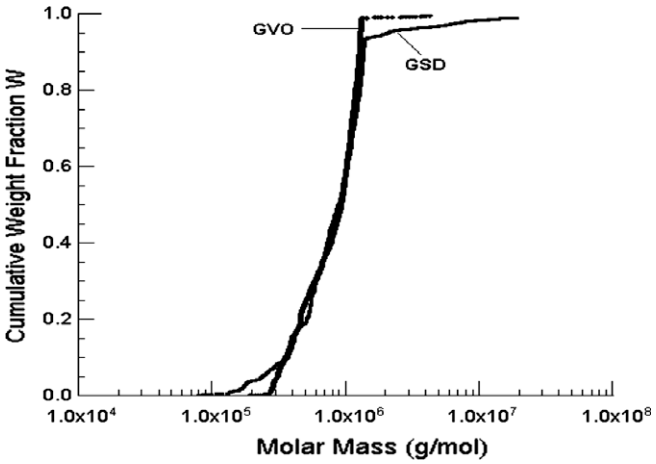

Fig. 2. Cumulative weight fraction *vs* molar mass profiles for GSD and GVO samples.

1.10^6 g/mol, and this abrupt change in the profile could be related to the presence of aggregates. In case of GSD sample, at least 10% of the molar mass values represent aggregates while, for GVO product, this percentage decreases to 2.5%, in agreement with the lower C_∞ and L_p values of GVO compared with GSD. According to Parker, Vigouroux, and Reed (2000), the thermodynamic path followed to produce the dry polymeric powder is of critical importance in dissolution and may influence the M_w determination. From the results obtained, one could hypothesize that the spray-drying process leads to higher chains entanglement, resulting in larger aggregation at molecular level in the GSD.

The loss on drying of both polymers was around 12–13% (Table 1), lower than the 15% limit established in US Pharmacopeia (2007). However, the total ash percentages (Table 1) were higher than the value of 1.5% specified for guar gum (US Pharmacopeia, 2007), probably due to the different seed composition and galactomannan source. The higher ash content for GSD compared with GVO might be attributed to the effect of the drying method on the thermal behavior of the polymers. Similar results were obtained by TGA at oxidant atmosphere (Fig. 3A insert). The aqueous galactomannans solutions showed a neutral pH (Table 1), in agreement with guar gum monograph (Rowe, Sheskey, & Owen, 2006).

Thermogravimetry (TG) and differential scanning calorimetry (DSC) measurements were carried out in order to better assess the thermal behavior of polymers. The results are illustrated in

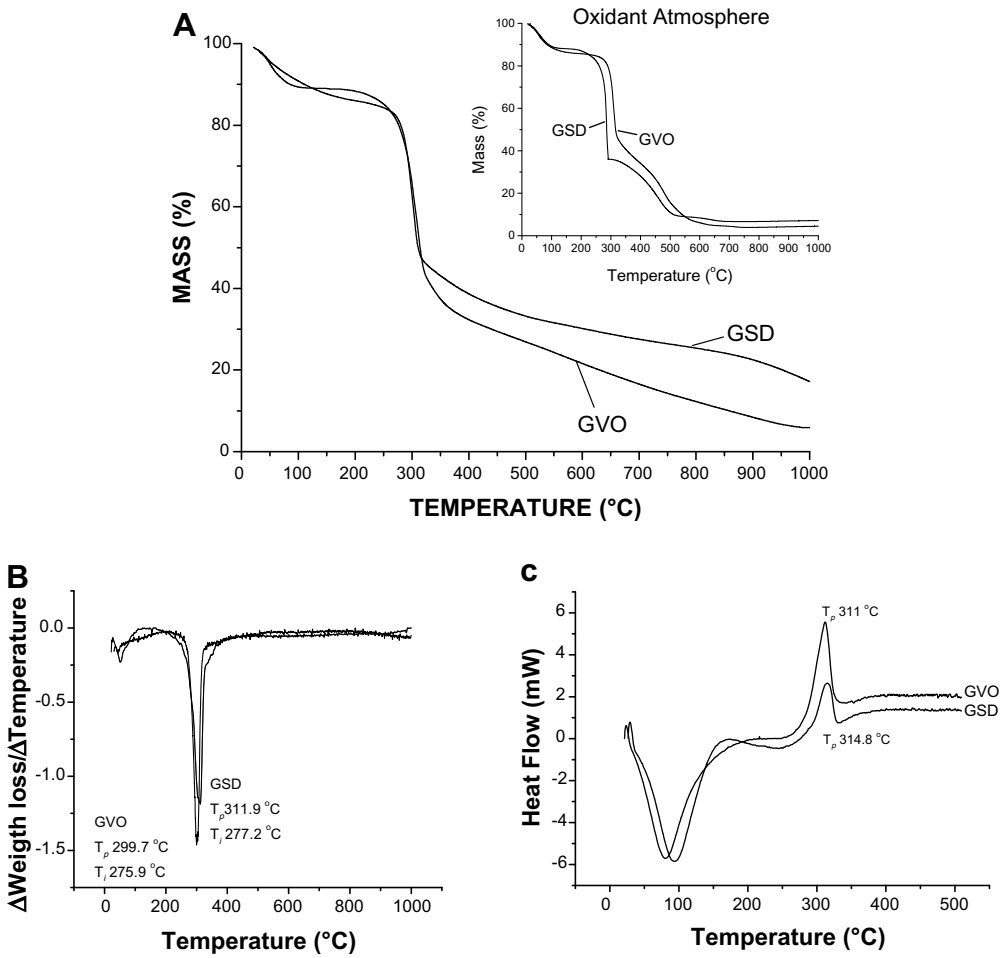

Fig. 3. (A) Weight loss curves under inert and oxidant atmosphere for GSD and GVO at a heating rate of 10 °C min^{-1}. (B) Differential TG curve for GSD and GVO at a heating rate of 10 °C min^{-1} in inert atmosphere. (C) DSC scans of GSD and GVO products; both in inert atmosphere.

Fig. 3. The TG experiments (Fig. 3A and B) show two mass loss events for both polymers, being the first near 100 °C, which may be attributed to the loss of adsorbed and structural water of biopolymers, as related by other authors (Kittur, Harish Prashanth, Udaya Sankar, & Tharanathan, 2002). The DSC experiments show, for both polymers, an endothermic event near 100 °C (Fig. 3C), probably due to the water evaporation, in agreement with TG analysis (Fig. 3A and B). The second mass loss event (Fig. 3B), with a T_o (onset temperature) of 275.9 and 277.2 °C, and a T_p (peak temperature) of 299.7 and 311.9 °C for GVO and GSD, respectively, resulted in a weight loss of approximately 60%, which may be attributed to the polysaccharide decomposition. Similar results were reported by Varma, Kokane, Pathak, and Pradhan (1997) when analyzed the thermal behavior of galactomannan guar gum, detecting a weight loss process with a T_p of 306 °C. An exothermic event was observed in DSC analysis (Fig. 3C) with a T_p of 311.0 and 314.8 °C for GVO and GSD, respectively, in good correlation with TG peak temperatures.

The amorphous nature of the galactomannans is confirmed by X-ray diffraction studies (Fig. 4). The better definition of the diffraction band for the oven-dried polymer suggests that the overall crystallinity, even being low, increases with this drying method. The oven-drying process could approach polymer chains, improving the chain organization and increasing the material crystallinity. The higher GSD crystallinity comparing with GVO, may be related to the slower decomposition of the former, observed in thermal analysis (Fig. 3A–C) and larger aggregation process of this derivative (Fig. 2). All the results are in agreement and pointed out the influence of drying method over the polymers properties.

3.2. Mechanical properties of galactomannans

Galactomannans powders are first studied at the particle level with size measurements and shape description. The results from particle size analysis reveal larger mean particle size for the oven-dried product (226 ± 115 μm). In comparison with GSD (173 ± 84 μm). The particle size distribution (data not show) as well as the kurtosis (−1.17 and 0.69, for GVO and GSD, respectively) and skewness coefficients (0.37 and 1.03, for GVO and GSD, respectively) show a nearly normocurtic distribution for GSD product. The negative value obtained for kurtosis coefficient in the case of GVO indicates a platicurtic distribution, although the symmetry was more significant in this sample, with skewness coefficient close to zero. Narrow particle size distributions for spray-dried powders have also been reported in the literature (Broadhead, Edmon Rouan, & Rhodes, 1992).

Differences in size and morphology of galactomannan particles due to the drying process are also shown by SEM microphotographs (Fig. 5). GSD product appears to have smaller and more spherical particles compared with those of GVO sample, which presented higher size and more irregular shapes. The turbulences in the spray-drying process can cause some erosion in the particle surface yielding particles more spherical in shape and with smoother surface texture.

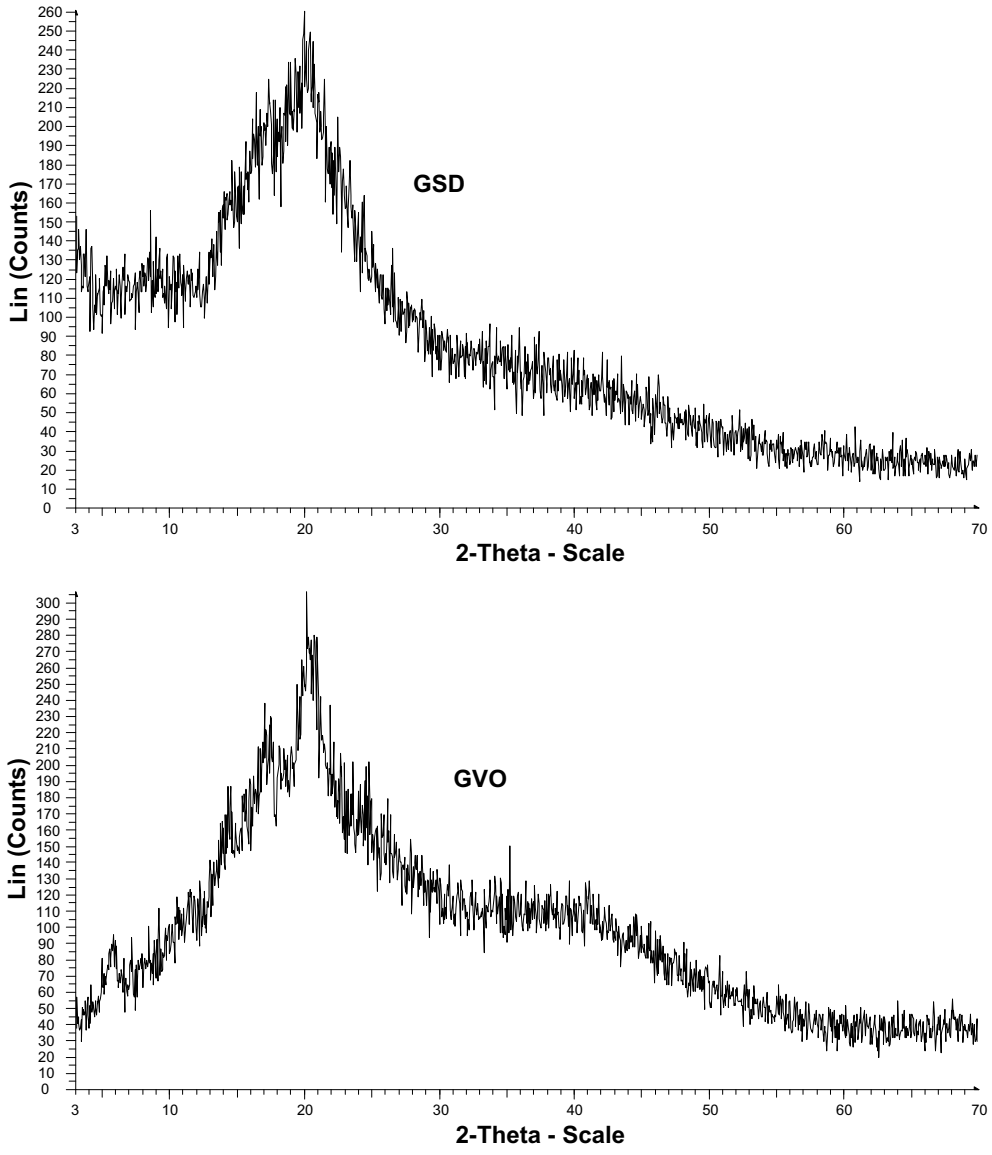

Fig. 4. X-ray powder diffraction patterns of GSD and GVO samples.

The apparent particle densities of the products under study are collected in Table 2. It must be pointed out the higher difficulty for achieving steady pressures for GSD, due to their low density. For this reason, it was necessary to setup a 10 s equilibration time in order to measure the pressure values. The larger density values obtained for GVO could be due to the higher shrinkage suffered by the sample after the oven-drying process. In contrast, spray-dried particles are hollow spheres with a lower particle density than the relatively solid oven-dried particles.

A good knowledge of powder flow properties is necessary to consider industrial application of an excipient. Flow data of galactomannans from indirect methods are described in Table 2. The angle of repose values do not allow to establish important differences between both products, although the results obtained reveal fair flow characteristics according to Carr's classification (US Pharmacopeia, 2007). With respect to powder packing characteristics, the small and spherical spray-dried particles would be expected to pack together closely leading to higher bulk density than the large and irregular oven-dried particles. However, spray-drying results in a decrease in both bulk and tap densities of the powder as compared to the effect of oven-drying, due to the influence of the particle density and particle packing on the powder density. Similar behavior was found by Rege, Garmise, and Block (2003) when evaluating the effect of drying methods (spray-drying *vs* tray drying) used in chitinosan manufacture on the resultant chitinosan micromeritic properties. Concerning the compressibility index and Hausner ratio values, GVO shows good flow properties while GSD sample is characterized by a very poor flow behavior (US Pharmacopeia, 2007), typical of fluid cohesive powders (Carr, 1970).

Although the spray-dried galactomannan is composed mainly of spherical particles, the results obtained from the flow rate measurements show an absence of flow for this material in all funnels used (Glass funnel of 10 mm; Stainless steel funnel of 5, 10, 15 and 20 mm) probably due to the smaller particle size and apparent particle density (Tables 2) of this product compared with its homologous oven-dried.

In case of GVO, a different behavior can be seen for the different funnels used. Thus, for the glass funnel, a flow rate of 19 g/s indicative of free flow was observed. However, this product does not flow through stainless steel funnels with apertures lower than 20 mm. This could be attributed to the different funnel design, which influences the powder discharge characteristics.

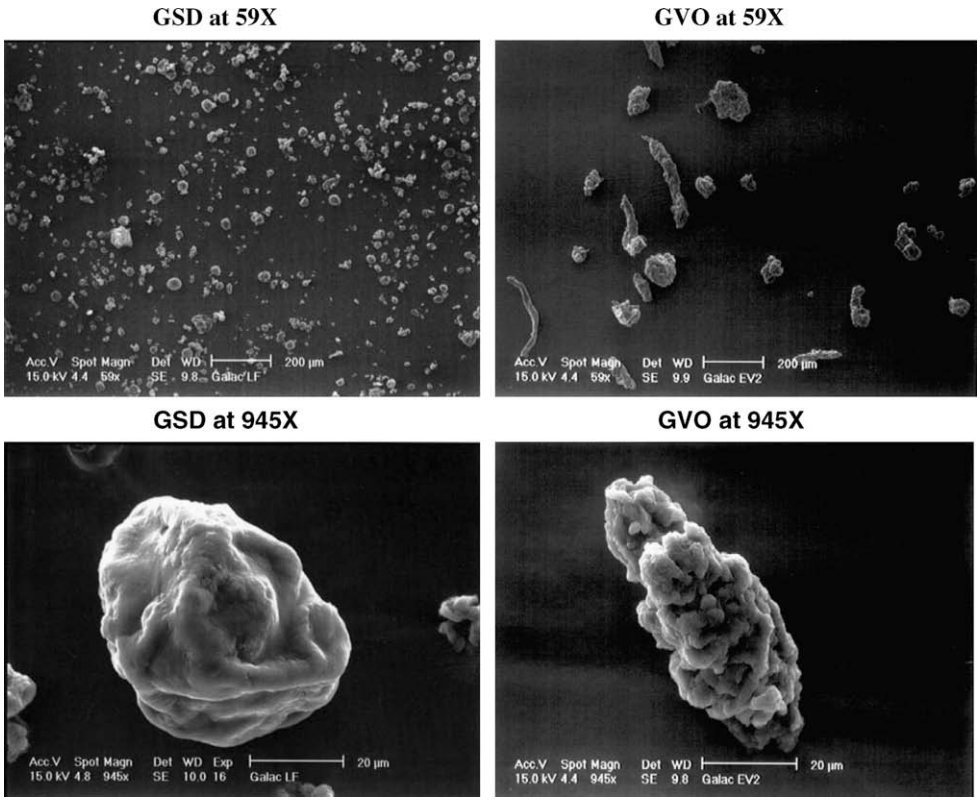

Fig. 5. SEM microphotographs of GSD and GVO samples.

Table 2
Apparent particle density, angle of repose and tap measurements (bulk density, d_0; tapped density, d_{1250}; compressibility index, %*C*; Hausner ratio, HR) of GSD and GVO powders.

Polymer	Apparent particle density (g/cm^3)*	Angle of repose (°)*	d_0 (g/mL)*	d_{1250} (g/mL)*	%*C**	HR*
GVO	1.522 (0.003)	40.03 (0.73)	0.564 (0.014)	0.638 (0.006)	11.7 (0.1)	1.133 (0.017)
GSD	1.009 (0.003)	35.51 (3.10)	0.305 (0.003)	0.449 (0.000)	32.2 (0.6)	1.476 (0.013)

* Average (standard deviation).

4. Conclusions

In general, both derivatives (GSD and GVO) satisfied the Pharmacopoeia specifications of guar gum monograph and their physicochemical characteristics agree well with those described in the literature for this polymer. The galactomannans are essentially amorphous polymers whose linear chain conformation in solution is not highly affected by the drying method. The chain flexibility parameters obtained by HPSEC–MALLS reveal that both products behave as semi-flexible polymers, although the spray-drying process results in a product with more aggregation at molecular level and higher chain stiffness. The effect of the drying technique was detected when evaluating the thermal behavior of both galactomannans by means of TGA and DSC measurements and the results suggest a higher stability of GSD comparing with GVO, as well as, the micromeritic studies showed a higher cohesiveness of GSD. These results are in agreement with the more aggregation observed in GSD, by HPSEC–MAALS.

Micromeritic properties of galactomannans vary according to the particular drying method of choice. GSD powder shows spherical particles with smaller sizes and narrower particle size distribution than the GVO one. In spite of its irregularly shaped particles, the larger particle size and apparent particle density values observed for GVO are responsible of its improved flow characteristics as compared with GSD. As vacuum oven-drying resulted in a like fibrous material, spray-drying appears as an alternative method easy to extrapolate in industry. Nevertheless, further optimization of the drying conditions or the incorporation of a glidant are needed to improve the powder flowability.

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