Plant-Derived Mucilage for Nanocarrier Fabrication

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Easily sourced mucus from various plant parts is an odorless, colorless and tasteless substance with emerging commercial potential in agriculture, food, cosmetics and pharmaceuticals due to its non-toxic and biodegradable properties. It has been found that plant-derived mucilage can be used as a natural thickener or emulsifier and an alternative to synthetic polymers and additives. Because it is an invisible barrier that separates the surface from the surrounding atmosphere, it is used as edible coatings to extend the shelf life of fresh vegetables and fruits as well as many food products. In addition to its functional properties, mucilage can also be used for the production of nanocarriers. We focus on mucus extraction methods and its use as a natural preservative for fresh produce. We detailed the key properties related to the extraction and preservation of food, the mechanism of the effect of mucus on the sensory properties of products, coating methods when using mucus and its recipe for preserving fruit and vegetables. Understanding the ecological, economic and scientific factors of production and the efficiency of mucus as a multi-directional agent will open up its practical application in many industries.

Keywords: nanohydrogel ; food applications ; biopolymers ; polysaccharide

1. Introduction

Plant-derived polymers have attained high demand in food and other industries due to their diverse industrial applications such as film coating, emulsifier, binder, and gelling agents, therefore they are excessively used in the textile industry, paper industry, and cosmetic industry [1][2]. Nowadays, due to the hazardous effect of synthetic polymers on human health, people showed major interest in plant-based naturally derived biopolymers (gums, mucilage, cellulose, and glucans) as an effective ingredient for the formulation of eco-friendly, sustainable, cost-effective products [3]. Moreover, a large number of polysaccharides can also be biosynthetically fabricated by several living organisms including plants, algae, animals, bacteria, and fungi [4]. Also, natural polysaccharides are used in the food industry as they are regarded as safe for human consumption [5]. Among various polysaccharides, plant-originated mucilage is widely used in various food industries due to its valuable broad-spectrum applications [6]. Generally, mucilage can be obtained from several plants or their different parts such as *Aloe vera*, *Salvia hispanica* seeds, *Cordia dichotoma*, *Basella alba, Plantago psyllium, Cyamopsis tetragonoloba*, *Cactaceae, Abelmoschus esculentus, Trigonella foenum-graecum*, *Moringa Oleifera,* and *Linum usitatissimum.* 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]. Structurally, mucilage (a complex of polymeric polysaccharide) is mainly composed of carbohydrates with highly branched structures that consist of monomer units of L-arabinose, D-xylose, D-galactose, L-rhamnose, and galacturonic acid. They also contain glycoproteins and different bioactive components such as tannins, alkaloids, and steroids [8][9][10]. Also, mucilage produces an indefinite number of monosaccharides on hydrolysis, depending on the type of hydrolysis products obtained due to the nature of the polysaccharide. It can also further classify into pentose sugars (xylan) and hexose sugars (cellulose and starch) and can be considered as gum like components due to their similar physiological properties. However, both mucilage and gum are mostly related to hemicelluloses in composition, except the sugars produced by hemicelluloses such as xylose, glucose, and mannose instead of sugars produced by the gums such as galactose and arabinose [11][12]. Moreover, that can be utilized in several applications such as edible coating, wound healing, tablet formation, encapsulation, water purification, and various nanocarriers. Mucilage exhibits an excellent functional property, however, due to the hydrogen bonding in between different functional and other polar groups, they also have an important role in film, emulsion, coated metal nanoparticles, and gel formation [13]. In recent years, nanostructured hydrogels and mucilage coated metal nanoparticles are intensively used as a significant delivery vehicle for various hydrophilic and hydrophobic components [14]. For the formulation of nanohydrogel, different types of biopolymers and cross-linking polymers can be used and mucilage can act as either a primary biopolymer or a cross-linking component for the formulation of nanohydrogel [15]. Several reports have been published on the formulation of stable nanohydrogels using mucilage as an active component and researchers revealed various therapeutic and food applications of the formulated nanohydrogels [11][12][13][14][15][16][17]. Furthermore, nanohydrogels formulated with mucilage exhibit higher stability than that of other conventional plant-based biopolymers. Furthermore, metal nanoparticles coated with polymeric carbohydrates such as starch, dextran, chitosan, and mucilage are the most abundant nanocarriers used for targeted drug delivery. Because, in addition to increasing blood circulation time by hiding them from the immune system, their polymeric shells enable them to transfer and release the drug during biodegradation [16][17].

2. Mucilage Based Nanocarriers and Their Application

Nowadays, synthetic and non-synthetic polymers have been successfully used for the formation of a hydrogel, but plant-derived (synthetic) polymers such as proteins, polysaccharides, and polypeptides are the most preferable choice, because of their extensive use of applications. Mucilage has an excellent potential to synthesize hydrogels because of its hydrophilicity, safety, and biodegradability. Hydrogels are hydrophilic and polymeric 3D material, which retains diffusive transport of liquids as well as also retains cohesive property of solids. They have attained high demand for technologists and researchers due to their extensive range of applications. The first synthetic hydrogel was prepared in 1960. Moreover, hydrogels from the plant-derived polymers are in high demand due to the presence of functional groups such as sulfate, amide, hydroxyl, and carboxylic which increases their swelling and water holding capacity, they are also interconnected with elasticity, and microscopic pores. There are many stimuli factors such as (pH, temperature, and electric field) [18]. There are generally two methods (physical and chemical crosslinking) that are used for the formation of hydrogel along with the principles of crosslinking of a polymer chain. The chemical crosslinking method includes the creation of new covalent bonds with the hydrogel's polymer chain, while physical interaction can be also present between the polymer chain of the hydrogel. Both chemical and physical crosslinking methods can be applied for the synthesize of hydrogel from the plant-derived polymers (gum and mucilage) [19]. The formation of a nanohydrogel is explained in **Figure 1**. These characteristics increase the value of hydrogel as an applicant in food, pharma, and several industries [20].

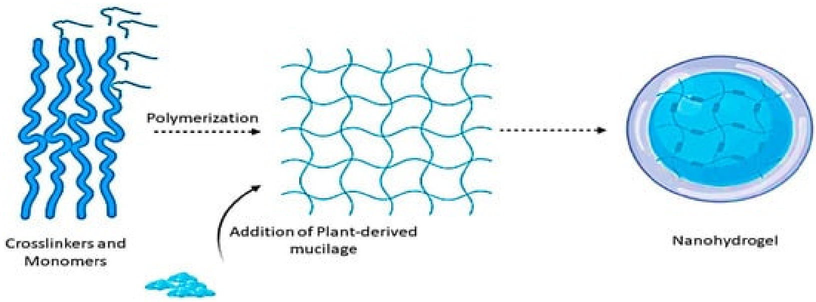

Figure 1. Synthesis of nanohydrogel using plant-based mucilage as an effective biopolymer.

The characterization of hydrogels is dependent upon the cross-linking (physical or chemical) measures during the formulation of the gel. Nanohydrogel is mostly similar to a normal hydrogel, which can be defined as a three-dimensional network of hydrophilic material (e.g., polysaccharide) with a diameter of less than 100 nm. Nanoparticulates have many benefits when compared to micro and macrocategorization in food and several other industries. The term nanohydrogel was first introduced to describe the cross-linking and networking of poly-anions [21]. They are used in several applications such as wound healing, drug delivery, vaccine delivery, the enhancement of film properties, and enzyme immobilization [22][23]. Mucilage-based hydrogels containing nanocomposites form a 3D network of extreme porosity, which allows a large absorption of food or drugs in water [24]. Nanocomposites are divided into three classes: ceramic matrix nanocomposites, polymer matrix nanocomposites, and metal matrix nanocomposites. They are chosen related to macro and microcomposites due to their excellent potential properties such as mechanical, barrier, and optical characteristics. The characterization of mucilage-based nanohydrogel can be performed through different methods such as field emission scanning electron microscope (FESEM), Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and high-resolution transmission electron microscopy (HRTEM) [25]. The mucilage-based hydrogels can act as a protector, which prevents active ingredients from degradation, oxidation, and destruction, and also has several applications in water purification, drug delivery, the food industry, tissue engineering, and agriculture. Nanomaterials improve the barrier and mechanical aspects of food packages, and other developments for intelligent and active applications in the food industry [26]. Polymers containing hydrophilic groups such as -COOH, -OH, -CONH-, -SO_3H, and -$CONH_2$ interact with each other. Nanohydrogels are responsible for several stimuli such as temperature, electromagnetic field, pH, ionic strength, and light. Moreover, mucilage-based nanohydrogel is mostly utilized for the preparation of the edible coatings of edible films, and it is estimated that high mucilage-containing seeds or fruits are a good source of edible gum and can be used for various applications [20]. Nanohydrogels combine the great characteristics of hydrogels, such as absorption capacity, hydrophilicity, flexibility, great water holding capacity, with the advantages of nanoparticles, allowing for obtaining better dispersion in food packaging material and decreasing the number of bioactive compounds to be applied [27]. Plant-derived mucilage-based nanohydrogels are in great demand due to their unique properties, such as biocompatibility, biodegradability, stimuli-responsive properties, and biological characteristics, making them a good material for selection in diverse applications. Furthermore, nanohydrogels have potential applications such as controlled drug delivery, biomimetic materials, and biological or chemical sensors. Nowadays, nanotechnology plays a very important role in drug delivery systems, food applications, and water purification [28]. Therefore, nanoparticles (magnetic and non-magnetic), nanofibers, nanocomposites, and nanoencapsulation are widely used as nanocarriers in various industrial applications, such as for the controlled delivery of drugs, the removal of dye, and the development of film, which are highlighted in **Table 1**.

Table 1. Application of seed mucilage with various nanocarriers.

Seed Mucilage	Nanocarrier	Applications	References
Basil seed mucilage	**Magnetic nanoparticles (Fe_3O_4)**	**Application for the controlled delivery of antibiotic (Cephalexin)**	[29]
Cress seed mucilage	**Nanofibers**	**Application for the delivery of vitamin A**	[30]
Quince seed mucilage	**Zinc oxide nanoparticles**	**Application for photocatalytic dye degradation**	[31]
Quince seed mucilage	**Magnetic nanocomposites**	**Application for removal of cationic dyes from the aqueous solutions**	[32]
Basil seed mucilage	**Zinc based magnetic bio nanocomposites**	**Application for removal of azo anionic and cationic dyes from the aqueous solutions**	[33]
Okra seed mucilage	**Zinc oxide nanoparticles**	**Application for nanocomposites-based films**	[26]
Basil seed mucilage	**ZnO nanocomposites**	**Application for wound healing**	[34]
Chia seed mucilage	**Nanoencapsulation**	**Application as wall material**	[35]

Moreover, Rayegan et al. [29] synthesized magnetic Fe_3O_4 nanoparticles coated with basil seed mucilage for the application of the controlled drug delivery of an antibiotic (cephalexin). The sample was characterized using XRD, FTIR, TEM, FESEM, and VSM. One-hundred and fifty magnetic nanoparticles were randomly selected for FESEM, which showed that the mean size of the nanoparticles was 6 nm and 12 nm, with 0.25 and 0.28 PDI values, respectively. Moreover, the antibacterial efficacy was evaluated by the disk diffusion method, and it was observed that there were no negative effects on the performance of drugs or on the structure by the loading of cephalexin onto the basil seed mucilage-coated magnetic nanoparticles. Moreover, it also increased the antibacterial properties of cephalexin. Consequently, Mohammadi et al. [26] prepared nanocomposite films based on okra mucilage (OM), carboxymethylcellulose (CMC), and ZnO nanoparticles, and evaluated their antibacterial and physicomechanical properties. In their study, they used different proportions of okra mucilage and carboxymethylcellulose (0/100, 30/70, 40/60, and 50/50, respectively). Colored films were observed with high levels of ZnO nanoparticles and okra mucilage. Moreover, due to the addition of mucilage, tensile strength was increased and elongation at the break value was decreased by the incorporation of ZnO nanoparticles into carboxy methylcellulose film.

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