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Review Article

A Look at the Role of Mucilage at the Industrial Level

María Paz Villegas Calero, Alejandro Esquivel Álvarez, Elías Quesada Morales, María Fernanda Rojas Salas, Marianela Chavarría-Rojas, German Madrigal Redondo*
Instituto de Investigaciones Farmacéuticas (INIFAR), Facultad de Farmacia, Universidad de Costa Rica, San José, COSTA RICA.

ABSTRACT
Introduction: This bibliographic review gathers information regarding mucilages, their characteristics, extraction methods for various plant species, and their uses at a pharmaceutical level and for other industries. **Methods:** This bibliographic review compiles documents printed before December 2020, were searched using Elsevier and Google Scholar databases. Studies that examined mucilages that were not derived from plants were excluded from this review. **Results:** Mucilages have properties that allow them to be used as excipients in pharmaceutical preparations. They also have pharmacological activities, and have applications in the cosmetics and food industries. **Conclusion:** The use of mucilages provides numerous benefits, particularly to the pharmaceutical industry.

Key words: Cosmetics, Extraction, Food industry, Mucilages, Pharmacy.

Correspondence:
Dr. German Madrigal Redondo
Instituto de Investigaciones Farmacéuticas (INIFAR), Facultad de Farmacia, Universidad de Costa Rica, San José, COSTA RICA.
Phone no: +506 8863-5813
E-mail: german.madrigal@ucr.ac.cr

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INTRODUCTION

Humankind has known about mucilages since before the Christian era and has used them widely in the cosmetic, food and pharmaceutical industries for creating suspensions suspending, and binding agents, as well as for their viscous, thickening, and quasi-emulsifying properties.[1] The pharmaceutical industry shows great interest in mucilages obtained from natural sources due to their high availability and chemical stability, plus their lower toxicity, cost, and better biodegradability than synthetic mucilages.[2]

The term mucilage is used as a general name for viscous substances extracted from plants, minerals, or animals, as well as semisynthetic substances produced by modifying the chemical structure or natural components. Therefore, mucilages can encompass gums and hydrogels such as xanthan gum, gum arabic, or the Carbopol 940.[1] Nonetheless, this review focuses on mucilages of natural origin. Mucilages from vegetable sources are a natural product of their metabolism (secondary metabolites), compared to gums, for which the plant must suffer some damage or physiological change to induce their production.[3]

The objective of this bibliographic review was to collect information on mucilages, their characteristics, general properties, and extraction methods, as well as studies carried out on specific mucilages derived from plant matter. This was done in order to highlight the potential use of mucilages at a pharmaceutical level and in other industrial fields including cosmetics and food production.

METHODOLOGY

A literature review was undertaken, searching the corresponding information was sought studies published before December 2020. We included studies in English and Spanish that addressed the following mucilage topics: General characteristics, physicochemical properties, extraction methods, pharmaceutical importance, and applications in the pharmaceutical, cosmetic and food industries. Additionally, patents for mucilages-based products or products which use them as components in their formulations were included. Research focusing on mucilage of non-vegetable origin was excluded.

The databases used were Elsevier and Google Scholar. Organizations such as National Coffe Research Center (Centro Nacional de Investigaciones de Café, Cenicafé, by its acronym in Spanish) from Colombia, and International Pharmaceutical Excipients Council, form Europe, were also consulted. Theses found in the databases of the following universities were also used: Universidad Nacional de Colombia, Escuela Superior Politécnica de Chimborazo, Universidad de San Carlos de Guatemala, Universidad de Sevilla, Universidad Tecnológica Equinoccial, Universidad de El Salvador and Universidad Autónoma de Nuevo León. To search for relevant patents, Google Patents was used.

To perform the search, the following keywords were used: “mucilage”, “extraction”, “pharmaceutical”, “cosmetic”, “applications”, “uses”, “medicinal” in the respective search engines, in both English and Spanish. No discrimination was made for publication dates. A pre-selection was made according to the title and abstract, and then those documents from which information could be extracted according to the sub-themes of the review were selected.

Writing was carried out by dividing the document into introduction, mucilage characteristics, mucilage extraction, pharmaceutical interest, applications in the industry (pharmaceutical, cosmetic, and food), related patents, and conclusions sections. From the bibliographic reviews consulted, concepts, definitions and other generalities including properties and utilities of mucilages were obtained. This information was also extracted in some cases from the introductions and theoretical foundation of the original theses and articles. The content of the methodologies and results from the experimental studies were used to determine their contributions to the current topic.

MUCILAGES CHARACTERISTICS

Mucilages of natural origin are produced by specialized plant cells, localized in multiple tissues including the external integument of seeds, roots, bulbs, tubers, flowers and leaves. They can be found across multiple plant families, including Malvaceae, Lilaceae, Linaceae, Plantaginaceae, and even in some seaweed species. Their structure consists of a heterogeneous polysaccharide with a high content of galactose, mannose, glucose, and uronic acids.[2,4]

These substances have diverse functions depending on their molecular weight and the plant they are found in. If mixed with water, they produce low viscosity colloids that show optical activity. The presence or absence of the secretory cells that produce them and their function as part of a structure depends on the degree of adaptation and the survivability of each species.[5,6] Mucilages can be classified into two groups:

Neutral mucilages

Neutral mucilages contain linear heterogeneous mannose polymers, although other carbohydrates in their structures. They can also be glucomannans if they have D-mannose and D-glucose containing saccharides present in subcellular organs e.g. in some monocotyledons that produce high viscosity solutions when they contact water. Galactomannans consisting of D-mannose chains with galactose branches may also be found, which are water-soluble and are located at the endosperm of seeds. Additionally, galactoglucomannans consisting of a glucomannan chain, also containing some D-mannans residues are also found in seeds. Carob gum, guar gum and tamarind gum can are examples of neutral mucilages.[2,4]

Acidic mucilages

Most of the structures of acidic mucilages consist of acid derivatives of carbohydrates. They are classified by the botanical family of their plants. Examples include Plantaginaceae, which is rich in D-galactose and uronic acids; Malvaceae, localized in leaves and flowers of the mallow and all organs of the marsh-mallow; and Linaceae, that possesses a neutral part, with a highly branched arabinoxylan structure, and an acid part consisting of L-rhamnose and D-galactose saccharides.[2,4]

The high concentration of hydroxyl groups that mucilages present grants them the capability of increasing their volume upon contact with an aqueous medium since they can be hydrated, creating hydrogen bonds. This property of bulging and forming viscous solutions and gels is greatly sought when mucilages are used in pharmaceutical and medicinal applications.[2,7] Notably, mucilages lose viscosity as they decompose, making a production of high quantities unsuitable unless a preservative is added.[5,6,8]

Specific studies of the characteristics of mucilages found in vegetal species have been conducted. In the case of the mucilage obtained from cladodes of *Opuntia spinulifera* Salm-Dyck, a prickly pear species, the composition analysis shows that it contains 87.2% carbohydrates, 9.8% crude protein, and 1.7% nitrogen. Notably, OH and C-H groups was found and attributed to the polysaccharide compionents; C-O groups were also detected, and were associated with glycosidic bonds; C-C were identified in pyranoid rings; C=O moieties were identified from esterified groups, carboxylic groups, carboxylic units, galactose, N-acetyl groups, alkyl groups, uronic acid, and aromatic compounds.[9] Likewise, crystalline structures characteristic of calcium salts (calcium oxalate) were identified. Morphological analyses revealed irregular-shaped particles with aggregate formations, and the presence of minerals within the polysaccharide matrix. The presence of occluded humidity and low molecular weight polysaccharides was also noted.[9]

Hung and Lai (2019)[10] studied the water-extracted mucilage of the *Basella alba L*. The ash content percentage was 15.6% for the leaf and 8.3% for the stem, with 6.7-7.4% water content, 1.2-2.5% protein and 83.2-89.1% carbohydrates. There was a higher carbohydrate content in the stem than in the leaf and the presence of uronic acid was noted. The molecular weight of the stem mucilage was higher than that of the leaf. The mucilage presented an anionic character. The viscosity of the stem mucilage (9,20 dL/g) was higher than that of the leaf (2,48 dL/g).

Another study focused on mucilage of *Linum usitatissiumum* L. showed that it contains 4.8% to 7.2% ash, 7.7% to 12.3% protein, 0.5 to 0.8 mg/mL pentoses and a sugar total concentration of 1.6-3.1%. Zinc and copper were the most abundant minerals in the mucilage, while lead, chromium, and cadmium were the lower. The mucilage had a solubility between 4.5% and 69.2% at 80°C, a viscoelastic fluid behavior, and a high decomposition temperature, which indicated its thermal stability.[11]

The mucilage extracted from chia (*Salvia hipanica* L.) seeds has a 23% uronic acid content. In addition, it contains calcium, which allows the formation of a gel without adding it to the mixture. When the mucilage was treated with calcium, the water content decreased due to the increasing ionic forces. The addition of calcium improves the gel performance, due to interactions between the saccharide components and the calcium ions, which favor integrating more polymer chains to the polymeric network. It is concluded that the uronic acid abundance and its esterification degree influence the physical properties of the chia seeds mucilage.[12]

The impact of the chia seed mucilage on the human gut microbiota was also studied. The results showed that the different concentrations of mucilage utilized did not influence the physical properties of the gut, including viscosity. However, it was noted that the mucilage affects the growth of some bacterial groups of the gut, including *Enterococcus* spp. and *Lactobacillus* spp, which suggests it could work as a potential substrate for gut microbiota growth.[13]

Ríos and Puerta (2011)[14] studied the chemical composition of the coffee mucilage according to its fermentation and refrigeration time to determine its stability until usage. The fresh mucilage contained 85-91% water and 6.2-7.4% sugars. Its sugar content, and its natural yeasts and bacteria, elicit a natural fermentation process. When fermented at room temperature, the sugar content decreased, the acidity increased, ethanol was produced, and lipids were degraded. In comparison, when refrigerated, the alcoholic and lactic fermentation degradation was delayed, and the properties of the mucilage were preserved for 24 hr.

MUCILAGE EXTRACTION

As summarized by Villa, Osorio and Villacis (2020),[15] there is a diversity of methods to extract mucilages according to the plant source and its anatomical zone. Therefore, the correct procedure choice is vital, along with the solvent choice and lab conditions, which must be controlled for pharmaceutical and industrial processes.

One of the most welled known mucilage extractions is that of *Aloe vera* L. The extraction method of this mucilage is widely known worldwide. The most standardized extraction method is by taking the plants' leaves, performing a washing operation to remove any dirt and other undesirable materials present on the leaves. After one must fillet the leaves by cutting the base and the apex of the leaves and longitudinally to separate the epidermis for the inner mucilaginous gel. This gel was later grinded to obtain a juice made from the mucilage of the leaves. The obtained Aloe vera gel then must be subjected to a heat treatment in a hot water bath at 70°C for 30 min, causing the Aloe juice's clarification. The final step is the purification of the juice, and it is generally performed by filtration of the juice through a cotton or nylon cloth. Other methods that have been described include the drying of the mucilage extract, usage of a microwave-assisted extraction, Soxhlet extraction, and ultrasound-assisted extraction.[16-18]

Calle[19] described methods for efficiently obtaining coffee mucilage by washing the beans beforehand. For that, the coffee pulp must be physically detached the same day that it is collected and washed in a continuous water stream for half an hour. The beans are then stored in a tank so that the mucilage may be detached (extracted) once it is exposed to ashaker, with small amounts of water periodically added produce a dense mucilage solution. It is possible to obtain 3L of concentrated mucilage for every 10kg of the coffee cherries using this method. More recent methods use a demucilaginator, which can rapidly extract high percentages of mucilage.[20]

To obtain chan (*Hyptis suaveolens* L.) mucilage, Hernandez *et al*. (2019)[21] review and summarise methods reported. Centrifuge extraction obtained better results and presented quite a few advantages over other methods, including the requirement for less solvent and less time. Furthermore, this method produces a white-colored product, which is more acceptable for most industrial purposes. The preferred method was reported to be: The seed is hydrated in a proportion of water 1:40 (w/v) for one hour at 37°C, with agitatation at 1900rpm. The mucilage is extracted via mesh (net) number 30 to obtain a filtered solution to which distilled water is subsequently added in a 1:3 (w/v) proportion and shaken for an hour at 600 rpm (34-37°C). The liquid is then extracted with a mesh (net) number 30 to obtain a second filtered solution. Both filtered solutions are then mixed and water is added in a 1:1 (v/v) ratio, and then physically separated with a mesh (net) number 20 and centrifuged in a continuous centrifuge (40000rpm, 5°C) performing 3 repetitions.

Another method to extract the chan (*Hyptis suaveolens* L.) mucilage consists of first hydrating the seed with demineralized water, grinding the plant material, centrifuging the resulting mixture (3000rpm, for 10 min) and decanting the liquid phase. This liquid is conserved, to later be filtered, precipitated, centrifuged, decanted with diluted ethanol, and the remaining solid is filtered, dried, grounded, and packaged in a vacuum.[22]

To extract mucilage from *Malvaviscus penduliflorus,* Gallardo, Pazmiño and Enriquez[23] reported that it is essential to moisturize the plant material with deionized water, in a 1:10 proportion (plant mass to deionized water). The plant material was slowly added to the water in a closed compartment and extracted at room temperature for an hour. The authors analyzed different methods, and extraction by reflux was the considered to have the best extraction efficiency in that study.

For *Linum usitatissimum* L. mucilage extraction, Castañeda *et al.*[24] studied several extraction protocols to determine the optimal process, with consideration to several factors. All of the extraction methods employed in their study are based on seed submersion in a solvent and extraction over time. It was determined that agitation gave better efficiency, but only when extraction occurs at 85-90°C, for at least 4.5-5 hr in a pH 7 solution in a seed-water ratio of 1:20. Under normal room temperatures, agitation does not affect the process. Finally, the solution was filtered, evaporated, precipitated, centrifuged, and dried to obtain the mucilage as a powder.

A proposed method for the *Opuntia ficus-indica* L. mucilage extraction is to rinse the stalks, remove the spines, and grind the paddles in an aqueous solution in a 1:2 ratio, at 80°C for an hour. The liquid is later decanted and filtered with a cloth-based strainer. Ethanol is added to the solution obtained in a 1:2 ratio. at 80°C, and the procedure is repeated to get rid of most of the liquid. To obtain mucilage in powder, ethanol must be evaporated.[25]

TRADITIONAL USES OF PLANTS CONTAINING MUCILAGES

Aloe vera is an useful substance to treat dry skin affections, especially eczemas around the eyes and sensitive facial skin, which makes it a topical use traditional remedy for its easy obtention by cutting the lower leaf of the plant. Aloe is commercialized as a treatment for cough, gastritis, diabetes, cancer, headaches, arthritis, and other diseases.[26] Due to its components, it has an antiulcer effect thanks to its antioxidant, anti-inflammatory, cytoprotective, curative and mucous-secretory properties.[27] Furthermore, this plant shows other pharmacologic activities such as hypoglycemic, hypolipidemic, scaring, immunomodulating, antifungal and hepatoprotective.[28]

Flax or linseed (*L. usitatissimum*) has been used used to reduce cholesterol's blood plasma concentrations, as well as to reduce the risk of heart disease. Other traditional use is for the treatment of the symptoms of the menopause and diabetes.[29-32] Chia (*Salvia hipanica*) has been traditionally used for the treatment of diabetes by regulation blood sugar levels, for weight loss because of the feeling of fullness it produces, reducing cardiovascular risks and cholesterol levels, and it favors intestinal regulation.[33,34]

Phoenix dactylifera L. has a great number of traditional uses that can be traced to hundreds of years ago, although most of them are not used today. In the past, the plant and its parts has been used to treat various symptoms and pathologies like digestive disorders, analgesia, anemia, erectile disfunction, excessive menstrual flow, diuretics, genitourinary tract disorders. It's also been used to treat skin lesions, hemorrhages, and hemorrhoids. In modern times, the main use of this plant is to treat oral cavity infections, throat irritation and as an expectorant and antitussive.[35]

Coffea arabica is mostly known for its dietary use in everyday life, due to its caffeine, with great economic relevance in many countries throughout the world. Though, in more recent years, medicinal properties have been taking more relevance such as, but not limited to, flu treatment, asthenia, cardiotonic, neurotonic and profilactic use for diabetes mellitus type 2 and inflammation, whose research keeps looking promising.[36]

PHARMACEUTICAL RELEVANCE

Mucilages possess relevant physiological properties for pharmaceutical applications. Their water retention capability allows the delaying of gastric emptying at a gastrointestinal level (producing a feeling of satiety), slows down digestion and absorption processes of some nutrients due to the hindering of their contact with enzymes, increases fecal bolus mass, and also rises intestinal motility. In addition, it causes saccharolytic fermentation at an intestinal level, which synthesizes short-chain fatty acids, increasing fecal mass and decreasing the levels of potentially toxic substances from bacterial metabolism.[2]

Among mucilages' medicinal properties, blood cholesterol-lowering and hypoglycemic effects are particularlty relevant.[2] They also show demulcent (or emollient) properties, which makes them adequate as digestive system irritation treatments, since they locally protect and lubricate the digestive tube mucosa; as cough remedies, due to their antitussive and anti-inflammatory effect on the respiratory mucosa; and as a treatment for skin injuries, since they hydrate and protect the affected area.[2,37] Mucilages also have a laxative effect, assist toxin disposal, constitute potential prebiotics, and regulate appetite, which is particularly useful for weight control.[2,38]

Besides above mentioned uses, mucilages have essential applications for drug transport. They can be used as binding gelling agents, either for external (topical) or internal use, for specific purposes such as bioavailability improvement, side effect control, and effective drug targeting.[39] They have also been utilized as stabilizing and disintegrating agents for suspensions (when used at >10% concentrations).[39]

Likewise, mucilages are known to work as film-forming agents in transdermal and periodontal films and are also used in buccal tablets and as coating agents in microcapsules.[8] Additionally, they are used as binders thanks to their adhesive nature; they work as key polymers in matrix systems for modulating drug release. They also function as coating agents to protect drugs from degradation in the stomach, or to provide delayed/continuous release.[40] They are also applied in mucoadhesive drug preparations since they are retained in the stomach for an extended period, increasing bioavailability, reducing drug waste, and improving solubility.[40]

Other pharmaceutically relevant properties of mucilages have also been reported, including their use as emollients, which allows for tissue removal and promoting regrowth during the scarring process.[41] The anti-inflammatory properties of some mucilages, including *Malva sylvestris* L., make them ideal for topical skin preparations. Due to their intrinsic viscosity, they can remain longer on the skin surface, which may increase and prolong the therapeutic effects.[41]

Some mucilages with potential as excipients can be obtained from the following plants: *Aloe vera* L., which is useful for sustained release matrix tablets formulation; *Plantago ovata* F. (psyllium seeds), which are used binding and disintegrating agents, as release retardants, gastro-retentive agents, and in hydrogels; *Phoenix dactylifera* L., as a binder; *Hibiscus rosa-sinensis* L., used for sustained release tablets development; and *Cassia tora* L., used as a binding agent and suspension stabilizer.[42]

INDUSTRIAL APPLICATIONS

Pharmaceutical industry

Akin *et al.*[43] evaluated the application of date palm (*Phoenix dactylifera* L.) mucilage as a polymer for the formulation of metformin-packed, sustained-release micro-pearls. The release of metaformin was controlled for formulations with mucilage/sodium alginate mixtures with a 33:67 and 25:75 ratio, although the 25:75 ratio preparation had a more substantial level of drug entrapment. The authors of that study concluded that the 25:75 ratio preparation could be used in the controlled release of metformin hydrochloride until 10% of the drug is released.

Shahid *et al.*[44] researched the same mucilage to encapsulate silver nanoparticles. *In vitro,* the formulation exhibited maximum bactericidal activity against *Escherichia coli* and maximum growth inhibition of *Fusarium solani* and *Aspergillus niger,* opening potential applications in foods and medicines due to its antibacterial and antifungal activity. The authors concluded that the mucilage has great potential both as a silver nanoparticle encapsulate, and as an antioxidant.

Another study[45] reported on the usage of *Althaea officinalis* L. and *Malva sylvestris* L. (commonly known as marshmallow) as antitussives due to their mucilage content. For marshmallow, the root and has been reported to contain a 5-11% mucilage content, which has shown demulcent, emollient, expectorant, and anti-inflammatory properties, as well as its antimicrobial, immunomodulating, and hypoglycemic activity.[45] Aqueous marsh-mallow extract is also an effective modulator of cellular activity and KB epithelial cells proliferation. Additionally, aqueous and methanolic extracts have bronchodilator effects since they inhibit tracheobronchial contractions. Marsh-mallow mucilage has antitussive effects, which are comparable to that of codeine at the highest trial dosage. Pharmacovigilance studies corroborated the effectiveness and safety of mash-mallow syrup. Its antimicrobial activity has been tested *in vitro.*[45]

Flowers from the *Malva sylvestris* L. contain 6-10% mucilage. The mucilage has antitussive, anti-inflammatory, antibacterial, antifungal, antioxidant, laxative, and hypoglycemic properties. It can be used to treat buccal irritation, as it protects and hydrates the tissue, suppresses cough, and its syrup is effective and safe to use as a treatment for functional constipation in adults.[45]

The properties of mucilages extracted from *Asparagus racemosus* W. and *Senna sophera* L. as binders in tablets were studied using paracetamol as a model drug. Analysis of the pH showed that mucilages prepared from these plants did not have irritant effects and were adequate for non-coated tablets. Furthermore, the medium particle size obtained was satisfactory for tablet preparation and tablet batches exhibited good content uniformity. The disintegration time values for both mucilages were within pharmacopoeial limits.[34] Drug release of the compressed tablets prepared with both mucilages was above 90% after 3 hr and drug release increased with mucilage concentration.[46]

Valdéz[47] analyzed the usage of coffee pulp mucilage from *Coffea arábiga* L. as a thickening agent in the preparation of syrups. A uniform syrup with stable and definite physicochemical properties was obtained, with a viscosity value commonly used in syrup preparation. The extracted mucilage met the microbiological criteria of the XXXVII USP. This research is of great importance since the coffee pulp is a waste product that could be exploited, and this mucilage allows low-cost formulations, as desirable viscosity properties can be obtained with a smaller mucilage quantity compared to other thickening agents.

A study was undertaken to examine the laxative activity of the mucilages obtained from *Salvia hispánica* L, *Borago officinalis* L., and *Ullucus tuberosus* C.[48] The results showed that the *S. hispánica* is a prolonged-effect laxative, as it naturally stimulates intestinal peristalsis without causing side effects. *Ullucus tuberosus* exhibited the most significant effect in that study (as well as lasting the longest), without causing adverse effects. In contrast, the *B. officinalis* took the longest to work and had the *B. officinalis* took the longest to act and had the lesser laxative effect It was concluded that all three mucilages had a positive effect as bulk-forming laxatives and the most effective solutions were those of *S. hispánica* and *U. tuberosus,* as long as they are consumed with sufficient water.[48]

Cosmetic industry

Machado[49] evaluated the anti-sponge effect of prickly pear (*Opuntia ficus-indica* L.) and *A. vera* and compared the effects to commercial shampoos. Anti-sponge effects were noted, with the *A. vera* shampoo having the better hair-fluffing reduction percentage, which was even better than the commercial shampoo. The quality assurance tests exhibited a pleasant smell, no signs of precipitation, and the microbiological analysis values were within acceptable limits. Additionally, stability tests verified that its properties (smell, color, appearance, pH, density) were not altered after two months. It was concluded that the best treatment option was the *A. vera* shampoo due to its effectiveness and accessibility of the raw material.

Cevallos[50] evaluated a hydrating body cream based on *Pyrus* L, *Jacaranda mimosifolia* D. and *Salvia hispánica L. mucilages*, with stearic acid, glycerin, cetyl alcohol, glyceryl stearate, triethanolamine and propylene glycol. The cream reduced skin dryness and was quickly absorbed at the applied area, thus confirming the hydrating effect of the cream. The cream also has good extensibility and homogeneity. When applied to the shaved skin of bunnies, it provided a smoother appearance. The cream was more effective and was more effectively absorbed than the positive control (Lubriderm).

It was determined that the *Opuntia ficus-indica* (L.) Mill. (commonly known as nopal) may have applications in cosmetics and as dermatologic therapeutics as it possesses a synergic effect in combination with conventional moisturizing agents usually found in cosmetics and dermatological products. This implies the mixture achieves a better moistening compared to the mucilage or the moisturizing agents by themselves. That combination may be useful in topical preparations for users who need to improve their skin moisturizing.[51]

Food industry

The use of mucilages for the clarification of sugar cane juice has been evaluated. The results indicated that the *Theobroma cacao* L. mucilage had a higher average waste removal than *Cordia lutea* Lam. mucliage, at a concentration of 13 g/L. It was concluded that the cocoa cortex mucilage was the most suitable to remove suspended solid waste.[52]

Ramos[53] evaluated the usage of mucilages obtained from balso blanco (*Heliocarpus americanus* L.*)* and cadillo (*Triumfetta mollissima* Kunth) to improve waste removal in the production of panela (unrefined or raw cane sugar). It was determined that a 2% balso blanco mucilage content was the best possible treatment since it improved the general organoleptic properties of the panela.

Treviño[54] assessed the utilization of mucilages as edible coverings to preserve the quality and extend the shelf life of fresh-cut pineapple. Flax

(*L. usitatissimum*) mucilage showed the best results, followed by the *A. vera* and nopal (*O. ficus-indica*) one The mucilages were determined to be composed mainly of soluble dietetic fiber. The nopal-based coverings exhibited antimicrobial activity against *Listeria monocytogenes* and *Staphylococcus aureus*. The coatings reduced weight and Vitamin C loss, firmness changes, aerobic mesophiles, psychotropics, and fungus. The pineapple's quality and useful life were therefore substantially improved.

Ubeyitogullari and Ciftci[55] made bioaerogels using *Camelina sativa* L. Crantz seed mucilage, and evaluated them for use in food products. An 11% mucilage yield was obtained using water extraction. The aerogels exhibited a high surface area, nanoporous structure, ultralow density, and high porosity; the structures were tridimensional, open, porous, and had a fibrillary network. The aerogels' rheological properties were compatible with those of xanthan gum, but the former has a lower cost since the source is more abundant and affordable. It is concluded that mucilage aerogels are excellent candidates for thickening and stabilizing agents in different applications related to food.

Lactic acid was produced by simultaneous fermentation and hydrolysis of coffee mucilage using *Lactobacillus bulgaricus* NRRL-B548. Lactic acid has applications in the food industry, but it can also be used in the pharmaceutic, cosmetic, and textile fields. This production method produced good yields and the final concentrations were comparable to those obtained with other substrates and microorganisms, with the advantage that the mucilage is a highly polluting waste that could be exploited for this procedure, thereby limiting its contribution to environmental waste. It was concluded that coffee mucilage is a potential substrate for lactic acid production via this method.[56]

Câmara *et al.*[57] studied the effects on appetite sensation of replacing pork loin fat with chia mucilage in sausages. Three experimental treatments were put to the test: A mucilage/fat combination, mucilage/chia-based emulsion gel mixture, and a control treatment with a pork fat sausage. Participants indicated that the appetite sensations were similar for all three treatments, making the mucilage an effective substitute that produces the same satiety as fats. In addition, *in vitro* analysis showed that the mucilage could interfere with protein digestion, producing satiety in less time.

Tamarindus indica L. seed mucilage was evaluated as a potential material for sesame oil microencapsulation. Two preparations were elaborated: M1, with a 1:1 nucleus ratio, and M2, with a 1:2 ratio. M1 microcapsules were thermally stable up to 227°C and M2 up to 178°. Encapsulation efficiency was 91.1% for the M1 and 81.2% for M2. Peroxide was found in the preparations after six weeks. It was concluded that this mucilage provides protection against oxidation and high-efficiency encapsulation for sesame oil.[58]

RELATED PATENTS

The application of a *Opuntia ficus-indica* mucilage as a controlled release excipient for gastric regeneration, used as a treatment for several conditions such as gastric ulcer and esophageal reflux, has been presented in a patent. The mucilage acts as a regenerative adjuvant for the gastrointestinal tract mucosa.[59] Carella *et al.*[60] developed a patent of the formulation and manufacture method for a low-carb, high-protein and high-fiber gelato that includes mucilages as dietetic fiber sources. Tian *et al.*[61] patented the usage of *Lactobacillus plantarum* to treat lead intoxications. The said formulation includes several mucilages, including sodium alginate and gum Arabic.[62]

CONCLUSION

Plant-derived mucilages have widespread usage since ancient times, which has increased as humankind has studied and discovered characteristics that make them useful. At an industrial level, they are primarily used in foods, cosmetics and pharmaceutical products. The latter use has ignited an ever-increasing interest since mucilages can be incorporated as excipients to improve the performance of pharmaceutical preparations. Additionally, mucilages possess properties that allow them to develop a pharmacological activity, both by themselves and in conjunction with other active principles.

Since plant-derived mucilages can fulfill the same role as synthetic substances in their various applications, they bring benefits including decreased costs. In addition, they are widely available in nature and can even be obtained from residues and waste products of other industrial processes, which provides a positive impact at an environmental and economic level, favoring human development.

The ongoing study of mucilages' physical structure and chemical properties may continue contributing to the mentioned fields, as new applications might be discovered. The development and optimization of extraction methods would make it possible to obtain greater quantities of these substances from the plant mass. In summary, scientific evaluation of the properties and uses of mucilages deserve attention due to the multiple direct benefits that their dedicated investigations bring to society.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

C: Carbon; **O:** Oxygen; **H:** Hydrogen; **L:** Liters; **kg:** Kilograms; **g:** Grams; **°C:** Degrees centigrade; **w:** weight; **v:** volume; **rpm:** revolutions per minute; **min:** minutes; **hr:** hours; **USP:** Unites States Pharmacopeia.

SUMMARY

The present review summarizes characteristics, methods of extraction, pharmaceutical relevance, and industrial applications of mucilages of natural origin. Mucilages from differents plants are widely available and have properties that can contribute to pharmaceutical, cosmetic and food industry, as it is shown in the development of this article. It can be concluded that the mucilages' research might bring benefits for multiple fields.

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