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Review

Emerging applications of *Sterculia striata* gum in medical, pharmaceutical, and environmental fields: Prospects and challenges

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ABSTRACT

Trees of the genus Sterculia produce acidic polysaccharides with high viscosity and the ability to form gels in water. This work emphasized the species *Sterculia striata* and the uses of its plant derivatives, such as seeds, fruits, stem bark, and exudates. The species showed prospects for industrial application (seeds with high protein content, fruits with antioxidant potential, and stem bark with anti-inflammatory, antinociceptive, and gastroprotective potential). From a physicochemical and rheological point of view, the exudate has a high molar mass value; it contains uronic acid, galactose, rhamnose, and xylose. *Sterculia striata* gum (SSG) is highly viscous in solution and can form thermoreversible gels where gelation conditions depend on the purification method, acetyl groups, and presence of salt. Due to the presence of carboxylic acid groups, polyanionic behaving SSG allow the formation of polyelectrolyte complexes, which have been used in drug delivery systems (DDS) to encapsulate drugs such as antimalarial drugs, improve essential oil stability and obtain films for antimicrobial purposes. This review contributes to the understanding of the use of this biomaterial, providing a basis for new research on its different applications and industrial use, with a focus on the pharmaceutical, medical, food, and environmental fields.

1. Introduction

The trees of the genus Sterculia are known for producing several plant derivatives that, through adequate technological processing, present materials with great potential for the food, pharmaceutical, and even energy industries, such as biodiesel. Among these plant derivatives, those in this genus have the characteristic of producing exudates such as *Sterculia urens* gum (karaya gum). This commercial gum, exhibiting emulsifying, stabilizing, and thickening properties, is used as a food additive in the paper industry and in pharmaceutical products, generating significant economic gains for producing industries. However, several species belonging to the genus Sterculia that exhibit the present plant derivatives have yet to be explored [1–4].

Sterculia striata gum (SSG), native to the Brazilian Cerrado, produces a unique exudate with industrial potential. Widely distributed in various Brazilian states, this plant's exudate acts as a natural defense

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mechanism, forming an aqueous solution to seal wounds and prevent infection. Abundantly available in the Brazilian flora, SSG shows promising characteristics for pharmaceutical, medical and environmental applications [5,6].

The costs inherent to research and development (R&D) aimed at plant-derived products must be used efficiently. There are several options for the development of innovations to choose the best target for this field. In R&D, bibliographic research is essential to asset the state of the art of each genus or plant species [7,8].

Although several reviews have explored the main critical points associated with the Sterculia genus [9–11] as well as the relevance of this genus' applications in the pharmaceutical and biomedical fields [12], no reviews exist in the literature comprising a multidisciplinary approach linking two different strands: (1) an overview of SSG and (2) a critical analysis of characterization results applied to modified SSG seeking to develop pharmaceutical, medical, food, and environmental applications.

The present study thus provides a detailed search of the state of the art regarding the SSG's scientific and technological aspects. This review was based on the research of scientific articles and patent applications on the characterization and current use of the exudate of *Sterculia striata* and new perspectives for its application in the pharmaceutical, medical, and environmental industries.

2. Methodology

This study was based on research articles and patents about *Sterculia striata* gum. The search was carried out in scientific article databases (Science Direct, PubMed, Scopus, Web of Science, VHL) and patent applications (Derwent Innovations Index - DII, European Patent Office-EPO, World Intellectual Property Organization - WIPO, United States Patent and Trademark Office - USPTO and database of the National Institute of Industrial Property - INPI).

Scientific articles were selected according to the following inclusion criteria: they were published in English, and their abstracts and full texts were available.

3. *Sterculia striata* tree

Sterculia striata tree from the Brazilian territory is incipient in technological and industrial exploitation. This plant is native to the Brazilian Cerrado. It is widely distributed in Piauí, Maranhão, Bahia, Tocantins, Mato Grosso, Mato Grosso do Sul, Goiás, Minas Gerais, and the Federal District [13]. As with other species of the Sterculia genus, an exudate can be obtained from *Sterculia striata*, which is produced as a natural defense mechanism of this plant when the stem or branches of the tree are injured. It consists of an aqueous solution produced to seal the wound and prevent infection and dehydration of the plant. Over time, this solution dries and exhibits a glass-like appearance when in contact with air and light [6]. *Sterculia striata* exudate can be abundantly obtained from the Brazilian flora and has interesting pharmaceutical uses [5].

These articles on *Sterculia striata* trees have explored the potential of these species for use as oils, seeds, stem bark, and exudates in different economic-industrial applications (Fig. 1). These results demonstrated less exploitation of this species than the potentialities observed for its genus but with extensive potential. For example, the oil extracted from the seeds of *Sterculia striata* demonstrated good physicochemical properties for use as biodiesel, suggesting promising economic exploitation of this raw material in semiarid regions [14,15]. A study showed the thermal behavior of the oil of this species in 2013, which was rich in fatty acids containing a cyclopropenyl ring in its chain, mainly malvalic acid (heptadec-8,9-methylene-8-1-ol) and sterculic acid (octadec-9,10-methylene-9-ene) [16]. Another study demonstrated the use of a methylation procedure to determine the cyclopropenoid fatty acids in oil extracted from the seeds of *Sterculia striata*. This feature suggested transmethylation with potassium hydroxide in methanol. An appropriate method is to prepare methyl esters of cyclopropenoid fatty acids and quantify them by analysis via gas chromatography and nuclear magnetic resonance spectroscopy [17].

Sterculia striata bark has revealed anti-inflammatory and antinociceptive effects at doses ranging from 12.5 to 50 mg/kg ethanolic extract, demonstrating its therapeutic potential [18]. The possible mechanism involved in the antinociceptive effect of this herb may

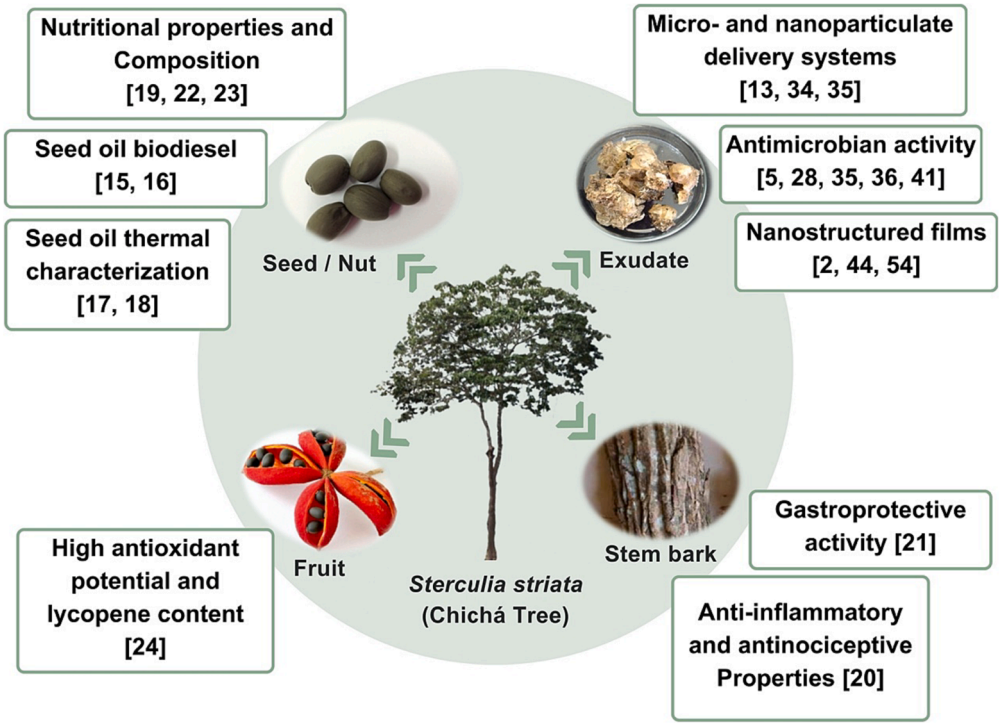

Fig. 1. Scientific literature addressing the use of plant derivatives obtained from *Sterculia striata* trees. EE and AE represent the **e**thanol extract and aqueous extract, respectively.

involve its action on opioid receptors [19]. The ethanol extract was shown to have gastroprotective effects in preclinical studies, inhibiting gastric lesions induced by ethanol, HCl/ethanol, and ischemia/reperfusion, with mechanisms of action involving nitric oxide and antioxidant compounds but not the modulation of prostaglandins [20].

Sterculia striata seeds have also shown potential in the food industry. A study demonstrated its good tolerability for consumption in rats [21]. Furthermore, the seeds were also free from anti-nutritional properties, such as trypsin inhibitory activity, which is responsible for the low digestibility of dietary proteins, urease activity, and lectin activity [21]. Studies have confirmed the absence of lectin and trypsin inhibitors in seeds. On the other hand, the seed contains a high content of the antinutrient phytate (10.6 mg/g) in raw almond, which is considered high compared to foods such as cashew nuts and Brazil nuts, macadamia nuts, pistachios, almond nuts, and walnut nuts. However, after roasting, the content of this antinutrient decreased, thus highlighting the possibility of using this seed in its roasted form [18].

Sterculia striata seeds and their by-products have also exhibited antioxidant activity related to many phenolic compounds, mainly ellagic, protocatechuic, and ferulic acids [22].

The fruits of *Sterculia striata* were explored as a food variety from the Brazilian Cerrado [23] and revealed to be nutritious and functional, suggesting that their future use in the food industry is possible. The fruits stand out for their total phenolic and lycopene contents. In addition, these ethanolic and aqueous fruit extracts also demonstrated antioxidant activity in the *in vitro* DPPH radical reduction test. In another study, fruits produced activated carbon from fruit peel, which was favorable for the adsorption of water contaminants [24].

In the next section, the structural characterization and composition of the *Sterculia striata* exudate are described.

4. Isolation and purification of *Sterculia striata* exudate

The extracted gum is an exudate heteropolysaccharide obtained due to a protection mechanism after an injury to the trunk or branches of the tree [25]. However, the collected exudate contains dust, plant bark, leaves, and other adhered impurities and must be purified to isolate the specific polysaccharide. *Sterculia striata* was isolated following the Rinaudo-Milas method, with modifications [26].

The exudate collected from the *Sterculia striata* tree bark was dissolved in 1% distilled water (w/v) by stirring at room temperature for 24h (Fig. 2). After dissolution, 1g of sodium chloride was added to the solution to reduce the viscosity and assist in filtration. The solution was filtered to remove impurities, and the pH of the filtered solution was adjusted to 7.0 with 0.1 mol/L sodium hydroxide solution. Ethanol was added to the solution at a ratio of 1:1 (v/v) to precipitate the SSG. The precipitated gum was transferred to Falcon tubes and washed first with ethanol and then with acetone to remove residual impurities from the filtration process. To finish the purification process, the SSG was dried at 40°C in an air oven for 24h and macerated to obtain power [13,27,28].

5. Composition and structural characterization of *Sterculia striata* gum

A structural study is essential for understanding the rheological behavior, gelling properties, and other physical behaviors of gums related to structural characteristics. For example, the chemical structure, monosaccharide composition, and molecular weight can affect the properties of gum in solution and its interactions with other compounds [29]. A detailed description of the characteristics of the *Sterculia striata* strains is presented in Tables 1 and 2.

5.1. Composition

SSG comprises uronic acid, galactose, rhamnose, and xylose. Several studies have analyzed the composition of SSG collected from native trees in the same city [1,30]. Gum's constituent sugar units were identified by acid hydrolysis, followed by separation of the released monosaccharides using different chromatographic techniques [31]. The monosaccharide compositions obtained were the same while their molar percentages varied, as shown in Table 1. These differences could be explained by seasonal variation and the hydrolysis process adopted by authors [1,30].

Gums, as polysaccharides, may contain polydisperse populations of molecules with a wide range of molecular weights. The molecular

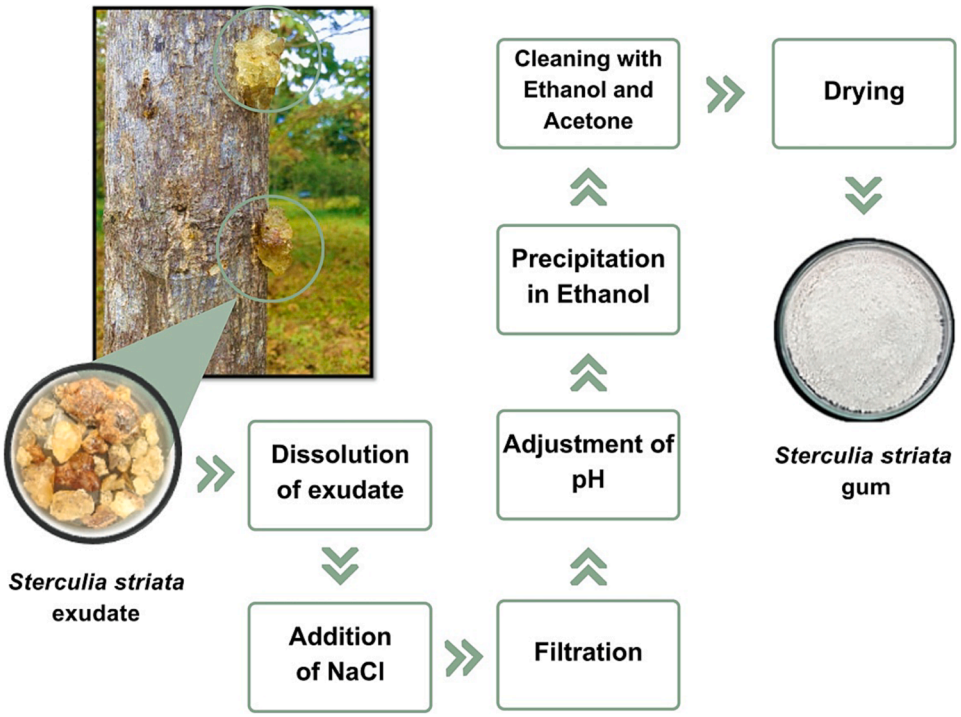

Fig. 2. Process of Isolation and Purification of *Sterculia striata* exudate.

Table 1
Composition and structural characterization of SSG.

Technique	Results	Reference
Chemical and Chromatography (% MOL)	Uronic acid (42.2 %), galactose (23.4 %), rhamnose (28.8 %), xylose (5.3 %) and acetyl groups (10.7 %).	[1]
	Uronic acid (49.2 %), galactose (19.3 %), rhamnose (23.1 %), xylose (7.7 %) and acetyl groups (9.6 %).	[30]
SEC:Molar mass	4.2×10^6 g/mol	[33]
	4.18×10^6g/mol	[34]
FTIR	O–H stretch (3380 cm^{-1}), C–H stretch (2930 cm^{-1}), C-O-C bond asymmetric stretching (1080 cm^{-1} and acid gum carbonyl group stretch (1740 cm^{-1}).	[34]
	Carbonyl groups of uronic acid and acetyl (1727 cm^{-1}). C-O stretch of acetyl groups of gum (1263 cm^{-1}).	[33]
	Acetyl groups (1736 and 1226 cm^{-1}), carboxylate group of uronic acid residues (1616 and 1418 cm^{-1}).	[1]
XRD	SSG diffractograms showed characteristics of an amorphous material.	[13,28,35]
NMR ^{13}C	Carbonyl groups of uronic acid (174.8 ppm), methyl group of rhamnose residues (17.5 ppm) and acetyl groups (21.3 ppm).	[1]

Table 2
Physical behavior of SSG obtained from viscosity tests and rheological analysis.

Performed Test	Evidenced Physical Behavior	Reference
- The viscosity was analyzed on a Canon-Ubbelohde viscometer with a water flow of 129 s at 25 °C. - Flow curves were obtained on a Brookfield DV-III instrument at 25 °C, in a concentration range of 0.1 to 1 % in 0.1 M NaCl for the polysaccharide samples.	- Highly viscous polysaccharide compared to other polysaccharides (cashew gum, Acacia senegal and *Enterolobium contortisilliquum*);-The electrostatic interaction between ions (mono and divalent) and the ionizable carboxylic groups of the gum promotes a contraction in the polymer chain, resulting in a reduction in viscosity; - SSG has a semirigid polymer chain conformation.	[1]
- The melting temperature of the gels (Tm) was determined by visually observing the onset of gel fluidity upon heating; -Dynamic oscillatory tests were performed on a Haake rheometer, model RS75.	- A model for the gelation of Sterculiacea gum was proposed;-SSG forms thermoreversible gels with gelation conditions (concentration and melting temperature) dependent on the purification method, acetyl group content, counterions present, and salt addition.	[3]
Dynamic rheological analysis was performed on a Haake oscillatory rheometer, model RS 75, C 60/2° sensor and a Peltier temperature control system.	- The behavior of aqueous solutions of SSG (concentration of 2–6 % m/v) is typical of gel; - A true gel was obtained in solutions with concentrations above 4 % (m/v); - SSG forms a weaker gel than karaya gum; - *Sterculia striata* and karaya gum gels did not show any significant conformational change with temperature variation; - The addition of NaCl decreased the strength of the SSG gel.	[30]

weight of gums can be determined using dilute solution viscometry, dynamic light scattering (DLS), and size exclusion chromatography (SEC) [32]. SEC was used to characterize the molecular mass of SSG. Its molecular mass was within the 10^6 g/mol range, similar to that of other gums, such as karaya gum (*Sterculia urens*) [33,34].

In gums, infrared spectroscopy has been used to qualitatively track eventual structural changes, which can result in improved properties such as biocompatibility and therapeutic activity. The Fourier transform infrared (FTIR) spectra of SSG presented by [3,34] exhibited characteristic bands of polysaccharides, such as the bands attributed to O–H and C–H and the acetyl and carbonyl groups of uronic acid (Table 1).

X-ray diffraction (XRD) is a structural analysis technique widely used to evaluate the crystallinity of different materials, and several publications have disclosed XRD results for SSG [13,28,35]. XRD showed that this gum has an amorphous character (Table 1) [13,36]. Natural gums such as karaya gum, gum arabic, and cashew gum also exhibit an amorphous nature [13,28].

Nuclear magnetic resonance (NMR) has become an essential technique in the characterization of polysaccharides that exhibit complex structures, including gums. The ^{13}C NMR spectrum of SSG did not present good resolution due to the high viscosity of the polysaccharide in deuterated water (D_2O). However, peaks attributed to the carbonyl groups of uronic acid, the methyl group of the rhamnose residue, and the acetyl group were observed [1].

5.2. Physicochemical properties

SSG contains a large amount of uronic acid (42.2 %–49.2 %), which in turn has ionizable carboxylic acid groups, giving the gum a polyanionic character [1]. This negative character enables electrostatic interactions with polycations to form polyelectrolyte complexes [3]. This feature has attracted the attention of researchers, and SSG has been applied as a component of pharmaceutical formulations, which are mainly new delivery systems such as hydrogels, nanoparticles, and films. The physical behavior results of the SSG upon viscosity tests and rheological analysis are displayed in Table 2.

5.3. Rheological behavior

5.3.1. Viscosity

SSG has a higher viscosity than other exudate polysaccharides. Aqueous solutions of gum at a concentration of 1% (m/v) at 25°C had an absolute viscosity of 400 mPa·s, a much higher value than that of polysaccharides from *Acacia senegal* (1.8 mPa·s), cashew gum (1.0 mPa·s), and the polysaccharide *Enterolobium contortisilliquum* (25.5 mPa·s). However, *Sterculia urens* gum showed an absolute viscosity of 700 mPa·s [1].

The resulting rheological behavior of SSG depends on its concentration and molecular weight, among other factors, and the influence of ionic forces cannot be neglected [1,3,30].

5.3.2. Influence of concentration

Researchers have evaluated the effect of concentration on aqueous SSG gum solutions. One study determined the viscoelasticity of SSG in aqueous solution by dynamic rheology. Aqueous solutions of purified gum at concentrations ranging from 2 to 6% (m/v) exhibited typical gel behavior ($G' > G''$, and the gel strength increased with increasing concentration. However, only solutions with concentrations greater than 4% (w/v) formed a true gel [30]. The viscoelastic behavior of deacetylated SSG solutions differed from that of pure gum [30]. Deacetylation contributed to the decrease in gel strength [30]. This result corroborated that obtained by [3]. The authors observed that the presence of an acetyl group contributes to the stability of polysaccharide junction zones, which results in a more potent gel [30].

5.3.3. Influence of ions

The addition of NaCl at different concentrations decreased the intrinsic viscosity with increasing salt concentration due to the interaction between the Na^+ ions and the anionic groups present in the gum

(ionized carboxylic groups). This interaction promoted contraction of the macromolecule, resulting in a reduction in viscosity. This effect confirmed that the polyelectrolytic behavior of SSG implies a certain flexibility to the polysaccharide chain as the salt concentration increases [1].

The effects of Na^{+}, Ca^{2+}, and Al^{3+} ions on reducing the viscosity of SSG were evaluated. The lowest intrinsic viscosity was observed in the presence of Al^{3+}, reflecting a strong contraction of the chain. The chain was less contracted in the presence of Na^{+}, while Ca^{2+} promoted an intermediate contraction [1].

A model for the gelation of Sterculiaceae gums (Fig. 3) that includes ionic interactions and hydrogen bonds was proposed. Ionic interactions between galacturonic acid residues and calcium ions (●) (junction zone A); hydrogen bonds between rhamnose segments (junction zone B); and ionic interactions involving galacturonic acid and counterions (calcium or other metal ions) (○) and (junction zone C) [3].

5.3.4. *Influence of pH*

A study evaluated the influence of pH on viscosity in SSG solutions (0.03%). With these results, it was possible to observe that pH influences viscosity. However, this influence did not occur linearly. Gradually increasing the pH of the solution from 1 to 6 caused a significant increase in viscosity. In parallel to this study, the influence of pH on the zeta potential was also evaluated. An increase in the negative charge of SSG was observed for this same pH range. An increase in the negative charge caused intramolecular electrostatic repulsion, which drove the expansion of the polysaccharide polymer chain. Therefore, an increased negative charge increased the viscosity [5].

Gradually increasing the pH from 6 to 10 decreased the viscosity of the SSG solution. The zeta potential values in this same pH range were close to those corresponding to pH 6. This effect was attributed to the electrostatic interaction between the negative charges of the gum and the NH^{+} cations added during pH adjustment, which caused the polymer chain to contract, decreasing the viscosity [5].

5.3.5. *Melting temperature*

The melting temperature (Tm) is a parameter used to characterize the gelation of polysaccharides. Tm corresponds to the temperature at which the junction zones in the gel network dissociate. A study revealed that SSG is capable of forming thermoreversible gels under gelation conditions (concentration and Tm) dependent on the purification method, acetyl group content, counterions present, and salt addition [3].

6. Chemical modifications of *Sterculia striata* gum

The properties of this polysaccharide can also be modulated by modifying their polymeric structure to expand the applications of SSG gum. Therefore, structural modifications have been carried out via

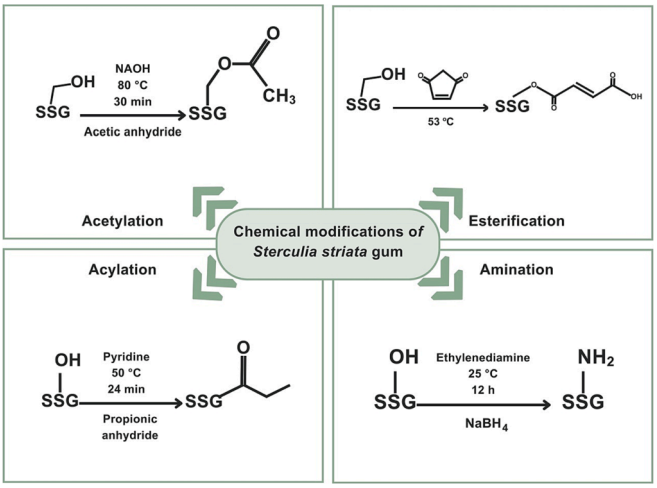

Fig. 4. Chemical modifications of SSG.

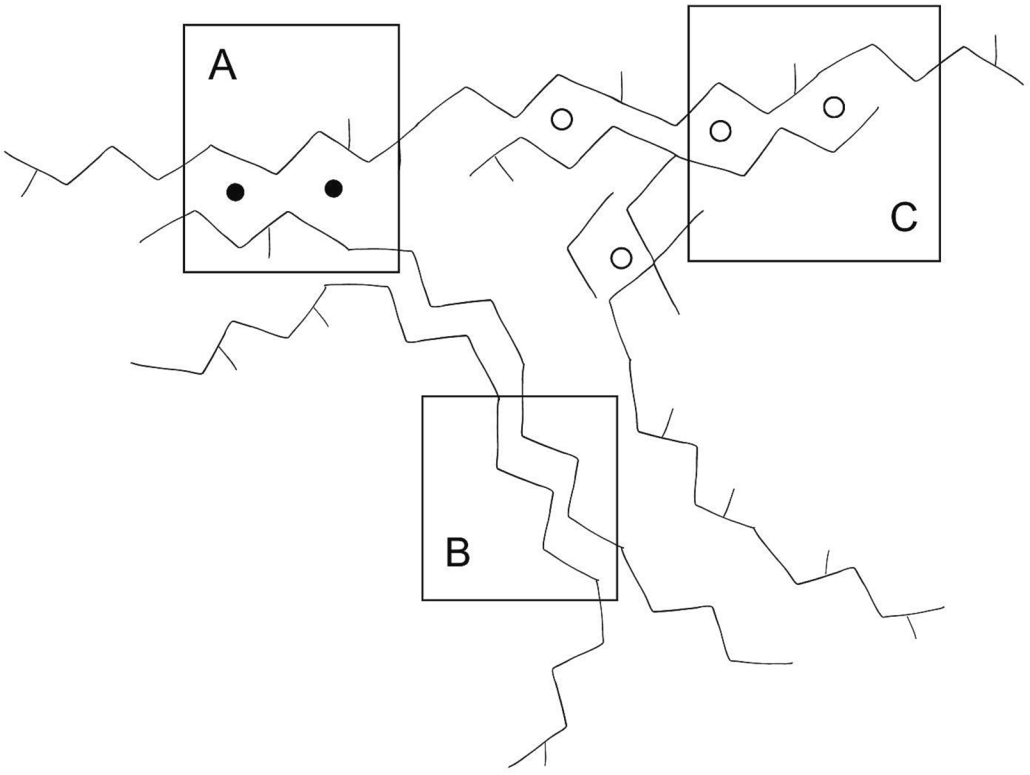

Fig. 3. Model proposed for the gelation of Sterculiaceae gum adapted from [3].

acetylation, acylation, esterification and amination [5,27,35,37,38], as shown in Fig. 4.

6.1. Acetylation

Acetylated polysaccharides can undergo acetylation in either an organic or aqueous medium. The traditional method for acetylating polysaccharides involves acetic anhydride and pyridine. During acetylation, polysaccharides are dissolved in specific organic solvents, such as formamide or DMSO, and acetylated by acetylating agents, such as acetic anhydride [39]. Moreover, catalysts such as pyridine or 4-dimethylaminopyridine (4-DMAP) can expedite the reaction and improve the degree of acetylation [40–42].

In the case of acetylation by aqueous medium, the unmodified polysaccharide is dispersed in water, the pH is adjusted to 8–9 using NaOH, and acetic anhydride is slowly added while cooling [43]. Subsequently, the mixture was pH neutralized with HCl to complete the reaction, then acetylated product was isolated from the reaction mixture, rinsed, and subjected to freeze-drying [40,44,45].

In a study aimed at producing acetylated SSG, four gum derivatives were obtained by varying the molar ratio of acetic anhydride to gum. Acetylated SSG exhibited a degree of substitution (DS) ranging from 0.48 to 1.68. Characterization by DS is essential for modified gums. The DS represents the average number of hydroxyl groups replaced by acetyl groups per monosaccharide unit. The results indicate that higher concentrations of acetic anhydride led to increased DS [37].

The acetylated SSG was also obtained using a different method without pyridine. The researchers incorporated SSG with acetic anhydride at 80°C for 30 min in a reflux system. Afterward, NaOH solution was added, and the reaction was maintained for four hours. The reaction product was precipitated in ethanol and dried at 40°C. The derivative had a DS of 0.55 [35].

Despite variations in the acetylation of SSG reported by both authors, the infrared spectra of acetylated SSG demonstrate similarities. Every infrared spectrum indicated heightened band intensity attributed to C=O and C–O–C of acetyl groups, accompanied by a simultaneous reduction in the band at 3500 cm^{-1} due to the substitution of hydroxyl groups [35,37].

6.2. Acylation

The acylation reaction refers to the addition of any acyl group to a substance. Acyl groups can vary and include, for example, groups such as benzoyl and propionyl groups. Acylation is often carried out using specific acid chlorides or acid anhydrides, depending on the desired acyl group [46,47]. The acyl group is generally represented as "RCO-", where R is an aliphatic or aromatic group. Some specific examples of common acyl groups include acetyl (CH_3CO–), propionyl (CH_3CH_2CO–), benzoyl (C_6H_5CO–), and butanoyl ($CH_3CH_2CH_2COO$–) groups [48,49].

Researchers developed and characterized a nanocarrier based on SSG modified via an acylation reaction with propionic anhydride and pyridine. Three gum derivatives were obtained by changing the molar ratio of the reactants. The reaction with propionic anhydride changed the hydrophilic balance of the gum. The propionate derivative of the SSG exhibited a substitution degree ranging from 0.48 to 1.68, along with hydrophobic characteristics. The infrared spectra of the derivatives also indicated chemical modification, which is primarily reflected in the increase in the intensity of the C=O vibration band. The derivative with the highest degree of substitution was selected for drug encapsulation [38].

6.3. Esterification

Another method for incorporating hydrophobic groups into biopolymers involves employing an esterification reaction. Researchers often opt for anhydrides, such as succinic, phthalic, and maleic anhydrides, as reagents in these esterification reactions [50–52]. The reaction occurs between the polysaccharide hydroxyl groups and the anhydride carbonyl groups. This chemical process can introduce amphiphilic groups, imparting a surfactant character to the biopolymer. Hence, numerous researchers have embraced this method to enhance the emulsifying properties of biopolymers [36,53].

Producing amphiphilic polysaccharides with emulsifying capabilities is essential for drug delivery system applications. The emulsifying feature contributes to nanoparticle stabilization [32]. Additionally, some research indicates that phthalate polysaccharides can exhibit diverse characteristics influenced by pH, which is helpful in gastrointestinal-modulated delivery systems, for example [50,53].

The amphiphilic nature achieved through the esterification reaction can also be specifically employed to enhance the interaction of the biopolymer with the double-membrane cell envelope found in Gram-negative bacteria [36,54].

Modifications of SSG through esterification were performed using two different types of reagents: maleic [27] and phthalic anhydride [36]. Modified and original gums were analyzed through elemental analysis, thermogravimetric analysis, XRD, and FTIR spectroscopy. The findings elucidated distinct differences between the natural gum and its modified counterpart. Nonetheless, acquiring nuclear magnetic resonance spectra is deemed indispensable for a more nuanced comprehension of the structural alterations in the modified gums.

6.4. Amination

The amination reaction refers to substituting the –OH group with the $–NH_2$ group at some positions in the monosaccharide units of polysaccharide backbones. Amination can be carried out by adding the reagents ethylenediamine and sodium borohydride. The OH group of the polysaccharide was replaced with $–NHCH2CH_2NH_2$. Then, sodium borohydride was added, and the $–NHCH_2CH_2NH_2$ group was reduced to the $–NH_2$ group [55–57].

A study showed that aminated-SSG presented a less negative zeta potential (−33.10 mV) than did the unmodified SSG (−59.10 mV). This change in the surface charge of the polysaccharide was attributed to the presence of positively charged amino groups. Aminated-SSG presented increased mucoadhesive activity, which was also justified by the presence of positively charged amino groups in the polymer chain that interact with the mucosa through electrostatic interactions since the mucosa has a negative character [5].

7. Industrial applications of *Sterculia striata* gum

The SSG structure is versatile and can promote electrostatic interactions. This feature allows this gum to be a component of large application areas, such as environmental, medical, and pharmaceutical formulations (hydrogels, nanoparticles, and films) [35,36,58–60], as shown in Fig. 5.

Pharmaceutical and biotechnological applications obtained from SSG either unmodified or modified, are discriminated in Table 3. This section will discuss all the opportunities and challenges related to SSG applications.

7.1. Pharmaceutical and medical applications

7.1.1. Micro- and nanoparticulate drug delivery systems

Drug delivery systems (DDS) are designing and technological strategies for improving the therapeutic efficacy of drugs or natural ingredients such as essential oils. DDS can protect ingredients from degradation conditions such as the gastric environment while in the gastrointestinal tract, but they can also enhance pharmacokinetics, such as intestinal absorption, and provide controlled release properties. Biopolymers such as gums have been studied for use in producing DDs because they are biocompatible and biodegradable [63].

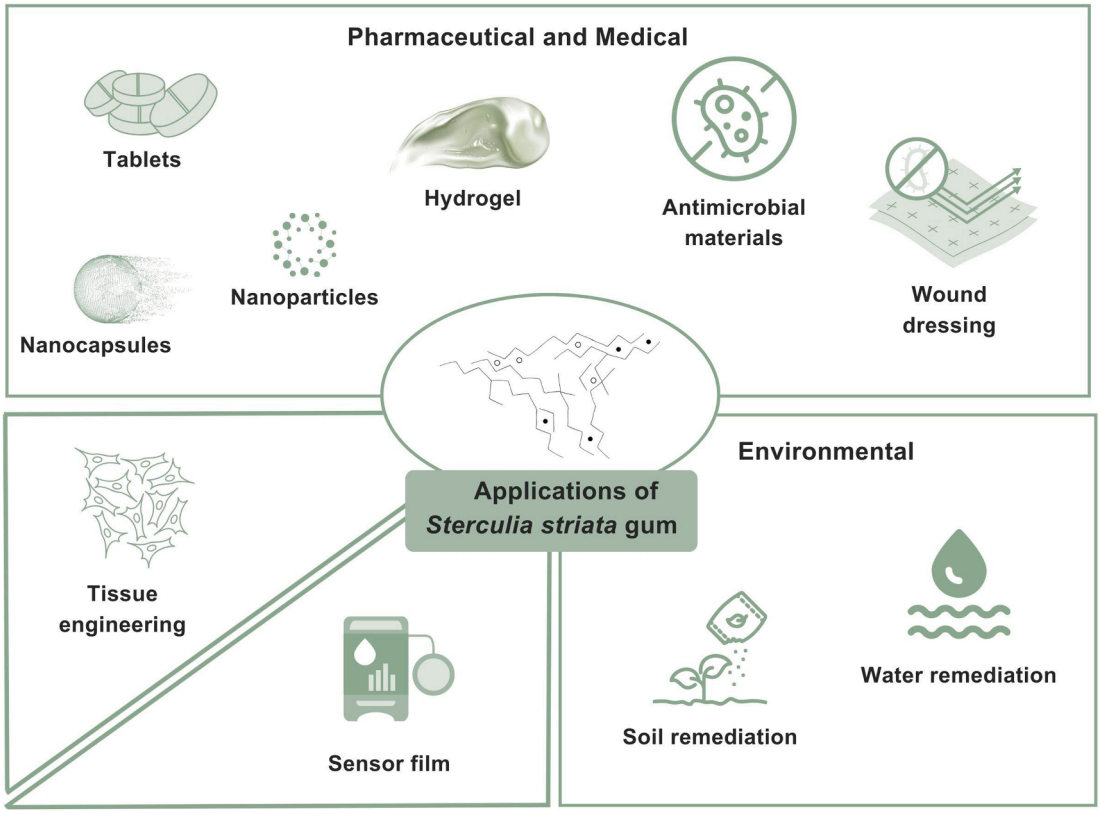

Fig. 5. Pharmaceutical, medical, biotechnological, and environmental applications of SSG.

Additional biopolymers (dextran sulfate, chitosan, and albumin) have been added to SSG in an oral delivery system to increase the oral bioavailability of insulin. The methods used to prepare the formulation were based on ionotropic pregelation followed by electrolytic complexation of oppositely charged biopolymers under controlled pH conditions. This study was the first to propose a SSG-based insulin delivery system with the potential for oral administration of protein drugs; this system was considered a valid alternative for efficiently delivering these drugs [13].

Because chitosan and SSG are positively and negatively charged, respectively, under certain experimental conditions, they can interact and produce charged nanoparticles through polyelectrolytic complexation. One study demonstrated the particle formation capacity of these materials by carrying chloroquine in a nanoparticle formulation. The study showed that the charge proportion between chitosan and SSG influences the incorporation efficiency and the chloroquine release rate. The nanoparticles prepared with excess SSG had greater incorporation efficiency and more prolonged drug release. The authors believe that this result is due to the interaction of the cationic drug with the excess gum present in the formulation. In this way, the nanocomplexes associated with chloroquine exhibited prolonged release for up to 12 days, indicating that these formulations can be applied in controlled drug release systems [33].

The acetylated SSG nanocapsule formulation was applied to the carrier amphotericin B, a drug widely used for treating fungal infections and leishmaniasis. Nanocapsules loaded with amphotericin B exhibit up to 99.2% encapsulation efficiency, controlled release, good hemocompatibility, and antifungal activity [37].

In another work, the authors developed and characterized a nanocarrier based on acylated SSG. This nanocarrier was also applied as an amphotericin B delivery matrix. The results indicated that the nanocapsules are potentially safe materials for the controlled release of amphotericin B for up to 120 h [38].

Essential oils are highly relevant in the pharmaceutical field. However, their use is limited because they are very labile substances and have low bioavailability. Many studies have shown that nanoparticles can protect essential oil properties [64,65].

One study investigated the nanocapsule production of the essential oils of SSG and *Lippia sidoides*. It was possible to verify that SSG protected the oil during the nanocapsule preparation process, which favored greater encapsulation efficiency due to less oil loss. The oils of the nanocapsules prepared with SSG were maintained without significant loss over 365 days, indicating protection against degradation by this material. These findings showed that researchers obtained a formulation based on chitosan and gum capable of preserving the properties of *Lippia sidoides* essential oil [34].

7.1.2. Gels/Hydrogels as mucoadhesive and wound healing formulations

Hydrocolloids are substances that can form gels or colloids when mixed with water. These compounds possess interesting properties, such as thickening, gelation, and stabilization of aqueous systems. They play a significant role in the food, cosmetic, and pharmaceutical industries and have a variety of applications [66]. SSG is a biopolymer with desirable characteristics for gel formulation, such as gelling ability and swelling capacity [30].

One study developed a gel with SSG, chitosan, and oil for wound treatment. The gel was tested on the skin of leased rats after topical application for 21 days. The material combination provided a gel with adequate support for the skin healing process [58].

SSG hydrogels were synthesized with nerolidol to improve their antimicrobial properties through a transdermal formulation. Nerolidol is an essential oil extract from citrus plants with antimicrobial activity potential. The hydrogel characterization confirmed the interaction between nerolidol and OH groups on the SSG polymeric chain. SSG nerolidol-based hydrogels also exhibited effective mechanical properties, such as adhesiveness and cohesion. The *in vivo* experiment demonstrated the practical effectiveness of the hydrogels in treating wounds, as these materials facilitated skin re-epithelialization. A wound

Table 3
Pharmaceutical and biotechnological products obtained from modified SSG.

SSG Chemical modification	Composition	Formulation Type	Purpose	Physicochemical Output	Biological output	Authors
NA	Chloroquine + SSG + high molecular mass chitosan or low molecular mass chitosan	Nanoparticle	Chloroquine encapsulation and understand the interaction between Chitosan and SSG.	Nanoparticles were assembled because of polysaccharides' opposite charges. The chloroquine nanoparticle formulation had an EE around 50 % and showed a drug release over 12 days.	NA	[33]
NA	SSG + Chitosan + *Lippia sidoides* essential oil	Nanoparticle	Encapsulation of *Lippia sidoides* essential oil and its protection against degradation.	Nanoparticles were obtained by spray drying. The most promising result of nanoparticle encapsulation efficiency was 59 %.	NA	[34]
NA	SSG + Chitosan + magnetite	Coated nanoparticles	To combine chitosan and SSG to produce a hydrogel and coat magnetic particles.	The coating was produced based on polyelectrolyte complexes between chitosan and SSG.	NA	[60]
NA	SSG + Chitosan + MFO	Gel	Wound healing	Chitosan and SSG have opposite charges and can interact to assemble a gel formulation.	The formulation proved a complete skin re-epithelization after 21 days.	[58]
NA	SSG + nerolidol essential oil	Gel	Wound healing	The hydroxyl groups in the SSG structure exhibited a chemical tendency to create hydrogels. This interaction facilitates the bonding with nerolidol thus enhancing its utilization in drug delivery systems.	A 83.6 % antibacterial growth inhibition effect against the bacterium *Staphylococcus aureus* was obtained.	[61]
NA	SSG + Pure Ionic Liquid + Lysozyme	Film	Sensor film to detect dopamine	NA	NA	[59]
NA	Poly-o-methoxyaniline (POMA) + SSG	Electroactive nanostructured film	NA	NA	NA	[62]
Acetylation	Acetylated SSG + Amphotericin B	Nanoencapsulation	Hydrophobic modification of gum for production of stable DDS without the use of surfactant	Nanocapsules based on modified gum were produced spontaneously with no use of a surfactant; a monomodal distribution profile of nanocapsules with no aggregation was observed.	Drug-loaded nanocapsules showed good hemocompatibility, inhibition of fungi, and a release profile of the drug for up to almost 9 days.	[37]
Acylation	Acylated SSG + Amphotericin B	Nanoencapsulation	Synthesis and characterization of a DDS based on SSG-modified gum	Change in the hydrophilic balance of SSG led to the formation of stable nanocapsules by spontaneous emulsification with no use of surfactant.	Modified SSG based nanocapsules are potential safety materials for controlled release of amphotericin B.	[38]
Esterification	Phthalated SSG	Antibacterial agent	Search for a new biologically active gum	The modification increased the hydrophobic behavior of the gum while maintaining its thermal stability.	Higher antimicrobial activity of modified gum suggested that SSG hydrophobization improved interaction with bacterial cell wall components	[36]
Esterification with maleic anhydride	Esterified SSG	Antibacterial Agent	to increase the antimicrobial activity of SSG	Modified SSG presented higher mass variation at lower decomposition temperature than CG's.	Modified SSG showed an anti-staphylococcal effect.	[27]
Acetylation	Acetylated SSG	Antibacterial and Antiparasitic Agent	Search for natural antibacterial agents	Higher hydrophobicity to the modified gum; increase in the degradation temperature of modified gum.	Acetylation led to an increase in antibacterial activity	[35]
NA	SSG + Chitosan + Insulin + Calcium Chloride + Dextran Sulfate + Albumin + Polyethylene Glycol + Poloxamer® 188.	Nanoparticle	To protect insulin from gastric pH	The formulation containing SSG was able to protect 64 % of insulin in simulated gastric conditions.	SSG-based formulation improves mucoadhesion in the gastrointestinal tract.	[13]
Amination	Aminated SSG	Antioxidant capacity, improved mucoadhesive and antimicrobial properties	To increase gum reactivity for the development of new DDS	Decreased the SSG's molar mass and surface charge; increased the crystallinity.	Increase in the mucoadhesive and antibacterial effect of aminated SSG.	[5]
NA	SSG	Tablets and hydrogels without drugs	To produce tablets and hydrogels with adhesive properties	SSG tables and hydrogel presented mucoadhesion proprieties;	NA	[28]

SSG-*Sterculia striata* gum; DDS-Drug delivery system; DS-Dextran sulfate; EE-Encapsulation efficiency; MFO- *Mauritia flexuosa* oil; NA-Not applicable; NiTsPC- Nickel tetrasulfonated phthalocyanines; PAH- Polyallylamine hydrochloride; PEG- Polyethylene glycol; POMA- Poly-o-methoxyaniline.

histological study revealed complete re-epithelization on the 14th treatment day [61].

Gel properties are also crucial for determining oral compositions. Formulations with mucoadhesive capabilities can increase retention in the gastrointestinal tract. This feature can promote sustained drug release [67].

One study tested the intestinal mucoadhesion of aminated SSG and unmodified gum. The test was conducted using a texture analyzer and pig intestinal mucosa. The present study demonstrated that both gums exhibited mucoadhesive properties. The mucoadhesive properties of SSG are connected to carboxyl and hydroxyl groups within its polymer chain, which promote mucoadhesion through hydrogen bonding with the mucosa. Aminated SSG can establish interactions with mucin through electrostatic interactions and hydrogen bonding involving the amino groups of aminated SSG and the glycoproteins of mucin, resulting in enhanced adhesion compared with that of unmodified gum [5].

Another study demonstrated that tablets containing SSG exhibited a mucin adhesion force superior to that of commercially available conventional excipients. Additionally, when subjected to the swelling rate test, the tablets showed a constant swelling rate with no visible erosion. These characteristics suggest that SSG-based tablets can be transformed into hydrogels through swelling in the gastrointestinal tract. Therefore, this combination of features implies the use of SSG as a sustained drug release system [28].

7.1.3. Antibacterial and antiparasitic agents

The acetylated SSG showed excellent antibacterial activity, as it had an inhibitory effect on all the strains tested, reaching almost 100 % inhibition of *P. aeruginosa* and *S. typhimurium*. In addition, the results against the promastigote form of *Leishmania amazonensis* indicated that chemical modification improved the antileishmanial activity of the gum, reaching an inhibitory effect above 70% at lower concentrations than that of the unmodified SSG [35].

The aminated SSG exhibited increased inhibitory activity against *Staphylococcus aureus*. Furthermore, it showed antioxidant capacity and an inhibitory effect on the α glucosidase enzyme and no cytotoxic activity was found [5].

Esterified SSG improved the antimicrobial properties of the original unmodified gum. The esterified SSG showed excellent antibacterial action, inhibiting almost 100% of bacterial growth, and did not cause significant cytotoxicity to mammalian cells, suggesting that it is promising for application in biomedical measures aimed at controlling infectious diseases caused by *S. aureus* [27].

7.2. Tissue engineering

Currently, tissue engineering has emerged as a promising approach for addressing tissue defects resulting from substantial damage or loss. This interdisciplinary field integrates biology, materials science, and engineering to generate a range of tissues essential for restoring, substituting, and maintaining existing tissues [68].

Over the past few years, biopolymers have garnered increased interest for their application as biomaterials in tissue engineering. Natural gum polysaccharides possess various qualities, such as biodegradability, nontoxicity, and biocompatibility. Due to their porosity and expansive surface area, polysaccharide polymers serve as scaffolds to mimic the extracellular matrix, offering robust support for cell growth. The notable geometric structure and surface properties of these polymers also play crucial roles in directing cell regeneration [69].

Currently, there are no published reports evaluating the use of SSG for scaffold production. However, the various properties of SSG mentioned earlier indicate that this material is promising for tissue engineering. The findings observed in articles with hydrogels of this gum compared to the evidence regarding the formulation that supported cell growth in wound healing suggest that SSG is a promising candidate for scaffold production [28,58,61].

7.3. Biosensor technology

Biosensor technology refers to the application of biological components, such as enzymes or antibodies, integrated with transducers or detectors to detect and quantify specific biological or chemical substances. This technology is used for various purposes, including medical diagnostics, food safety, and industrial processes. Biosensors work by recognizing a target molecule and producing a measurable signal, providing valuable information about the presence or concentration of the target analyte. The versatility of biosensor technology makes it a powerful tool in fields where accurate and rapid detection of specific substances is crucial [70,71].

The polyanionic character of SSG also aroused researchers' interest in using this material to develop self-assembled films via the layer-by-layer technique. The formation of self-assembled films involves deposition layers through electrostatic interactions between the gum COO– group and a cationic polyelectrolyte [2,59,62,72].

Multilayer thin films were also developed using SSG and poly-o-methoxyaniline, a cationic conductive polymer. The presence of gum in the films increased the electrochemical stability compared to films made with conventional polyelectrolytes. In addition, the films produced with SSG stood out for their uniformity at the nanometer scale and high material adsorption by bilayers with other films produced from other gums [62].

Another study obtained nanocomposites in the form of ultrathin films that combined a metallic phthalocyanine (nickel tetrasulfonated phthalocyanine) and SSG in a tetralayer architecture together with conventional polyelectrolytes. They investigated the ability of nanocomposites to act as electrodes for detecting dopamine. The presence of gum led to the efficient adsorption of phthalocyanine and increased the electrochemical response of the films. Furthermore, the films are significant electrodes capable of detecting dopamine at concentrations as low as 10–5 M [72].

7.4. Food applications

Materials with antimicrobial activities are essential for the food industry. Gums can be used in various applications to help inhibit the growth or presence of unwanted microorganisms. Adding gums with antimicrobial properties to foods can help extend their shelf life by inhibiting the growth of bacteria, fungi, and other microorganisms that cause deterioration. Additionally, antimicrobial gums can be incorporated into food packaging materials, preventing the growth of microorganisms and helping preserve product freshness [73].

Immobilizing lysozyme, an enzyme with antimicrobial properties in SSG films, was used to obtain antimicrobial surfaces with potential application in packaging or coatings. The results showed that the gum films favored the enzymatic activity of the immobilized enzyme. Similar studies with other enzymes are being developed to provide additional data to establish a correlation between the surface properties of immobilized enzymes and enzymatic activity [59].

7.5. Environmental and agronomic applications

Over time, gums have been discovered in diverse applications in the environmental field, contributing to more sustainable and environmentally friendly approaches. These biopolymer materials can be used in wastewater treatment to assist in removing pollutants and coagulating solids, thereby facilitating water purification [74,75].

Gums also possess properties that allow for the remediation of contaminated soils; they are applied to encapsulate contaminants and reduce their mobility, contributing to the recovery of degraded areas [76,77].

Moreover, certain gums, which aid microorganisms in the process of degrading pollutants, have characteristics that favor bioremediation. Gummy use in bioremediation is beneficial in areas contaminated by

hydrocarbons and other chemical compounds [78,79].

SSG was applied to prepare a hydrogel with chitosan to coat magnetic particles. The work revealed that the hydrogel was suitable for magnetite coating, suggesting its potential for future application as a water remediation agent. Due to their heavy metal adsorption capability, the hydrogels obtained are likely candidates for use in water treatment for the adsorption of heavy metals [60].

8. Technological prospecting of *Sterculia striata* gum

Technological prospecting is a systematic means of mapping scientific and technological development to identify, through the information contained in patents, areas of strategic research, relevant technologies, technological routes, innovations, processes, products, and trends in R&D. In other words, it can help predict possible future states of invention, innovation, and technology use. Thus, combining scientific review with technical data is essential since there is a growing need for technology transfer between academia and industry to build a connection that favors industrial-technological development [80,81].

From this perspective, a search was carried out with the terms "*Sterculia striata*", "Sterculia and gum", "Sterculia and delivery system", and "chicha" in the technological databases EPO (European Patent Office), WIPO (World Intellectual Properties Organization), DII (Derwent Innovations Index), (USPTO) United States Patent and Trademark Office and Brazilian patent office called the Nacional Institute of Intellectual Protection (INPI) (Fig. 6).

We found only three patent applications for SSG: one with the INPI base and two with the DII base. This result corroborates the small number of scientific publications published on this topic in recent years. However, the number of patents is still far below the number observed for scientific articles, demonstrating a need for greater industrial use because of the scientific relevance of chicha gum.

The patents found concern SSG (chicha) and were applied for in Brazil. In the patent (MU 8200908-2U) found at the INPI, a technological route to obtaining regional gums was requested. Therefore, the cashew, angico, timbaúba, and chicha gums are included in the claims. This route effectively obtains gums that can be applied as thickeners and stabilizers in the pharmaceutical, food, and brewing industries[82].

The two patents found in the DII database are related to the use of SSG as a pharmaceutical formulation. The first invention (BR 102018012321-1 A2) consists of a formulation based on natural polymers, including SSG, to increase the oral bioavailability of protein drugs [83]. The second invention (BR 102019016087-0 A2) is a pharmaceutical composition for the delivery of plant actives such as phenolic compounds. These preferably compounds are isolated or associated with conventional nonplant actives, and characterized by their association with gums, including SSG [84].

Therefore, despite being a product that can be abundantly obtained from the Brazilian flora and shows interesting characteristics for use in the industrial field, with the pharmaceutical, medical, environmental, and agronomic industries, it is still scarcely explored in patent banks. This finding encourages the hypothesis that there is a need for better promotion of research and technology transfer of this material, which may have significant economic and marketing importance in the future to be explored by various industrial branches [83,84].

9. Conclusion

This study provides an overview and perspectives on the scientific and innovation potential of *Sterculia striata* gum (SSG).

SSG is a material capable of being modified by esterification, acylation, amination, and acetylation. This feature confirmed that SSG is a versatile material suitable for several applications. However, a more detailed analysis of the impact of the modification on the derived gum, specifically on the molecular weight and degree of substitution, is needed. It is also urgent to carry out stability studies (for example, studies of physicochemical alterations) and guarantee the absence of toxicity in modified SSG.

Studies characterizing the use of its exudate from a physicochemical and rheological perspective have been described. The ability of SSG to form thermoreversible gels was found, which indicates the potential of these materials from pharmaceutical and technical points of view. In addition, the polyanionic character of these gums allows the formation of polyelectrolyte complexes, which denote excellent prospects for encapsulating drugs and producing innovative formulations. Studies have suggested its use in the formation of gels, nanostructured systems, and films. The impact of the rheological properties of modified SSG on relevant drug delivery systems (DDS) attributes, such as size, charge and eventually biological performance, including mucoadhesion and antimicrobial activity, cannot be neglected. The technological prospection of patents related to the SSG is presented here, with a few related patents, thus demonstrating an overview of the need for greater use of this

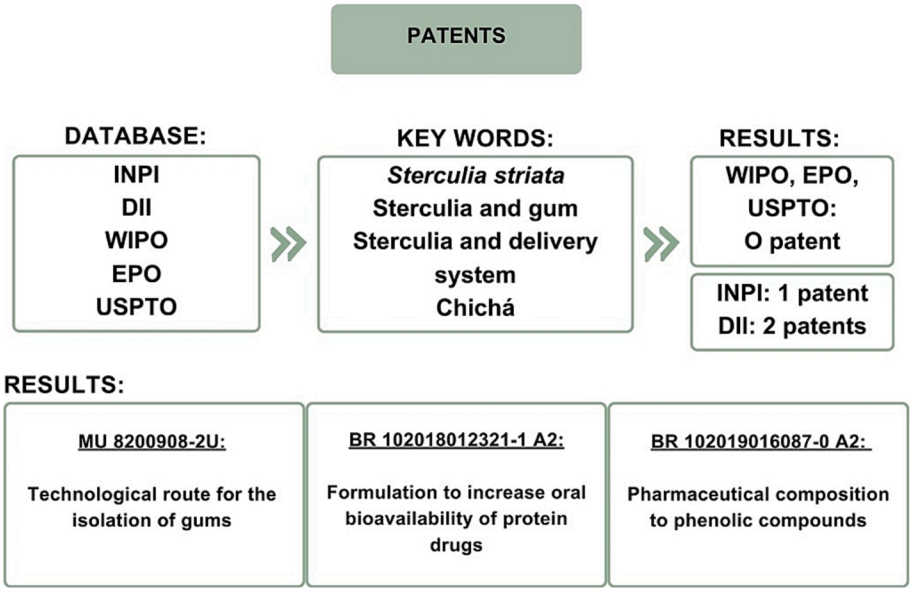

Fig. 6. Patent search protocol and results DII: Derwent Innovations Index ®; WIPO: World Intellectual Properties Organization; EPO: Europe Patent Office; USPTO: United States Patent and Trademark Office; INPI: Brazilian National Institute of Industrial Property.

material in the field of marketing and industry.

Additional biocompatibility investigations according to standardized and international methodologies are needed for pharmaceutical formulations produced from SSG. Similarly, further preclinical studies are needed to determine the impact of new delivery systems containing SSG on the pharmacokinetic profile of the drug. The most different potentialities of the Sterculia genus were found in the pharmaceutical, medical, food, biotechnological, and environmental domains.

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CRediT authorship contribution statement

Alessandra Ribeiro Freitas: Writing – original draft, Writing – review & editing. **António José Ribeiro:** Supervision, Writing – review & editing. **Pauline Sousa Santos:** Writing – original draft. **Thaísa Cardoso de Oliveira:** Writing – original draft. **Jabson Herber Profiro de Oliveira:** Writing – original draft. **Josy A. Osajima:** Formal analysis. **Alessandra Braga Ribeiro:** Formal analysis. **Francisco Veiga:** Project administration. **Roosevelt D.S. Bezerra:** Formal analysis. **Albert S. Silva:** Formal analysis. **José Lamartine Soares-Sobrinho:** Formal analysis, Resources. **Edvani Curti Muniz:** Conceptualization. **Edson C. Silva-Filho:** Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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References

[1] A.C.F. Brito, D.A. Silva, R.C.M. de Paula, J.P.A. Feitosa, Sterculia striata exudate polysaccharide: characterization, rheological properties and comparison with Sterculia urens (karaya) polysaccharide, Polym. Int. 53 (2004) 1025–1032, https://doi.org/10.1002/pi.1468.

[2] C. Eiras, A.C. Santos, M.F. Zampa, A.C.F. de Brito, C.J. Leopoldo Constantino, V. Zucolotto, J.R. dos Santos, Natural polysaccharides as active biomaterials in nanostructured films for sensing, J. Biomater. Sci. Polym. Ed. 21 (2010) 1533–1543, https://doi.org/10.1163/092050609X12519805626077.

[3] D.A. Silva, A.C.F. Brito, R.C.M. De Paula, J.P.A. Feitosa, H.C.B. Paula, Effect of mono and divalent salts on gelation of native, Na and deacetylated Sterculia striata and Sterculia urens polysaccharide gels, Carbohydr. Polym. 54 (2003) 229–236, https://doi.org/10.1016/S0144-8617(03)00163-2.

[4] B. Singh, N. Sharma, Mechanistic implication for cross-linking in sterculia-based hydrogels and their use in GIT drug delivery, Biomacromolecules. 10 (2009) 2515–2532, https://doi.org/10.1021/bm9004645.

[5] A.R. Freitas, A.J. Ribeiro, A.B. Ribeiro, M.D.M. Collado-Gonzalez, L.R. Silva, L. Alves, E. Melro, F.E. Antunes, F. Veiga, A.I.S. Morais, R.D.S. Bezerra, J.L. Soares-Sobrinho, J.A. Osajima, E.C. Silva-Filho, Modification of chicha gum: antibacterial activity, ex vivo mucoadhesion, antioxidant activity and cellular viability, Int. J. Biol. Macromol. 228 (2023) 594–603, https://doi.org/10.1016/j.ijbiomac.2022.12.204.

[6] D. Verbeken, S. Dierckx, K. Dewettinck, Exudate gums: occurrence, production, and applications, Appl. Microbiol. Biotechnol. 63 (2003) 10–21, https://doi.org/10.1007/s00253-003-1354-z.

[7] J.A. DiMasi, H.G. Grabowski, R.W. Hansen, Innovation in the pharmaceutical industry: new estimates of R&D costs, J. Health Econ. 47 (2016) 20–33, https://doi.org/10.1016/j.jhealeco.2016.01.012.

[8] G.A. Van Norman, Drugs, devices, and the FDA: Part 1, JACC Basic Transl. Sci. 1 (2016) 170–179, https://doi.org/10.1016/j.jacbts.2016.03.002.

[9] V. Raj, J.H. Lee, J.J. Shim, J. Lee, Recent findings and future directions of grafted gum karaya polysaccharides and their various applications: a review, Carbohydr. Polym. 258 (2021) 117687, https://doi.org/10.1016/J.CARBPOL.2021.117687.

[10] S. Barak, D. Mudgil, S. Taneja, Exudate gums: chemistry, properties and food applications - a review, J. Sci. Food Agric. 100 (2020) 2828–2835, https://doi.org/10.1002/JSFA.10302.

[11] M. Bilal, H. Munir, M.I. Khan, M. Khurshid, T. Rasheed, K. Rizwan, M. Franco, H.M. N. Iqbal, Gums-based engineered bio-nanostructures for greening the 21st-century biotechnological settings, Crit. Rev. Food Sci. Nutr. 62 (2022) 3913–3929, https://doi.org/10.1080/10408398.2020.1871318.

[12] J.S.F. da Silva, A.C. de J. Oliveira, M.F. de L.R. Soares, J.L. Soares-Sobrinho, Recent advances of Sterculia gums uses in drug delivery systems, Int. J. Biol. Macromol. 193 (2021) 481–490, https://doi.org/10.1016/j.ijbiomac.2021.10.145.

[13] A.R. Freitas, A.J. Ribeiro, A.C. Santos, F. Veiga, L.C.C. Nunes, D.A. Silva, J. L. Soares-Sobrinho, E.C. Silva-Filho, Sterculia striata gum as a potential oral delivery system for protein drugs, Int. J. Biol. Macromol. 164 (2020) 1683–1692, https://doi.org/10.1016/J.IJBIOMAC.2020.07.276.

[14] C. Gomes Filho, F. Barbosa Bispo, M. Lu, C. Corazza, P. Felipe Arce, F. Augusto Pedersen Voll, D. de Gusma, L. Ferreira-Pinto, S. Helena Vieira de Carvalho, I. Soletti, Liquid−liquid equilibrium measurement and thermodynamic modeling of the sterculia striata biodiesel + glycerol + ethanol system, cite this, J. Chem. Eng. Data. 66 (2021) 3293–3299, https://doi.org/10.1021/acs.jced.1c00341.

[15] M.B.P. Mangas, F.N. Rocha, P.A.Z. Suarez, S.M.P. Meneghetti, D.C. Barbosa, R. B. dos Santos, S.H.V. Carvalho, J.I. Soletti, Characterization of biodiesel and bio-oil from Sterculia striata (chicha) oil, Ind. Crops Prod. 36 (2012) 349–354, https://doi.org/10.1016/J.INDCROP.2011.10.021.

[16] M.B.P. Mangas, V.M. Mello, P.A.Z. Suarez, Thermal behavior of Sterculia striata oil, Thermochim. Acta. 564 (2013) 39–42, https://doi.org/10.1016/J.TCA.2013.03.035.

[17] S. Aued-Pimentel, J.H.G. Lago, M.H. Chaves, E.E. Kumagai, Evaluation of a methylation procedure to determine cyclopropenoids fatty acids from Sterculia striata St. Hil. Et Nauds seed oil, J. Chromatogr. A. 1054 (2004) 235–239, https://doi.org/10.1016/j.chroma.2004.07.090.

[18] A.G. de M. e Silva, K.F. Fernandes, Composição química e antinutrientes presentes nas amêndoas cruas e torradas de chicha (Sterculia striata A. St. Hill & Naudin), Rev. Nutr. 24 (2011) 305–314, https://doi.org/10.1590/S1415-52732011000200011.

[19] F.V. Silva, I.S. Oliveira, K.A. Figueiredo, F.B. Melo Júnior, D.A. Costa, M.H. Chaves, M.P.M. Amaral, F.R.C. Almeida, F.A. Oliveira, R.C.M. Oliveira, Anti-Inflammatory and Antinociceptive Effects of Sterculia striata A. St.-Hil. & Naudin (Malvaceae) in Rodents, J. Med. Food. 17 (2014) 694–700, https://doi.org/10.1089/jmf.2013.0062.

[20] J.A. Sousa, I.S. Oliveira, F. V. Silva, D.A. Costa, M.H. Chaves, F.A. Oliveira, P.H.M. Nunes, R.C.M. Oliveira, Gastroprotective activity of Sterculia striata A. St. Hil. & Naudin (Malvaceae) in rodents, Zeitschrift Für Naturforsch. C. 67 (2012) 163–171.

[21] J.T.A. Oliveira, I.M. Vasconcelos, L.C.N.M. Bezerra, S.B. Silveira, A.C. Monteiro, R. A. Moreira, Composition and nutritional properties of seeds from Pachira aquatica Aubl, Sterculia striata St Hil et Naud and Terminalia catappa Linn, Food Chem. 70 (2000) 185–191, https://doi.org/10.1016/S0308-8146(00)00076-5.

[22] P. de Britto Policarpi, L. Turcatto, F. Demoliner, R.A. Ferrari, V.L.A.F. Bascuñan, J. C. Ramos, I. Jachmanián, L. Vitali, G.A. Micke, J.M. Block, Nutritional potential, chemical profile and antioxidant activity of Chichá (Sterculia striata) nuts and its by-products, Food Res. Int. 106 (2018) 736–744, https://doi.org/10.1016/J.FOODRES.2017.12.069.

[23] M.S. Rocha, R.W. de Figueiredo, M.A. da M. Araújo, R.S. dos R. Moreira-Araújo, Caracterização físico-química e atividade antioxidante (in vitro) de frutos do cerrado Piauiense, Rev. Bras. Frutic. 35 (2013) 933–941, https://doi.org/10.1590/S0100-29452013000400003.

[24] H.B. Quesada, T.P. De Araújo, L.F. Cusioli, M.A.S.D. De Barros, R.G. Gomes, R. Bergamasco, Evaluation of novel activated carbons from chichá-do-cerrado (Sterculia striata St. Hil. et Naud) fruit shells on metformin adsorption and treatment of a synthetic mixture, J. Environ Chem. Eng. 9 (2021), https://doi.org/10.1016/J.JECE.2020.104914.

[25] P.L.R. da Cunha, R.C.M. de Paula, J.P.A. Feitosa, Polissacarídeos da biodiversidade brasileira: uma oportunidade de transformar conhecimento em valor econômico, Quim. Nova. 32 (2009) 649–660, https://doi.org/10.1590/S0100-40422009000300009.

[26] S.M.O. Costa, J.F. Rodrigues, R.C.M. De Paula, Monitorização do processo de purificação de gomas naturais: Goma do Cajueiro, Polímeros Ciência e Tecnol, Abr/jun (1996) 49–55.

[27] S.C.C.C. Silva, E.M. de Araujo Braz, F.A. de Amorim Carvalho, C.A.R. de Sousa Brito, L.M. Brito, H.M. Barreto, E.C. da Silva Filho, D.A. da Silva, Antibacterial and cytotoxic properties from esterified Sterculia gum, Int. J. Biol. Macromol. 164 (2020) 606–615, https://doi.org/10.1016/J.IJBIOMAC.2020.07.031.

[28] S.R. dos S. Ferreira, M.V.N. Mesquita, L.L.F. de Sá, N.C. Nogueira, M. dos S. Rizzo, E.C. Silva-Filho, M.P. da Costa, A.B. Ribeiro, Sustainable natural gums for industrial application: physiochemical and texturometric evaluation, J. Drug Deliv Sci. Technol. 54 (2019) 101306, https://doi.org/10.1016/J.JDDST.2019.101306.

[29] H. Mirhosseini, B.T.T. Amid, Corrigendum to A review study on chemical composition and molecular structure of newly plant gum exudates and seed gums

[Food Res. Int. 46, 387–398], Food Res. Int. 52 (2013) (2012) 429, https://doi.org/10.1016/j.foodres.2013.03.021.
[30] A.C.F. de Brito, M.R. Sierakowski, F. Reicher, J.P.A. Feitosa, R.C.M. de Paula, Dynamic rheological study of Sterculia striata and karaya polysaccharides in aqueous solution, Food Hydrocoll. 19 (2005) 861–867, https://doi.org/10.1016/J.FOODHYD.2004.10.035.
[31] V.D. Prajapati, G.K. Jani, N.G. Moradiya, N.P. Randeria, Pharmaceutical applications of various natural gums, mucilages and their modified forms, Carbohydr. Polym. 92 (2013) 1685–1699, https://doi.org/10.1016/j.carbpol.2012.11.021.
[32] T.C. De Oliveira, A.C. de J. Oliveira, Y.B.G. Patriota, L.L. Chaves, F. de O.S. Ribeiro, R.C.M. De Paula, E.C. Silva-Filho, D.A. da Silva, M.F. de L.R. Soares, J.L. Soares-Sobrinho, Eco-friendly synthesis of phthalate angico gum towards nanoparticles engineering using Quality by Design (QbD) approach, Int. J. Biol. Macromol. 190 (2021) 801–809. https://doi.org/10.1016/j.ijbiomac.2021.09.012.
[33] G.A. Magalhães, E. Moura Neto, V.G. Sombra, A.R. Richter, C.M.W.S. Abreu, J.P. A. Feitosa, H.C.B. Paula, F.M. Goycoolea, R.C.M. de Paula, Chitosan/Sterculia striata polysaccharides nanocomplex as a potential chloroquine drug release device, Int. J. Biol. Macromol. 88 (2016) 244–253, https://doi.org/10.1016/j.ijbiomac.2016.03.070.
[34] H.C.B. Paula, E.F. Oliveira, M.J.M. Carneiro, R.C.M. de Paula, Matrix effect on the spray drying nanoencapsulation of lippia sidoides essential oil in chitosan-native gum blends, Planta Med. 83 (2017) 392–397, https://doi.org/10.1055/s-0042-107470.
[35] E.M.A. Braz, S.C.C.C. Silva, C.A.R.S. Brito, F.A.A. Carvalho, M.M.M. Alves, H. M. Barreto, D.A. Silva, R. Magalhães, A.L. Oliveira, E.C. Silva-Filho, Modified chicha gum by acetylation for antimicrobial and antiparasitic applications: Characterization and biological properties, Int. J. Biol. Macromol. 160 (2020) 1177–1188, https://doi.org/10.1016/J.IJBIOMAC.2020.05.219.
[36] S.C.C.C. Silva, E.M.A. Braz, C.A.R.S. Brito, M.M.M. Alves, F.A.A. Carvalho, H. M. Barreto, A.L. Oliveira, D.A. Silva, E.C. Silva-Filho, Phthalic anhydride esterified chicha gum: characterization and antibacterial activity, Carbohydr. Polym. 251 (2021), https://doi.org/10.1016/j.carbpol.2020.117077.
[37] F. Matoso Sombra, A.R. Richter, A.R. de Araújo, F. de Oliveira Silva, J. de Ribeiro, R.O. dos Fátima Souza Mendes, D.A. da Santos Fontenelle, H.C.B. Silva, J. de Paula, P. de Andrade, F.M. Feitosa, R.C.M. Goycoolea, de Paula, Nanocapsules of Sterculia striata acetylated polysaccharide as a potential monomeric amphotericin B delivery matrix, Int. J. Biol. Macromol. 130 (2019) 655–663, https://doi.org/10.1016/J.IJBIOMAC.2019.02.076.
[38] F.M. Sombra, A.R. Richter, A.R. de Araújo, F. de Oliveira Silva, J. de Ribeiro, F. Souza Mendes, R.O. dos Santos Fontenelle, D.A. da Silva, H.C.B. Paula, J.P. A. Feitosa, F.M. Goycoolea, R.C.M. de Paula, Development of amphotericin B-loaded propionate Sterculia striata polysaccharide nanocarrier, Int. J. Biol. Macromol. 146 (2020) 1133–1141, https://doi.org/10.1016/J.IJBIOMAC.2019.10.053.
[39] N.A.O. Pitombeira, J.G. Veras Neto, D.A. Silva, J.P.A. Feitosa, H.C.B. Paula, R.C. M. De Paula, Self-assembled nanoparticles of acetylated cashew gum: Characterization and evaluation as potential drug carrier, Carbohydr. Polym. 117 (2015) 610–615, https://doi.org/10.1016/J.CARBPOL.2014.09.087.
[40] H. Li, Y. Wang, P. Zhao, L. Guo, L. Huang, X. Li, W. Gao, Naturally and chemically acetylated polysaccharides: Structural characteristics, synthesis, activities, and applications in the delivery system: a review, Carbohydr. Polym. 313 (2023) 120746, https://doi.org/10.1016/J.CARBPOL.2023.120746.
[41] I. Lima, L. Moreno, S. Dias, D. Silva, A.C. Oliveira, L. Soares, R. Sousa, D. Dittz, H. Rolim, L. Nunes, Acetylated cashew gum nanoparticles for mesalazine delivery, Carbohydr. Polym. Technol. Appl. 5 (2023) 100265, https://doi.org/10.1016/J.CARPTA.2022.100265.
[42] S.F.L. Dias, S.S. Nogueira, F. De França Dourado, M.A. Guimarães, N.A. De Oliveira Pitombeira, G.G. Gobbo, F.L. Primo, R.C.M. De Paula, J.P.A. Feitosa, A.C. Tedesco, L.C.C. Nunes, J.R.S.A. Leite, D.A. Da Silva, Acetylated cashew gum-based nanoparticles for transdermal delivery of diclofenac diethyl amine, Carbohydr. Polym. 143 (2016) 254–261, https://doi.org/10.1016/J.CARBPOL.2016.02.004.
[43] S. Huang, G. Huang, Extraction, structural analysis, and activities of rice bran polysaccharide, Chem. Biol. Drug Des. 98 (2021) 631–638, https://doi.org/10.1111/CBDD.13916.
[44] L.M. Jiang, S.P. Nie, D.F. Huang, Z.H. Fu, M.Y. Xie, Acetylation Modification Improves Immunoregulatory Effect of Polysaccharide from Seeds of Plantago asiatica L, J. Chem. 2018 (2018), https://doi.org/10.1155/2018/3082026.
[45] S. Kumar, R. Kumar, Role of acemannan O-acetyl group in murine radioprotection, Carbohydr. Polym. 207 (2019) 460–470, https://doi.org/10.1016/J.CARBPOL.2018.12.003.
[46] Y. Zhang, Y. Zhang, J. Lin, Z. Li, H. Huang, Radical acylation: concepts, synthetic applications and directions, Org. Chem. Front. 10 (2023) 1056–1085, https://doi.org/10.1039/D2QO01846B.
[47] R. Santayanon, J. Wootthikanokkhan, Modification of cassava starch by using propionic anhydride and properties of the starch-blended polyester polyurethane, Carbohydr. Polym. 51 (2003) 17–24, https://doi.org/10.1016/S0144-8617(02)00109-1.
[48] Y. Shen, Y. Li, Acylation modification and/or guar gum conjugation enhanced functional properties of pea protein isolate, Food Hydrocoll. 117 (2021) 106686, https://doi.org/10.1016/J.FOODHYD.2021.106686.
[49] B.V.M. Rodrigues, R.T. Polez, O.A. El Seoud, E. Frollini, Cellulose acylation in homogeneous and heterogeneous media: Optimization of reactions conditions, Int. J. Biol. Macromol. 243 (2023) 125256, https://doi.org/10.1016/J.IJBIOMAC.2023.125256.
[50] K. Aiedeh, M.O. Taha, Synthesis of chitosan succinate and chitosan phthalate and their evaluation as suggested matrices in orally administered, colon-specific drug delivery systems, Arch. Pharm. (weinheim) 332 (1999) 103–107, https://doi.org/10.1002/(SICI)1521-4184(19993)332:3<103::AID-ARDP103>3.0.CO;2-U.
[51] A.P. Vieira, S.A.A. Santana, C.W.B. Bezerra, H.A.S. Silva, J.C.P. de Melo, E.C.d. S. Filho, C. Airoldi, Copper sorption from aqueous solutions and sugar cane spirits by chemically modified babassu coconut (Orbignya speciosa) mesocarp, Chem. Eng. J. 161 (2010) 99–105, https://doi.org/10.1016/j.cej.2010.04.036.
[52] A.C. de J. Oliveira, A.R. de Araújo, P.V. Quelemes, D. Nadvorny, J.L. Soares-Sobrinho, J.R.S. de A. Leite, E.C. da Silva-Filho, D.A. da Silva, Solvent-free production of phthalated cashew gum for green synthesis of antimicrobial silver nanoparticles, Carbohydr. Polym. 213 (2019) 176–183, https://doi.org/10.1016/j.carbpol.2019.02.033.
[53] A.C. de J. Oliveira, L.L. Chaves, F. de O.S. Ribeiro, L.R.M. de Lima, T.C. Oliveira, F. García-Villén, C. Viseras, R.C.M. de Paula, P.J. Rolim-Neto, F. Hallwass, E. C. Silva-Filho, D. Alves da Silva, J.L. Soares-Sobrinho, M.F. de L.R. Soares, Microwave-initiated rapid synthesis of phthalated cashew gum for drug delivery systems, Carbohydr. Polym. 254 (2021), https://doi.org/10.1016/j.carbpol.2020.117226.
[54] E.M. de A. Braz, S.C.C.C.E. Silva, D.A. da Silva, F.A. de A. Carvalho, H.M. Barreto, L. de S. Santos Júnior, E.C. da Silva Filho, Modified chitosan-based bioactive material for antimicrobial application: synthesis and characterization, Int. J. Biol. Macromol. 117 (2018) 640–647, https://doi.org/10.1016/j.ijbiomac.2018.05.205.
[55] R. Murali, P. Vidhya, P. Thanikaivelan, Thermoresponsive magnetic nanoparticle – aminated guar gum hydrogel system for sustained release of doxorubicin hydrochloride, Carbohydr. Polym. 110 (2014) 440–445, https://doi.org/10.1016/J.CARBPOL.2014.04.076.
[56] M. Jelkmann, C. Leichner, S. Zaichik, F. Laffleur, A. Bernkop-Schnürch, A gellan gum derivative as in-situ gelling cationic polymer for nasal drug delivery, Int. J. Biol. Macromol. 158 (2020) 1037–1046, https://doi.org/10.1016/J.IJBIOMAC.2020.04.114.
[57] P. Bassi, G. Kaur, Fenugreek gum derivatives with improved bioadhesion and controlled drug release: in vitro and in vivo characterization, J. Drug Deliv. Sci. Technol. 29 (2015) 42–54, https://doi.org/10.1016/J.JDDST.2015.06.006.
[58] M.O.G. Ferreira, A.B. Ribeiro, M.S. Rizzo, A.C. de J. Oliveira, J.A. Osajima, L.M. Estevinho, E.C. Silva-Filho, Potential wound healing effect of gel based on Chicha gum, chitosan, and mauritia flexuosa oil, Biomed. 10 (2022) 899. https://doi.org/10.3390/BIOMEDICINES10040899.
[59] A.F. Dario, R.C.M. de Paula, H.C.B. Paula, J.P.A. Feitosa, D.F.S. Petri, Effect of solvent on the adsorption behavior and on the surface properties of Sterculia striata polysaccharide, Carbohydr. Polym. 81 (2010) 284–290, https://doi.org/10.1016/J.CARBPOL.2010.02.015.
[60] V. de A. Pereira, I.S. Ribeiro, H.C.B. Paula, R.C.M. de Paula, R.L. Sommer, R.J. S. Rodriguez, F.O.M.S. Abreu, Chitosan-based hydrogel for magnetic particle coating, React. Funct. Polym. 146 (2020) 104431, https://doi.org/10.1016/J.REACTFUNCTPOLYM.2019.104431.
[61] I.S. de Lima, M.O.G. Ferreira, E.M.L. Barros, M. dos S. Rizzo, J. de A. Santos, A. B. Ribeiro, J. Anteveli Osajima Furtini, E.C. Silva-Filho, L.M. Estevinho, Antibacterial and healing effect of chicha gum hydrogel (sterculia striata) with nerolidol, Int. J. Mol. Sci. 24 (2023), https://doi.org/10.3390/ijms24032210.
[62] C. Eiras, I. Nayana, G. Passos, A.C. Facundo De Brito, J. Ribeiro, S. Júnior, V. Zucolotto, O.N. Oliveira, I.L. Kitagawa, C.J.L. Constantino, Nanocompósitos eletroativos de poli-o-metoxianilina e polissacarídeos naturais, Quim. Nov. 30 (2007) 1158–1162.
[63] J. Jacob, J.T. Haponiuk, S. Thomas, S. Gopi, Biopolymer based nanomaterials in drug delivery systems: a review, Mater. Today Chem. J. (2018) 43–55, https://doi.org/10.1016/j.mtchem.2018.05.002.
[64] J. Liu, Y. Wang, Y. Liu, S. Shao, X. Zheng, K. Tang, Synergistic effect of nano zinc oxide and tea tree essential oil on the properties of soluble soybean polysaccharide films, Int. J. Biol. Macromol. 239 (2023) 124361, https://doi.org/10.1016/J.IJBIOMAC.2023.124361.
[65] D. Liang, C. Wang, X. Luo, Z. Wang, F. Kong, Y. Bi, Preparation, characterization and properties of cinnamon essential oil nano-emulsion formed by different emulsifiers, J. Drug Deliv. Sci. Technol. 86 (2023) 104638, https://doi.org/10.1016/J.JDDST.2023.104638.
[66] M.C. Cortez-Trejo, M. Gaytán-Martínez, M.L. Reyes-Vega, S. Mendoza, Protein-gum-based gels: effect of gum addition on microstructure, rheological properties, and water retention capacity, Trends Food Sci. Technol. 116 (2021) 303–317, https://doi.org/10.1016/J.TIFS.2021.07.030.
[67] K.A. Foster, H. Sun, R.M. Fancher, M. Proszynski, G. Dixon, K. Ford, G. Cornelius, O.S. Gudmundsson, M.J. Hageman, Utility of gastric-retained alginate gels to modulate pharmacokinetic profiles in rats, J. Pharm. Sci. 102 (2013) 2440–2449, https://doi.org/10.1002/jps.23630.
[68] S. Wu, R. Xiao, Y. Wu, L. Xu, Advances in tissue engineering of gellan gum-based hydrogels, Carbohydr. Polym. 324 (2024) 121484, https://doi.org/10.1016/J.CARBPOL.2023.121484.
[69] A. Koyyada, P. Orsu, Natural gum polysaccharides as efficient tissue engineering and drug delivery biopolymers, J. Drug Deliv. Sci. Technol. 63 (2021) 102431, https://doi.org/10.1016/J.JDDST.2021.102431.
[70] A.M.A. Melo, M.R.F. Oliveira, R.F. Furtado, M. de Fatima Borges, A. Biswas, H. N. Cheng, C.R. Alves, Preparation and characterization of carboxymethyl cashew gum grafted with immobilized antibody for potential biosensor application, Carbohydr. Polym. 228 (2020) 115408, https://doi.org/10.1016/J.CARBPOL.2019.115408.
[71] S. Qasemi, M. Ghaemy, Novel superabsorbent biosensor nanohydrogel based on gum tragacanth polysaccharide for optical detection of glucose, Int. J. Biol.

Macromol. 151 (2020) 901–908, https://doi.org/10.1016/J.IJBIOMAC.2020.02.231.
[72] M.F. Zampa, A.C.F. de Brito, I.L. Kitagawa, C.J.L. Constantino, O.N. Oliveira, H. N. da Cunha, V. Zucolotto, J.R. dos Santos, C. Eiras, Natural gum-assisted phthalocyanine immobilization in electroactive nanocomposites: physicochemical characterization and sensing applications, Biomacromolecules. 8 (2007) 3408–3413, https://doi.org/10.1021/bm700528u.
[73] H. Jiang, F. Wang, R. Ma, Y. Tian, Advances in gum Arabic utilization for sustainable applications as food packaging: Reinforcement strategies and applications in food preservation, Trends Food Sci. Technol. 142 (2023) 104215, https://doi.org/10.1016/J.TIFS.2023.104215.
[74] A. Subash, M. Naebe, X. Wang, B. Kandasubramanian, Biopolymer – a sustainable and efficacious material system for effluent removal, J. Hazard. Mater. 443 (2023) 130168, https://doi.org/10.1016/j.jhazmat.2022.130168.
[75] Y. Wu, A. Parandoust, R. Sheibani, F. Kargaran, Z. Khorsandi, Y. Liang, C. Xia, Q. Van Le, Advances in gum-based hydrogels and their environmental applications, Carbohydr. Polym. 318 (2023) 121102, https://doi.org/10.1016/J.CARBPOL.2023.121102.
[76] F. Hassanzadeh-Afruzi, A. Maleki, E.N. Zare, Efficient remediation of chlorpyrifos pesticide from contaminated water by superparamagnetic adsorbent based on Arabic gum-grafted-polyamidoxime, Int. J. Biol. Macromol. 203 (2022) 445–456, https://doi.org/10.1016/J.IJBIOMAC.2022.01.157.
[77] P. Han, J. Xie, X. Qin, X. Yang, Y. Zhao, Experimental study on in situ remediation of Cr(VI) contaminated groundwater by sulfidated micron zero valent iron stabilized with xanthan gum, Sci. Total Environ. 828 (2022) 154422, https://doi.org/10.1016/J.SCITOTENV.2022.154422.
[78] M. Zubair Mohsin, J. Huang, M. Hammad Hussain, W. Qamar Zaman, Z. Liu, Y. Salim-ur-Rehman, M. Zhuang, A.M. Guo, Revolutionizing bioremediation: advances in zeolite-based nanocomposites, Coord. Chem. Rev. 491 (2023) 215253, https://doi.org/10.1016/J.CCR.2023.215253.
[79] R.B. Sashidhar, S.K. Selvi, V.T.P. Vinod, T. Kosuri, D. Raju, R. Karuna, Bioprospecting of gum kondagogu (Cochlospermum gossypium) for bioremediation of uranium (VI) from aqueous solution and synthetic nuclear power reactor effluents, J. Environ. Radioact. 148 (2015) 33–41, https://doi.org/10.1016/J.JENVRAD.2015.05.016.
[80] P.S. Santos, T.C. Oliveira, L.M.R. Júnior, A. Figueiras, L.C.C. Nunes, β-caryophyllene delivery systems: enhancing the oral pharmacokinetic and stability, Curr. Pharm. Des. 24 (2018) 3440–3453, https://doi.org/10.2174/1381612824666180912151412.
[81] L.P. Texeira, Prospecção Tecnológica: importância, métodos e experiências da Embrapa Cerrados, Embrapa Cerrados - Doc. 317 (2013) 34.
[82] H.C.B. De Paula, Rota Tecnológica para a obtenção de gomas regionais, MU 8200908-2U, 2003.
[83] E.C. da Silva-Filho, A.R. Freitas, A.N.A. Claudia, P. Santos, B. Ribeiro, J. Anteveli, O. Furtini, M.L. Cristina, Composição de um sistema biopolimérico para veiculação oral de fármacos proteicos, BR 102018012321-1 A2, 2018.
[84] L.A.L. Soares, L.B. de Lima, M.R.A. Ferreira, J.H.P. de Oliveira, Composição farmacêutica para veiculação de ativos vegetais, preferencialmente compostos fenólicos, isolados ou associados com ativos não vegetais convencionais, respectivo processo de obtenção e usos, BR 102019016087-0 A2, 2019.