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Review Article

An Inclusive Review on Mucilage: Extraction Methods, Characterization, and its Utilization for Nanocarriers Manufacturing

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Abstract

Mucilages have attracted a lot of study and commercial interest as a result of the growing interest in natural ingredients. Mucilages are polysaccharide hydrocolloids having a wide range of physicochemical and structural properties, as well as functional and health benefits. Plant-derived mucilage has been discovered to be a natural thickening and emulsifier, as well as a substitute for manufactured polymers and chemicals. It is used as an edible coating to increase the shelf life of fresh vegetables and fruits, as well as many other food products, because it is an invisible barrier that separates the surface from the surrounding atmosphere. Mucilage can also be utilised to make nanocarriers in addition to its functional features. The most extensively used traditional and developing extraction and purification procedures are explained in this overview, which is supplemented with information on the important criteria for determining the physicochemical and functional qualities of mucilages. The biodegradable and biocompatible features of these low-cost excipients make them more suitable for the development of innovative formulations. Understanding the ecological, economic, and scientific aspects that influence production, as well as the efficacy of mucus as a multi-directional agent, will allow it to be used in a variety of businesses.

Keywords: Bioactive compounds, Mucilages, Extraction, Polysaccharides, Food applications, Biopolymers

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Introduction

Plant-derived polymers have a high demand in the food and other industries due to their wide range of industrial uses, including film coating, emulsifiers, binder, and gelling agents; as a result, they are widely employed in the textile, paper, and cosmetic industries.[1, 2] . People are increasingly interested in plant-based naturally produced biopolymers (gums, mucilage, cellulose, and glucans) as an useful ingredient for the formulation of eco-friendly, sustainable, and cost-effective products[3] because to the harmful effects of synthetic polymers on human health. Furthermore, various living species, such as plants, algae, mammals, bacteria, and fungi, may biosynthetically produce a vast number of polysaccharides[4]. Natural polysaccharides are also employed in the food industries because they are considered safe to eat[5]. Plant-derived mucilage is one of the most extensively utilised polysaccharides in the food industry, owing to its wide range of applications[6]. Mucilage can be found in *Aloe vera, Salvia hispanica* seeds*, Cordia dichotoma, Basella alba, Plantago psyllium, Cyamopsis tetragonoloba, Cactaceae, Abelmoschus esculentus, Trigonella foenum-graecum, Moringa oleifera, and Linum usitatissimum,* among other plants and components. Plant-derived mucilage, due to its distinctive health (anticancer, angiotensin-converting enzyme inhibition extends to diabetes, and immunity stimulation) and food properties, is widely used as an active ingredient for the formulation of pharmaceutics, functional and nutraceutical products[7]. Mucilage (a polymeric polysaccharide complex) is mostly made up of carbohydrates with highly branched structures, such as L-arabinose, D-xylose, D-galactose, L-rhamnose, and galacturonic acid monomer units. Glycoproteins and several bioactive components such as tannins, alkaloids, and steroids are also present[8-10]. Furthermore, due to the structure of the polysaccharide, mucilage produces an endless number of monosaccharides when hydrolyzed, depending on the type of hydrolysis products obtained. It can also be divided into pentose sugars (xylan) and hexose sugars (cellulose and starch), both of which are regarded gum-like components due to their physiological similarities. However, the sugars produced by hemicelluloses such as xylose, glucose, and mannose, rather than sugars produced by gums such as galactose and arabinose, are largely connected to hemicelluloses in composition[11,12]. Furthermore, it can be used for a variety of purposes, including edible coating, wound healing, tablet production, encapsulation, water filtration, and different nanocarriers. Mucilage has good functional properties, but they also play a vital role in film, emulsion, coated metal nanoparticles, and gel production because to hydrogen bonding between distinct functional and other polar groups[13]. Nanostructured hydrogels and mucilage-coated

metal nanoparticles have been used extensively as a substantial delivery vehicle for diverse hydrophilic and hydrophobic components in recent years[14]. Different types of biopolymers and cross-linking polymers can be employed in the formulation of nanohydrogel, and mucilage can be used as either a primary biopolymer or a cross-linking component[15]. Several studies on the formulation of stable nanohydrogels with mucilage as an active component have been published, and researchers have discovered a variety of therapeutic and dietary applications for the nanohydrogels[16-17]. Nanohydrogels produced with mucilage also have a higher stability than other plant-based biopolymers. Metal nanoparticles coated with polymeric carbohydrates including starch, dextran, chitosan, and mucilage are also the most commonly utilised nanocarriers for targeted drug delivery. Because their polymeric shells enable them to transmit and release the medication during biodegradation, in addition to prolonging blood circulation time by hiding them from the immune system[16,17]. However, because there are few publications on the entire knowledge of plant-derived mucilage, the focus of this study will be on the physicochemical qualities, characterisation, health, and functional features of mucilage. Also explored is the use of mucilage crosslinked nanohydrogels and mucilage coated metal nanoparticles.

Occurrence

Plant-based polymers are used in a variety of industries, including pharmaceuticals, food, cosmetics, and paper, and plant seed polysaccharides are classified into three groups: Non-starch endosperm components, mucilaginous seed coat elements, and endosperm cell wall material are the three types of endosperm components. Gums and mucilages, for example, are cheap polymers that are easily available. Mucilages are similar to gums in that they are metabolic products that are produced without harming the plant. Mucilages are abundant in nature, particularly in higher plants. They contribute to the plant's water and food reserves, as well as assisting in seed germination, by forming as a required component of the cell or as a component of plant cell walls.[18]. Slimy aggregate gums and mucilages disintegrate fast in water[19]. Mucilages are also nontoxic, nonirritant, biocompatible, and have a wide range of chemical properties. Mucilages are polysaccharide hydrocolloids that, in most cases, have sugar molecules linked to uronic acids. Following hydrolysis, a mixture of sugars and uronic acids can be obtained. Mucilages are hydrophilic molecules that, when hydrolyzed, mix with water to generate slimy solutions or gels.

Sources

Mucilage is a water-soluble sticky material made composed of carbohydrates and uranic acid units that can be found in a variety of plant tissues, including the mucous epidermis of the seed coat, bark, leaves, and buds[20]. The majority of plants produce mucilage in their seed coats, a process known as Myxospermy, while others produce it in their fruit epicarps, a process known as Myxocarpy. Plantaginaceae, Acanthaceae, Linaceae, and Brassicaceae are among the families that produce mucilage from seed coats, whereas Poaceae, Asteraceae, and Lamiaceae[21] produce Myxocarpy (fruit mucilage). Mucilage on the seed coat protects the plant from early seedling development and drought stress during germination. Hair secretion, intracellular mucilage, and cell membrane mucilage are just a few of the many types of mucilage that can be classified based on their origins[11]. The three types of mucilage obtained from the seed coat are endosperm non-starch polysaccharide (galactomannans), endosperm cell wall material (soybean hemicelluloses and xyloglucans), and mucilaginous parts of the seed coat (flaxseed, Chia seed, and yellow mustard) [22,23]. Mucilage forms a jelly-like layer around fruit, retaining moisture and preventing seeds from drying out entirely, acting as both a hydrating agent and an energy reservoir[24,25]. Root mucilage is primarily made up of flavonoids, phenolic acids, amino acids, galactosidase, antibiotics, sugars, peroxidase, proteins, and anthocyanins[26], which are formed by root border cells and polysaccharides. Mucilage is also involved in germination, dispersal, and soil adhesion control. Root mucilage is also important for plant growth in a number of ways, including root-to-soil contact, root tip lubrication, soil microaggregate stability, water storage ability, selective storage, and ion absorption through root cells (Na+, Cd2+, Pb2+, and Al3+). Furthermore, mucilage is mostly secreted as a coagulated polysaccharide (poly-galacturonic acid) by the secretory vesicles of hypersecretory root cap cells and then transported to older root areas during root extension, but epidermal cells can also secrete mucilage[27-29]. Mucilage is also formed in the leaves and buds of numerous plant species; it helps to store food and water by allowing the leaves to retain water capacity when soil water deficiencies occur.

Extraction and purification

Plant seeds contain mucilages that are very hydrophilic, thus they can be removed by soaking the plant in water. The extraction process can be sped up by providing gentle shaking throughout the soaking duration. These methods may extract 30% to 35% of mucilages from plant seeds, with yields changing depending on extraction parameters (pH, temperature, time), seed properties (genotype, morphology, mucilage composition, and arrangement), and extracting solvent (nature, ratio) [30]. To boost mucilage extraction yield, several physical, chemical, and enzymatic treatments have been examined. The extraction procedure and circumstances impact the yield and quality of extracted mucilage.

Conventional techniques

Solvent treatment

In a conventional aqueous process, the mucilage is removed from the dry part of the plant or seed using hot distilled water. This procedure is carried out in an environment that is constantly churning or shaking. The solution is then filtered, and the process can be repeated as needed. By adding alcohol to the filtrate, the mucilage is precipitated. The precipitated mucilage is dried in an oven or freeze-dried to form the final mucilage powder[31]. On the other hand, the natural occurrence of mucilage can be a limiting issue, needing more unit operations. The ratio of mannose to galactose in mesquite seeds ranges from 2:1 to 4:1. The mucilage is difficult to extract due to the tough seed pods. As a result, mechanical activities such as crushing and hulling are required; to achieve these requirements, an alkali/acid treatment at various temperatures has proven to be effective. By far the most used extraction method is solvent extraction. In a study conducted by Nazir, Wani, and Masoodi, the effect of extraction parameters such as temperature, time, and water-to-seed ratio on the extraction yield of aqueous extract of basil seed mucilage was shown to be significant (2017). In this study, the most critical factor in yield was the water-to-seed ratio, followed by temperature and extraction time. Using a central composite rotatable design, the temperature, extraction time, and water-to-seed ratio were tweaked, and the best temperatures, extraction time, and water-to-seed ratio were reported to be 56.7^{0}C, 1.6 h, and 66.84:1 respectively. The amount of aqueous basil seed mucilage found ranged from 7.86 to 20.5 g/100 g[32]. Temperature, followed by seed-to-water ratio, was found to have the highest impact on chia mucilage extraction yield[33]. As a result, optimising the operating conditions of an extraction process is critical for

maximising yield. The quality of the extracted mucilage is also affected by these conditions. In their study[34], they found that alkaline extraction yielded a high yield (24.9 percent), while also keeping the polysaccharide's viscosity and foaming properties. The mucilage's chemical composition's complexity could also be a problem. Chia mucilage, for example, is a polysaccharide that contains b-D-xylose, a-D-glucose, and 4-O-methyla-D-glucuronide, giving it a complex structure that requires ethanoic pretreatments and the extraction of chemical non-polar solvents like hexane[35]. Although supercritical fluids have been used in various extraction applications[36], a transition to more environmentally friendly alternatives is required.

Agitation and centrifugation

In some situations, agitation might be a simple technique to separate mucilage. The medicinal herb *Ocimum americanum*, for example, has seeds that are encased in a jelly-like fluid that dries to form a thin covering. When the seeds come into contact with mucilage, it absorbs water and can be separated with agitation (against the use of solvent treatments). The seeds were agitated at various speeds (ranging from 200 to 4000 rpm) and for varying periods of time in a study conducted by[37]. The process was conducted at 2000 rpm for 50 minutes to maximise mucilage yield. In a recent work, De Campo et al. (2017) employed centrifugation to extract chia seed mucilage38. Chia seeds were soaked in distilled water for around two hours while regularly stirring the solution. A vacuum pump was used to extract the mucilage from the seeds, and cheesecloth was used to filter out the suspended microscopic particles. To make chia seed mucilage powder, the filtered solution was dried in an oven. The extraction of mucilage from cress seeds followed a similar technique[39]. The pH of the water was corrected to 10 using NaOH 0.1 M in this method. The solution was dried and processed to obtain a powder after soaking, stirring, and separating the mucilage. 0.02 percent sodium azide was added to the deionized water as an antibacterial agent during the extraction of quince seed mucilage, and the extraction was continued[40].

Emerging techniques

Ultrasonication

Non-thermal ultrasound treatment is utilised in the food industry for a variety of applications, including extraction. Low-frequency ultrasound has been used to eliminate mucilages by shattering the biological cell wall through the creation of holes. Cavitation is the name for the process in which pores allow solvents to permeate more efficiently, enhancing detachment and yield. To separate the mucilage, the seeds were treated to ultrasound-assisted extraction, with yields ranging from 7.02 percent to 16.29 percent due to changes in extraction conditions. This study found that the optimal extraction time for separating mucilage was 7.68 minutes at 380°C and pH 6.35, with a maximum mucilage yield of 14.09 percent[41]. The mucilage of chia seeds, on the other hand, is high in soluble fibres and omega-3 fatty acids. To extract the oil, the mucilage was removed using an ultrasonic probe treatment at 500°C for 3 minutes with pressurised polar solvents[35]. Mucilage extraction from Arabidopsis seed coat is difficult due to the presence of two layers of mucilage. The exterior adhesive layer, which is formed of rhamnogalacturonan I, may be removed by shaking, but the inner adhesive layer, which is composed of rhamnogalacturonan I, is difficult to separate. Various chemical therapies were tried, but a 20-second ultrasonic therapy produced the best results[44]. In another study, ultrasound-assisted extraction was used to extract the mucilage from flaxseeds. Aside from the extraction, the treatment has the potential to reduce anti-nutritional components such as tannins[43].

Microwave treatment

Microwave treatment is a relatively new thermal processing technology for extracting mucilages from a variety of plant and seed sources[44]. The mucilage found in *Opuntia ficusindica* L. Miller is a high-molecular-weight hetero-o-polysaccharide that accounts for up to 14% of the dry weight. The effect of temperature, pH, and solvent on the structural, functional, and nutritional value of mucilages[45] is a feature of traditional water extraction procedures. Conventional hot water extraction procedures, for example, have been shown to result in the loss of heat sensitive chemicals in investigations on *Lepidium perfoliatum* seed mucilage. To address this limitation, microwave-assisted extraction was used with an extraction period of 120 to 180 seconds and a power of 300 to 400 watts, resulting in significant mucilage content[46]. Upon increasing the power level to 400 W, the treatment time was reduced, with a drastic reduction in mucilage yield. Conventionally, applying hot water extraction with a long extraction time is known to be cost-effective, but may hamper the quality of the mucilage. Microwave-assisted extraction is a prospective alternative technology that can save time, minimise solvent use, and enhance extraction efficiency. Microwave extraction was utilised to generate the maximum qualitative and quantitative yield[47] in a study on polysaccharide extracts of jujube, which are known to be potent in antioxidants. An attempt was undertaken to extract mucilage from Opuntia ficus-indica using microwave-assisted extraction, with a yield of 83 percent [48]. Microwave extraction was also employed for ficus seed, with a 25 percent increase in yield compared to traditional methods[49].

Enzymatic treatment

In the food sector, enzymes can be used in a variety of ways. Enzyme-assisted extraction is a highly precise and environmentally safe method. The polysaccharides in Asplenium australasicum leaves were extracted using enzymes (J. Sm.) Endo-1,4-b-xylanase and/or b-glucanase were used to extract the mucilages, and the findings showed a high yield and excellent physicochemical qualities[50]. A fascinating study was published on the waste usage of Chinese yam, a tuber having therapeutic potential. During industrial processing, yam drying waste was obtained, and the mucilage contained therein was removed. The yam's mucilage is considered a functional food. Enzymatic hydrolysis was used to reduce molecular weight, and different enzymes such protease, a-amylase, mannanase, galactanase, xylanase, arabinase, and rhamnase were tested with the improved procedure. Mannose content was shown to decrease dramatically after protease hydrolysis, from 62.52 percent to 3.96 percent. Apart from eliminating proteins that come together with polysaccharides like mannose, which have significant promise as a functional food[51], enzymatic treatment can substantially lower the molecular weight and viscosity. Single/dual enzymatic modifications were performed for the extraction of *Asplenium australasicum* mucilage. The quality of the mucilage was shown to improve when proteinaceous matter was removed using trichloroacetic acid and proteinase enzyme treatments. Physical qualities were improved at the same time, and enzymatic treatment with proteinase and xylanase resulted in structural changes and better functional properties[52].

Several other extraction techniques have proven the potential for the extraction of bio-based ingredients [53]. Considering a balance between yield, purity, cost, time, and simplicity, these can be explored for the extraction of mucilages as well. Generally, crude mucilages possess off-flavors that must be

removed. Further, the presence of protein-matter and endogenous enzymes can affect the stability of the solution. Hence, it is necessary to purify mucilages with solvents like ethanol, isopropanol, methanol, copper, or barium complexes. Accordingly, the purification of cress seed mucilages was done using a series of solvents like ethanol, followed by isopropanol and ethanol-isopropanol, resulting in a reduction of the molecular weight of polysaccharides and the removal of ash and protein[54]. Mucilage's characteristics can be drastically altered during the purification process. Purified basil seed mucilage, guar gum[55], and *Lallemantia royleana* seed mucilages[56], for example, had increased viscosity after protein impurities were removed. Purification of crude mucilages can also be accomplished utilising molecular weight-based column separation techniques. To purify crude polysaccharide, columns such as diethylaminoethylcellulose and Sephadex G-100 were utilised. Polysaccharides isolated from jujube by microwave treatment, for example, were purified on a G-100 column, and the purified mucilage was then lyophilized[47].

Characterization of the mucilage

This method is used to determine the chain configuration, or microstructure, of a polymer while it is in either a solid or liquid condition. This method can be used on any type of sample that contains a spin-filled nucleus. In this context, Singh *et al.,* [2] observed nuclear magnetic resonance spectra (1H and 13C) of the mucilage of the seed/fruit of *Diospyros melonoxylon* Roxb at 400 MHz, and revealed that many sugar compositions are consist of CH and OH groups of mannose (*d* 3065 to *d* 3060 ppm), CH group of rhamnose (*d* 72.2 ppm), CH group of arabinose (*d* 70.1-*d* 71.8 ppm), the CH2 group of arabinose (*d* 3.81 to *d* 3.55 ppm), and the CH group of mannose (*d* 72.3 ppm), respectively. Likewise, Deore et al.[57] and Dehghani et al. [58] studied the composition of the mucilage of Cassia obtusifolia and chia seeds and concluded that the mucilage of *Cassia obtusifolia* contains the CH group of arabinose (*d* 69.61–*d* 71.25 ppm), glucose (*d* 4.15 and *d* 3.84 ppm), OH and CH groups of mannose (d 3.62 and d 3.41 ppm), methyl group (1.23 ppm), non-anomeric protons (3.1 and 4.1 ppm), OH and CH2 groups of arabinose (*d* 3.55 and *d* 3.39 ppm), while chia seed mucilage contains OH and CH groups of mannose (3.6 and 3.65 ppm), OH and CH groups of arabinose (3.55 and 3.81 ppm), and the bond between methyl and protons with C6 and C4 of galactose. Devi et al. [59] found that flaxseed mucilage contained methylene and thio parts of thioglycolate resonance at peak values of 4.14 and 5.56 ppm, respectively. FTIR spectroscopy can be employed in wavelength areas between 4000 and 400 cm-1 with a resolution of 2 cm-1 or 4 cm-1 to determine the chemical structure and functional groups of mucilage. The carbohydrate fingerprinting area is defined as the area between 800 and 1200 cm-1. Mucilage comprises polymers such CH2, O-H, C-H, and C-O-C, as well as the carboxylate group, which has been detected in many investigations. It was also observed that the spectra obtained from mucilage showed a huge peak value at the range of 3500–3300 cm^{-1}, the absorption band at around 3000–2800 cm^{-1}, 1270–1080 cm^{-1}, at 1600 cm^{-1}, and 1400 cm^{-1} confirming the vibrational stretching of the polymeric O-H group, CH2 and C-H group, C-O group, Carboxylate asymmetric stretching, and symmetric stretching respectively[60-62]. The FTIR examination of basil seed mucilage by Naji- Tabasi et al. [63] revealed the presence of uronic acids, with absorptions at wavelengths of 1600 and 1400 cm-1 confirming the presence of uronic acid ascribed to C-OO asymmetrical and symmetrical stretching, respectively. As a result, Pratik and Shadique [64] isolated mucilage from Tilkor (Mamoradica monadelpha) fruits, and the mucilage sample was freeze-dried into powder form. FTIR result confirmed the presence of complex carbohydrate (starch), moreover, FTIR of Tilkor mucilage showed the vibrational stretching of C-H bending of Alkynes, C-H bending in aromatic rings, C-C Stretching vibrations, free O-H groups Vibrations, and C=N bond showed Aminoacids/ proteins and the absorption band wavelength at around 685 cm^{-1} –665 cm^{-1}, 900 cm^{-1} –625cm^{-1}, 822 cm^{-1}, 3710–3513 cm^{-1}, and 1623 cm^{-1} respectively. Rheological characterisation examines the shear rate-dependent flow behaviour of mucilage solutions throughout a shear rate range of 0 to 100 Hz. Several scientists studied the rheological properties of the mucilage in seeds from various plants. Punia et al.[65] used an oscillatory shear to measure the rheological characteristics of chia seed mucilage (range of frequency stress sweep is about 1 Hz to 10 Hz) and found that the chia seed had the highest correlation coefficient (R2 > 98.58) and that the viscosity of the solution decreased rapidly as the shear rate was increased. Another study by Capitain et al. [66] found that raising the concentration from 0.25 to 1.00 (w/v) enhances the viscosity of chia seed dispersions. Similarly, Abbastabar et al. [67] identified quince seed mucilage and found that at strain 11.4 percent, the curve deviated from the linear range. In the presence of 0.2 M NaCl, increases in storage modulus and decreases in viscoelastic linear range (7.7%) were found, indicating that NaCl has dual activity on mucilage or gum. Quince seed mucilage has a rather high activation energy of 6988.74 J mol1. The activation energy of biopolymers is commonly used to measure chain flexibility. In their investigation, Keshani-Dokht et al.[68] discovered a decrease in the magnitude of Cordia myxa mucilage as well as an increase in solution concentration from 0.99 to 0.89 and 0.2–2%, respectively. They discovered that at high concentration levels, the mucilage solution has a tendency to shear thin more. Cordia myxa mucilage has an estimated activation energy of 446.23 KJ. The thermogravimetry analysis (TGA) method is used to determine the mass variation in a mucilage-containing sample as a function of temperature in a controlled environment[62]. When a portion of the sample is changed into vapour, the vibration of mass can be negative, and when the sample is subjected to corrosion or oxidation, it can be positive[69]. Mucilage's thermal stability can be tested in two ways: isothermal (temperature remains constant) and dynamic (temperature changes) (temperature is increased at a linear rate)[6]. According to the derivative thermograms and primary thermograms, heating Manilkara zapota seed mucilage at 100C/min from 0C to a maximum of 9000C resulted in two mass loss events. Furthermore, there was 41.17% weight loss at 178.6–359.7^{0}C temperature range in the first Decomposition stage and 30.06% weight loss at 359.7–600.6 ^{0}C in the second Decomposition stage. Besides, at the same temperature range the enthalpy (315.8729 and 3624.787 J/g), DTG peak (350.3^{0}C and 614.4 ^{0}C), and heat change (138.4354 and 1082.215 µVs/mg) were observed for both first and second decomposition stages[70]. Differential scanning calorimetry (DSC) has developed as a promising physical tool for investigating physical and chemical changes in mucilage after thermal processing[71]. Mucilage's strong thermostability can be used in paintings to stabilise suspensions or emulsions, increase bake-stability in cakes, prevent crystal formation, and improve freeze-thaw stability[6], among other things. The glass transition temperature of Diospyros melonoxylon Roxb seed mucilage was discovered to be 780C during DSC examination. Differential scanning calorimetry thermograms revealed a high-intensity peak at roughly 2000C, indicating an endothermic transition. The significant endothermic peak of chia seed mucilage aligns with the hydrophilic nature of the functional groups, and could be attributable to the gums' irregular packing structure[72]. The endothermic peak transition temperatures (Te, To, Tp) of chia seed mucilage were 215^{0}C, 52.8^{0}C, and 107.9^{0}C, respectively. 233.9 J/g was enthalpy change value of chia seed mucilage. In the case of exothermic peak transition temperatures (Te, To, Tp) of chia seed mucilage were 354.9^{0}C, 277.7 ^{0}C, and 316.8^{0}C,

respectively, and the enthalpy value of exothermic peak (101.9 J/g) was lower than endothermic. Mucilage's high enthalpy value shows that it takes a lot of energy to release water, which is linked to crystallisation loss and hydrogel boundedness[65].

Mucilage based nanocarriers and their application

Synthetic and non-synthetic polymers have been effectively employed to make hydrogels in the past, although plant-derived (synthetic) polymers such as proteins, polysaccharides, and polypeptides are the most popular due to their wide range of applications. Because of its hydrophilicity, safety, and biodegradability, mucilage offers a lot of potential for making hydrogels. Hydrogels are hydrophilic, polymeric 3D materials that allow liquids to diffuse while simultaneously maintaining solids' cohesive properties. Because of their wide range of uses, they are in high demand among technologists and researchers. In 1960, the first synthetic hydrogel was created.

Furthermore, hydrogels made from plant-derived polymers are in great demand due to the presence of functional groups including sulphate, amide, hydroxyl, and carboxylic, which boost swelling and water holding capacity, as well as flexibility and microscopic holes. Many stimuli exist, including (pH, temperature, and electric field) [73]. The principles of crosslinking a polymer chain are employed in conjunction with two ways (physical and chemical crosslinking) for the creation of hydrogels. Chemical crosslinking involves forming new covalent connections with the hydrogel's polymer chain, although physical contact between the hydrogel's polymer chains is also possible. For the production of hydrogel from plant-derived polymers (gum and mucilage), both chemical and physical crosslinking methods can be used 74. Figure 1 depicts the development of a nanohydrogel.

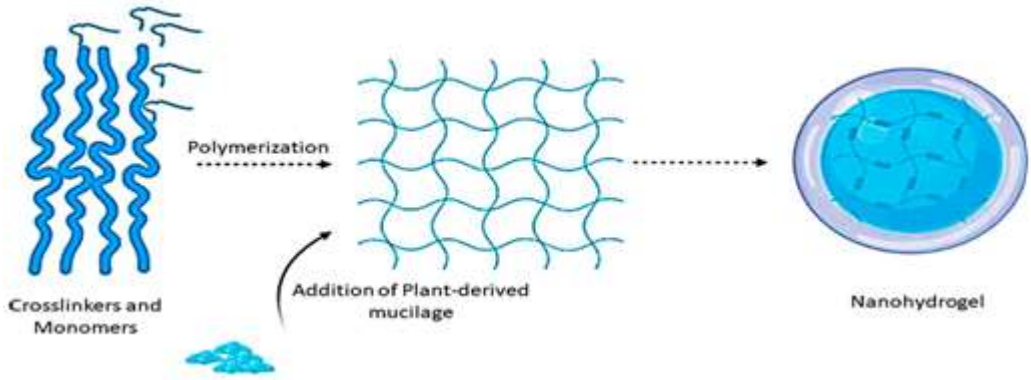

Figure 1: Plant-based mucilage as an efficient biopolymer in the synthesis of nanohydrogel[74]

These properties raise the value of hydrogel as a potential application in food, pharmaceuticals, and other industries[75]. The cross-linking (physical or chemical) parameters taken during the gel formulation are used to characterise hydrogels. A nanohydrogel is a three-dimensional network of hydrophilic material (e.g., polysaccharide) with a diameter of less than 100 nm, which is identical to a regular hydrogel. When compared to micro and macrocategorization, nanoparticulates offer numerous advantages in the food and other industries. The term "nanohydrogel" was used to describe the cross-linking and networking of polyanion molecules[76]. They're employed for a variety of things, including wound healing, medicine delivery, vaccine distribution, film enhancement, and enzyme immobilization[77], [78]. Mucilage-based hydrogels with nanocomposites generate a 3D network with exceptional porosity, allowing for extensive food or medicine absorption in water[79]. Ceramic matrix nanocomposites, polymer matrix nanocomposites, and metal matrix nanocomposites are the three types of nanocomposites. They were chosen for their potential properties in macro and microcomposites, including as mechanical, barrier, and optical features. Field emission scanning electron microscopy (FESEM), Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and high-resolution transmission electron microscopy (HRTEM) [80] can all be used to characterise mucilage-based nanohydrogels. The mucilage-based hydrogels can operate as a protector, preventing active substances from degradation, oxidation, and destruction, and have a variety of uses in water purification, medicine delivery, food processing, tissue engineering, and agriculture. Mucilage-based nanohydrogels can be characterised by field emission scanning electron microscopy (FESEM), Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and high-resolution transmission electron microscopy (HRTEM) 80. Mucilage-based hydrogels can act as a protector, preventing active chemicals from being degraded, oxidised, or destroyed, and have a wide range of applications in water purification, drug delivery, food processing, tissue engineering, and agriculture[75]. Nanohydrogels combine the benefits of hydrogels, such as absorption capacity, hydrophilicity, flexibility, and high water holding capacity, with the benefits of nanoparticles, allowing for improved dispersion in food packaging materials and a reduction in the amount of bioactive substances required[81]. Due to their unique qualities, such as biocompatibility, biodegradability, stimuli-responsive properties, and biological characteristics, plant-derived mucilage-based nanohydrogels are in high demand, making them a good material for use in a variety of applications. Nanohydrogels could also be used for controlled medication delivery, biomimetic materials, and biological or chemical sensors, among other things. Nanotechnology is now used extensively in medicine delivery systems, food processing, and water purification[82]. As a result, nanoparticles (magnetic and non-magnetic), nanofibers, nanocomposites, and nanoencapsulation are widely used as nanocarriers in a variety of industrial applications, including medicine delivery, dye removal, and film creation. In addition, Rayegan et al.[83] created magnetic Fe_3O_4 nanoparticles coated with basil seed mucilage for the controlled delivery of an antibiotic (cephalexin). XRD, FTIR, TEM, FESEM, and VSM were used to characterise the material. FESEM revealed that the mean size of the nanoparticles was 6 nm and 12 nm, with 0.25 and 0.28 PDI values, respectively. One hundred and fifty magnetic nanoparticles were randomly selected for FESEM. Furthermore, the antibacterial efficacy was assessed using the

disc diffusion method, and it was discovered that loading cephalexin onto basil seed mucilage-coated magnetic nanoparticles had no detrimental effects on drug performance or structure. Furthermore, it improved cephalexin's antimicrobial characteristics. As a result, Mohammadi et al.[84] developed nanocomposite films containing okra mucilage (OM), carboxymethylcellulose (CMC), and ZnO nanoparticles, and tested their antibacterial and physicomechanical capabilities. In their study, they used different proportions of okra mucilage and carboxymethylcellulose (0/100, 30/70, 40/60, and 50/50, respectively). High quantities of ZnO nanoparticles and okra mucilage were found in coloured films. Furthermore, the introduction of ZnO nanoparticles into carboxy methylcellulose film increased tensile strength and lowered elongation at the break value due to the addition of mucilage.

Synthesis of Nanoparticles with Mucilage

Nanoparticles have gotten a lot of interest because of the development of green, simple, and long-lasting nanoparticle synthesis. Direct precipitation, microwave, and hydrothermal techniques are commonly utilised physicochemical methods[85,86]. As a result, plant-derived polymers including gums and mucilages are effective for nanoparticle production and functionalization. Vitamin D-loaded nanoparticles on cress seed mucilage and gelatin were used in nano-formulations employing mucilage used in microparticle formulation. With better in vitro release percentages of vitamin D in intestinal fluids and mimicked gastroitestinal conditions[83], the produced particles improved encapsulation efficiency (about 70%). As a result, Pathak et al.[87] detailed how they were able to synthesise nanoparticles with a cationic polysaccharide polymer employing mucilage as an anionic ocular polymer (chitosan). The produced material was tested for antibacterial activity against Gram-positive (*Bacillus cereus* and *Staphylococcus aureus*) and Gram-negative bacteria (*Salmonella typhimurium* and *Escherichia coli*). This form of nanoparticle could be valuable in the pharmaceutical business to keep medications from losing their antibacterial activity. Additionally, the negative charge of the mucilage was suppressed by creating cephalexin-loaded/basil seed mucilage-coated iron oxide (Fe_3O_4) magnetic nanoparticles. At pH 7.4, the in vitro release of antibiotic (cephalexin) from drug-loaded coated nanoparticles was biphasic, with an initial fast release phase followed by a continuous release phase. For the manufacture of mucilage nanoparticles loaded with the cytotoxic drug paclitaxel, phase inversion techniques and antisolvent supercritical gas employing supercritical carbon dioxide as an anti-solvent were used, in addition to abusing the negative charge of the mucilage. The nanoparticles had a high drug loading of more than 75 percent and a small particle size of roughly (200 nanometers) [88]. Mucilage is high in flavonoids and polyphenols. These chemicals can effectively bind zinc ions in an aqueous media and act as stabilisers and natural reducers during the nanoparticle manufacturing process. Several carbohydrates and counter acetate ions are also destroyed during the oxidation process, resulting in large amounts of carbonate ions (Ag, Zn, Cu, and Co) and carbon dioxide, allowing the binders to be eliminated[89].

Conclusions, future research perspectives, and challenges

Plant-derived polymeric carbohydrates have gained popularity in the food industry in recent years due to their wide range of applications, including film coatings, emulsifiers, binders, and gelling agents. Mucilage, among all carbohydrate polymers, has been widely used in modern research due to its wide range of uses. Mucilage formed from plants can be extracted from the specific mucilage cells found in various plant parts. Mucilage is also made up of L-arabinose, D-xylose, D-galactose, L-rhamnose, and galacturonic acid, which are all complex carbohydrate polymers with highly branching structures. Glycoproteins and several bioactive components such as tannins, alkaloids, and steroids are also present. Plant-derived mucilages can be utilised as an active functional component, emulsifier, surfactant, stabiliser, encapsulating material, or cross-linker because of their qualities, and thus they could be used to make many types of nanocarriers. Furthermore, researchers discovered a wide range of medicinal and food science uses for biopolymer produced nanocarriers, particularly nanohydrogels and metal nanoparticles. Mucilage is a polymer generated from plants, and its availability fluctuates depending on the season and the climate. These changes, in addition to agronomical variables, may alter the quality and production of mucilages; nevertheless, the extraction and purifying processes are quite complex. Mucilage output and consistency may be affected by insufficient mucilage removal, physical damage to the seed, and morphological aspects of plant portions containing mucilage, offering a severe challenge to associated costs and the ability for mass production. The chemical makeup and manner of action of mucilages in food systems determine their toxicity. As a result, it's critical to figure out how poisonous mucilages are, specifically the prevalence of heavy metals in various plant sources. The fixed-dose approach, as recommended by the Organization for Economic Cooperation and Development's guideline number 425, can be used to determine the harmful effects of mucilages (OECD). Because mucilage has a moisture level of roughly 10%, the potential of microbial contamination throughout any stage of processing is substantial. This is due to the presence of biological molecules that encourage microbe growth and production under ideal conditions. Furthermore, the length of storage is a significant role in mucilage contamination. Variations in storage conditions have been linked to changes in mucilage quality, according to studies. This frequently necessitates strict monitoring of the various handling methods employed at various levels of the supply chain. Uncontrolled biodegradability, shear instability, thermal decomposition, pH dependence, thickening, and uncontrolled hydration are all issues that can be addressed with adjustments.

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