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Physicochemical Properties of Edible Seed Hemicelluloses

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Abstract

In this work, galactomannans and xyloglucans were isolated from the seed endosperm and cotyledon of Brazilian non-conventional sources, respectively. Extraction yields, monosaccharide ratios, macromolecular parameters and molar mass distributions were determined and compared to commercial guar gum and Locust Bean Gum (LBG). The extraction yield in relation to seed mass ranged from 7.0% to 40.63%, with xyloglucan yields being higher than galactomannan yields. *Schizolobium parahyba* and *Caesalpinia pulcherrima* galactomannans exhibited the lowest protein contents, 0.05% and 0.08%, respectively. Flow curves of 1% hemicellulose solutions (w:v) were measured by varying the shear rate from 0.1 to 100 s^{-1}. The resulting data were fitted to a Power Law model, and all the hemicelluloses presented shear-thinning behavior. Galactomannans and xyloglucans with different monosaccharide ratios showed similar consistency indices. Rheological properties were also compared, and the results suggest new hemicellulose sources, which can be studied for additional applications in areas such as materials science, medicine and biology.

Subject Areas

Biochemistry, Biodiversity, Biotechnology, Plant Science

Keywords

Galactomannan, Xyloglucan, Intrinsic Viscosity, Rheology

1. Introduction

Plant cell walls are composed of polysaccharides such as hemicelluloses that have

β-(1 → 4)-linked backbones with equatorial configurations. Hemicelluloses include xyloglucans, xylans, mannans, glucomannans, and β-(1 → 3, 1 → 4)-glucans, and the detailed structures of hemicelluloses and their abundances vary widely among species and cell types. The most important biological role of hemicelluloses is their contribution to strengthening the cell wall via their interactions with cellulose and, in some cases, lignin [1] [2].

Leguminosae is a major plant family, with more than 18,000 species worldwide. Although the species in this family analyzed to date represent a small fraction of its members, approximately half of the species studied have an endosperm that contains galactomannan hemicellulose [3]. In legumes, the main function of the endosperm cell wall appears to be storage, with galactomannan yields reaching more than 30% of the seed dry weight in many species. These walls are thickened with galactomannan, and in certain cases (e.g., *Schizolobium parahyba*), essentially no cytoplasm is present [3] [4].

Galactomannans are heteropolysaccharides composed of β-(1 → 4)-d-mannan backbones with single d-galactose branches linked as α-(1 → 6). Individual galactomannans differ from each other in their mannose to galactose ratio, distribution pattern of galactose residues along the mannan backbone, molecular weight, and molecular weight distribution. Furthermore, the degree of galactose substitution in a galactomannan determines its physicochemical properties. These polymers, which are water-soluble and form highly viscous, stable aqueous solutions even at low concentrations, have been used as thickeners and stabilizers in the food, cosmetics, paper, and textile industries [5] [6] [7].

Among hemicelluloses, seed xyloglucans are polysaccharides with potential industrial applications. Xyloglucans are found in the primary cell walls of higher plants as well as in the cotyledons of some dicotyledonous seeds, where they function as structural and storage polysaccharides [8] [9]. Xyloglucans have a backbone composed of β-(1 → 4)-linked glucans and regular branching with α-(1 → 6)-linked xylosyl residues that can be branched further with β-(1 → 2)-linked galactosyl residues. Fucosyl residues can sometimes be found attached, mainly in leaf cell walls but not in storage xyloglucans [1] [3].

Both xyloglucans and galactomannans are considered hydrocolloids, and these molecules have been studied in a variety of applications, including as matrices to isolate lectins, as fiber sources, and for many other functions based on their rheological properties [10]. Recently, there has been increased interest in the physical and functional properties of seed gums from various sources, and interesting papers have been published investigating the suitability of these polysaccharides for food and pharmaceutical applications (e.g., gum polysaccharides and mixed gels) [11] [12] [13] [14]. Within this context, the rheological parameters of gum solutions are useful for quality control because they are correlated with sensory assessment, handling applications, and characterization of the sizes and shapes of macromolecules [15].

Guar gum (a galactomannan from *Cyamopsis tetragonolobus* seeds), locust bean gum (LBG, a galactomannan from *Ceratonia siliqua* seeds) and xyloglucans

from *Tamarindus indica* are widely used in food products as thickening and stabilizing agents, usually in amounts of <1% of the food weight [16]. The production of guar gum is concentrated in countries such as India, Pakistan and the USA, and its cultivation is extremely dependent on weather and rainfall, which can affect the yield per acreage depending on the season. *C. siliqua*, also called carob tree or algarroba, is a leguminous evergreen tree that grows throughout the Mediterranean region, mainly in Spain, Italy, Portugal and Morocco. The processing of its seeds to yield the corresponding endosperm (rich in galactomannans) involves the removal of the husks and germ fractions, either by chemical or thermo-mechanical treatment [17].

To develop alternatives sources of hydrocolloids, we compared the physicochemical properties of seed hemicelluloses from leguminous plants that grow throughout Brazil to commercial hydrocolloids such as guar gum and LBG (**Figure 1**). Galactomannans were extracted from the seeds of *Adenanthera pavonina*, *Caesalpinia pulcherrima*, *Dimorphandra mollis*, *Delonix regia*, *Prosopis glandulosa*, and *S. parahyba*, whereas xyloglucans were extracted from the seeds of *Hymenaea courbaril*, *Mucuna sloanei* and *Tamarindus indica.*

2. Materials and Methods

2.1. Materials

Adenanthera pavonina (56,964), *Caesalpinia pulcherrima* (56,367), *Dimorphandra mollis* (25,902), *Delonix regia* (57,491), *Schizolobium parahyba* (35,468), *Hymenaea courbaril* (56,476), *Mucuna Sloanei* (24,482) and *Tamarindus indica* (56,965) seeds were collected in the state of Ceara-Brazil; the numbers in parentheses indicate voucher specimens registered at the Herbarium Prisco Bezerra-EAC (UFC). The seeds were isolated from their pods, cleaned and stored in plastic containers at room temperature. *Prosopis glandulosa* seeds were obtained

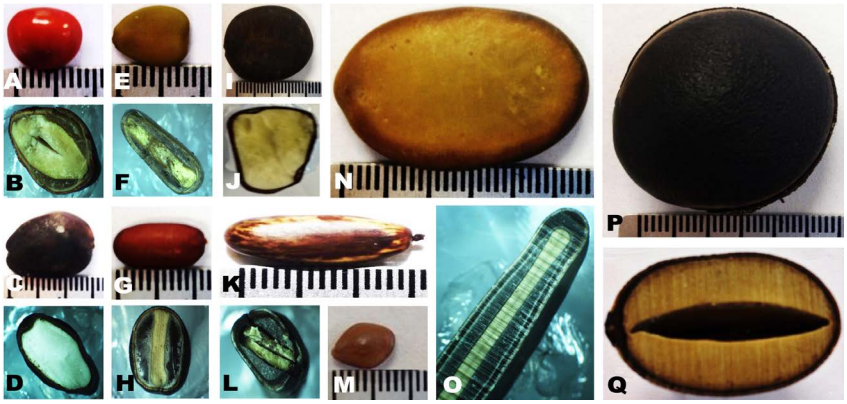

Figure 1. A whole (A) and cross-sectioned (B) *Adenanthera pavonina* seed. A whole (C) and cross-sectioned (D) *Tamarindus indica* seed. (E) A whole and cross-sectioned (F) *Caesalpinia pulcherrima* seed. A whole (G) and cross-sectioned (H) *Dimorphandra mollis* seed. A whole (I) and cross-sectioned (J) *Hymenaea courbaril* seed. A whole (K) and cross-sectioned (L) *Delonix regia* seed. A whole (M) *Prosopis glandulosa* seed. A whole (N) and cross-sectioned (O) *Schizolobium parahyba* seed. A whole (P) and cross-sectioned (Q) *Mucuna sloanei seed.*

from Germplasm Center in Saltillo, Coahuila, Mexico. Guar gum and LBG were purchased from Sigma Aldrich.

2.2. Galactomannan Extraction

Polysaccharide extractions from *A. pavonina*, *D. mollis*, *D. regia*, *S. parahyba* and *C. pulcherrima* seeds were performed as described [18]. *C. pulcherrima* seeds were milled, and the endosperm was separated from the cotyledon and hull. Thereafter, the endosperm was immersed in a boiling 96% ethanol solution for 10 min to deactivate enzymes [19]. For the other species, whole seeds were boiled in distilled water to isolate endosperms, which were suspended in water (w:v, 1:5) and kept at 7˚C for approximately 12 h. The suspensions were then added to 10 volumes of water and mixed in a blender at 500 rpm. Two volumes of 96% ethanol were added to the viscous solution that was obtained, and the precipitated galactomannan was immersed in acetone in a 1:5 proportion (w:v, precipitate:acetone) for 15 min, followed by airflow drying. The powder that was obtained was then suspended in water at 1:100 (w:v), and the precipitation process was repeated. Finally, the resulting biopolymer was milled and passed through a 0.125 mm mesh. For *P. glandulosa* galactomannan, the extraction was carried out as reported by [20].

2.3. Xyloglucan Extraction

Polysaccharide extraction was performed according to methodology reported by [21], with modifications. *T. indica*, *H. courbaril* and *M. sloanei* seeds were pooled, milled and swelled in distilled water at 40 g L^{-1} for 12 h at 8˚C. The viscous extracts were filtered through a nylon net and centrifuged at 4˚C and 10,000 × g for 20 min. Two volumes of ethanol 96% were added to the supernatant; the precipitate was then re-suspended in water (1:10, w:v), and the precipitation process was repeated. The ethanol was decanted, and the xyloglucan was immersed in acetone in a 1:5 proportion (w:v, precipitate:acetone) for 15 min, followed by airflow drying.

2.4. Protein Content

The nitrogen content was determined according to a method published by [22], and the total protein content was estimated by the factor N x 5.7.

2.5. Analysis of Monosaccharide Composition

Hemicellulose hydrolysis and monosaccharide derivatization processes were carried out as described by [23]. Galactose, glucose, mannose and xylose contents were determined using gas chromatography with mass spectrometry detection (GCMS-QP2010, Shimadzu, Tokyo, Japan). Samples were injected in split mode (1:25) using helium as a carrier gas at a constant flow of 1.16 mL/min, with an injection volume of 1 μL. Monosaccharide separation was performed on an RTX-5MS column (30 m × 0.25 mm i.d. × 0.25 μm film thickness) (Restec, Bellefonte, USA). The oven temperature was programmed as follows: it was held

constant at 160˚C for 3 min, then raised at a rate of 1˚C/min to 190˚C and finally raised at 15˚C/min to 240˚C and held for 1 min. Each sample was run in triplicate.

2.6. Macromolecular Characterization

Dispersions were obtained in distilled water using a Turratec TE 102 homogenizer for 10 min at 20,500 rpm and then stored at 8˚C overnight. The dispersions were re-homogenized under the same conditions and centrifuged at 4˚C and 10,000 x g for 30 min to remove air bubbles and insoluble matter.The determination ofviscosity parameters was performed with exactly 10 mL of solution sample using an Ostwald-Fensk capillary viscometer (series 200) at 26˚C ± 0.1˚C. Hemicellulose solutions at 0.5% (w/w) were used to prepare a range of dilutions to obtain relative viscosity values of $1.2 < \eta_r < 2.0$, which were considered to maintain good linearity of extrapolation to a zero concentration. Huggins-Kramer plots of η_{sp}/C and $\ln\eta_r/C$ versus C were used to estimate intrinsic viscosity $[\eta]$, according to Equations (1) and (2):

$$\left[\eta_{sp}\right] = [\eta] + k_H [\eta]^2 C \quad \text{(Huggin's equation)} \tag{1}$$

$$\ln(\eta_r)/C = [\eta] + k_K [\eta]^2 C \quad \text{(Kraemer's equation)} \tag{2}$$

where η_{sp} = specific viscosity, η_r = relative viscosity, $[\eta]$ = intrinsic viscosity, C = polymer concentration, k_H = Huggins's constant and k_K = Kraemer's constant.

Molar Mass Distribution

The weight average molar mass (Mw) and number average molar mass (Mn) were determined by gel permeation chromatography (GPC) using a Shimadzu LC-10AD instrument with an Ultrahydrogel linear column (7.8 × 300 mm). An aqueous solution of polysaccharides (0.1%; w/v) was subjected to a flow rate of 0.5 mL/min, and 0.1 M $NaNO_3$ served as the eluent. A differential refractometer was used as a detector at 40˚C. Pullulan samples (Shodex Denko) with Mws of 5.9×10^3, 2.28×10^4, 4.73×10^4, 1.12×10^5, 4.04×10^5 and 7.88×10^5 g/mol were used as molecular standards.

2.7. Functional Properties

Water absorption (WAC) and emulsifying (EC) capacities were determined according to [20]. Samples of 0.4 g of each of the hemicelluloses were placed in sealed tubes with 40 mL of distilled water for 30 min. After centrifugation at 25˚C and 5000 x g for 10 min, the supernatant was decanted, and the WAC value was obtained by the difference in weight. For EC, 40 mL samples of hemicellulose dispersions at 1% (w:v) were mixed with Sadia® soybean oil (5 mL) and homogenized in a Turratec TE 102 homogenizer at 20,500 rpm for 1 min at room temperature. The suspensions were then centrifuged at 4˚C and 7000 × g for 10 min, and the emulsifying capacity was calculated according to Equation (3):

$$\% \text{ EC} = \frac{ev}{tv} \times 100 \quad (3)$$

where *ev* is the emulsion volume and *tv* is total volume. A mean comparison of treatments was performed using one-way ANOVA with a multiple range Tukey test ($p < 0.05$).

2.8. Rheological Analysis

Hemicellulose dispersions at 1% (w:v) were used to compare rheological properties; these preparations were stored at 4˚C for 24 h before analysis. An Advanced Rheometer AR 550 with a Peltier temperature control system was used to acquire the rheological behaviors of the samples, and the analyses were performed using cone-plate methodology (cone: 1˚, 40 mm diameter and 28 mm gap). Steady rheological properties were obtained at 25˚C with an operating shear rate ranging from 0.1 to 100 s^{-1}. To predict flow curves, the shear stress (τ) versus shear rate (γ) was determined, and the rheological consistency index (k) and flow behavior index (n) were calculated according to the Power Law model, as per Equation (4):

$$\tau = k \cdot \gamma^n \quad (4)$$

The analyses were run in triplicate, and the data analysis was performed using Origin 8.0 (OriginLab Corporation, MA, USA).

3. Results and Discussion

3.1. Polysaccharide Extraction

Polysaccharide yields in relation to seed mass for all galactomannans and xyloglucans are presented in **Table 1**. The values ranged from 7.0% to 40.63%, and xyloglucan yields were higher than galactomannan yields for all the seeds tested. Many plants have been chemically analyzed and proposed as potential sources of plant gum exudates. For instance, [24] reported guar with 19% - 43% gum, *Cassia brewsteri* with 33.7% ± 0.4% gum and mesquite with 24.9% gum. The obtained hemicelluloses were white in color because the endosperms were isolated prior to the extraction procedure, which prevents contamination of the endosperm with pigments and tannins from the hulls and cotyledons. An absence or low content of biomolecules such as proteins is desirable for rheological analyses because these molecules can promote aggregation with carbohydrates and affect viscosity. A high protein content was observed for *D. mollis* (1.56), *D. regia* (2.25) and *P. glandulosa* (5.88) galactomannans when compared to the guar and LBG gums; however, when the seeds were ground and sieved before extraction, the values increased, as reported by [25]. Because they are found in seed cotyledons, xyloglucans presented the highest protein content among the hemicelluloses (**Figure 1**: (D), (J) and (K)).

The hemicellulose-monosaccharide ratios obtained are presented in **Table 1**. These data add to those previously reported by [26], in which a relationship between taxonomic position (at the subfamily level) and galactomannan yields and

Table 1. Yield, protein content, WAC and monosaccharide ratio.

Species	Yield (%)	Protein (%)	Monosaccharide ratio	WAC (gg^{-1})
Guar gum	-	0.35 ± 0.00	1.8:1.0*	33.20 ± 3.09[a]
LBG	-	0.42 ± 0.03	4.4:1.0*	11.41 ± 0.22[c]
A. pavonina	7.00	0.11 ± 0.00	1.7:1.0*	8.7 ± 0.93[bc]
C. pulcherrima	27.0	0.08 ± 0.00	4.1:1.0*	21.70 ± 1.96
D. mollis	9.90	1.56 ± 0.01	3.0:1.0*	20.13 ± 0.95
D. regia	31.07	2.25 ± 0.03	6.1:1.0*	13.63 ± 0.23b[c]
P. glandulosa	16.53	5.88 ± 0.24	1.5:1.0*	13.83 ± 0.79[b]
S. parahyba	10.29	0.05 ± 0.00	3.2:1.0*	20.15 ± 0.73
H. courbaril	35.4	2.73 ± 0.52	1.0:0.9:0.5**	14.36 ± 1.62[b]
M. sloanei	16.01	6.44 ± 0.16	1.0:0.6:0.6**	24.31 ± 0.60
T. indica	40.63	7.34 ± 0.64	1.0:0.5:0.2**	7.81 ± 0.93[b]

Mean ± SEM compared using one-way ANOVA with a multiple range Tukey test. The same superscripted letters correspond to no significant differences ($p > 0.05$) among the samples and guar gum (a) and LBG (b).*Man **:** Gal. **Glc:Xyl:Gal.

Man:Gal ratios among Leguminosae was observed. Pure mannans and cellulose are insoluble in cold water at neutral pH; as a result, the water solubility of both galactomannans and xyloglucans are affected by proportional increases in galactose content. These increases are attributed to extensive hydration in galactose-rich regions, and galactose sidechains can prevent a mannan backbone from forming hydrogen-bonded aggregates [27] [28]. In aqueous solution, galactomannans such as LBG interact strongly through galactose-depleted chain segments with compatible helices (e.g., xanthan, k-carrageenan) or by self-interaction, producing network-type gels that are useful texturants in many food products. In contrast, galactomannans with high degrees of galactose substitution do not interact strongly with other polysaccharides and are primarily used as mass-efficient thickeners [29]. Although the monomeric sugar content of a hemicellulose is generally determined by gas chromatography after partial or total hydrolysis via acid catalysis, such data can be affected by the hydrolysis processes and subsequent reactions. This phenomenon can explain the M/G ratio for *C. pulcherrima* (4.1:1) determined in this work, which was previously reported to range between 2.88 and 3.65 [18] [30] [31].

3.2. Molar Mass Distribution

The weight average molar mass (Mw), number average molar mass (Mn) and polydispersity were estimated through comparisons of hemicellulose chromatograms obtained with pullulan standard curves (**Table 2**). The Mw values ranged from 0.09 to 3.37×10^7 g mol^{-1}. [29] listed a range of galactomannan Mw values of 0.09 - 0.31 $\times 10^7$ g mol^{-1} and associated mannosyltransferase activity with chain length regulation and chain termination during the biosynthesis of less-substituted galactomannans, resulting in longer chains. [32] highlighted that

Table 2. Hemicellulose macromolecular parameters.

Species	Viscosimetric parameters				Molar mass distribution		
	Intrinsic viscosity Huggins' extrapolation (dL g^{-1})	Intrinsic viscosity Kraemer's extrapolation (dL g^{-1})	Intrinsic viscosity (average values) (dL g^{-1})	Huggins' coefficient. K_H	Mw (g mol^{-1}, $\times 10^7$)	Mn ($\times 10^6$)	Mw/Mn
Guar gum	10.33	10.56	10.44	0.73	2.62	4.31	6.09
LBG	2.56	2.57	2.57	0.77	1.20	1.93	6.21
A. pavonina	4.13	4.16	4.14	0.43	1.45	2.14	6.75
C. pulcherrima	9.49	9.80	9.64	1.08	1.34	2.64	5.09
D. mollis	9.58	9.91	9.74	1.15	1.55	2.60	5.95
D. regia	5.37	5.42	5.40	0.86	0.64	0.68	9.38
P. glandulosa	10.68	11.29	10.98	1.10	3.07	0.59	5.17
S. parahyba	7.01	7.23	7.12	1.14	1.00	1.29	7.73
H. courbaril	7.84	7.82	7.83	0.23	0.09	0.19	4.58
M. sloanei	14.82	14.55	14.69	0.36	1.32	2.58	5.11
T. indica	3.63	3.78	3.71	1.10	0.12	0.23	5.27

high molecular weight xyloglucan chains present several limitations, such as uncontrolled water solubility and high polydispersity due to their ability to form large aggregates via hydrogen bonding.

3.3. Molecular Characterization

The values of intrinsic viscosity averages and Huggins' constants are shown in Table 2. Viscosimetric methods are based on the fact that the viscosity of a liquid to which a polymer is added increases proportionally with the volume of the polymer, providing interesting information of the polymer's size in solution and polymer-solvent interactions [33] [34]. A reduced viscosity plot or inherent viscosity, when extrapolated to a zero concentration, yields the intrinsic viscosity. The constant kH is termed the Huggins constant and reflects the solute–solvent interactions and aggregation states of macromolecules; in adequate solvents and for flexible macromolecules, the constant ranges $0.3 < kH < 0.7$ but can be higher than 1.0 in cases of aggregation [35].

In this study, the high values observed for the Huggins constant most likely reflect some degree of intermolecular aggregation in the hemicellulose samples, which has been interpreted as reflecting the existence of non-specific physical entanglements in polysaccharide solutions. [27] reported that for galactomannans, associations occur in a region with more than six consecutive, unsubstituted mannose residues.

The intrinsic viscosities of the hemicelluloses included in this work ranged from 2.56 to 14.82 dL g^{-1} (Table 2). [18] reported intrinsic viscosity values ranging from 8.74 to 11.34 dL g^{-1} for galactomannans extracted from four different sources. Although the galactomannans in the present study exhibited different intrinsic viscosities, they had similar Man:Gal ratios. Indeed, even the xy-

loglucans from *H. courbaril* and *M. sloanei*, which have similar degrees of galactose substitution (Glc:Xyl:Gal, 1.0:0.9:0.5 and 1.0:0.6:0.6, respectively), had different intrinsic viscosities, 7.84 and 14.82, respectively. This distribution is not yet fully understood, though it is believed to be important for the functional properties of these polysaccharides [36].

3.4. Functional Properties

The WAC values obtained are shown in **Table 1**. *C. pulcherrima* (20.69), *D. mollis* (19.12) and *M. sloanei* (23.30) presented significant differences when compared to LBG. The high WAC for guar gum might be associated with the granulometry of commercial gums and with the industrial extraction methods, which can alter water retention by these polysaccharides. In addition, the backbone substitution pattern reduces chain-to-chain interactions and allows water solvation of the molecules [20].

P. glandulosa, *C. pulcherrima* and *M. sloanei* showed the highest values for emulsifying capacity, as illustrated in **Figure 2**.

With the exception of *T. indica* xyloglucan, all hemicelluloses presented emulsion properties similar to the commercial gums. The functional properties of polysaccharides are influenced by the rheological behaviors of the molecules in water as well as inter-chain interactions under specific conditions. Arabic gum (*Acacia senegal*) is an important emulsifying agent in industry and maintains its function effectively under different conditions (e.g., low pH, high ionic strength); however, it also presents a low thickener capacity that limits its use in producing stable emulsions. Therefore, many studies have recently been performed to replace this emulsifier [37] [38].

3.5. Rheological Behavior

Similar to other gum polysaccharides, such as carrageenan, pectin and starch [13] [39], all the galactomannan solutions exhibited shear-thinning behavior ($n < 1$) at 1% (w/v) concentration, indicating that their apparent viscosities de-

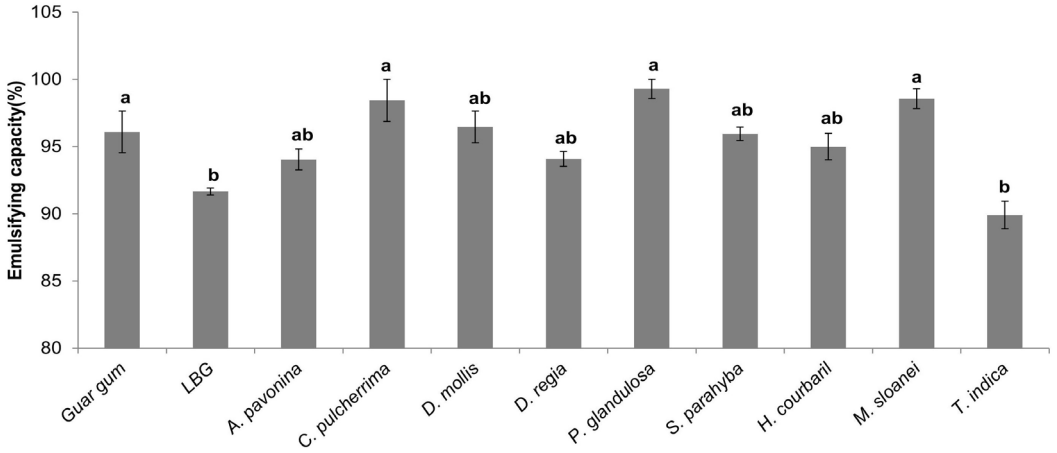

Figure 2. Emulsifying capacities of hemicelluloses. Mean ± SEM. The same letters correspond to no significant differences ($p > 0.05$) among the samples and guar gum (a) and LBG (b).

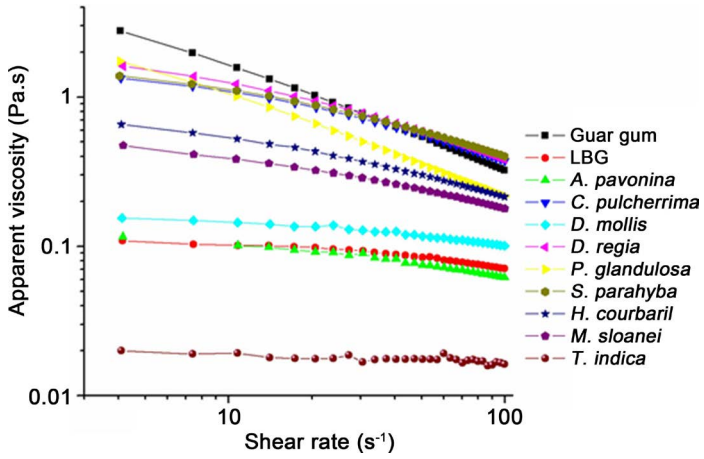

Figure 3. Flow curves of hemicellulose solutions at 25˚C.

Table 3. Rheological parameters by the Power Law model.

	Consistency coefficient (k)	Behavior index (*n*)	Regression coefficient (R^2)
Guar gum	8.62	0.29	0.9977
LBG	0.19	0.79	0.9985
A. pavonina	0.21	0.74	0.9984
C. pulcherrima	3.89	0.50	0.9915
D. mollis	0.25	0.81	0.9992
D. regia	4.91	0.45	0.9889
P. glandulosa	5.23	0.31	0.9954
S. parahyba	3.79	0.52	0.9934
H. courbaril	1.57	0.57	0.9968
M. sloanei	1.00	0.63	0.9977
T. indica	0.04	0.93	0.9989

crease with increasing shear rates (Figure 3). Decreased viscosity values are common in polysaccharide solutions, as polysaccharide chains are known to be able to form ordered structures through chain–chain entanglements, which are disrupted under the application of shear force to a system, consequently leading to decreases in viscosity in response to increases in shear rates [40].

Using the Power Law model, we observed that the flow behavior index values for *A. pavonina* (0.74), *D. mollis* (0.81) and LBG (0.79) were close to n = 1, a value that is characteristic of Newtonian fluids. Although the above galactomannans showed similar consistency index values, an increased Man:Gal ratio might lead to a corresponding increase in viscosity (Table 3). However, it may have been influenced by the patterns of galactose distribution on the chains and the interactions among these molecules. The same was observed for *S. parahyba*, *D. regia* and *C. pulcherrima* galactomannans. *P. glandulosa* and guar gum have similar Man:Gal ratios and flow behavior index values and showed the highest consistency index values.

P. glandulosa has a higher molar mass (3.07×10^7) than guar gum (2.62×10^7),

which may be a reason for its higher shear thinning. We also observed that guar gum and *P. glandulosa* presented the highest shear-thinning behavior among the galactomannans, with values of 0.29 and 0.31, respectively, which is consistent with their higher molar masses.

As is always the case with natural polysaccharides, the structures are complicated in the sense that the arrangement and distribution of repeating units are not homogeneous. Indeed, the chemical formulas of repeating units that are shown in papers and textbooks are idealized or averaged and do not represent the specific structures of the experimental samples that have been described [41].

When xyloglucans from *M. sloanei* and *H. courbaril* were compared, similarities could be observed in their flow behavior indices, even though they produced solutions with different viscosities, as demonstrated by their consistency indices of 1.00 and 1.57, respectively. The degree of galactose substitution and the composition of their repeating units affect the properties of aqueous solutions of xyloglucans. *T. indica* xyloglucan largely exhibited Newtonian behavior and a low consistency index.

Cyamopsis tetragonoloba, the source of guar gum, is an annual legume that is resistant to drought and tolerant of high temperatures. *C. pulcherrima*, a perennial shrub that can reach 3 to 4 m in height and bloom all year long with significant seed production, bears seeds that show high germination percentages over a wide temperature range, allowing this species to colonize a wide variety of habitats and expand its tropical geographic distribution [42]. Furthermore, in our experience, *C. pulcherrima* is capable of producing seeds during an average of 6 months, whereas other arboreal species require years to begin producing seeds.

4. Conclusions

All the studied hemicelluloses displayed shear-thinning behavior. Galactomannans and xyloglucans with different monosaccharide ratios presented similar values of behavior and consistency indices, which might be attributed to differences in their fine structures. A better understanding of the physiological functions and chemical and rheological properties of hemicelluloses constitutes a challenging task for the near future and should encourage the synthesis of the studied sources and more profound applications in areas such as materials science, medicine and biology.

Large changes in price prompt companies to seek alternative sources for commercial gums, though the hemicelluloses investigated herein have not yet been industrially exploited. Based on the yield and physicochemical properties of *Caesalpinia pulcherrima* galactomannan, we can suggest that it represents a suitable potential substitute for guar gum in tropical countries as well as a renewable resource capable of fulfilling a wide range of applications in the pharmaceutical and food industries.

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