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Biotechnological Applications of Galactomannan Matrices: Emphasis on Immobilization of Biomolecules

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Authors' contributions

This work was carried out in collaboration among all authors. Authors PBSA and LCBBC managed the literature searches and wrote the first draft of the manuscript. Authors MTSC, JAT and MGCC designed the study and managed the study performed. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Polysaccharides are natural polymers extracted from plants, algae, animals, fungi or obtained via fermentation that can be applied on a wide range of uses, from food to biomedical industries. Galactomannans are polysaccharides mostly extracted from the endosperm of leguminous seeds and responsible to perform functions of energy reservation and hydration. They have singular properties that direct their potential use as films/coatings, gel agents, a part of mixed systems such

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as hydrogels, emulsion stabilizers, thickeners, and cosmetics. The characterization of galactomannans from conventional and nonconventional sources were reported as capable to produce the broad range of galactomannan matrices (films/membranes, coatings, gels and hydrogels). Matrices based on galactomannans, in addition, were explored as effective supports for immobilization of different functional compounds. The knowledge of the application of galactomannans as films and coatings is still limited compared with those already reported for other polysaccharides; moreover, the some publications brought new insights of the properties and characterization of edible films. The works in which galactomannan films are used as support for immobilization of biomolecules are still scarce, especially in health care. Due to their viscous and elastic properties, galactomannans have been widely investigated in mixed gels containing two or more biopolymers with the aim to improve cohesion, appearance, stability and durability of the gel. Studies involving the use of galactomannans in gels for immobilization of biomolecules have also been developed with the important purpose of evaluating the controlled release of suspensions contained in nanostructures. This review article aimed to approach the most recent literature dealing with galactomannan-based matrices and exposes the main strategies for the immobilization of biomolecules and their potential applications in industry.

Keywords: Galactomannan; film; gel; hydrogel; immobilization; matrices.

1. INTRODUCTION

Medicines, foods, fibers, natural and essential oils, cosmetics, chemical compounds and biofuels are examples of products that can be manufactured from a broad class of chemical substances from plant and animal species. Polysaccharides represent one of the most important classes, since they are natural polymers extracted from plants, algae, animals, fungi, or obtained by fermentation, with a wide range of applications, especially in food, biomedical, pharmaceutical and cosmetic fields [1].

Galactomannans are polysaccharides mostly extracted from the endosperm of leguminous seeds (Fig. 1) and responsible to perform functions of energy reservation and hydration. They have special properties such as high molar mass, water solubility and non-ionic character [2], which direct their potential use as films/coatings [3-8], as gel agents [9], as a part of mixed systems such as hydrogels [10,11], as emulsion stabilizers [12], thickeners [13], and cosmetic materials [14].

The characterization of galactomannans from conventional [3] and nonconventional [15-17] sources were reported as capable to produce the broad range of galactomannan matrices (films/membranes, coatings, gels and hydrogels). Matrices based on galactomannans, in addition, were explored as effective supports for immobilization of different functional compounds, such as peptides [4], antioxidants [8], lectins [18], and medicines [19].

Regarding the formulation of galactomannans as films/membranes and coatings, it is important to note the differences between the terms: Films or membranes are formed by drying of a polymeric

Fig. 1. Seed of Leguminosae family: representation of the constituents hull, endosperm and germ

solution, while coating is a suspension that can be directly applied to the product. Films based on galactomannans have been used in several applications, including pharmaceutical field and food industry. The most common polysaccharides used for production of edible films are cellulose, chitosan, agar and starch; galactomannans emerge as alternative materials that can be used for the production of edible films based on their edibility and biodegradability [5,20].

On the other hand, gel is considered a three-dimensional network obtained by the linkage of macromolecules wrapped in a solvent, which support their own weight and maintain its shape. The presence of non-covalent cross-links complicates the description of physical properties from such networks due to the influence of temperature and time in the number and position of these connections [21].

The gels generally exhibit viscous and elastic properties, with a predominance of the elastic mode. The functional properties of galactomannans are widely used in industry; then to optimize this industrial use, it is necessary to develop methods that would allow predicting the structure and the function of these polymers through the knowledge of their conformations.

Among the physicochemical methods used in this evaluation are the rheological techniques, which describe the mechanical properties of materials under distinct deformation conditions, since they exhibit the ability to flow and/or accumulate reversible deformations [22].

Galactomannans have been widely investigated in mixed gels containing two or more biopolymers with the aim to improve cohesion, appearance, stability and durability of the gel. The synergy between galactomannans and other polysaccharides, such as agar and galactomannan [23,24], galactomannan and xanthan [25], pectin and galactomannan [26], galactomannan and k-carrageenan [11], and unconventional galactomannans with xanthan and carrageenan [9] have been described.

This review article consider the most recent literature dealing with galactomannan matrices and emphasizes their potential use for the immobilization of distinct biomolecules. Moreover, their broad range of applications in industry was also exposed.

2. INTRODUCTION TO GALACTO-MANNANS

Galactomannans are polysaccharides composed by a linear chain of β-1,4-D-mannopyranose to which α-1,6-D-galactopyranose units are attached. They could be obtained from microbial sources, in particular yeasts and other fungi, and from plants. In what concerns the vast majority of galactomannans derived from plants, those polysaccharides display a reserve function and their main source is the endosperm of seeds, especially from members of the Leguminosae family [27]. The legume species are spread throughout the world, especially in tropical and subtropical regions, ranging from emergent trees to tiny and ephemeral herbs [28].

Polysaccharides from seeds are examples of natural compounds that have contributed to the Leguminosae family classification, but special emphasis has been given to galactomannans [29]. According to Engler classification [30], the Leguminosae family is divided into the subfamilies Caesalpinioideae, Mimosoideae and Faboideae. The use of galactomannans as a taxonomic character has been proposed by many authors due to the yield of extraction from the endosperm of the seeds as well as the ratio between the residues of mannose and galactose in the molecule and the contents of these compounds in the seeds [31].

Another utility of the galactomannans considers the Leguminosae family as the second most important into the Dicotyledoneae class and the first in economic importance. Three possibilities for the fine structure of the molecule, corresponding to the distribution of galactose along the mannose main chain, have already being proposed (Fig. 2).

To provide differences in density and viscosity of solutions, the proportion and distribution of galactose units has an essential role in solubility of galactomannans, its water solubility increasing with rising content of galactose (i.e. with decreasing M/G ratio). A polysaccharide chain composed of at least 85 to 95 % mannose units will provide intermolecular interactions like hydrogen bonds between cis hydroxyls of mannose, leading to formation of insoluble aggregates [32]. The presence of branched chains of galactose creates steric impediment between intermolecular hydrogen bonds, minimizing the formation of aggregates. Moreover, galactomannans with few side chains (greater ratio mannose/galactose) may interact better with other polysaccharides due to the long unsubstituted regions [12]. For a better understanding of sources of galactomannans and their main properties, Table 1 summarizes those characteristics and the most important applicability of galactomannans from Leguminosae family.

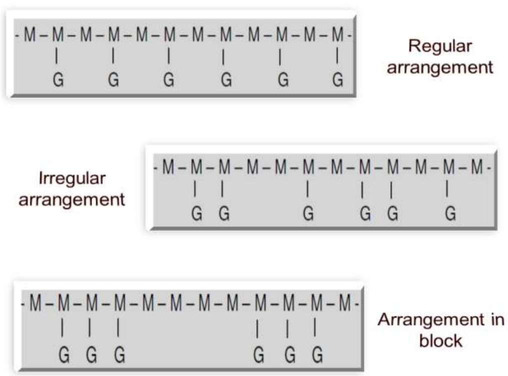

Fig. 2. Distribution of galactose units along the mannose main chain

M: representation of mannose units linked by β(1→4); G: representation of substitution by galactose units with linked α(1→6). Based upon Dea and Morrison [27]

3. BIOTECHNOLOGICAL APPLICATIONS OF GALACTOMANNANS

The three main commercially used galactomannans in food and non-food industries are guar gum (*Cyamopsis tetragonolobus*), tara gum (*Caesalpinea spinosa*) and locust bean gum (*Ceratonia siliqua*) [27,33]. Other galactomannans commercially known are the gum extracted from *Cassia tora* [12] and the galactomannan from fenugreek *Trigonella foenum-graecum*, marketed on a smaller scale as well as that extracted from the seeds of *Prosopis juliflora* (Please see Table 1).

In food industry, guar gum and locust bean gum are the most used species [34], while tara gum has been accepted as an alternative to those already used [35]. In general, galactomannans improve the texture and appearance of foods and increase its resistance to temperature changes, been especially applied as thickeners and fat substitutes; they also can be used in dairy products, desserts (especially ice cream), jellies, powders, cake mixes and frosting, spices, sauces, soups and canned and frozen foods [36].

Galactomannans enter into the composition of dietetic foods since they are not digested by the body. The addition of guar gum to meals that are rich in carbohydrates reduces the postprandial rise of glucose and insulin in the blood. Moreover, the use of pharmaceutical preparations of pure guar gum and the gum added to foods improved the metabolism of carbohydrates and lipids in insulin-dependent and insulin-independent patients. The physiological action of guar gum appears to depend mainly on their ability to rapid hydration, increasing the viscosity of the bolus in the stomach and small intestine. The high viscosity in the small intestine decreases both digestion and absorption of carbohydrates, which tends to reduce postprandial hyperglycemia. There are also studies demonstrating that guar gum is able to lower blood low density lipoproteins/ LDL [37]. Also as regards the food industry, studies related to the mechanical and thermal properties of films based on galactomannans have been widely exploited for biotechnological application especially as edible films [5], for example for tropical fruits [7] and ricotta cheese [38].

In what concerns non-food industries, galactomannans are used as thickeners and stabilizers in pharmaceutical formulations, such as creams and lotions for cosmetic fields [39]. In addition, these polysaccharides have been applied as matrix in the controlled release of drugs, such as the formulation composed by galactomannan and xanthan gum, which has been used as controlled release drug carrier of sodium diclofenate and theophylline. Galactomannans were also employed as thickeners in effervescent tablets and formed a stable suspension, thus preventing the settlement of the particles and promoting a pleasant feeling in the mouth [40,41].

Galactomannans were also applied for the controlled release of drugs in the large intestine. The polysaccharide have been used as coating capsules and tablets in combination with proteins. Individually, these polysaccharides cannot be applied as drug carriers to the colon due to their solubility in water. However, the coating based on galactomannan and pectin in pH 7 becomes elastic and insoluble in gastric and intestinal fluids, thus able to pass through the upper gastrointestinal tract and allow the release just in the intestine [42].

Further, galactomannans are adsorbed by cellulose fibers and used in paper industry to improve the mechanical properties of paper by regulating the flocculation state of cellulosic fiber suspension [43].

Table 1. Galactomannans from Leguminosae family and their main properties including M/G ratio and applications

Leguminosae family		M/G ratio	Applications	Reference
Subfamily	**Species**			
Caesalpinioideae	*Cassia absus*	3.0	Medicinal purposes.	[44,45,46]
	C. alata	3.3	-	[47]
	C. emarginata	2.70	-	[27]
	C. fistula	3.0	Possess antitumoral activity.	[48,49]
	C. grandis	2.44-3.15	-	[15,50]
	C. marylandica	3.76	-	[51]
	C. nodosa	3.5	-	[52]
	C. occidentalis	3.1	-	[51]
	C. tora	3.0	Disintegrant in the formulation of orodispersible tablets. Thickener or gelling agent.	[12,53,54]
	C. spectabilis	2.65	-	[55]
	C. spinosa	2.70-3.0	Possess protective colloidal properties and interfacial tension activity. Important agent of synergism with other polysaccharides.	[12,56]
	Caesalpinia pulcherrima	2.88	Used as coating for tropical fruits.	[7,57]
	Ceratonia siliqua	3.5-3.75	Binder, lubricator, and stabilizer. Provides heat-shock resistance in ice cream products. Speeds coagulation of cheeses. Used as beads for drug controlled release. Important agent of synergism with other polysaccharides.	[33,34,51,56]
	Caesalpinia cacalaco	2.5	-	[12]
	Delomix regia	4.28	-	[27]
	Gleditsia amorphoides	2.5	-	[58]
	G. triacanthos	2.82	Food industry purposes. Reduce intestinal absorption.	[8,13,17,59]

Leguminosae family		M/G ratio	Applications	Reference
Subfamily	**Species**			
			Possess immunomodulatory activity and anti-inflamatory and antioxidant effects	
	Gymnocladus dioica	2.71	-	[51]
	Parkinsonia aculeata	2.70	-	[51]
Mimosoideae	*Besmanthus illinoensis*	2.69	-	[12]
	Leucaena glauca	1.33	-	[12]
	Adenanthera pavonina	1.35	Used as coating for tropical fruits.	[7,57]
	Mimosa scabrella	1	Used as tablets for oral controlled drug delivery.	[19,48]
	Prosopis juliflora	1.1-1.6	Potential for use in the food industry.	35,60]
Faboideae	*Sophora japonica*	5.75	Food industry purposes.	[17,61]
	Trigonella foenum-graecum	0.95-1.1	Reduce surface tension. Possess anti-inflamatory and antioxidative effects.	[56,62,63]
	Cyamopsis tetragonoloba	1.8	Thickener, stabilizer, emulsifier, and firming agent. Important agent of synergism with other polysaccharides. Used as blends for food industry. Part of mixed gels for topical drug delivery.	[51,56,64,65]

Several studies have been developed about the purification, description of the physical, chemical and biological properties, and use of galactomannans obtained from different and varied sources. Galactomannans of distinct plant species have been well characterized, such as the *Prosopis ruscifolia* [16], *Senna tora* [66], *Cassia grandis* [15,50], *Dimorphandra gardneriana* Tul. [1], *Caesalpinia ferrea* var. *férrea* [67], *Caesalpinia pulcherrima*, *Gleditsia triacanthos* and *Adenanthera pavonina* [57].

The degree of substitution of the galactose units in the mannose backbone is an important character in the interaction of galactomannans with other polymers. One of the first reports on the characteristics and properties of systems formed from binary mixtures of galactomannans and other polysaccharides were performed by McCleary et al. [68], who described rheological analysis between xanthan and the guar gum galactomannan and demonstrated that this interaction decreases with increasing the degree of substitution of galactomannans. Bresolin et al. [69] also evaluated the synergistic effect of xanthan and the galactomannans from *Mimosa scabrella* and *Schizolobium parahybum*. Grisel et al. [70] evaluated the synergistic effect of guar gum galactomannan and locust bean gum with xanthan and confirmed that the impact distribution of galactose units along the main chain of mannose is attached to the synergy mechanism. Lucyszyn et al. [23] applied gel mixtures of galactomannans and agar for plant cell cultures.

Another widely studied gel comprises k-carrageenan and galactomannan. Gonçalves et al. [71] observed that the addition of galactomannan improved the gel quality when compared to the pure k-carrageenan gel. In combination with galactomannan, the mixture became less brittle, stronger, and less vulnerable to syneresis. Pinheiro et al. [9] quantified the synergistic interactions between the galactomannans extracted from *Sophora japonica* and *Gleditsia triacanthos* with k-carrageenan and xanthan and compared the results with the traditional guar gum galactomannan and locust bean gum. The results demonstrated once more that the synergistic effect of the system depends on the ratio of mannose and galactose; in addition, the fine structure of the galactomannan.

There is a worldwide trend related to researches on purification, characterization and application of galactomannans, indicating the need to find seeds, which are alternative sources for the extraction of this polysaccharide, especially for industrial production. The possible sources for galactomannan extraction in Latin America are still unfamiliar despite the rich biodiversity of the local flora [1].

Brazil has rich sources of diversified species for the extraction of galactomannans from seeds that could leverage the marketing of this polysaccharide. Considering the prices for commercial galactomannans including guar gum and locust bean gum (0,10 euros per gram, approximately) [72], it is important to note the potential of the Amazon as supplier of seeds with high potential for galactomannan extraction yield, which has important highlight in trade and promising scientific researches.

3.1 Immobilization of Biomolecules in Galactomannan Supports

Enzymes, antibodies, proteins, drugs and cellular receptors are examples of biomolecules already immobilized by chemical or physical means in different biomaterials for applications ranging from diagnostic and therapeutic areas to separation methods and other bioprocesses.

Among the different classes of biomaterials that can be used as carriers, polymers have special interest due to reactive groups on its surface or other derivative groups that may covalently bind to biomolecules. Moreover, an advantage of polymeric supports for biomolecules relates to distinct processes for manufacture these systems, including films, membranes, tubes, fibers, particles, gels, hydrogels, capsules and porous structures [73].

Several immobilization methods are based on physical or chemical linkages between the biomolecule and the polymeric support. The main used methods are physical adsorption (hydrophobic interactions, hydrogen bonds or van der Waals forces), chemical adsorption (covalent or ionic bonds), immobilization by containment matrix and crosslinks (Fig. 3). It is important to note that the term immobilization refers both for a transient location as a permanent immobilization of the biomolecule in or on the polymeric support. Moreover, if the polymeric carrier is biodegradable, the immobilized biomolecule can be released by degradation of the matrix [73].

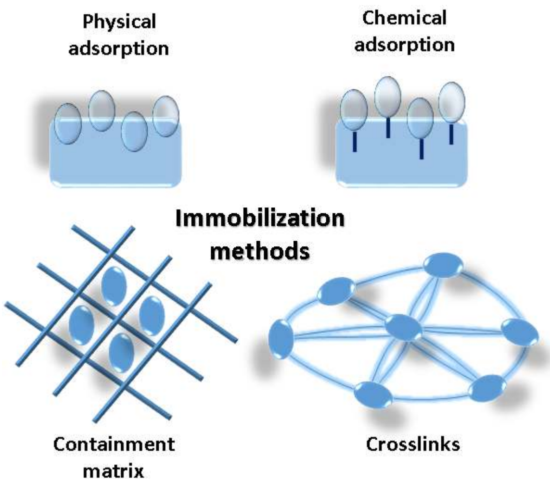

Fig. 3. Immobilizations based on physical or chemical linkages; containment matrix and crosslinks between the biomolecule and the polymeric support are represented

Currently, polysaccharides are reported as efficient polymers for biomolecule immobilization, for example, chitosan films from animal and microbial sources, added to glycerol, were used for the immobilization of bromelain [74]; the results suggested that the films with low molecular weight chitosan are suitable for application in wine industry. Proteases were immobilized on chitosan films and demonstrated an excellent anti-biofilm effect, especially against *Staphylococcus* cultures [75]. Bioengineering and medicine fields also reported innovations such as the combination of chitosan, gelatin and alginate with carbon nanotubes for protein immobilization [76]. Biomolecule immobilizations in polymeric matrices has also been developed for micro scale, for example the development of a glucose biosensor by immobilizing glucose oxidase in chitosan particles [77], in addition to the microparticles of gel produced from alginate and lactoferrin [78].

Considering the above-mentioned results, one can note that galactomannans are still little explored in most research carried out with polysaccharides for immobilization of biomolecules.

3.1.1 Galactomannan films/membranes as supports of immobilization

The polymers, whether natural or synthetic, are molecules whose chains are longer and able to produce continuous matrices vital for structuration of films, membranes and coatings. In order to avoid misinterpretations, it is important to distinguish the above-mentioned terms: Films or membranes are formed by drying (casting) of a polymeric solution, which can later be applied to a product; the coating can be a suspension or emulsion applied directly to the product surface and, after drying, leads to the formation of a film. These terms have been improved by the food industry to clarify the difference between coatings and edible films [79].

The preparation of films from biodegradable materials such as natural polymers has aroused the interest of the scientific community in recent decades, especially due to the importance given to the replacement of synthetic polymers. Films developed from polysaccharides (Fig. 4) are excellent barriers to oxygen due to packing of molecules, forming a structural network ordered through hydrogen bonds; however, there are hygroscopic characteristics that can reduce its potential for many applications [80].

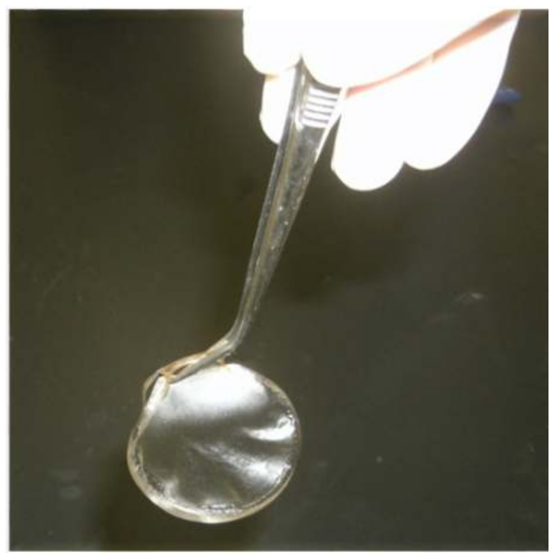

Fig. 4. Representation of films based on polysaccharides obtained from natural sources

The properties of films depend on the used polymer, the manufacturing conditions and environmental conditions, which are important factors due to the hygroscopic nature of the polymers [81]. The formulation of these products most often requires the use of plasticizers, since films without plasticizer addition exhibit a brittle and hard structure due to interactions among polymer molecules [79].

Plasticizers are low molecular weight agents that, once incorporated into films, are able to position themselves among the polymer molecules. They interfere with the polymer-polymer interactions and result in increased flexibility and processing capacity [82], as well as improve the product resistance to penetration of vapours and gases [40]. Water is a very effective plasticizer in the composition of films; other plasticizers are also hydrophilic and able to attract water molecules. Due to this feature, the relative humidity of films under storage becomes one of the main analysed properties especially due to the influence of water on the structure of the products [83].

Surfactants are considered amphipathic substances due to their hydrophilicity and hydrophobicity. They are usually added to enhance the emulsion stability of films. Surfactants could be incorporated to reduce surface tension of solutions, improving the wettability of the products [82].

The polysaccharides evaluated and/or employed to form films can be applied in the pharmaceutical field in encapsulation processes and release of active principles; as edible films in the food industry; in the cosmetic industry; in agriculture, such as pesticides and nutrients release agent; among other applications. The main polysaccharides reported on the production of films and coatings include: Starch [84,85], cellulose [86-88], alginate [89-91], carrageenan [92-94], chitosan [95-97] and natural gums, such as Policaju [98,99] and agar [100,101].

The knowledge of characterization and application of galactomannans as films is still limited compared with those already reported for other polysaccharides. Apart from this fact, the main publications brought new insights of the properties and uses of edible films, as reported below.

Cerqueira et al. [7] studied the application of coatings constituted by galactomannans from different natural sources (*Caesalpinia pulcherrima* and *Adenanthera pavonina*) in five tropical fruits: acerola (*Malpighia emarginata*), cajá (*Spondias lutea*), mango (*Mangifera indica*), pitanga (*Eugenia uniflora*) and seriguela (*Spondias purpurea*). The surface properties of the five fruits were determined for different aqueous solutions of galactomannans plus glycerol. Lima et al. [102] also used the galactomannans obtained from *C. pulcherrima* and *A. pavonina* to coat fruits, but added collagen and glycerol to the filmogenic solutions and evaluated the application of the coatings on mangoes and apples. The influence of storage temperature on the gas exchange rate of cheese coated with galactomannan was also evaluated [38] and the study of the physicochemical properties of edible films with different concentrations of locust bean gum and k-carrageenan was performed [3]. In general, edible films based on galactomannans tend to improve the appearance of the food and can be used as immobilizing media of nature preservatives in order to reduce microbial contamination, increasing the shelf life of foods coated with this polysaccharide.

It is important to highlight that mannose/galactose ratio, degree of substitution and degree of polymerization have been reported to directly affect edible films [103]. In addition, the immobilization of compounds in galactomannan films must be evaluated by the impact on the functionality of the final product, since the immobilized molecule can affect functional properties of the polysaccharide [5].

Martins et al. [4] developed a galactomannan film extracted from *Gleditsia triacanthos* with immobilized nisin and have been successful in preventing microbial contamination in cheese ricotta. Cerqueira et al. [8] used the same galactomannan from *G. triacanthos* to immobilize antioxidant extracts and implement the antioxidant activity of the final product. Valenga et al. [18] performed the immobilization of the lectin from *Canavalia ensiformis* seeds, ConA (glucose/ mannose binding), in galactomannan films obtained from the seeds of *Leucaena leucocephala*. They suggested that, as the backbone of the galactomannan is comprised of β-D-mannose units in which some α-D-galactose units are linked at the C-6 position, the recognition of ConA may occur through OH groups at C-3 or C-6 positions, if the latter mannose unit is free. These results demonstrate that the works in which galactomannan films are used as support for immobilization of biomolecules are still scarce, especially in health care.

3.1.2 Galactomannan gels and hydrogels as immobilizing supports

Gels are semi-solid systems in which small amounts of solid are dispersed in relatively larger quantities of liquid, a characteristic that provides a nature more solid than liquid to the system [104]. There is an inadequate interpretation in polymer science under the use of the terms gel and hydrogel as synonyms. Even though gels and hydrogels are chemically similar polymeric networks (Fig. 5), they have distinct physical structures [105]. Hydrogels are characterized as crosslinked networks of hydrophilic polymers capable of absorbing large quantities of water and swell while retaining its three-dimensional structure. Sometimes hydrogels are also described as aqueous gels due to the hydro prefix, although the term hydrogel implies a material already swollen in water [106].

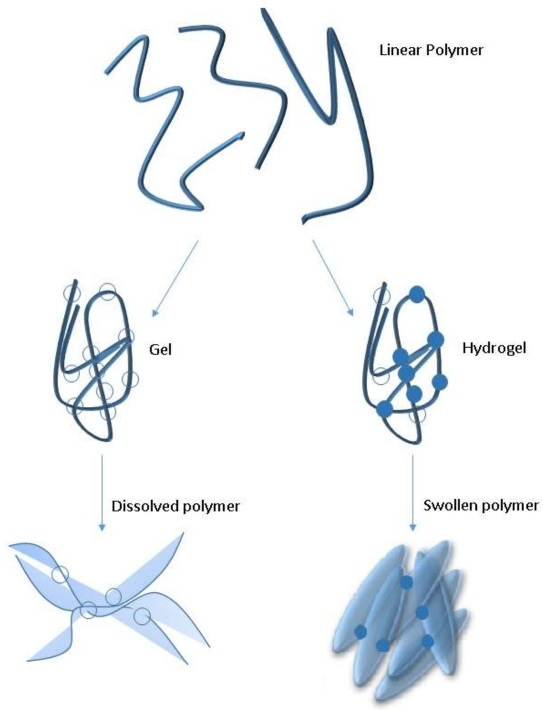

Fig. 5. Differential behavior of a polymer in aqueous solution

The closed circles represent covalent bonds and the open circles represent virtual entangled links

Although some gels are sufficiently rigid to maintain their structure under low stress, after exceeding a certain threshold value, the flow of the gel emerges as a characteristic linked to the loss in the polymer structure. Hydrogels can swell in aqueous medium for the same reason that a similar polymer can be dissolved in water to form a polymeric solution. Therefore, the central feature to form a hydrogel is its inherent crosslinking (ability to form cross-links). Conventional gels can also develop small levels of cross-links because of the energy gain under the influence of stress forces, but this process is reversible due to the involvement of weak physical forces [105].

Galactomannans themselves are nongelling agents, while some galactomannans are able to form gels with certain metal salts and others interact synergistically with different polysaccharides such as agar, xanthan, carrageenan, pectin and yellow mustard gum to form a three-dimensional gel network in appropriate conditions. Hydrated galactomannan molecules occupy a large hydrodynamic volume in aqueous solution and control the rheological behaviour of the entire solution [39]. The evaluation of this behaviour plays an important role in the characterization of galactomannan solutions, since these are often used to modify textural attributes [107]. This characterization can be performed through shear (steady and dynamic conditions) and extensional rheology [13].

Regarding the technical applications of galactomannan solutions, attention is drawn to the chemical behaviour of the different galactomannans. There are uses which benefit from the excellent viscosity formation of some galactomannans or their derivatives and there are utilizations which benefit from water absorption or from the formation of hydrogen bonds as well as gel formation [39].

Biologically active molecules such as proteins, peptides, saccharides, lipids, drugs, hormones, cell surface receptors, conjugates, nucleotides and nucleic acids can be immobilized based on physical or chemical linkages on polymeric supports. Biomolecules can be immobilized on the outer surface of the gel or within the hydrogel polymer network [73]. Applications ranging from the food to the pharmaceutical industry have used gels based on galactomannans as matrices for controlled release of compounds.

The galactomannan extracted from the seeds of *Mimosa scabrella*, for example, was prepared with xanthan and tested as hydrophilic matrix for controlled release of theophylline [40] and sodium diclofenac [41]. Koop et al. [108] utilized the galactomannan of the latter species as matrix for stabilizing ascorbic acid. The locust bean gum was mixed with xanthan and evaluated for promoting emulsion stability [109]. Rocha et al. [110] used silica and chitosan to immobilize *Aspergillus* and *Penicillium* fungal.

Studies involving the use of galactomannans in gels for immobilization of biomolecules have also been developed with the important purpose of evaluating the controlled release of suspensions contained in nanostructures [111,112]. Nanometric systems of polysaccharides have been studied intensively [113], especially in the biological field [114,115]. Nanocapsules, nanoparticles, liposomes, microspheres, microcapsules and nanospheres, belonging to the group of systems dispersed in nanometric scale, are pharmaceutical forms that intend to reduce side effects of many substances while increase its effectiveness after administration, even by different routes, including the cutaneous barrier. In this sense, the technological development of novel dosage forms in nanometric scale has been a promising strategy to increase the penetration of drugs through the skin in a controlled manner [116].

4. CONCLUSION

The purpose of this review was to approach the most recent scientific literature dealing with matrices based on galactomannans. Moreover, this review emphasis the main strategies for immobilization of biomolecules and their potential industrial applications. Solutions of galactomannans are considered viscoelastic materials since they exhibit both viscous (liquid) and solid (elastic) characteristics, which proposes its use as supports ranging from films/membranes to gels. This review article was motivated by the lack of adequate knowledge about the immobilization of biomolecules in galactomannan matrices and the impact on the functionality of the final product, since the immobilized biomolecule can affect functional properties of the polysaccharide.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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