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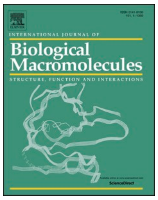

Mucilage polysaccharide as a plant secretion: Potential trends in food and biomedical applications

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ABSTRACT

Current trends are shifting away from using synthetic compounds in favor of discovering new natural component sources that will allow them to create goods that are healthful, environmentally friendly, sustainable, and profitable. The food industry, in light of these trends, has opted to look for safe natural ingredients that will allow the production of low-fat, artificial-additive-free, gluten-free, prebiotic, and fortified foods. Similarly, the pharmaceutical and medical industries have attempted to apply natural ingredients to address the challenges related to biomaterials more efficiently than synthetic ingredients. Against this background, plant mucilage has proven to be a polysaccharide with excellent health features and technological properties, useful for both food and biomedical applications. Many studies have shown that its inclusion in different food matrices improves the quality of the products obtained under appropriate reformulations. At the same time, plant mucilage has been indicated to be a very interesting matrix in biomedical field especially tissue engineering applications since it has been emerged to favor tissue regeneration with its highly biocompatible structure. This concise review discusses the most recent advances of the applications of plant mucilage in different foods as well as its recent use in biomedical field. In this context, firstly, a general definition of mucilage was made and information about plant-based mucilage, which is frequently used, about the plant parts they are found in, their content and how they are obtained are presented. Then, the use of mucilage in the food industry including bakery products, meat emulsions, fermented dairy products, ice cream, and other foods is presented with case studies. Afterwards, the use of plant mucilage in the biomedical field, which has attracted attention in recent years, especially in applications with tissue engineering approach such as scaffolds for tissue regeneration, wound dressings, drug delivery systems and pharmaceutical industry was evaluated.

1. Introduction

Mucilage is a sticky and mucus-like substance secreted by almost all plants and a large number of protista, especially phytoplankton and green algae. The main constituents of this substance are mostly polysaccharides, proteins, minerals, lipids and uranic acids units [1] (Fig. 1). The most notable among the sources of mucilage, marine mucilage occurs when microscopic algae called phytoplankton release mucilage through various mechanisms, including overgrowth, exudation, death and decomposition [2,3]. On the other hand, plant-derived mucilage can be obtained under normal conditions, so different from marine mucilage which is generated from organisms when they are subjected to damage and/or stress conditions. Therefore, plant mucilage can be obtained more easily and can be reached in more abundant quantities. In

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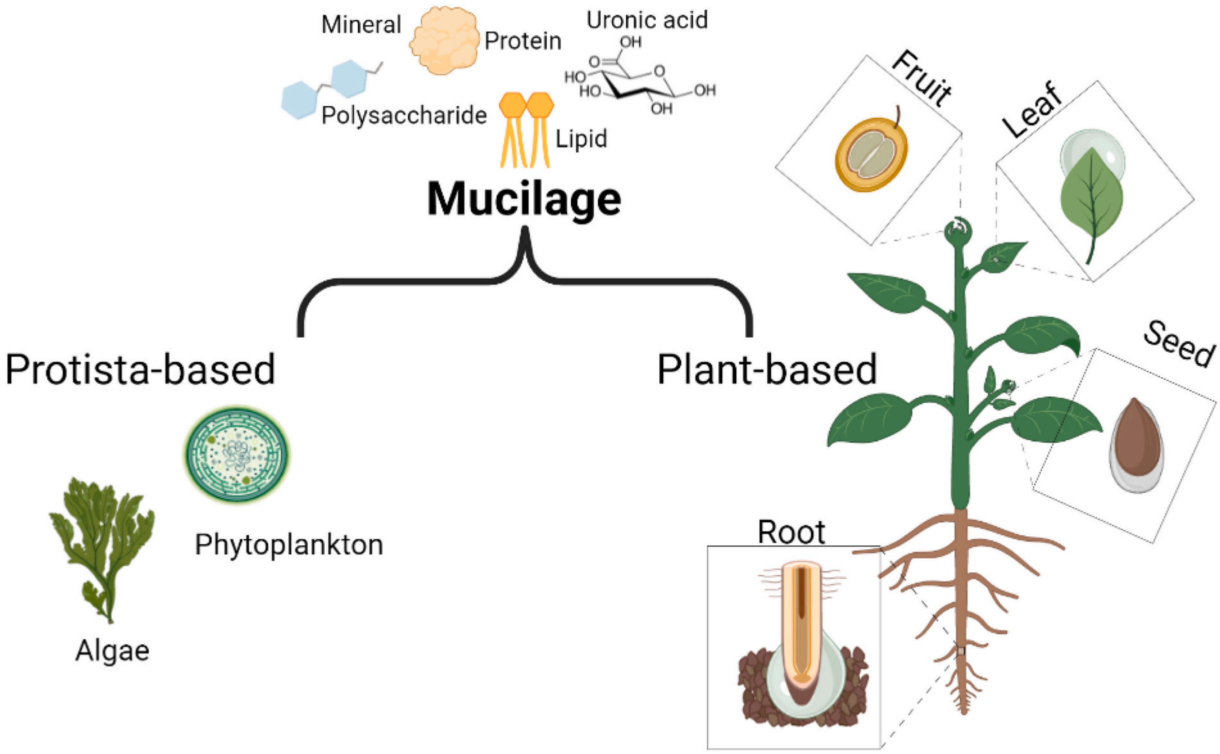

Fig. 1. Sources of mucilage and location of it in different parts of plants.

Table 1
Some types of mucilage obtained from different plant parts.

Part of plant	Scientific name	Family	Common name	Bioactive compounds	Ref
Leaf	*Hibiscus rosa-sinensis* L.	Malvaceae	Chinese hibiscus	l-Rhamnose, d-galactose, d-galacturonic acid, d-glucuronic	[13]
	Malva parviflora L.	Malvaceae	Cheeseweed	Galactose, rhamnose, arabinose, glucose, mannose	[9]
	Brasenia Schreberi	Cabombaceae	Watershield	d-Galactose, d-glucuronic acid, l-fucose, d-mannose	[14]
	Aloe barbadensis Miller	Liliaceae	Aloe Vera	Arabinose, xylose, mannose, galactose, glucose, uronic acids	[15]
	Corchorus olitorius L.	Malvaceae	Jute mallow	Rhamnose, xylose, galactose, glucose, arabinose, fucose glucuronic acid galacturonic acid	[16]
Seed	*Cydonia oblonga*	Rosaceae	Quince seed	Mannose, rhamnose, glucose, galactose d-xylose	[17]
	Linum usitatissimum	Linaceae	Flax/linseed	d-Galacturonic acid, l-rhamnose, l-galactose, dxylose	[18]
	Salvia hispanica L.	Lamiaceae	Chia seed	d-Xylose, d-mannose, l-arabinose, D-glucose, galacturonic acid, glucuronic acid	[19]
	Plantago psyllium L.	Plantaginaceae	Psyllium	Rhamnose, galacturonic acid, xylose, arabinose	[20]
Fruit	*Opuntia* spp.	Cactaceae	Prickly pear	Phenolic compounds, betacyanins, betaxanthins	[21]
	Abelmoschus esculentus L.	Malvaceae	Okra	Monosaccharides, d-galactose, l-rhamnose, galacturonic acid	[22]
Root	*Zea mays* L.	Poaceae	Maize	Galactose, fucose, mannose, arabinose, xylose, glucose, glucuronic acid	[1]

addition, environmentally friendly, sustainable, cost-effective, biologically sourced, non-toxic features are among its other advantages [4]. In plants, mucilage forms as an essential ingredient of the cell or as a portion of the cell walls and executes various functions in plants, including water and food storage, membrane thickening, and seed germination and it can be found dispersed in different parts of plants including leaves, buds, roots, bark, fruits and seeds [5–10]. Specifically, mucilage is usually found in the mucous epidermis, which is usually contained within the leaf of succulent plants such as aloe vera (*Aloe barbadensis* mill.), prickly pear cactus (*Opuntia* spp.), and century plant (*Agave americana* L.). In addition, the seed coats of many plants belonging to the *Plantaginaceae*, *Acanthaceae*, *Linaceae*, and *Brassicaceae* families also produce mucilage. Some of these include galactomannans (endosperm non-starchy polysaccharide), soybean hemicelluloses, and xyloglucans (cell wall material of endosperm), and flaxseed, basil seed, chia seed, quince seed, and yellow mustard (mucilage components of the seed coat) [11,12]. The mucilage in different parts of the plants is summarized in Table 1, taking into account the plant species, parts, families and active ingredient contents (Fig. 2).

Regarding the chemical composition, mucilage is formed mainly of a complex of polymeric polysaccharides of high molecular weight joined with organic acids. Concretely, mucilage contains galactose, pentose, and methyl pentose linked to uronic acid (six-carbon molecule with aldohexose in carboxylic acid form) residues by glycosidic bonds [23]. Plant mucilage reveals the existence of two different polysaccharide fractions in its composition, namely a fraction composed of pectin (primarily originated of rhamnogalacturonan I, RG-I) and another fraction composed of hemicellulose (formed mainly of arabinoxylans, AX) [24]. Mucilage RG-I comprehends a backbone of the α-(1,2)-rhamnose and α-d-(1,4)-galacturonic acid repeated disaccharide, whereas mucilage AX consists of β-1,4-linked xylose backbones that are mostly replaced by 1-3 sugar residues at O-2 and/or O-3 positions [25]. Additionally, RG-I can covalently bind to hemicellulose through side chains, forming a super-macromolecule polymeric network [4]. The neutral sugar found in mucilage structure are fundamentally the monomers D-galactose, L-arabinose, and D-xylose. To a lesser extent, mucilage also contains proteins, minerals, lipids, and bioactive compounds such as tannins, phenolic compounds, alkaloids, and steroids, as

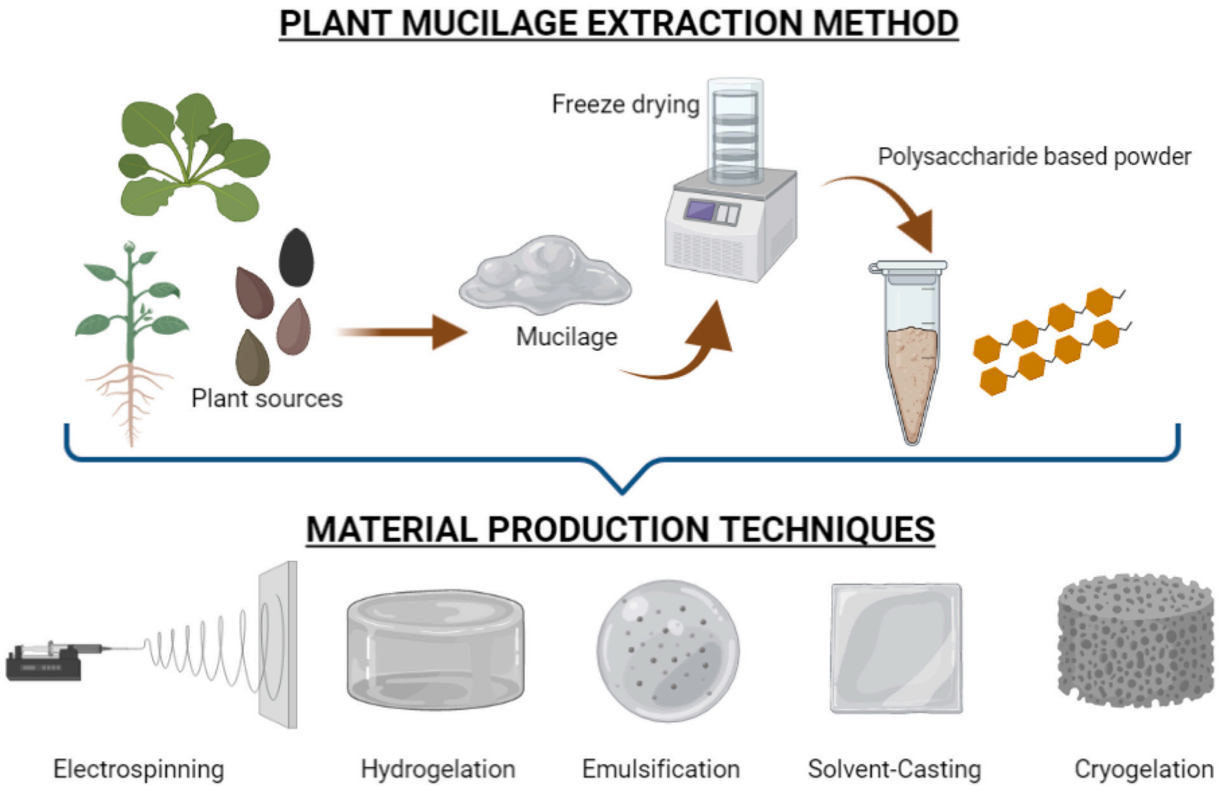

Fig. 2. A schematic overview of plant based mucilage extraction and the methods used for the fabricated of this sticky material.

well as monosaccharides produced by hydrolysis [26–28]. Mucilage can interact with other cationic polymers due to its anionic structure. A polyelectrolyte complex was formed as a result of cross-bridging between the anionic structure of mucilage and cationic structure of other polymers such as chitosan [29].

The composition and chemical structure of the mucilage are responsible for the excellent technological properties of plant mucilage and originated this compound to present a potential use in the food, pharmaceutical, and biomedical industries. One of its excellent performances is its thickening and structuring (gel-forming) capacity, which are a consequence of the high structure conformational diversity on account of the intermolecular interaction of the side groups of the polymer chain through hydrophobic interactions or hydrogen bridges. Thus, mucilage causes a sticky solution or gel in the presence of water (known as hydrocolloid) with potential use in the food, pharmaceutical, and biomedical industries [16,24]. Moreover, the hydroxyl groups and protein substituents present in the mucilage structure are responsible for the high water holding capacity of these natural hydrocolloid [4] meanwhile the presence of non-polar molecules favors at the same time the oil holding capacity, which may favor its use as a texture improver in different nourishments [30]. For its part, the presence of protein residues and hydrophobic side chain groups (such as the methyl and ethyl groups) is related to the surface and interfacial activity of the mucilage in oil-water or air-water emulsions. In addition, the simultaneous presence of hydrophobic and hydrophilic groups gives the mucilage an amphiphilic character that favors its acting as a stabilizer in emulsions [31], and the structural flexibility of the mucilage decreases the surface tension in foams, also favoring its stability [32]. Furthermore, the greater presence of proteins also helps to increase the viscosity of the hydrocolloid and therefore helps to stabilize emulsion systems [16].

The use of mucilage in the food and pharmaceutical industry entails its prior extraction from the plant (roots, bark, leaves, buds, fruits, or seeds). There are different methods that facilitate obtaining the mucilage. However, usually all the procedures consist of two successive operations, namely maceration and precipitation, which are performed using different conditions (solvent, time, temperatures, etc.) [4,33]. Maceration consists of dissolving the desired part of the plant in the selected solvent (water, ethanol, acetone, etc.) at a predetermined temperature and with regular agitation, while precipitation is performed to facilitate the isolation of the mucilage using certain solvents (such as ethanol) and generally followed by a centrifugation process [34]. This extraction procedure can be completed with different treatments that improve the efficiency of the process, such as physical treatments (for example, ultrasound and microwave assistance [35–37]), chemical treatments (addition of compounds such as ethylenediaminetetraacetic acid (EDTA), ammonium oxalate, sodium hydroxide and hydrochloric acid [35]), and enzymatic procedures (such as the use of hydrolases [38,39]). It should be noted that depending on the technique employed, different extraction yields are obtained (frequently between 3 and 35 %) and also the chemical composition, and the physicochemical and functional characteristics of the mucilage obtained can vary [24].

On the other hand, at present, there is a growing demand for the application of natural ingredients in several industrial sectors such as food, cosmetics, pharmacy, medicine, etc., because these permit the replacement of certain synthetic compounds. In this context, vegetable biopolymers have been continued to be studied as an effective ingredient for the formulation of health-friendly, ecological, sustainable, and profitable products [40]. As a consequence, in recent years the benefits of plant mucilage have been explored since this substance is non-toxic, non-irritating, and environmentally friendly [11]. In fact, throughout the last years, different patents have been successfully developed that have focused on the methods of obtaining, preparing, and/or applying plant mucilage [41–43]. Moreover, historically mucilage has been widely utilized by humans as a food additive and in medicine considering its many healthy properties and its very interesting technological properties [27,44]. Concretely, mucilage is characterized by being a very good structuring, texturizing, emulsifying and thickening agent, which means that it can be employed successfully for different purposes

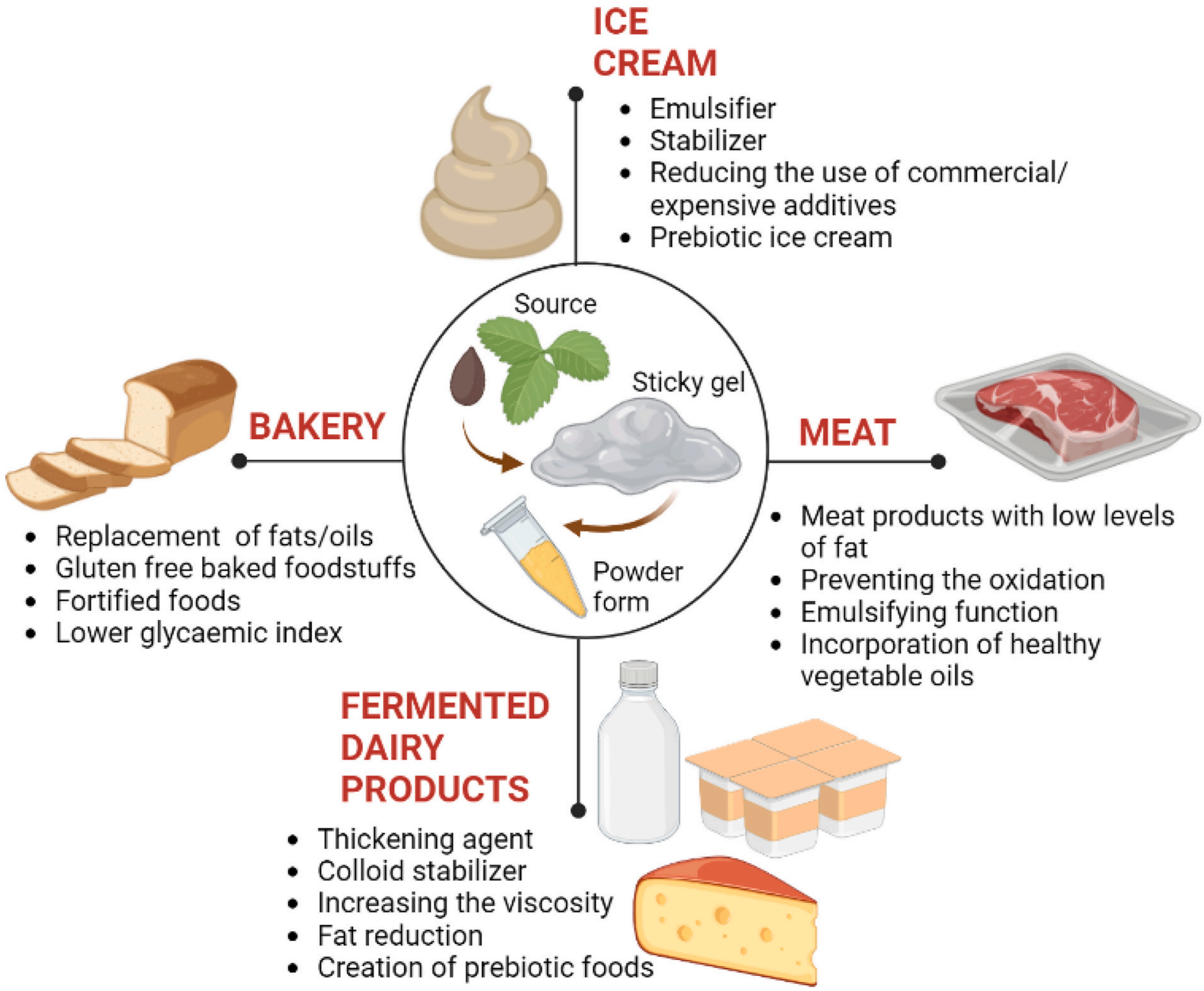

Fig. 3. The use of plant-based mucilage in different food products and the improvements it has made in each product group.

in the food industry (Fig. 3). Thus, mucilage is used in the development of low-fat [45–49], low-additive [45,50,51], gluten-free [52–56], fortified [57–59], and prebiotic [60,61] foods, and facilitates the development of probiotic products [48,60].

Additionally, plant mucilage is characterized by being generally biocompatible, hydrophilic, multifunctional and has good versatility for chemical modifications which has attracted wide research attention for tissue engineering applications in recent years (Fig. 4). Thus, plant mucilage has recently been used as scaffolds for tissue regeneration [62–65], wound treatment [66–69], and for the development of mucoadhesive drug delivery systems [70–74] since it can provide structural support and physical tissue to cells. Furthermore, unlike synthetic polymers, mucilage shows biological signals, and degrades without producing toxic compounds providing striking benefits. Besides, the gelling ability of mucilage makes this substance a suitable material for scaffold production by supplying excellent properties such as high swelling capacity, bioactivity, and antioxidant and anti-inflammatory capacity [62].

Assessing the present need to develop natural ingredients for major industries such as food and biomedical ones and the technological potential of plant mucilage, this work aims to study its utilization in the development of healthier foods and how the addition of mucilage influences nutritional, technological, and sensory characteristics of reformulated healthy foods. In addition, this review goals to analyse the application of plant mucilage in tissue engineering to provide detailed and objective information to the pharmaceutical and medical industries on this multifunctional ingredient.

2. Mucilage applications in food industry

The technological characteristics that plant mucilage possesses mean that it can be successfully used in the food industry for different purposes. In the following sections, the studies on its applications in different food matrices are discussed (Fig. 3).

2.1. Bakery products

On many occasions, bakery products contain high amounts of fat, which means that these foods are not considered healthy products. However, the fat in products such as cakes, cookies, crackers, and even some types of bread plays a fundamental role in their properties since this constituent helps to maintain an adequate texture and extends the shelf life of the product [75,76]. Therefore, the current trend to reduce fat in these foods must be accompanied by the use of ingredients that allow the characteristics of the bakery products to be maintained. In this line, mucilage has been extensively investigated as a possible replacement (total or partial) of fats/oils in bakery products (Table 2) since its utilization allows to increase the shelf life of bakery products and helps to improve their final texture [77]. For example, Felisberto et al. [78] investigated the use of different concentrations of chia (*Salvia hispanica*) seed mucilage (0.2-0.9 g of lyophilised mucilage/total dough) introduced as an aqueous gel in the development of low-fat pound cakes. Specifically, these authors observed that the reduction of up to 100 % of vegetable fat by chia mucilage did not significantly modify the specific volume, symmetry, uniformity, moisture, and water activity of the

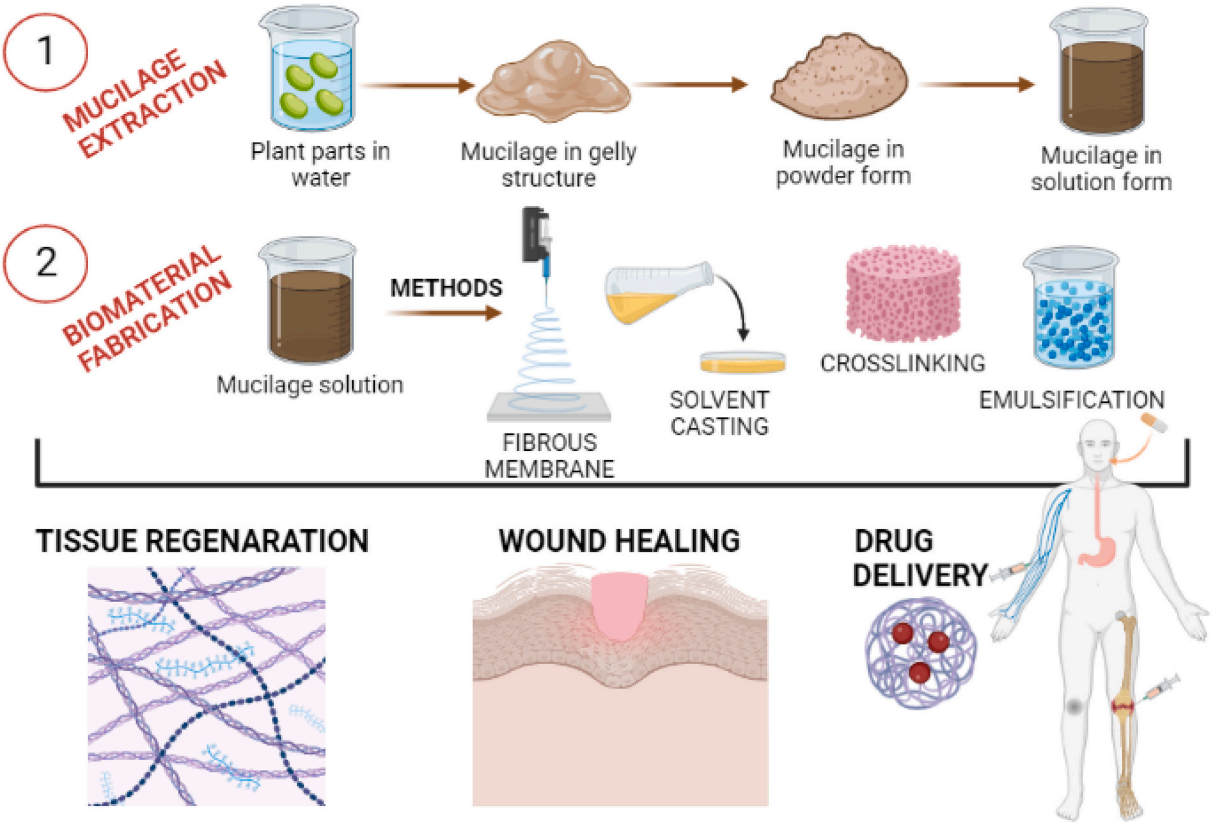

Fig. 4. Obtaining, processing and potential application areas of plant mucilage as a raw material in biomaterial production.

cakes. However, the substitutions greater than 50 % negatively modified the cake colour since the foods formulated with the highest concentrations of chia mucilage displayed their L* and b* values altered due to the greyish and brownish colour of the mucilage gel. In the same way, the cake texture was affected with a fat replacement greater than 50 % after the storage period, because they had a higher crumb firmness. Therefore, Felisberto et al. [78] indicated that the development of reduced-fat cakes showed technological guarantees in the case of 25 % substitution by chia mucilage gel. In a similar study, Fernandes & Salas-Mellado [79] investigated the influence of different concentrations of hydrated chia seed mucilage (dry and freeze-dried) on the production of bread and chocolate cakes (mucilage concentrations between 0.05–0.18 % and 0.08–0.3 %, respectively) with reduced fat content. Thus, they determined that the substitution of 50 % of the fat employed (vegetable fat for bread and margarine for cake) provided products with technological properties identical to their counterparts with 100 % fat, while greater substitutions caused a slight worsening of the technological features. In addition, after a sensory analysis of the samples, Fernandes & Salas-Mellado [79] demonstrated that breads and chocolate cakes added with dried chia mucilage had an excellent acceptance and purchase intention. Also, with the addition of chia seed mucilage, it was possible to replace part of the fat (corresponding to butter) in cookies [80]. The utilization of this plant mucilage in powder form (1.18–3.54 %) allowed to obtain a low-fat biscuit with acceptable sensory characteristics in the case of the 10 and 20 % substitutions, despite changes in the colour (reduction of L* and b* values) and texture (hardness increase in the substitution of 20 and 30 %) of the biscuits formulated.

On the other hand, plant mucilage has also been used as an ingredient to meet the current challenge of making gluten-free baked foodstuffs (Table 2), without diminishing its technological and sensory properties [52,81], because gluten-free baked products are characterized by structural and textural defects as a result of the absence of this protein in the dough [82]. In this field, Korus et al. [83] prosperously employed *Linum usitatissimum* Linn seed (linseed) mucilage in the preparation of gluten-free bread that was not incorporated with pectin and/or guar gum. They concluded that the addition of linseed mucilage had a minimal influence on the texture and rancidity of the crumb, while providing greater acceptance at the sensory level. In the same way, Dick et al. [53] prepared gluten-free crackers with the addition of *Opuntia monacantha* mucilage cladodes, which had a greater sensory acceptance than the control with commercial gum (sodium carboxymethyl cellulose and guar gum), while the physical properties of the crackers were not affected. Furthermore, the inclusion of this natural mucilage increased the total phenol content in the bakery product, while also increasing the antioxidant capacity being able to provide a functional food. The mucilage of *Cydonia oblonga* (quince) seed was also investigated to replace the commercial gum (carboxymethyl cellulose) in the production of a gluten-free bread. However, on this occasion, no improvements were observed, since its use did not enhance the rheological properties of the dough, although at a sensory level this natural mucilage did provide enhancements with respect to the control bread (without the addition of gum or mucilage).

Additionally, the use of mucilage in bakery products is also being investigated to obtain fortified foods (Table 2). An example is a study carried out by Liguori et al. [57], where they used mucilage from *Opuntia ficus-indica* cladodes to modify a fortified bread. In this case, the authors replaced the water in the bread formulation (150 mL) with the cladode mucilage (90 % of water) with promising results, since the bread obtained was enriched in bioactive components, which had antioxidant capacity. Besides, this increase in health properties did not affect the fermentation process or the quality attributes of the bread obtained, while achieving an acceptable sensory evaluation by the panellists.

Different ingredients obtained from chia (whole seeds, whole chia seed flour, semi-defatted chia seed flour, and low-fat chia seed flour), which are rich in mucilage, were also used in different concentrations

Table 2
Applications of plant mucilage in bakery products.

Product	Mucilage source	Mucilage concentration	Application	Main findings	Ref
Pound cake	Chia (*Salvia hispanica*) seed	0, 0.23, 0.45, 0.66, and 0.9 g/mass of total dough (replacing 0, 25, 50, 75, and 100 % of fat, respectively)	Low-fat cake	Did not affect the specific volume, symmetry, uniformity, moisture, and water activity Substitution of 50-100 % negatively affected colour (L* and b*) and crumb firmness 25 % replacement provides cakes with feasible technological characteristics	[78]
Bread and chocolate cake	Chia (*Salvia hispanica*) seed	0, 0.05, 0.09, 0.14, and 0.18 % for bread 0, 0.08, 0.15, 0.23, and 0.3 % for cake (dry or lyophilised) (replacing 0, 25, 50, 75, and 100 % of fat, respectively)	Low-fat bakery products	Adequate technological properties with substitution of 25 and 50 % Slight technological deterioration with substitutions of 75 and 50 % Acceptable sensory evaluation	[79]
Cookie	Chia (*Salvia hispanica*) seed	0, 1.18, 2.36, and 3.54 % (replacing 0, 10, 20, and 30 % of fat, respectively)	Low-fat cookie	Modified the colour by lowering L* and b* values Increased the hardness in the substitution of 20 and 30 % Sensory evaluation acceptable for replacement of 10 and 20 %	[80]
Bread	Linseed (*Linum usitatissimum* Linn)	0, 1.2, 1.8 and 2.4 % (of the flour)	Gluten-free bread	Rheological properties like control Dough susceptible to mechanical stress Improved sensory acceptance	[83]
Cracker	*Opotunia manacantha* cladodes	0 and 2 %	Gluten-free and functional cracker	Did not generally affect physicochemical properties Improved sensory acceptability Increased the total phenols content Enlarged antioxidant activity	[53]
Bread	Quince (*Cydonia oblonga*) seed	0, 5, 7.5, and 10 % (in hydrocolloid form)	Gluten-free bread	Did not improve dough properties Improved sensory properties Mucilage was worse than the carboxymethyl cellulose gum	[52]
Bread	*Opuntia ficus-indica* cladodes	0 and150 mL fresh mucilage/406 g dough	Functional bread	Did not affect dough fermentation Did not influence quality attributes Sensory analysis showed adequate acceptability Increased antioxidant activity of bread	[57]
Bread	Chia (*Salvia hispanica*) seed	0, 5, and 10 % on flour basis (whole seeds and whole, semi-defatted and low-fat chia seed flour)	Functional bread	Decreased glycaemic index Increased the content of high biological value proteins Incremented omega fatty acids Enlarged mineral content	[58]

for modifying a functional bread [58]. Thus, the bread obtained with the addition (5 and 10 %) of chia seeds (rich in mucilage) presented a lower glycaemic index than a control bread (without the addition of chia seeds or their flour). This fact was attributed mainly to the presence of mucilage in the chia composition due to its ability to prevent starch gelatinization during baking and therefore to prevent enzymatic vulnerability. Moreover, the bread with a lower glycaemic index had a higher nutritional value by containing a higher concentration of high biological value proteins, lipids with a higher proportion of omega fatty acids, and a greater amount of minerals [58].

2.2. *Emulsified meat products*

As with baked products, in emulsified meat products (for example, sausage, frankfurters, patties, mortadella, bologna, and nuggets) fat plays a fundamental role because it is both a structuring and flavouring agent [84]. Thus, preparing meat products with low levels of fat (and consequently healthier) is a major challenge for the meat industry. For this reason, the use of natural substances such as mucilage is being investigated more and more with the aim of solving the problems involved in the elimination of fat (total or partial) in different meat matrices (Table 3) since they can act by improving the texture of low-fat emulsified meat products [24]. The ability of mucilage to stabilize water-oil interfaces in an emulsion is associated with the formation of heterogeneous viscoelastic structures in the vicinity of the water-oil interface. This ability is attributed to polysaccharides and proteins as well as microstructural diversity of these molecules [85]. Thus, the polysaccharides present in the mucilage are good emulsion stabilizing agents due to their high molecular weight and their gelling behavior [86]. In this way, the mucilage exerts a significant interfacial activity capable of stabilizing the water-lipid interfaces in the meat emulsions, avoiding coalescence and separation [85,87]. In this field, Yüncü et al. [88] investigated the development of a low-fat beef patty using different concentrations of chia seed mucilage (5–20 %) as a substitute for beef fat at various levels (i.e., 25–75 %). Thus, these authors observed that the addition of mucilage in replacement of fat improved cooking characteristics while it did not affect texture parameters or sensory attributes. Moreover, the addition of chia mucilage helped prevent the oxidation produced during the frying of the hamburgers. For their part, Câmara, Okuro, et al. [87] studied the influence of using a chia seed mucilage gel (with 15, 20 and 25 % freeze-dried mucilage) simultaneously with the addition of freeze-dried mucilage (powder). The gels were added at different concentrations (10–33 %) depending on the formulation, while the lyophilised mucilage was added at 2.5 or 5 % in a meat emulsion model system. The authors observed that the stability of the meat emulsion was enhanced by the addition of the mucilage gel without the influence of the different concentrations added. Furthermore, the chia mucilage gel decreased the water exudation in the meat system tested. Nevertheless, the level of mucilage powder (2.5 or 5 %) was more critical, increasing hardness and decreasing elasticity and cohesiveness when added at the 5 % level. Additionally, the colour of the meat model was negatively influenced.

Another function of mucilage in the development of healthy meat products is their emulsifying function, which makes it possible to reduce

Table 3
Applications of plant mucilage in emulsified meat products.

Product	Mucilage source	Mucilage concentration	Application	Main findings	Ref
Cooked beef patty	Chia (*Salvia hispanica*) seed	0, 5, 10, and 20 %	Low-fat patty	Improved cooking characteristics Did not affect texture parameters Maintained sensory properties Prevented oxidation during frying	[88]
Meat emulsion model system	Chia (*Salvia hispanica*) seed	0-33 % of different gels; and 2.5 and 5 % of powder	Low-fat emulsified meat	Gel improved emulsion stability Gel decreased exudation Increased hardness and decreased elasticity and cohesiveness (5 % powder) Colour was negatively affected	[87]
Mortadella	*Pereskia aculeata* Miller leaf	0, 0.05, and 0.10 %	Low-fat *mortadella*	High emulsifying power Good emulsion stability Reduced the caloric level Colour did not affect Acceptance ratio like the control (0.05 %)	[46]
Beef patty	Chia (*Salvia hispanica*) seed	0, 0.2, 0.6, 0.8, and 1 % (forming part of an emulsified olive oil gel)	Low-fat patty with olive oil replacement	Enhanced the lipid profile Health indices improved Up to 60 % substitution maintained sensory properties Affected texture parameters Increased lipid oxidation	[89]
Bologna sausage	Chia (*Salvia hispanica*) seed	0, and 1 % (forming part of an emulsified olive oil gel)	Low-fat, reduced phosphate, and addition of olive oil	Enhanced the lipid profile Health indices improved Affected the emulsion structure Provided products with darker tonality Low fluid exudations Did not affect the texture, aroma, and global acceptance determined by consumers	[45]
Bologna sausage	Chia (*Salvia hispanica*) seed	0, 2, and 4 % (powder or gel form)	Low-fat and reduced phosphate sausage	Overall firmness and chewiness decreased Negatively modified the colour The gel showed products with greater stability and better texture The 2 % contraction in gel form provided the best characteristics The 2 % concentration was shown to be feasible in reducing phosphate to 50 %	[50]

the saturated animal fat used habitually. For example, Lise et al. [46] employed the mucilage from the *Pereskia aculeata* Miller leaves (0.05 and 0.10 %) as an emulsifying agent in the replacement of chicken skin (rich in saturated fats) in the production of *mortadella*. The mucilage was found to have a high emulsifying power while also having good emulsion stability in the final product and an attractive nutritional composition (as it contains all the essential amino acids and is rich in minerals). However, its use in *mortadella* has a concentration limit since, despite the instrumental differences in texture were hardly observed, the sensory analysis revealed that the highest concentration (0.1 %) resulted in higher firmness values, and thus lower acceptance rates.

The emulsifying properties of mucilage also allow the incorporation of healthy vegetable oils in substitution (total or partial) of animal fat (Table 3). In this field, Liu et al. [89] employed chia seed mucilage at different concentrations (0.2–1 %) in beef patties with the aim of replacing pork back fat at different levels (20–100 %) with a gel that included olive oil (39 %). In this way, they obtained fat-reduced patties with a better lipid profile and better health indices (namely, polyunsaturated fatty acid/saturated fatty acid ratio, atherogenicity index, and thrombogenicity). Also, these authors observed that the replacement of fat up to 60 % managed to maintain the sensory characteristics, with the substitution of 40 % being the most acceptable. Moreover, the use of the emulsified gel positively influenced the cooking of the patties, without affecting their colour. However, the reformulated patties displayed their texture parameters modified, while they presented higher lipid oxidation. Another similar study was carried out on Bologna sausages by Câmara et al. [45], where chia seed mucilage was also used as an emulsifying and stabilizing agent in the preparation of a gel emulsion that contained 5 % mucilage, 40 % olive oil, and differently combined collagen (2 %), sodium alginate (2 %) and whey protein (3 %). The use of mucilage in the preparation of the gel allowed to reformulate the Bologna sausage completely replacing the pork back fat with promising results both at a healthy and a sensory level, since the reformulated sausages showed better health indices and did not indicate differences in global acceptance or in sensory perceived aroma and texture attributes. However, the use of the chia-based gel did influence the structure of the meat emulsion and the colouration of the samples, providing less cohesive and more elastic sausages with darker tonality. Also, the use of mucilage in the preparation of the sausage permitted a 50 % reduction in the phosphate employed in the formulation of the meat emulsion, since even though the water holding capacity was lower than the control (without phosphate reduction) subsequently low liquid exudation was obtained. Identically, this same research group previously determined that chia mucilage used at 2 % (in powder or gel form) presented a feasible strategy in reducing 50 % phosphate in reduced-fat Bolognia sausages, while its use at 4 % presented greater defects in the meat emulsion [50]. Additionally, these authors observed that the mucilage added in a gel form provided more desirable characteristics than added directly in powder form.

2.3. Fermented dairy products

Plant mucilage has acquired a special interest in the development of different dairy products (Table 4) due to its potential as a thickening agent and colloid stabilizer [90]. Thus, for example, this polysaccharide has been extensively investigated in the manufacture of yogurt with the aim of improving their texture and avoiding the release of whey proteins from the yogurt body (syneresis) during storage, since the mucilage can increase the viscosity of the continuous phase of yogurt due to interactions formed between polysaccharide and proteins [91]. However, mucilage in products such as fermented milk and cheeses provides other benefits such as an adequate fat reduction [48,92,93] and the creation of prebiotic foods [48,60,61,92], as well as favoring the production of probiotic products [60,92] and providing certain colours without the

Table 4
Applications of plant mucilage in fermented dairy products.

Product	Mucilage source	Mucilage concentration	Application	Main findings	Ref
Set yogurt	*Plantago ovata* Forsk seed	0, 0.5, 1, and 2 %	Symbiotic low-fat yogurt	Promotes the survival of *Lactobacillus acidophilus* Affected the yogurt colour Increases water retention capacity Decreases syneresis Did not affect sensory attributes	[92]
Set yogurt	Linseed (*Linum usitatissimum* Linn)	0, 0.10, 0.15, and 0.20 %	Low-fat yogurt	Increased viscosity, consistency, and water retention capacity decreased syneresis Increased a* and b* values Adequate sensory attributes (0.15 %)	[49]
Yogurt	Chia (*Salvia hispanica*) seed	0, 2.5, 5, and 7.5 %	Low-fat yogurt	Reduced syneresis Improves technological properties Increased fibre content Did not modify the acidity, creaminess, or the viscosity Did modify the colour and granularity and acceptability decreased (7.5 %)	[93]
Doogh	*Plantago psyllium* seed	0, 0.15, 0.30, and 0.75 %	Symbiotic Doogh	Decreased phase separation Increased viscosity Increased the viability of *Lactibacillus casei* Symbiotic product with adequate sensory characteristics (0.30 % up to 15 days of storage)	[60]
Kefir	Faba bean (*Vicia faba* Linn) and chickpea (*Ciser arietinum*)	0 and 3 %	Prebiotic kefir	Increased microbial growth Decreased syneresis Provided a source of complex carbohydrates Slightly decreased sensory acceptability	[61]
Mozzarella	Okra (*Abelmoschus esculentus*) pod	0, 0.25, 0.5, and 1 %	Low fat *mozzarella*	Improved melting, stretchability and spreadability (1 %) Improved texture profile Favorable sensory analysis (0.25 %)	[95]
Cream cheese	Linseed (*Linum usitatissimum* Linn)	Not known	Probiotic fat-free cream cheese	Increased protein and ash content Increased viscosity Enhanced texture Promoted the survival of probiotic bacteria Improved sensory characteristics	[48]

use of artificial additives [94]. A recent example is found in the study carried out by Choobari et al. [92], where they modified a set of yogurt samples with different concentrations of *Plantago ovata* Forsk seed mucilage (0.5–2 %). Thus, the probiotic bacteria of yogurt (*Lactobacillus acidophilus*) in combination with the prebiotic mucilage gave rise to a symbiotic yogurt since it was observed that the survival of *Lactobacillus acidophilus* during storage was positively correlated with the concentration of mucilage. Furthermore, the investigated polysaccharide decreased syneresis without affecting sensory properties. The yogurt containing 1 % *Plantago ovata* Forsk seed mucilage was rated as having the best appearance and texture. Similarly, Arabshahi-Delouee et al. [49] observed that an intermediate concentration (0.15 %) of linseed mucilage in the preparation of a low-fat set yogurt provided the best sensory characteristics within the mucilage concentration range investigated (0.10–0.20 %). Moreover, the addition of this mucilage led to different physicochemical changes, some of which were positive (increased water retention capacity, viscosity, consistency, and decreased syneresis). Chia mucilage has also been shown to be a suitable ingredient in the preparation of low-fat yogurts, since its addition (2.5–7.5 %) reduced syneresis during storage, improved nutritional values by increasing dietary fibre content and favored the technological properties of the yogurt (greater consistency, firmness, viscosity, resistance to stress, and better net-work structure) compared to full-fat and skimmed yogurts [93]. In addition, sensory analysis (at a concentration of 7.5 % mucilage) revealed that the inclusion of this polysaccharide did not modify the acidity, creaminess, and viscosity of the low-fat yogurt, although it did affect its granularity and colour, which decreased its acceptability.

The suitability of using mucilage in the development of other types of fermented milk different from yogurts, such as Doogh and kefir, has also been studied (Table 4). For example, the use of *Plantago psyllium* seed mucilage (0.15–0.75 %) has been presented to improve symbiotic dough stability (decreasing phase separation during storage) while increasing the viscosity and increasing the viability of *Lactibacillus casei* [60]. However, the highest concentration of mucilage (0.75 %) affected the global acceptance of the dairy product, determining that the best formulation was the one with 0.30 % of *Plantago psyllium* seed mucilage. This fact implied that the shelf life was extended exclusively to 15 days, to guarantee adequate counts of *Lactibacillus casei* and provide a symbiotic dairy product (containing prebiotics and probiotics at the same time). For their part, Saadi et al. [61] found that the addition of faba bean minor (*Vicia faba* Linn) and chickpea (*Ciser arietinum*) mucilage to kefir could be a potential prebiotic source since they are a source of complex carbohydrates. Thus, their presence favored the gut microbiota growth. Moreover, kefir with legume mucilage did not see increased syneresis during storage time, unlike a control without mucilage, but its sensory acceptability was slightly modified.

Regarding cheeses, few studies used plant mucilage in their formulation. Nevertheless, recent research has shown that the use of mucilage from okra (*Abelmoschus esculentus*) pods in different concentrations (0.25–1.0 %) can represent improvements in the development of low-fat mozzarella [95]. Specifically, low-fat mozzarella produced with 1 % okra mucilage stood out for having a positive impact on the functional (melting, stretchability, and spreadability) and textural attributes. Although, it should be noted that the formulation containing 0.25 % of the mucilage was considered the most suitable due to its better organoleptic properties. Similarly, linseed mucilage was used to produce fat-free cream cheese with prebiotic properties [48], thus achieving a dairy product with better survival of probiotic bacteria, at the same time with better sensory characteristics. Additionally, the use of the plant mucilage increased the protein content, increased the viscosity, and enhanced the texture of the cream cheese.

Table 5
Applications of plant mucilage in ice cream development.

Product	Mucilage source	Mucilage concentration	Application	Main findings	Ref
Kahramanmaras ice cream	Chia (*Salvia hispanica*) seed	0, 0.2, 0.4, 0.6, and 0.8 %	Salep reduction (low-cost ice cream)	Did not affect pH or acidity Decreased first dripping time Increased melting rate Affected viscosity and overrun of the ice cream mix Reduced hardness and stickiness Quality maintained down to 0.4 % in combination with salep	[98]
Vanilla flavoured ice cream	Yam (*Dioscorea rotundata*)	0.02, 0.16, 0.2, 0.32, 0.4 0.64, and 0.8 %	Carboximetilcelulose reduction	Increased protein and ash content Increased air volume (at higher ratios) Increased melting times (at higher ratios) Delayed drops falling time (at higher ratios)	[51]
Ice cream	Chia (*Salvia hispanica*) seed	0, 0.1, 0.2, and 0.3 %	Substitute for guar gum	Increased viscosity Decreased overrun and melt rate Did not influence fat globules size Incremented destabilised fat index Characteristics very similar to ice cream with guar gum (0.2 %)	[99]
Chocolate flavoured ice cream	Psyllium (*Plantago ovata*)	2 % (gel or dry)	Increased technological and functional properties	Gel mucilage incremented overrun Dry mucilage increased melting time High acceptances Low purchase intentions	[100]
White chocolate flavoured ice cream	Chia (*Salvia hispanica*) seed	0.6, 1.2, and 1.8 %	Substitute for emulsifier in prebiotic ice cream	Did not affect the chemical composition Did not influence acceptability Darker colourations (1.2 and 1.8 %) Decreased melt resistance Reduced firmness 0.2 % was the best concentration	[101]

2.4. *Ice cream*

Ice creams are aerated and frozen dairy systems with unique characteristics that must be maintained during storage. For this reason, during their preparation, different additives are added such as emulsifiers and stabilizers, among which are mono- and diglycerides, gum, gelatines, and cellulose-derived compounds [96]. However, several recent studies tried to eliminate or reduce the use of commercial and/or expensive additives using plant mucilage to obtain ice creams with good technological and sensory properties meanwhile being healthier and/or cheaper (Table 5) since the use of mucilage can compensate for the absence of different stabilizing commercial additives acting as an excellent cryoprotectant [97]. In this field, Lozano et al. [51] investigated the use of yam (*Dioscorea rotundata*) mucilage to reduce the commercial stabilizer carboxymethylcellulose in a vanilla-flavoured ice cream. For this, they utilized different combinations of mucilage and carboxymethylcellulose (ratios between 100–20:0–80; corresponding to a mucilage concentration between 0.02 and 0.8 %). Thus, they observed that the inclusion of the highest ratios of mucilage added nutritional value to the formulated ice creams (increased the value of protein and ashes), increased the volume of air, and conferred stability to the product (longest melting times and delay drops falling time). For their part, Arnak & Tarakçi [98] utilized different concentrations of chia seed mucilage (0.2–0.8 %) with the aim of reducing/eliminating the use of salep (an expensive stabilizer obtained from dried tubers of an orchid plant) in the preparation of Kahramanmaras ice cream. However, these authors observed that the use of vegetable mucilage decreased the first dripping time and increased the melting rate. Furthermore, the addition of chia seed mucilage affected the viscosity and overrun (percentage of air incorporated) of the ice cream mix while reducing the hardness and stickiness. Despite these modifications, it was concluded that the mucilage/salep combinations (2 %/0.6 % and 0.4 %/0.4 %) maintain the quality of the ice cream obtained. For their part, Lozano et al. [51] investigated the use of yam (*Dioscorea rotundata*) mucilage to reduce the commercial stabilizer carboxymethylcellulose in a vanilla-flavoured ice cream. For this, they used different combinations of mucilage and carboxymethylcellulose (ratios between 100–20:0–80; corresponding to a mucilage concentration between 0.02 and 0.8 %). Thus, they observed that the inclusion of the highest ratios of mucilage added nutritional value to the formulated ice creams (increased the value of protein and ashes), increased the volume of air, and conferred stability to the product (longest melting times and delay drops falling time).

Chia mucilage was investigated (in concentrations ranging from 0.1 to 0.3 %) with promising results in the elimination of guar gum, since addition at a 0.2 % level in substitution of the said commercial additive provided ice creams with characteristics very similar to commercial ice creams [99]. Thus, the group with 0.2 % chia mucilage presented an attractive hardness, smooth texture, and creamy mouthfeel without the perception of ice crystals or off-flavours. Furthermore, chia mucilage generally increased viscosity, while decreasing the melting rate and overrun. However, it was observed that the addition of mucilage provided ice creams with a higher destabilised fat index, even though it did not influence the size of fat globules. Similarly, psyllium (*Plantago ovata*) mucilage has also been evaluated for use in ice cream. Specifically, Souza et al. [100] investigated the use of psyllium mucilage (2 %) in a gel or dry form (after evaluating the best extraction conditions). In this way, they observed the characteristics of the ice cream were influenced by the type of mucilage used, noting that the ice cream added with the gel mucilage presented a greater overrun, but a shorter melting time due to the greater amount of water present in its composition. Despite these differences, the two ice creams emerged similar degrees of acceptance with attributes that could satisfy consumer demands. However, the intention to purchase both ice creams was low.

The use of mucilage in the development of prebiotic ice creams has also been investigated for the replacement of emulsifying agents (Table 5). In this field, Maestrello et al. [101] researched the use of chia mucilage (0.6–1.8 %) in the preparation of a chocolate-flavoured ice cream that contained inulin in its formulation. The results figured out that the utilization of chia seed mucilage did not affect the chemical composition or the acceptability of chocolate-flavoured ice cream. However, it should be noted that a higher concentration of mucilage provided darker colouration to the product, as well as reducing the melting resistance and firmness.

Table 6
Applications of plant mucilage in the production of pasta, mayonnaise, and beverages.

Product	Mucilage source	Mucilage concentration	Application	Main findings	Ref
Pasta	Chia (*Salvia hispanica*) seed	0, 5, and 10 %	Gluten-free pasta	Acted as a good thickening agent Improved the nutritional value of pasta (higher protein content, and dietary fibre) (10 %) Increased the total phenol content (10 %)	[56]
Noodles	*Neolitsea cassia* leaves	0 % (with other gum), and 2.5 %	Gluten-free pasta	Improved the cooking and textural qualities Enhanced quality compared to Arabic gum Quality worsened compared to Xanthan gum	[55]
Noodles	*Dillenia retusa* fruit	0 % (with other gum), and 8 %	Gluten-free pasta	Improved the cooking and textural qualities Quality worsened compared to other gum (Xanthan and Arabic)	[55]
Mayonnaise	*Opuntia robusta* cladodes	0, 3.17, 6.33, and 12.33 % (replacing 0, 25, 50, and 100 % of egg, respectively)	Egg replacer	Mayonnaise with 20 % substitution obtained the highest scores for all quality attributes Mayonnaise with 15 and 50 % substitution was sensorially comparable to the control	[103]
Mayonnaise	*Opuntia robusta* cladodes	0, 11.74, and 23.49 % (replacing 0, 15 %, and 30 % of oil, respectively)	Oil replacer	Mayonnaise with 30 % substitution obtained the highest scores for taste Mayonnaise with 15 % substitution was comparable in appearance to the control	[103]
Chocolate Drink	Psyllium (*Plantago ovata*)	0, 5, and 15 %	Drink enriched in antioxidant substances	Comparable to Xanthan gum Maintains overall appearance Maintains purchase intention	[59]
Moisturizing drink	Cocoa (*Theobroma cacao* Linn) (two different varieties)	25, 35, and 45 %	Moisturizing drink	Increased the nutritional value of beverages	[105]
Alcohol-based beverage	Cocoa (*Theobroma cacao* Linn) mucilage, pulp, or beans	9.4 % (mucilage) 45.3 % (pulp), or 54.7 % (beans)	Alcohol-based beverage	The addition of pulp imparted better sensory properties	[106]

2.5. Other food products

As in baked products, mucilage has been used in the production of other gluten-free foods such as pasta (Table 6) with the aim of improving the rheological properties of the dough and subsequently the physicochemical and sensory characteristics of the finished food products. In addition, the use of mucilage in gluten-free pasta helps to improve its nutritional profile, since it increases the content of various nutrients such as protein, fibre, and antioxidant compounds [102]. An example is found in the research carried out by Menga et al. [56], where they studied the use of mucilage and milled chia seeds (5 and 10 %) in the preparation of fresh gluten-free pasta based on rice flour. With these new formulations, the authors indicated that chia is a good substitute that adequately mimics the three-dimensional network of gluten while it allows obtaining pasta with cooking characteristics like commercial gluten-free pasta but with higher nutritional values (higher protein, dietary fibre, and phenolic acids content) in the case of 10 % mucilage or milled chia seeds. Likewise, Kasunmala et al. [55] investigated the use of mucilage from *Neolitsea cassialeaves* leaves and *Dillenia retusa* fruit (2.5 and 8 %, respectively) and different gum (Xanthan gum and Arabic gum) in the preparation of gluten-free noodles (besides that studying other variables of the noodle manufacturing process). This study revealed that the mucilage employed as a binding agent significantly enhanced the cooking qualities and texture of the rice noodles. More specifically, the noodles with *Neolitsea cassia* leaves mucilage declared a much higher cooking quality and texture than the noodles containing Arabic gum. However, the noodles with the highest technological quality were those containing Xanthan gum.

On the other hand, the characteristics presented by mayonnaise (that is, high-fat content and the presence of eggs) have favored the development of innovative products that try to reduce the oil content and minimize the presence of eggs (rich in cholesterol). In this context, various studies have tried to employ the use of different mucilage (Table 6) with the aim of obtaining healthier sauces with adequate technological and organoleptic characteristics since mucilage provides a stable emulsion [103,104]. Thus, du Toit et al. [103] observed that the use of *Opuntia robusta* mucilage successfully replaced up to 50 % of egg yolk and 30 % of oil, contributing positively to the nutritional quality and texture of this product.

Finally, mucilage has also been utilized in the development of different types of beverages (Table 6). For example, Souza, dos Santos, et al. [59] utilized psyllium mucilage (5 and 15 %) in the preparation of a chocolate drink, after determining the extraction conditions that provided better antioxidant properties. Thus, they found that the use of this ingredient acted as a potential thickener, comparable to Xanthan gum, since in most of the sensory attributes determined no significant differences were obtained between the drinks, maintaining the general appearance and the purchase intention in the same range. For their part, Paulina et al. [105] studied the use of mucilage from two varieties of cocoa (*Theobroma cacao* Linn) in different concentrations (25, 35, and 45 %) in the preparation of a moisturizing drink, observing that the cocoa variety affected the physicochemical characteristics of the mucilage obtained, and that the mucilage concentration was positively related to the nutritional value of the moisturizing drink. Recently, the use of cocoa mucilage in an alcohol-based beverage was studied [106]. The addition of mucilage, in this case, was made by direct addition of cocoa pulp (45.3 %), or through mucilage with beans (54.7 %) or mucilage exclusively (9.4 %). Thus, it was observed that the addition of mucilage through the pulp imparted better sensory properties when compared to alcohol-based beverages produced with mucilage beans or mucilage exclusively [106].

3. Mucilage for biomedical applications

Tissue engineering is a multidisciplinary branch of science that aims to transport cells, growth factors, or drug-active substances on a scaffold to the damaged area and to heal damaged tissues or form new tissue with the coordinated work of biological sciences, medicine, and engineering. One of the key components of all tissue engineering applications is a three-dimensional (3D) matrix structure known as a scaffold, which can mimic the natural extracellular matrix (ECM) required to recruit and direct host cells to regenerate damaged tissue. ECM are macromolecule-based network structures organized in a cell/tissue-specific manner which provides the structural support and physical environment for cells

Table 7
Studies on plant mucilage-based biomaterials produced with tissue engineering approach, their production methods, and applications.

Mucilage source	Additive	Method	Application	Ref
Quince seed	Nano-hydroxyapatite	Freeze drying	Biomimetic osteogenic bioscaffold	[63]
Basil seed	Sodium alginate magnetic nanoparticle	Encapsulation	pH sensitive beads for drug delivery	[74]
Mimosa pudica seed	–	Hydrogelation	Drug delivery applications	[71]
Ocimum basilicum seed	Alginate hyaluronic acid	Solvent casting	Multilayer drug release system	[73]
Quince seed	Bacterial cellulose	Solvent casting	Wound dressing	[68]
Aloe vera Artemisia vulgaris	Potassium persulphate acrylic acid methylene bisacrylamide	Free-radical copolymerization	Safe for oral ingestion, drug delivery applications	[72]
Allemantia royleana seed	Chitosan chitin	Crosslinking at subzero temperature	Drug loaded wound dressing	[124]
Balangu (*Lallemantia royleana*) seed	Polyvinyl alcohol	Electrospinning	Cell culture scaffolds	[117]
Quince (*Cydinia oblonga* Miller) seed	Silica	Microwave-assisted sol–gel reaction	3D bone substitute	[119]
Quince seed	Cellulose nanofibrils	3D printing	Scaffold for soft tissue engineering	[64]
Quince seed	Glucuronoxylan	Crosslinking with glutaraldehyde	Scaffold for 3D cell culture and tissue engineering	[62]
Jackfruit (*Artocarpus heterophyllos*)	Poly (ε-caprolactone)	Melt blending	Potential applications in tissue engineering	[118]
Quince seed (*Cydonia oblonga*)	Poly-caprolactone polyethylene Polyethylene glycolchitosan	Crosslinking at subzero temperatures	Wound dressings and skin tissue-engineered substrates	[66]
Quince (*Rosaceae* family) seed	Polycaprolactone	Electrospinning	Cell culture scaffolds	[65]
Fenugreek (*Trigonella foenum-graecum*) seed	Polyvinyl alcohol	Microwave-assisted process	Tissue engineering scaffold and drug delivery device	[70]
Chan (*Hyptis suaveolens*) seeds Linseed (*Linum usitatissimum*) Mozote (*Triumfetta semitriloba*) stem	Polyvinyl alcohol	Electrospinning	Potential applications in tissue engineering	[114]
Jack fruit (*Artocarpus heterophyllus* Lam.) Okra (*Abelmoschus esculentus* L.)	PVP K30 Curcumin	Solvent evaporation technique	Colon targeting bio carrier (mucoadhesive tablet)	[139]
Basil seed (*Ocimum basilicum*)	Thiolated alginate Polydopamine	Crosslinked with $CaCl_2$	Bilayer mucoadhesive film for drug delivery	[140]
Thorn apple (*Datura stramonium*) leaves	Ethyl Cellulose	Solvent evaporation	Buccoadhesive drug delivery with exceeding hepatic first pass metabolism and increasing bioavailability	[141]

in the tissue of interest to attach, grow, migrate, and respond to signals [107]. It gives the tissue its mechanical properties, such as stiffness and elasticity, which are structural and therefore associated with tissue functions. In addition, it provides many biological cues that direct cell migration, adhesion, and differentiation, while being degraded to allow neovascularization and remodelling in response to developmental, physiological, and pathological challenges during tissue dynamic processes such as morphogenesis, homeostasis, and wound healing, respectively [108,109]. In order to imitate all these physical and biological properties ECM exhibits, scientists have designed scaffolds with a wide range of morphologies and properties, using different techniques such as electrospinning, solvent casting/ particulate leaching, phase separation, freeze-thawing, gas foaming, cryogelation, emulsification and 3D printing. A variety of macromolecules ranging from synthetic to natural polymers are used in the production of scaffolds obtained by using these techniques alone or in combination. Despite the advantages of flexible material properties, favorable mechanical stability, and the ability to be prepared at the desired molecular weight, most synthetic polymers are of limited use in tissue engineering applications because they lack the biological cues found in natural polymers [110]. Since natural polymers, such as plant mucilage, are composed of proteoglycans, glycosaminoglycans, glycoproteins and glycolipids inherently found in the ECM structure, the scaffold to be produced offers structures and functions related to the natural ECM. Besides its similarity to ECM components, the importance of glycan moieties as biomolecular cues and the combinatorial possibilities of carbohydrates reveal polysaccharides, from the family of natural polymers, as a key player in the design of scaffolds for tissue engineering [109,111]. They offer superior properties such as naturally occurring, biocompatibility, hydrophilicity, water solubility, multifunctionality, high chemical reactivity, biodegradability, and non-toxicity of degradation products [111].

One of the first studies to indicate that mucilage is a polysaccharide that can be used for biomedical applications was reported by Archana et al. [112]. They extracted and characterized mucilage from the waste of okra (*Abelmoscus esculentus*) by hot extraction and further compared it with seaweed polysaccharide for its potential role in the development of biopolymer for tissue engineering [112]. Thus, they introduced a new trend towards using agricultural wastes from food processing industries to develop cheaper, biocompatible, and biodegradable biopolymers for tissue engineering applications. In the following years, studies on the use of plant mucilage polysaccharide continued increasingly. When the literature is reviewed, it is seen that especially in the last ten years, studies have produced scaffolds with different morphologies on the basis of plant mucilage to be used as tissue regeneration, drug release or wound dressing material. However, we can say that it is an untouched field where studies continue on the identification of different plant sources as a fairly new source of polysaccharides, elucidation of the relationship between different cell types and mucilage, and the production and functionalization of new types of materials. In this context, plant mucilage sources used in the fabrication of scaffolds produced with tissue engineering approach, fabrication methods and application areas are compiled in Table 7. In the following sections, the studies on tissue regeneration, drug delivery systems and wound dressing materials, where mucilage is used more frequently, will be evaluated in detail (Fig. 4).

3.1. Scaffolds for tissue regeneration

A large number of scaffolds produced from various natural sources using different manufacturing techniques are used in attempts to regenerate different tissues and organs. Among these natural resources, plant mucilage, as a newly discovered source of polysaccharides, has begun to be evaluated as scaffolds for tissue regeneration or new tissue formation. One of the first studies to report on using plant-derived mucilage as scaffolds was made by Huang et al. [113], in which they examined the mucilage obtained from the stalked glands of in vitro cultured sundew (*Drosera* spp.) plants. This study investigated the feasibility of applying sundew mucilage (adhesive) for tissue engineering. The results showed that the fibrous scaffolds from sundew adhesive can exhibit weak cytotoxic activity in a long-term test period and enhance adhesion of many cell types, including fibroblast cells (MC3T3 mouse pre-osteoblastic cells and NIH3T3 mouse embryo fibroblast cells) and smooth muscle cells (MSMCs and RSMCs) [113]. In the following years, the studies carried out the production of mucilage-based scaffolds in the form of nanofibers by electrospinning [114] and 3D porous structures as a result of freeze-drying [115] or chemical crosslinking [66]. When designing new scaffolds for tissue regeneration, it is of great importance to consider the workability of the material and its architecture as a scaffold, as well as the biological properties of the material to be used in production. Although plant mucilage exhibits biological properties suitable for cell attachment and proliferation with its high biocompatibility, regenerative features and biodegradable structure, its low mechanical properties limit its use. For this reason, it is discussed that they are combined with other polymers such as chitosan [116], polyvinyl alcohol [117] and polycaprolactone [65,118]. In addition, the bio-functionality and mimic properties of the scaffolds can be enhanced with the incorporation of inorganic minerals. In a recent study, nano-hydroxyapatite (nHAp) particles were added to the structure of quince seed mucilage-based scaffolds (QSM-nHAp) to improve the osteoconductive features and osteogenic development. The cellular proliferation, viability and morphology of human adipose-derived stem cells on the developed biocomposites were evaluated in vitro. The obtained MTT results were compared with the results obtained by the research group from their previous study in which they produced quince seed mucilage (QSM)-based bioscaffolds. In their previous study, the QSM gel was found to be non-cytotoxic and they supported cell attachment and proliferation [119]. With the addition of nHAp to the scaffold structure, cellular infiltration and growth were observed more than QSM scaffolds due to the mineral structure of nHAp and the increased surface roughness of biocomposites [63].

3.2. *Wound dressings*

A wound can be defined as any lesions that disrupt or damage normal anatomical structure and integrity. The effectiveness of the method to be applied in the treatment of wounds depends on the determination of the right method, the right material, and the wound type. In this context, the skin substitutes produced for tissue engineering purposes was designed to create a microenvironment to ensure cell proliferation and migration and to mimic the 3D porous natural ECM, which encourages wound healing [120]. Polysaccharides, including plant mucilage, with significant characteristics such as biocompatibility, biologically degradability and not being toxic are promising natural resources for the production of different types of wound dressings. Moreover, it is known that plant mucilage has beneficial effects on burns, wounds, inflammations and irritations [121]. For example, quince seed mucilage was used for the treatment of skin wounds/burns in Iranian traditional medicine [122]. The healing effects of quince seed mucilage on skin wounds in animal models were also evaluated in many studies [122,123]. As another source, mucilage extracted from the seeds of *Lallemantia royleana* (commonly known as balangu) is also known to have antimicrobial, antioxidant, and many pharmacological effects. This plant has been used as a folk remedy for many ailments in Pakistan [124]. However, it is seen that there are many undiscovered mucilage sources with different pharmacological properties besides quince seeds and balangu seeds. So far, mucilages from basil seeds [125,126], quince seeds [67], *Hibiscus* leaves [69], and balangu seeds [124] have been used in the production of wound dressing material. Balangu mucilage-based wound dressings were produced with chitosan/chitin using glutaraldehyde as a crosslinker, incorporating ciprofloxacin as a model drug and silver nanoparticles to prevent the microbial invasion of the wound site. The healing potential of composite dressings was evaluated in vivo on a wound (around 1×1 cm^2) created on the dorsal side of Wistar rats. The results figured out that the prepared composite dressings cured the wound effectively over a period of 9 days [124].

3.3. *Mucoadhesive drug delivery systems*

Conventional drug delivery systems often cause side effects and gastric upset due to limited targeting ability, low therapeutic index, poor water solubility, and the tendency to induce drug resistance [74,127]. In tissue engineering, the controlled release of drugs (drug active ingredients, small molecule chemicals, peptides, proteins, growth factors, cytokines and other bioactive molecules) from a scaffold can accelerate the local healing process while eliminating concerns about the potential undesirable systemic effects of the drug in the body [128]. In the production of scaffolds used as drug carriers, we see that mucilage has been used in recent years, as well as other natural and synthetic polymers. The use of mucilage as a drug delivery system in the production of scaffolds is defined in the class of mucoadehesized drug delivery systems. The term mucoadhesion, which is defined as the main feature in these systems, is generally expressed as the adhesion between two materials, at least one of which is the mucosal surface of biological origin. Designed with prolonged retention at the site of administration and to provide a controlled rate of drug release for improved therapeutic outcome, these systems are also useful for the delivery of orally unsuitable drug molecules, such as those subject to acid degradation or extensive first pass metabolism [129,130].

The first studies in which mucilage was used in drug release applications were based on its use as a matrix forming agent. A polysaccharide mucilage derived from the seeds of fenugreek was investigated for use in matrix formulations containing propranolol hydrochloride. The extracted mucilage and drug were mixed and compressed directly using a manual tableting machine. The results showed that fenugreek mucilage was a good release retarder [131]. In the same context, sustained-release diclofenac tablets were prepared by direct compression on a rotary tablet press using *Hibiscus rosasinensis* Linn mucilage powder. It has been demonstrated that the mucilage used in the preparation of a sustained-release tablet dosage form for 12 h can be used as a disintegrating agent, gelling agent, and modified-release dosage form [132]. With the development of material science and a significant increase in the use of inexpensive, natural, and biodegradable compounds in the pharmaceutical industry, mucilage-based drug delivery vehicles started to be prepared as hydrogels in film [73], bead [74], microsphere [17], and disc [133] forms. Moreover, mucilage was used to coat iron oxide nanoparticles designed for gene delivery [134]. Even, nano-hydrogel network drug delivery systems have also been studied [135].

It is noteworthy that plant derived mucilage is also used in the preparation of dosage forms in the pharmaceutical industry, similar to drug delivery systems. In recent years, it is seen that the interest in biocompatible, cheap, and easily available natural binders for use in drug formulations has been increasing. Among these agents, plant mucilage has been used as a binding factor and drug excipient in many pharmaceutical formulations of tablets, capsules, pellets, granules, suspensions and gels as disintegrating, binding, emulsifying, suspending, gelling, and thickening agents [136,137]. To date, many types of mucilage obtained from different parts of plants have been used for these applications. An example of one of these applications is the evaluation of mucilage isolated from *Vigna mungo* (black gram) seed by precipitation method as a gelling, binder, dispersant, and suspending agent for pharmaceutical applications. It has been emphasized that mucilage with increasing concentration shows better binding compared to standard binder (PVP K30), drug release time and amount remain almost the same compared to the presence of standard binders [138].

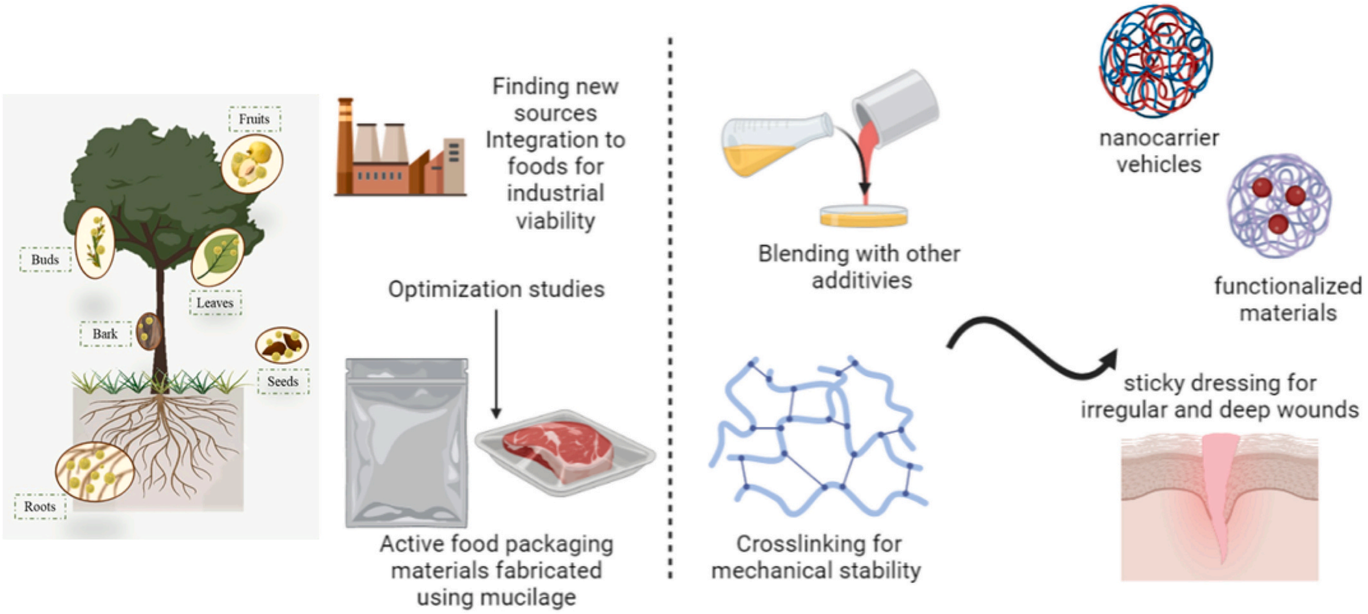

Fig. 5. Future perspective of use plant derived mucilage for food and biomedical applications.

4. Conclusions

This study is on the identification of plant-based mucilage as an accessible, inexpensive, and sustainable source of polysaccharides and elucidating its main application areas. Its application area is based on its use in the food industry for purposes such as food additive, fat replacer, emulsifier, and stabilizer, as well as its use as tissue regeneration, wound healing and drug delivery system for biomedical applications. The use of plant mucilage in the biomedical industry, especially with the tissue engineering approach, continues to attract the attention of researchers due to the adhesiveness, biocompatible, water retention, and biodegradability properties of the mucilage. Although the application of plant mucilage in food systems is promising, it still has limitations since its addition to different food matrices can negatively affect various food characteristics such as colour parameters, texture, and even technological properties. In addition, all these modifications can influence the shelf life of the food and its sensory quality, affecting at the same time the intention to buy from consumers. Therefore, the use of the mucilage plant still needs to be explored in greater depth.

5. Future perspectives

The functional properties of plant mucilage together with its excellent technological features have permitted its use to be widely investigated both in the preparation of healthier foods in the food industry and in the design of useful biomaterials in tissue engineering. Thus, this review work displayed that the mucilage plant is presented as a unique opportunity in important industrial sectors.

Despite the potential of mucilage in both food and non-food applications, its research is still quite limited and its properties are still far from being optimal, and thus further research is needed. Firstly, it should be noted that the sources of mucilage available in nature are very vast, while mucilage that has been studied are only from a few plant species. Regarding this, new sources that could provide plant mucilage more easily and effectively along with more suitable characteristics should be explored and studied. In addition, the optimization of the extraction processes of mucilage, as well as the development of clean technologies to achieve it, require further investigation in order to minimize the environmental impact while obtaining adequate yields for the demanding industry.

On the other hand, in the food industry, how to add mucilage (that is, mucilage accompanied with the matrix from which the mucilage is extracted (integrated into seeds, fruits, pods, etc.), or purified mucilage in form of dehydrated powder or lyophilized, or dispersed in water in gel form) to obtain the best nutritional, technological, and sensory results for the final products still requires deeper investigations to establish adequate protocols to include mucilage into foods. Likewise, investigations must consider consumers' perspectives of mucilage-added products, which help to guarantee industrial viability. In addition to adding mucilage to directly in food structure, we can say that it is a good candidate for active food packaging applications, with the workability of mucilage as a material. In this context, studies can be conducted on the optimization of the processability parameters of mucilage for the production of packaging materials that are robust, flexible and can prevent bacterial contamination, and as a result, aiming to extend the shelf life of foods (Fig. 5).

As for non-food applications such as biomedical (e.g., tissue engineering) field, more tests are necessary in order to obtain materials based on plant mucilage with appropriate mechanical characteristics, since mucilage does not always offer ideal properties. The mucilage can be crosslinked according to its functional groups to improve its loose structure with appropriate agents. Since studies in the biomedical field are still on bringing mucilage into a material form and then demonstrating biocompatibility, it can be combined with other bioactive agents or nanoparticle systems to add functionality to mucilage-based biomaterials. In addition, studies can be carried out on the filling of deep and chronic wounds that do not have a certain shape, especially on the production of squeezable gel-like tissue scaffolds that will allow the formation of new tissue in that area, by making use of its viscous consistency and its traditional use for wound healing. For all these application areas, the mechanism between mucilage and other polymer/active agent/natural additives/nanoparticle systems needs to be elucidated in more depth and detail (Fig. 5).

Declaration of competing interest

The authors declare that there is no conflict of interest with this manuscript.

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References

[1] M. Nazari, S. Riebeling, C.C. Banfield, A. Akale, M. Crosta, K. Mason-Jones, M. A. Dippold, M.A. Ahmed, Mucilage polysaccharide composition and exudation in maize from contrasting climatic regions, Front. Plant Sci. 11 (2020), https://doi.org/10.3389/FPLS.2020.587610/FULL.

[2] B. Savun-Hekimoğlu, C. Gazioğlu, Mucilage problem in the semi-enclosed seas: recent outbreak in the sea of Marmara, Int. J. Environ. Geoinformatics 8 (2021) 402–413, https://doi.org/10.30897/ijegeo.955739.

[3] V. Flander-Putrle, A. Malej, The evolution and phytoplankton composition of mucilaginous aggregates in the northern Adriatic Sea, Harmful Algae 7 (2008) 752–761, https://doi.org/10.1016/J.HAL.2008.02.009.

[4] M.M. Tosif, A. Najda, A. Bains, R. Kaushik, S.B. Dhull, P. Chawla, M. Walasek-Janusz, A comprehensive review on plant-derived mucilage: characterization, functional properties, applications, and its utilization for nanocarrier fabrication, Polymers (Basel) 13 (2021) 1066, https://doi.org/10.3390/polym13071066.

[5] A. Driouich, A. Gaudry, B. Pawlak, J.P. Moore, Root cap-derived cells and mucilage: a protective network at the root tip, Protoplasma 258 (2021) 1179–1185, https://doi.org/10.1007/s00709-021-01660-y.

[6] F. Fernandes, A. Dantas, L. de Carvalho, W.K.A. da Costa, M. Lima, M. Magnani, G. Borges, R.de S. Silva, Juá (Ziziphus joazeiro Mart.) mucilage and juá by-product phenolic extract improve quality parameters and retain bioactive compounds in fresh-cut pineapple during storage, Food Research International. 2022 (2022) 111826, https://doi.org/10.1016/J.FOODRES.2022.111826.

[7] E.A.S. Paiva, G.A. Couy-Melo, I. Ballego-Campos, Colleters, extrafloral nectaries, and resin glands protect buds and young leaves of Ouratea castaneifolia (DC.) Engl. (Ochnaceae), Plants 10 (2021) 1680, https://doi.org/10.3390/PLANTS10081680.

[8] A. Roy, M. Patra, S. Sarkhel, S. Sengupta, S. Saha, S. Jha, G. Sarkhel, S. L. Shrivastava, Fucose-containing Abroma augusta mucilage hydrogel as a potential probiotic carrier with prebiotic function, Food Chem. 387 (2022), 132941, https://doi.org/10.1016/J.FOODCHEM.2022.132941.

[9] A. Munir, F.S. Youssef, S. Ishtiaq, S.H. Kamran, A. Sirwi, S.A. Ahmed, M. L. Ashour, S.S. Elhady, Malva parviflora leaves mucilage: an eco-friendly and sustainable biopolymer with antioxidant properties, Polymers (Basel) 13 (2021) 4251, https://doi.org/10.3390/POLYM13234251.

[10] M. Knott, M. Ani, E. Kroener, D. Diehl, Effect of environmental conditions on physical properties of maize root mucilage, 2022, https://doi.org/10.21203/rs.3.rs-1260909/v1.

[11] R. Waghmare, R. Preethi, J.A. Moses, C. Anandharamakrishnan, Mucilages: sources, extraction methods, and characteristics for their use as encapsulation agents, Crit. Rev. Food Sci. Nutr. 62 (2022) 4186–4207, https://doi.org/10.1080/10408398.2021.1873730.

[12] M.M. Tosif, A. Najda, A. Bains, G. Zawiślak, G. Maj, P. Chawla, Starch–mucilage composite films: an inclusive on physicochemical and biological perspective, Polymers (Basel) 13 (2021) 2588, https://doi.org/10.3390/polym13162588.

[13] N. Shimizu, M. Tomoda, I. Suzuki, K. Takada, Plant mucilages. XLIII. A representative mucilage with biological activity from the leaves of Hibiscus rosa-sinensis, Biol Pharm Bull. 16 (1993) 735–739, https://doi.org/10.1248/BPB.16.735.

[14] Q. Luo, M. Wu, Y. Sun, J. Lv, Y. Zhang, H. Cao, D. Wu, D. Lin, Q. Zhang, Y. Liu, W. Qin, H. Chen, Optimizing the extraction and encapsulation of mucilage from Brasenia schreberi, Polymers (Basel) 11 (2019), https://doi.org/10.3390/POLYM11050822.

[15] M. Añibarro-Ortega, J. Pinela, L. Barros, A. Ćirić, S.P. Silva, E. Coelho, A. Mocan, R.C. Calhelha, M. Soković, M.A. Coimbra, I.C.F.R. Ferreira, Compositional features and bioactive properties of Aloe vera leaf (fillet, mucilage, and rind) and flower, Antioxidants. 8 (2019), https://doi.org/10.3390/ANTIOX8100444.

[16] S. Oh, D.Y. Kim, Characterization, antioxidant activities, and functional properties of mucilage extracted from Corchorus olitorius L, Polymers (Basel) 14 (2022), https://doi.org/10.3390/polym14122488.

[17] S.A. Ghumman, A. Mahmood, S. Noreen, M. Rana, H. Hameed, B. Ijaz, S. Hasan, A. Aslam, M.F. ur Rehman, Formulation and evaluation of quince seeds mucilage – sodium alginate microspheres for sustained delivery of cefixime and its toxicological studies, Arabian Journal of Chemistry. 15 (2022) 103811, https://doi.org/10.1016/J.ARABJC.2022.103811.

[18] M. Bhatia, S. Lohan, Flax seed mucilage-chitosan polyelectrolyte complex nanoparticles: optimization, characterization and evaluation, Acta Pharm. Sci. 57 (2019), https://doi.org/10.23893/1307-2080.APS.05716.

[19] I.F. da Silveira Ramos, L.M. Magalhães, P.M.Pinheiro Ferreira, M. dos Santos Rizzo, J.A. Osajima, E.C. Silva-Filho, C. Nunes, F. Raposo, M.A. Coimbra, A. B. Ribeiro, M.P. Costa, C. do O Pessoa, New properties of chia seed mucilage (Salvia hispanica L.) and potential application in cosmetic and pharmaceutical products, Ind. Crops Prod. 171 (2021) 113981, https://doi.org/10.1016/J.INDCROP.2021.113981.

[20] J.L. Phan, J.M. Cowley, K.A. Neumann, L. Herliana, L.A. O'Donovan, R.A. Burton, The novel features of Plantago ovata seed mucilage accumulation, storage and release, Scientific Reports 10 (1) (2020) 1–14, https://doi.org/10.1038/s41598-020-68685-w.

[21] P. Hernández-Carranza, M. Rivadeneyra-Mata, M.E. Ramos-Cassellis, X. Aparicio-Fernández, A.R. Navarro-Cruz, R. Ávila-Sosa, C.E. Ochoa-Velasco, Characterization of red prickly pear peel (Opuntia ficus-indica L.) and its mucilage obtained by traditional and novel methodologies, Journal of Food Measurement and Characterization 13 (2) (2019) 1111–1119, https://doi.org/10.1007/S11694-018-00026-Y.

[22] T.L. Dantas, F.C.Alonso Buriti, E.R. Florentino, Okra (Abelmoschus esculentus L.) as a potential functional food source of mucilage and bioactive compounds with technological applications and health benefits, Plants 10 (2021) 1683, https://doi.org/10.3390/PLANTS10081683.

[23] M. Cai, N. Wang, C. Xing, F. Wang, K. Wu, X. Du, Immobilization of aluminum with mucilage secreted by root cap and root border cells is related to aluminum resistance in Glycine max L, Environ. Sci. Pollut. Res. 20 (2013) 8924–8933, https://doi.org/10.1007/s11356-013-1815-6.

[24] C. Soukoulis, C. Gaiani, L. Hoffmann, Plant seed mucilage as emerging biopolymer in food industry applications, Curr. Opin. Food Sci. 22 (2018) 28–42, https://doi.org/10.1016/j.cofs.2018.01.004.

[25] S. Naji-Tabasi, S.M.A. Razavi, Functional properties and applications of basil seed gum: an overview, Food Hydrocoll. 73 (2017) 313–325, https://doi.org/10.1016/j.foodhyd.2017.07.007.

[26] M.J. Amicucci, A.G. Galermo, A. Guerrero, G. Treves, E. Nandita, M.J. Kailemia, S.M. Higdon, T. Pozzo, J.M. Labavitch, A.B. Bennett, C.B. Lebrilla, Strategy for structural elucidation of polysaccharides: elucidation of a maize mucilage that harbors diazotrophic bacteria, Anal. Chem. 91 (2019) 7254–7265, https://doi.org/10.1021/acs.analchem.9b00789.

[27] I.M. Sims, A.M. Smith, G.A. Morris, M.U. Ghori, S.M. Carnachan, Structural and rheological studies of a polysaccharide mucilage from lacebark leaves (Hoheria populnea a. Cunn.), Int. J. Biol. Macromol. 111 (2018) 839–847, https://doi.org/10.1016/j.ijbiomac.2017.12.142.

[28] V.E. Manhivi, S. Venter, E.O. Amonsou, T. Kudanga, Composition, thermal and rheological properties of polysaccharides from amadumbe (Colocasia esculenta) and cactus (Opuntia spp.), Carbohydr. Polym. 195 (2018) 163–169, https://doi.org/10.1016/j.carbpol.2018.04.062.

[29] S.A. Ghumman, A. Mahmood, S. Noreen, A. Aslam, Chitosan-linseed mucilage polyelectrolyte complex nanoparticles of methotrexate: in vitro cytotoxic efficacy and toxicological studies, Arab. J. Chem. (2022), 104463, https://doi.org/10.1016/j.arabjc.2022.104463.

[30] P. Kalegowda, A.S. Chauhan, S.M.Nanjaraj Urs, Opuntia dillenii (Ker-Gawl) Haw cladode mucilage: physico-chemical, rheological and functional behavior, Carbohydr Polym. 157 (2017) 1057–1064, https://doi.org/10.1016/j.carbpol.2016.10.070.

[31] F. Ma, Y. Zhang, Y. Yao, Y. Wen, W. Hu, J. Zhang, X. Liu, A.E. Bell, C. Tikkanen-Kaukanen, Chemical components and emulsification properties of mucilage from Dioscorea opposita Thunb, Food Chem. 228 (2017) 315–322, https://doi.org/10.1016/j.foodchem.2017.01.151.

[32] N. Mahfoudhi, M. Sessa, M. Chouaibi, G. Ferrari, F. Donsì, S. Hamdi, Assessment of emulsifying ability of almond gum in comparison with gum arabic using response surface methodology, Food Hydrocoll. 37 (2014) 49–59, https://doi.org/10.1016/j.foodhyd.2013.10.009.

[33] S. Rodríguez-González, H.E. Martínez-Flores, C.K. Chávez-Moreno, L.I. Macías-Rodríguez, E. Zavala-Mendoza, M.G. Garnica-Romo, L. Chacõn-García, Extraction and characterization of mucilage from wild species of opuntia, J. Food Process Eng. 37 (2014) 285–292, https://doi.org/10.1111/jfpe.12084.

[34] L. Brütsch, F.J. Stringer, S. Kuster, E.J. Windhab, P. Fischer, Chia seed mucilage - a vegan thickener: isolation, tailoring viscoelasticity and rehydration, Food Funct. 10 (2019) 4854–4860, https://doi.org/10.1039/c8fo00173a.

[35] X. Zhao, L. Qiao, A.M. Wu, Effective extraction of Arabidopsis adherent seed mucilage by ultrasonic treatment, Sci. Rep. 7 (2017), https://doi.org/10.1038/srep40672.

[36] A. Farahnaky, S. Bakhshizadeh-Shirazi, G. Mesbahi, M. Majzoobi, E. Rezvani, G. Schleining, Ultrasound-assisted isolation of mucilaginous hydrocolloids from Salvia macrosiphon seeds and studying their functional properties, Innov. Food Sci. Emerg. Technol. 20 (2013) 182–190, https://doi.org/10.1016/j.ifset.2013.06.003.

[37] B.N. Shah, A.K. Seth, B.S. Nayak, Microwave assisted isolation of mucilage from the fruits of Lagenaria siceraria, Pharm. Lett. 2 (2010) 202–205. https://www.researchgate.net/publication/267425943.

[38] Y.C. Yeh, L.S. Lai, Effect of extraction procedures with ultrasound and cellulolytic enzymes on the structural and functional properties of Citrus grandis osbeck seed mucilage, Molecules 27 (2022), https://doi.org/10.3390/molecules27030612.

[39] C.F. Chiang, L.S. Lai, Effect of enzyme-assisted extraction on the physicochemical properties of mucilage from the fronds of Asplenium australasicum (J. Sm.) hook, Int. J. Biol. Macromol. 124 (2019) 346–353, https://doi.org/10.1016/J.IJBIOMAC.2018.11.181.

[40] D. Tufaro, A. Bassoli, C. Cappa, Okra (Abelmoschus esculentus) powder production and application in gluten-free bread: effect of particle size, Food

Bioprocess Technol. 15 (2022) 904–914, https://doi.org/10.1007/s11947-022-02784-6.

[41] L. Qin, W. Lili, The Preparation Method and Applications of the Fresh-keeping Emulsion of Plant Mucilage, CN 109,043,306A, China, 2017.

[42] N.A. Alcantar, D. Morgan, Z. Veisi, L. Breydo, V.N. Uversky, R.G. Toomey, T. Peng, E.S. Lobbens, Inhibition of formation of amyloid b-protein fibrils using cactus mucilage extracts, in: US 10,946,056 B2, United States, 2021.

[43] P.A. Pham, Compositions containing plant mucilage, in: US 11,110,040 B2, United States, 2021.

[44] X. Yang, J.M. Baskin, C.C. Baskin, Z. Huang, More than just a coating: ecological importance, taxonomic occurrence and phylogenetic relationships of seed coat mucilage, Perspect. Plant Ecol. Evol. Syst. 14 (2012) 434–442, https://doi.org/10.1016/J.PPEES.2012.09.002.

[45] A.K.F.I. Câmara, M. Midori Ozaki, M. Santos, V.A. Silva Vidal, W. Oliveira Ribeiro, C. de Souza Paglarini, O.D. Bernardinelli, E. Sabadini, M.A. Rodrigues Pollonio, Olive oil-based emulsion gels containing chia (Salvia hispanica L.) mucilage delivering healthy claims to low-saturated fat Bologna sausages, Food Structure 28 (2021), 100187, https://doi.org/10.1016/j.foostr.2021.100187.

[46] C.C. Lise, C. Marques, M.A.A. da Cunha, M.L. Mitterer-Daltoé, Alternative protein from Pereskia aculeata miller leaf mucilage: technological potential as an emulsifier and fat replacement in processed mortadella meat, Eur. Food Res. Technol. 247 (2021) 851–863, https://doi.org/10.1007/s00217-020-03669-8.

[47] K. Gutiérrez-Luna, D. Ansorena, I. Astiasarán, Flax and hempseed oil functional ingredient stabilized by inulin and chia mucilage as a butter replacer in muffin formulations, J. Food Sci. 85 (2020) 3072–3080, https://doi.org/10.1111/1750-3841.15407.

[48] E.M. Akl, S.M. Abdelhamid, S.M. Wagdy, H.H. Salama, Manufacture of functional fat-free cream cheese fortified with probiotic bacteria and flaxseed mucilage as a fat replacing agent, Curr. Nutr. Food Sci. 16 (2020) 1393–1403, https://doi.org/10.2174/1573401316666200227112157.

[49] S. Arabshahi-Delouee, S.R. Ghochani, A. Mohammadi, Effect of flaxseed (Linum usitatissimum) mucilage on physicochemical and sensorial properties of semi-fat set yoghurt, J. Food Biosci. Technol. 10 (2020) 91–100.

[50] A.K.F.I. Câmara, V.A.S. Vidal, M. Santos, O.D. Bernardinelli, E. Sabadini, M.A. R. Pollonio, Reducing phosphate in emulsified meat products by adding chia (Salvia hispanica L.) mucilage in powder or gel format: a clean label technological strategy, Meat Sci. 163 (2020), 108085, https://doi.org/10.1016/j.meatsci.2020.108085.

[51] E. Lozano, K. Padilla, J. Salcedo, A. Arrieta, R. Andrade-Pizarro, Effects of yam (Dioscorea rotundata) mucilage on the physical, rheological and stability characteristics of ice cream, Polymers (Basel) 14 (2022) 3142, https://doi.org/10.3390/polym14153142.

[52] S. Benazir, D. Majeed, M. Maswal, M. Gani, S.A. Mir, B.N. Dar, Influence of hydrocolloids on rheological properties of gluten-free dough based on corn flour, J. Postharvest Technol. 7 (2019) 72–83. http://www.jpht.info.

[53] M. Dick, C. Limberger, R.Cruz Silveira Thys, A. de Oliveira Rios, S. Hickmann Flôres, Mucilage and cladode flour from cactus (Opuntia monacantha) as alternative ingredients in gluten-free crackers, Food Chem. 314 (2020) 126178, https://doi.org/10.1016/j.foodchem.2020.126178.

[54] M. Humane, D.T. Bornare, K.P. Babar, Utilization of dry bael mucilage powder in the preparation of gluten free cereal vermicelli, Bopomfolet (2018) 235–236.

[55] I.G.G. Kasunmala, S.B. Navaratne, I. Wickramasinghe, Effect of process modifications and binding materials on textural properties of rice noodles, Int. J. Gastron. Food Sci. 21 (2020), 100217, https://doi.org/10.1016/j.ijgfs.2020.100217.

[56] V. Menga, M. Amato, T.D. Phillips, D. Angelino, F. Morreale, C. Fares, Gluten-free pasta incorporating chia (Salvia hispanica L.) as thickening agent: an approach to naturally improve the nutritional profile and the in vitro carbohydrate digestibility, Food Chem. 221 (2017) 1954–1961, https://doi.org/10.1016/j.foodchem.2016.11.151.

[57] G. Liguori, C. Gentile, R. Gaglio, A. Perrone, R. Guarcello, N. Francesca, S. Fretto, P. Inglese, L. Settanni, Effect of addition of Opuntia ficus-indica mucilage on the biological leavening, physical, nutritional, antioxidant and sensory aspects of bread, J. Biosci. Bioeng. 129 (2020) 184–191, https://doi.org/10.1016/j.jbiosc.2019.08.009.

[58] K. Miranda-Ramos, M.C. Millán-Linares, C.M. Haros, Effect of chia as breadmaking ingredient on nutritional quality, mineral availability, and glycemic index of bread, Foods 9 (2020) 663, https://doi.org/10.3390/foods9050663.

[59] G.S. Souza, S.S. dos Santos, R. Bergamasco, J. Antigo, G.S. Madrona, Antioxidant activity, extraction and application of psyllium mucilage in chocolate drink, Nutr Food Sci. 50 (2020) 1175–1185, https://doi.org/10.1108/NFS-07-2019-0211.

[60] S.S. Arabshahi, M. Sedaghati, Production of synbiotic doogh enriched with Plantago psyllium mucilage, J. Food Sci. Technol. 2022 (2022) 1–8, https://doi.org/10.1007/s13197-022-05401-8.

[61] L.O. Saadi, F. Zaidi, T. Sanz, C.M. Haros, Effect of faba bean and chickpea mucilage incorporation in the structure and functionality of kefir, Food Sci. Technol. Intl. 26 (2020) 503–511, https://doi.org/10.1177/1082013220908089.

[62] M. Guzelgulgen, D. Ozkendir-Inanc, U.H. Yildiz, A. Arslan-Yildiz, Glucuronoxylan-based quince seed hydrogel: a promising scaffold for tissue engineering applications, Int. J. Biol. Macromol. 180 (2021) 729–738, https://doi.org/10.1016/J.IJBIOMAC.2021.03.096.

[63] C.C. Genc, H.D. Yilmaz, B. Karaca, F. Kiran, Y.E. Arslan, Nano-hydroxyapatite incorporated quince seed mucilage bioscaffolds for osteogenic differentiation of human adipose-derived mesenchymal stem cells, Int. J. Biol. Macromol. 195 (2022) 492–505, https://doi.org/10.1016/J.IJBIOMAC.2021.12.054.

[64] H. Baniasadi, R.T. Polez, E. Kimiaei, Z. Madani, O.J. Rojas, M. Österberg, J. Seppälä, 3D printing and properties of cellulose nanofibrils-reinforced quince seed mucilage bio-inks, Int. J. Biol. Macromol. 192 (2021) 1098–1107, https://doi.org/10.1016/J.IJBIOMAC.2021.10.078.

[65] A. Allafchian, S.A.H. Jalali, S.E. Mousavi, S.S. Hosseini, Preparation of cell culture scaffolds using polycaprolactone/ quince seed mucilage, Int. J. Biol. Macromol. 155 (2020) 1270–1276, https://doi.org/10.1016/j.ijbiomac.2019.11.096.

[66] A.I. Aghmiuni, S.H. Keshel, F. Sefat, A.A. Khiyavi, Quince seed mucilage-based scaffold as a smart biological substrate to mimic mechanobiological behavior of skin and promote fibroblasts proliferation and h-ASCs differentiation into keratinocytes, Int. J. Biol. Macromol. 142 (2020) 668–679, https://doi.org/10.1016/J.IJBIOMAC.2019.10.008.

[67] M. Jafari, H. Baniasadi, A. Rezvanpour, M. Lotfi, Fabrication and characterisation of a wound dressing composed of polyvinyl alcohol and quince seed mucilage, J. Wound Care 30 (2021) 14–23, https://doi.org/10.12968/JOWC.2021.30.SUP9A.XIII/ASSET/IMAGES/LARGE/JOWC.2021.30.SUP9A.XIII_F08.JPEG.

[68] D. Oran, S. Unal, O. Gunduz, Evaluation of bacterial cellulose/quince seed mucilage composite scaffold for wound dressing, Emergent Mater. 5 (2022) 315–321, https://doi.org/10.1007/s42247-022-00352-4.

[69] S. Sen, T. Bal, A.D. Rajora, Green nanofiber mat from HLM-PVA-pectin (Hibiscus leaves mucilage-polyvinyl alcohol-pectin) polymeric blend using electrospinning technique as a novel material in wound-healing process, Appl. Nanosci. 12 (2022) 237–250, https://doi.org/10.1007/s13204-021-02295-4.

[70] T. Bal, S. Swain, Microwave assisted synthesis of polyacrylamide grafted polymeric blend of fenugreek seed mucilage-polyvinyl alcohol (FSM-PVA-g-PAM) and its characterizations as tissue engineered scaffold and as a drug delivery device, DARU J. Pharm. Sci. 28 (2020) 33, https://doi.org/10.1007/S40199-019-00237-8.

[71] U.V. Deore, H.S. Mahajan, Hydrogel for topical drug delivery based on Mimosa pudica seed mucilage: development and characterization, Sustain. Chem. Pharm. 27 (2022), 100701, https://doi.org/10.1016/J.SCP.2022.100701.

[72] T. Frasat, U.R. Tulain, A. Erum, U. Saleem, M.F. Sohail, R. Kausar, Aloe vera and Artemisia vulgaris hydrogels: exploring the toxic effects of structural transformation of the biocompatible materials, Drug Dev. Ind. Pharm. 47 (2022) 1753–1763, https://doi.org/10.1080/03639045.2022.2050751.

[73] M.S. Hosseini, B. Kamali, M.R. Nabid, Multilayered mucoadhesive hydrogel films based on Ocimum basilicum seed mucilage/thiolated alginate/dopamine-modified hyaluronic acid and PDA coating for sublingual administration of nystatin, Int. J. Biol. Macromol. 203 (2022) 93–104, https://doi.org/10.1016/J.IJBIOMAC.2022.01.031.

[74] N. Srikhao, K. Chirochrapas, N. Kwansanei, P. Kasemsiri, A. Ounkaew, M. Okhawilai, C. Likitaporn, S. Theerakulpisut, H. Uyama, Multi-responsive optimization of novel pH-sensitive hydrogel beads based on basil seed mucilage, alginate, and magnetic particles, Gels 8 (2022) 274, https://doi.org/10.3390/GELS8050274.

[75] K. Gutiérrez-Luna, I. Astiasarán, D. Ansorena, Gels as fat replacers in bakery products: a review, Crit. Rev. Food Sci. Nutr. 62 (2022) 3768–3781, https://doi.org/10.1080/10408398.2020.1869693.

[76] F. Mohtarami, Z. Rashidi, S. Pirsa, Extraction of flaxseed and plantago psyllium mucilage: investigation of rheological properties and efficiency as a fat substitute for the production of low-calorie cookies, J. Food Process. Preserv. (2022), https://doi.org/10.1111/jfpp.16964.

[77] Z. Kohajdová, J. Karovičová, Application of hydrocolloids as baking improvers, Chem. Pap. 63 (2009) 26–38, https://doi.org/10.2478/s11696-008-0085-0.

[78] M.H.F. Felisberto, A.L. Wahanik, C.R. Gomes-Ruffi, M.T.P.S. Clerici, Y.K. Chang, C.J. Steel, Use of chia (Salvia hispanica L.) mucilage gel to reduce fat in pound cakes, LWT Food Sci. Technol. 63 (2015) 1049–1055, https://doi.org/10.1016/J.LWT.2015.03.114.

[79] S.S. Fernandes, M.de las M. Salas-Mellado, Addition of chia seed mucilage for reduction of fat content in bread and cakes, Food Chem. 227 (2017) 237–244, https://doi.org/10.1016/j.foodchem.2017.01.075.

[80] M.C. Rocha, W.C. de Abreu, A.M.Maradini Filho, M.da P. Píccolo, M.de F. P. Barcelos, Physicochemical properties and use of chia mucilage (Salvia hispanica L.) in the reduction of fat in cookies gluten-free breads, Brazilian Journal of Development. 6 (2020) 69019–69034, https://doi.org/10.34117/bjdv6n9-374.

[81] N.M. Dilek, N. Bilgiçli, Effect of taro [Colocasia esculenta (L.) Schott] flour and different shortening ratio on physical and chemical properties of gluten-free cookie, J. Food Process. Preserv. 45 (2021) 15894, https://doi.org/10.1111/JFPP.15894.

[82] S.K. Chakraborty, N. Kotwaliwale, S.A. Navale, Selection and incorporation of hydrocolloid for gluten-free leavened millet breads and optimization of the baking process thereof, LWT-Food Sci. Technol. 119 (2020), 108878, https://doi.org/10.1016/j.lwt.2019.108878.

[83] J. Korus, T. Witczak, R. Ziobro, L. Juszczak, Linseed (Linum usitatissimum L.) mucilage as a novel structure forming agent in gluten-free bread, LWT Food Sci. Technol. 62 (2015) 257–264, https://doi.org/10.1016/j.lwt.2015.01.040.

[84] I.M. Geremias-Andrade, N.P.D.B.G. Souki, I.C.F. Moraes, S.C. Pinho, Rheological and mechanical characterization of curcumin-loaded emulsion-filled gels produced with whey protein isolate and xanthan gum, LWT-Food Sci. Technol. 86 (2017) 166–173, https://doi.org/10.1016/J.LWT.2017.07.063.

[85] G. Avila-de la Rosa, J. Alvarez-Ramirez, E.J. Vernon-Carter, H. Carrillo-Navas, C. Pérez-Alonso, Viscoelasticity of chia (Salvia hispanica L.) seed mucilage dispersion inthe vicinity of an oil-water interface, Food Hydrocoll. 49 (2015) 200–207, https://doi.org/10.1016/j.foodhyd.2015.03.017.

[86] A.K.F.I. Câmara, M.V. Geraldi, P.K. Okuro, M.R. Maróstica, R.L. da Cunha, M.A. R. Pollonio, Satiety and in vitro digestibility of low saturated fat Bologna sausages added of chia mucilage powder and chia mucilage-based emulsion gel, J. Funct. Foods 65 (2020), https://doi.org/10.1016/j.jff.2019.103753.

[87] A.K.F.I. Câmara, P.K. Okuro, R.L. da Cunha, A.M. Herrero, C. Ruiz-Capillas, M.A. R. Pollonio, Chia (Salvia hispanica L.) mucilage as a new fat substitute in emulsified meat products: technological, physicochemical, and rheological characterization, LWT Food Sci. Technol. 125 (2020), 109193, https://doi.org/10.1016/j.lwt.2020.109193.

[88] Ö. Yüncü, H.S. Kavuşan, M.S. Serdaroğlu, Effects of using chia (Salvia hispanica L.) mucilage and different cooking procedures on quality parameters of beef patties, in: 61st International Meat Industry Conference, Atlanta, US, 2021, p. 12107, https://doi.org/10.1088/1755-1315/854/1/012107.

[89] S. Liu, J. Lu, J. Zhang, X. Su, X. Peng, H. Guan, C. Shi, Emulsion gels prepared with chia mucilage and olive oil as a new animal fat replacer in beef patties, J. Food Process. Preserv. (2022), https://doi.org/10.1111/JFPP.16972.

[90] Z. Gürbüz, T. Erkaya-Kotan, M. Şengül, Evaluation of physicochemical, microbiological, texture and microstructure characteristics of set-style yoghurt supplemented with quince seed mucilage powder as a novel natural stabiliser, Int. Dairy J. 114 (2021), 104938, https://doi.org/10.1016/j.idairyj.2020.104938.

[91] S. Basiri, N. Haidary, S.S. Shekarforoush, M. Niakousari, Flaxseed mucilage: a natural stabilizer in stirred yogurt, Carbohydr. Polym. 187 (2018) 59–65, https://doi.org/10.1016/j.carbpol.2018.01.049.

[92] M.S.Z. Choobari, A.A. Sari, A. Daraei Garmakhany, Effect of Plantago ovata forsk seed mucilage on survivability of Lactobacillus acidophilus, physicochemical and sensory attributes of produced low-fat set yoghurt, Food Sci Nutr. 9 (2021) 1040–1049, https://doi.org/10.1002/FSN3.2074.

[93] S. Ribes, N. Peña, A. Fuentes, P. Talens, J.M. Barat, Chia (Salvia hispanica L.) seed mucilage as a fat replacer in yogurts: effect on their nutritional, technological, and sensory properties, J. Dairy Sci. 104 (2021) 2822–2833, https://doi.org/10.3168/jds.2020-19240.

[94] P. Hernández-Carranza, K.Y. Jattar-Santiago, R. Avila-Sosa, I. Pérez-Xochipa, J. A. Guerrero-Beltrán, C.E. Ochoa-Velasco, I.I. Ruiz-López, Antioxidant fortification of yogurt with red cactus pear peel and its mucilage, CYTA - Journal of Food. 17 (2019) 824–833, https://doi.org/10.1080/19476337.2019.1654548.

[95] A. Akhtar, R. Khan, N. Khalid, Formulation and evaluation of functional attributes of low-fat mozzarella cheese using okra mucilage as a fat replacer, Int. J. Food Sci. Technol. (2022), https://doi.org/10.1111/IJFS.15952.

[96] J.H. Chiang, D.S.M. Ong, F.S.K. Ng, X.Y. Hua, W.L.W. Tay, C.J. Henry, Application of chia (Salvia hispanica) mucilage as an ingredient replacer in foods, Trends Food Sci. Technol. 115 (2021) 105–116, https://doi.org/10.1016/j.tifs.2021.06.039.

[97] M. Bahramparvar, H. Goff, H.Goff Basil, M. BahramParvar, H.Douglas Goff, Basil seed gum as a novel stabilizer for structure formation and reduction of ice recrystallization in ice cream, in: Dairy Science & Technology, EDP Sciences 93, 2013, pp. 273–285, https://doi.org/10.1007/s13594-013-0122-9ï.

[98] B.G. Arnak, Z. Tarakçi, Use of chia (Salvia hispanica L.) mucilage powder as a replacer of salep in ice cream production, J. Food Process. Preserv. 45 (2021), e16060, https://doi.org/10.1111/jfpp.16060.

[99] R. Feizi, K.K.T. Goh, A.N. Mutukumira, Effect of chia seed mucilage as stabiliser in ice cream, Int. Dairy J. 120 (2021), 105087, https://doi.org/10.1016/j.idairyj.2021.105087.

[100] G.S. Souza, A.P. Stafussa, G.S. Madrona, R.de C. Bergamasco, Ultrasound-assisted extraction of Psyllium mucilage: Evaluation of functional and technological properties, Emir. J Food Agric. 32 (2020) 238–244, https://doi.org/10.9755/ejfa.2020.v32.i4.2089.

[101] C. Maestrello, I. de Lima Figueiredo, G.Caroline de Souza Takahashi, T. C. Pimentel, J.V. Visentainer, R. de Cassia Bergamasco, G.S. Madrona, Replacing emulsifier in a prebiotic ice cream: Physical and chemical evaluation and acceptance, J. Culinary Sci. Technol. 16 (2018) 76–87, https://doi.org/10.1080/15428052.2017.1333934.

[102] D. Çakmakçı, Ü.İ. Konak, Y. Yavuz Abanoz, Physical, nutritional, textural and sensory qualities of turkish noodles produced with siyez wheat (Triticum monococcum), kale (Brassica oleracea var. acephala) and chia seed (Salvia hispanica L.), Food Health 8 (2022) 35–45, https://doi.org/10.3153/fh22004.

[103] A. du Toit, M. de Wit, H.J. Fouché, M. Taljaard, S.L. Venter, A. Hugo, Mucilage powder from cactus pears as functional ingredient: influence of cultivar and harvest month on the physicochemical and technological properties, J. Food Sci. Technol. 56 (2019) 2404–2416, https://doi.org/10.1007/s13197-019-03706-9.

[104] M.G. Dehnayebi, M. Ghorbani, A.S. Mahoonak, M. Aalami, M. Kashiri, Application of balangu (Lallementia royeana) mucilage and soy protein isolate as egg replacement in mayonnaise and study on its physicochemical properties, J. Res. Innov. Food Sci. Technol. 6 (2018) 351–360 (accessed August 3, 2022), https://www.cabdirect.org/globalhealth/abstract/20183236421.

[105] S. Paulina, V. Jaime, V. Christian, A. Andry, Mucilage of cacao, national and trinitario to obtain a moisturizing drink, universidad, Cienc. Tecnol. 4 (2018) 179–189.

[106] K.C. Yadav, R. Subba, L.D. Shiwakoti, P.K. Dhungana, R. Bajagain, D. K. Chaudhary, B.R. Pant, T.R. Bajgai, J. Lamichhane, S. Timilsina, J. Upadhyaya, R.H. Dahal, Utilizing coffee pulp and mucilage for producing alcohol-based beverage, Fermentation 7 (2021) 53, https://doi.org/10.3390/FERMENTATION7020053.

[107] B. Yue, Biology of the extracellular matrix: an overview, J. Glaucoma 23 (2014) S20, https://doi.org/10.1097/IJG.0000000000000108.

[108] B.P. Chan, K.W. Leong, Scaffolding in tissue engineering: general approaches and tissue-specific considerations, Eur. Spine J. 17 (2008) 467, https://doi.org/10.1007/S00586-008-0745-3.

[109] A. Tchobanian, H. Van Oosterwyck, P. Fardim, Polysaccharides for tissue engineering: current landscape and future prospects, Carbohydr. Polym. 205 (2019) 601–625, https://doi.org/10.1016/J.CARBPOL.2018.10.039.

[110] S. Tiwari, R. Patil, P. Bahadur, Polysaccharide based scaffolds for soft tissue engineering applications, Polymers (Basel) 11 (2019), https://doi.org/10.3390/POLYM11010001.

[111] M. Jin, J. Shi, W. Zhu, H. Yao, D.A. Wang, Polysaccharide-based biomaterials in tissue engineering: a review, Tissue Eng. Part B Rev. 27 (2021) 604–626, https://doi.org/10.1089/TEN.TEB.2020.0208.

[112] G. Archana, K. Sabina, S. Babuskin, K. Radhakrishnan, M.A. Fayidh, P.Azhagu Saravana Babu, M. Sivarajan, M. Sukumar, Preparation and characterization of mucilage polysaccharide for biomedical applications, Carbohydr Polym. 98 (2013) 89–94, https://doi.org/10.1016/J.CARBPOL.2013.04.062.

[113] Y. Huang, Y. Wang, L. Sun, R. Agrawal, M. Zhang, Sundew adhesive: a naturally occurring hydrogel, J. R. Soc. Interface 12 (2015), https://doi.org/10.1098/RSIF.2015.0226.

[114] H. Urena-Saborio, E. Alfaro-Viquez, D. Esquivel-Alvarado, S. Madrigal-Carballo, S. Gunasekaran, Electrospun plant mucilage nanofibers as biocompatible scaffolds for cell proliferation, Int. J. Biol. Macromol. 115 (2018) 1218–1224, https://doi.org/10.1016/J.IJBIOMAC.2018.04.129.

[115] E. Şimşek, B. Karaca, Y.E. Arslan, in: Bioengineered Three-dimensional Physical Constructs From Quince Seed Mucilage for Human Adipose-derived Mesenchymal Stem Cells 35, 2020, pp. 240–253, https://doi.org/10.1177/0883911520918390.

[116] F. Beheshti, H.A. Ahangar, E. Poorazizi, Fabrication and characterization of Plantago psyllium mucilage/ chitosan composite scaffold: physico-mechanical and antibacterial properties, Journal of Materials Research 37 (8) (2022) 1440–1450, https://doi.org/10.1557/S43578-022-00544-Y.

[117] A. Allafchian, S. Saeedi, S.A.H. Jalali, Biocompatibility of electrospun cell culture scaffolds made from balangu seed mucilage/PVA composites, Nanotechnology 33 (2021), 075302, https://doi.org/10.1088/1361-6528/AC3860.

[118] A. Prakash, R. Lata, P.J. Martens, D. Rohindra, Characterization and in-vitro analysis of poly(ε-caprolactone)-“Jackfruit” mucilage blends for tissue engineering applications, Polym. Eng. Sci. 61 (2021) 526–537, https://doi.org/10.1002/PEN.25597.

[119] H.D. Yilmaz, U. Cengiz, Y.E. Arslan, F. Kiran, A. Ceylan, From a plant secretion to the promising bone grafts: cryogels of silicon-integrated quince seed mucilage by microwave-assisted sol–gel reaction, J. Biosci. Bioeng. 131 (2021) 420–433, https://doi.org/10.1016/J.JBIOSC.2020.11.008.

[120] J. Qin, F. Chen, P. Wu, G. Sun, Recent advances in bioengineered scaffolds for cutaneous wound healing, Front. Bioeng. Biotechnol. 10 (2022) 244, https://doi.org/10.3389/FBIOE.2022.841583/BIBTEX.

[121] J.F. Morton, Mucilaginous plants and their uses in medicine, J. Ethnopharmacol. 29 (1990) 245–266, https://doi.org/10.1016/0378-8741(90)90036-S.

[122] P. Tamri, A. Hemmati, M.G. Boroujerdnia, Wound healing properties of quince seed mucilage: in vivo evaluation in rabbit full-thickness wound model, Int. J. Surg. 12 (2014) 843–847, https://doi.org/10.1016/J.IJSU.2014.06.016.

[123] A.A. Hemmati, F. Mohammadian, An investigation into the effects of mucilage of quince seeds on wound healing in rabbit, Int. J. Geogr. Inf. Syst. 7 (2009) 41–46, https://doi.org/10.1300/J044V07N04_05.

[124] S. Massey, F. Iqbal, A.U. Rehman, M.S. Iqbal, F. Iram, in: Preparation, Characterization and Biological Evaluation of Silver Nanoparticles and Drug Loaded Composites for Wound Dressings Formed From Lallemantia Royleana Seeds’ Mucilage 33, 2021, pp. 481–498, https://doi.org/10.1080/09205063.2021.1992590.

[125] S. Tantiwatcharothai, J. Prachayawarakorn, Property improvement of antibacterial wound dressing from basil seed (O. Basilicum L.) mucilage- ZnO nanocomposite by borax crosslinking, Carbohydr. Polym. 227 (2020), 115360, https://doi.org/10.1016/J.CARBPOL.2019.115360.

[126] M.S. Hosseini, M.R. Nabid, Synthesis of chemically cross-linked hydrogel films based on basil seed (Ocimum basilicum L.) mucilage for wound dressing drug delivery applications, Int. J. Biol. Macromol. 163 (2020) 336–347, https://doi.org/10.1016/J.IJBIOMAC.2020.06.252.

[127] J.Y.C. Edgar, H. Wang, Introduction for design of nanoparticle based drug delivery systems, Curr. Pharm. Des. 23 (2017), https://doi.org/10.2174/1381612822666161025154003.

[128] K.J. Rambhia, P.X. Ma, Controlled drug release for tissue engineering, J. Control. Release 219 (2015) 119, https://doi.org/10.1016/J.JCONREL.2015.08.049.

[129] R. Shaikh, T. Raj Singh, M. Garland, A. Woolfson, R. Donnelly, Mucoadhesive drug delivery systems, J. Pharm. Bioallied Sci. 3 (2011) 89, https://doi.org/10.4103/0975-7406.76478.

[130] S. Mansuri, P. Kesharwani, K. Jain, R.K. Tekade, N.K. Jain, Mucoadhesion: a promising approach in drug delivery system, React. Funct. Polym. 100 (2016) 151–172, https://doi.org/10.1016/J.REACTFUNCTPOLYM.2016.01.011.

[131] A. Nokhodchi, H. Nazemiyeh, A. Khodaparast, T. Sorkh-Shahan, H. Valizadeh, J. L. Ford, An in vitro evaluation of fenugreek mucilage as a potential excipient for oral controlled-release matrix tablet, Drug Dev. Ind. Pharm. 34 (2008) 323–329, https://doi.org/10.1080/03639040701662594.

[132] G.K. Jani, D.P. Shah, Evaluation of mucilage of hibiscus rosasinensis Linn as rate controlling matrix for sustained release of diclofenac, Drug Dev. Ind. Pharm. 34 (2008) 807–816, https://doi.org/10.1080/03639040801925768.

[133] A. Mahmood, A. Erum, S. Mumtaz, U.R. Tulain, N.S. Malik, M.S. Alqahtani, Preliminary investigation of Linum usitatissimum mucilage-based hydrogel as

possible substitute to synthetic polymer-based hydrogels for sustained release oral drug delivery, Gels 8 (2022) 170, https://doi.org/10.3390/GELS8030170.

[134] B. Nikforouz, A. Allafchian, S.A.H. Jalali, H. Shakeripour, R. Mohammadinezhad, Quince seed mucilage coated iron oxide nanoparticles for plasmid DNA delivery, Nanotechnology 33 (2021), 075102, https://doi.org/10.1088/1361-6528/AC3576.

[135] Z. Sanaei, M. Sabzevar, Mohammad Mehrshad, M. Naimipour, A biological magnetic nano-hydrogel based on basil seed mucilage: study of swelling ratio and drug delivery, Iranian Polymer Journal 30 (5) (2021) 485–493, https://doi.org/10.1007/S13726-021-00905-0.

[136] M.S. Amiri, V. Mohammadzadeh, M.E.T. Yazdi, M. Barani, A. Rahdar, G.Z. Kyzas, Plant-based gums and mucilages applications in pharmacology and nanomedicine: a review, Molecules 26 (2021) 1770, https://doi.org/10.3390/MOLECULES26061770.

[137] S. Navale, J. Nagare, N. Mehetre, V. Mhaske, V. Chaudhari, A. Professor, Plant based mucilage and its application in different pharmaceutical formulation, Int. J. Creat. Res. Thoughts 10 (2022) 2320–2882.

[138] G. Lal, M. Bajpai, Extraction and physiochemical characterization of black gram mucilage for potential use as pharmaceutical excipient, Curr. Trends Biotechnol. Pharm. 16 (2022) 384–395, https://doi.org/10.5530/ctbp.2022.3.52.

[139] P. Kurra, K. Narra, R. Orfali, S.B. Puttugunta, S.A. Khan, D.U. Meenakshi, A. P. Francis, S.M.B. Asdaq, M. Imran, Studies on jackfruit-okra mucilage-based curcumin mucoadhesive tablet for colon targeted delivery, Front. Pharmacol. 13 (2022) 1–13, https://doi.org/10.3389/fphar.2022.902207.

[140] M. Sadat Hosseini, B. Kamali, M.R. Nabid, Multilayered mucoadhesive hydrogel films based on Ocimum basilicum seed mucilage/thiolated alginate/dopamine-modified hyaluronic acid and PDA coating for sublingual administration of nystatin, Int. J. Biol. Macromol. 203 (2022) 93–104, https://doi.org/10.1016/J.IJBIOMAC.2022.01.031.

[141] H.A. Ahad, H. Chinthaginjala, M. Sai Priyanka, D.R. Raghav, M. Gowthami, V. Naga Jyothi, Datura stramonium leaves mucilage aided buccoadhesive films of aceclofenac using 32 factorial design with design-expert software, Indian J. Pharm. Educ. Res. 55 (2021) s396–s404, https://doi.org/10.5530/ijper.55.2s.111.