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Article

Biopolymer-based Edible Film for Food Packaging Application: Review

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Abstract

Edible films serve as an effective barrier to prevent mass transfer between the product and its environment. This innovation facilitates the development of environmentally sustainable food packaging alternatives that promote the efficient use of natural resources. A variety of biopolymers are utilized in the formulation of edible films, primarily polysaccharides, proteins, and composite materials. Polysaccharides can be further categorized according to their origin, including plant, animal, marine, microbial, and industrial waste sources. Proteins are generally classified into plant- and animal-based categories. Composite films, which combine multiple biopolymer types, offer enhanced structural properties. The application of biopolymer-based edible films presents a promising strategy for mitigating commercial plastic waste accumulation. Nevertheless, the incorporation of additives—such as plasticizers, antioxidants, and antimicrobial agents—is essential to enhance film properties and ensure compliance with quality standards for food packaging application

Keywords: Edible film, Food packaging, Polysaccharide, Protein, Composite

1. Introduction

The huge production of plastic waste is associated with low recycling or reuse rates and no sustainable policies that support a circular economy of plastic waste to environment [1]. The food industry uses plastics for packaging single-use food consumption which has increased substantially in recent decades. With an annual growth rate of 5%, the worldwide packaged food market was valued at $1.9 trillion in 2020 and is expected to reach $3.4 trillion by 2030. Food packaging is able to maintain food safety, increase food shelf life, and prevent food waste or loss [2]. In addition, the widespread use of commercial food packaging derived from petroleum-based plastics contributes to the release of chlorofluorocarbons (CFCs) into the atmosphere and exacerbates environmental pollution. This issue is further compounded by the fact that such packaging is typically designed for single use and requires up to 1,000 years to degrade. In light of these concerns, the development of edible films as a sustainable alternative to conventional plastic packaging is essential.

Edible film is a food wrapping that can improve product quality and shelf life [3]. Because of edible films can improve microbiological and physicochemical stability in low temperature storage [4], it can be found in products such as chedar cheese, sausages, candy and fruit. Edible film can be produced from biopolymer, such as proteins, polysaccharides (starch, alginate, pectin, chitosan, and cellulose derivatives), lipids (waxes,

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fatty acids, and acylglycerols), or a combination of both [5]. Biopolymer-based edible film offering some benefits, including consumption safety, economic value, and environmental sustainability [6]. These materials are expected to has mechanical characteristics similar to commercial food packaging. To improve its properties such as flexibility, tensile strength, and resistance to high humidity environments of edible films, plasticizers are used, including glycerol, chitosan, and sorbitol [7]. The selection of the type of plasticizer needs to be considered [8]. The modification of biopolymer-based edible films has the potential to enhance their contribution to the food security sector. Accordingly, this review aims to examine the role of edible films in food packaging and to explore the various types of biopolymers suitable for their production.

2. Edible Film

Edible film is a thin layer made from environmental friendly materials to coat a product and role as a barrier to prevent moisture loss, then protect food products from degradation and enhance food safety [9]. In addition to controlling moisture, edible film perform as an effective inhibitor against oxygen, which is a major cause of oxidative reactions that can result in discolouration, off flavours, and nutrient loss. [10]. One of the advantages of edible film is that it can be consumed along with the packaged product, since it is made from edible materials. Several advantages of using edible film depicted in Fig 1. The addition of antimicrobial agents and plasticizers in the formulation of edible films can also improve their mechanical properties, including tensile strength, compressive strength, biodegradability, and the inhibition of microbial growth that may compromise product quality.

3. Biopolymer-based Edible Film

The use of biopolymers would increase bioaccessibility of biosynthesis which has an impact on the scattering of plastic waste. The advantages of biopolymers in making edible films as packaging materials can also act as carriers of antimicrobials, antioxidants, prebiotics, probiotics, nutraceuticals, flavors, colors, and other additive and bioactive compounds [11]. Therefore, edible film would enhance the nutrition of food products and store mass because the biopolymer system functions as a barrier between food that can inhibit the growth of microorganisms and prevent oxidation phenomena, hence it has good product quality. The formulation of edible food packaging is biopolymer, plasticizer, and additives [12].

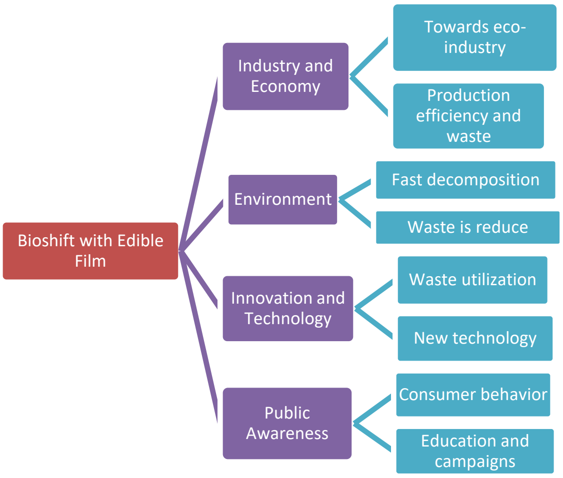

Fig. 1. The benefits of using edible film

3.1. Polysaccharide

Polysaccharides are complex polymers that form chains of monomers or disaccharides connected by glycosidic bonds. This compound can be a surface coating agent containing natural polymer components such as alginate, pectin, chitosan, starch, cellulose chitin, carrageenan, pullulan or a combination of polymers so that it can improve food preservation and safety [13]. This is because polysaccharides are tasteless, colorless, non-toxic, and have a compact structure that affects mechanical properties in the form of hardness, crispness, adhesion, viscosity. Even so, polysaccharides are hydrophilic, namely low water vapor barrier properties so that airtight particles and hydrophobic lipids are needed to increase their low barrier properties to water vapor [14]

Starch is a polysaccharide consisting of amylose and amylopecrine that can be found in plants, such as cereals, seeds, tubers, and nuts [15]. Starch produce a thin layer with low oxygen permeability in the formation of a layer which influenced by the specific ratio between component fractions to starch solubility [16]. Therefore, the addition of plasticizers is needed to enhance the elasticity of starch-based layers, improve tensile strength and reduce water solubility. However, control of the plasticizer concentration is essential, as excessive amounts may interfere the degradation process and allow side effects and affect the mechanical properties of the film [15].

Cellulose is an organic compound used in the manufacture of edible films because of the form a water-soluble layer through carboxymethylcellulose (CMC) and the trigger thermal gelatinase process that produced a good edible film structure [17]. Cellulose can be found in plants such as wood, cotton and bagasse through an aerobic synthesis. In addition, cellulose synthesis can be obtained including microorganisms such as bacteria, algae, and tunicates [18]. Edible films made from CMC, microcrystalline cellulose (MC), hydroxypropyl methylcellulose (HPMC), Hydroxypropyl cellulose (HPC) as types of cellulose derivatives have the advantages of being resistant to oil and fat, flexible, and have moderate oxygen barrier properties [19]. Because of crystallinity structure, cellulose-based edible films may increase mechanical strength and decrease absorption capacity.

Pectin is a heteropolysaccharide as a source of fiber that can provide flexibility to the formation of edible films [20]. Pectin also has oxidation properties, then provide safety as a food packaging because of probiotics contain [8]. Pectin can be found through fruit cell extraction and produces film-forming characteristics similar to starch. It also be used or combined with other biopolymers with the addition of plasticizers to improve its mechanical properties and solubility [21]

Chitosan comes from chitin through deacetylation using alkaline media to obtain a copolymer in the form of β-(1–4)-2-acetamido-D-glucose and β-(1–4)-2-amino-D-glucose. Chitosan has a permeability disorder to air vapor so that control is needed to improve the physical properties of biopolymer-based films. This control can be in the form of adding lipids to increase hydrophobicity, but it will affect the mechanical stability of edible films [22]

Alginate possesses antimicrobial properties and can be found in brown algae (*Phaeophyceae*). It is a polysaccharide composed of α-L-guluronate (G) and β-D-mannuronate (M) units linked through (1–4) glycosidic bonds [17]. This polymer is synthesized by bacteria such as *Pseudomonas* and *Azotobacter*. In edible film formation, alginate can inhibit microbial growth and prevent flavor changes caused by oxidation. It also exhibits favorable mechanical properties, including tensile strength and flexibility. However, its porous structure results in high permeability to water and oxygen, which can affect its barrier performance [23].

Carrageenan consists of sulfated galactose units, namely α-D-1,3 and β-D-1,4, which are classified into various fractions (λ, ϰ, ι, ε, and μ) based on their solubility in potassium chloride. Carrageenan can be found in hydrophilic red seaweed. The characteristics of carrageenan have the potential as an edible film material because it can reduce humidity, gas exchange, prevent color changes and form membranes with good mechanical properties [24]

Xanthan gum is a heteropolysaccharide that has high elasticity because it quickly returns to its original shape while maintaining the consistency of the edible film shape. Xanthan gum provides the effect of increasing pH and absorbing water vapor. The heteropolysaccharide compound is obtained from the synthesis of xanthomonas culture through fermentation. Another effect of using xanthan gum is pseudoplastic rheohi (shear dilution) in the formation of edible films [25]

Pullulan is a polysaccharide consisting of maltotriose and α (1,6) glycoside units. It produced by *Aureobasidium pullulans* that has antimicrobial properties. Like other edible film making materials, pullulan has the characteristics of being soluble in water, flexible, and forming a heat-permeable layer so that the addition of lipids or others is required [17]. Pullulan can also be mixed with other biopolymers, active agents, and additives to produce multifunctional packaging materials with better barriers and mechanical properties [26].

Recent innovations in edible film of polysaccharide illustrated in Table 1.

Table 1. Polysaccharide-based edible film

Type of Polysaccharide	Characteristics	Additional materials	Application
Corn Starch	Reduces moisture migration, controls respiration, enhances food texture [27]	Plastizers (Glycerol, glycrol and erythritol)	Packaging in fresh to meat and meat products Rahmadi Putri et al., 2023), packaging for fresh fruits and vegetables [18], [28]
CMC	Moisture barrier, improve gloss, delays ripening	Glycerol and other biopolymer	Fruit coating, combining it with other polymer materials [29], [30]
Pectin	Forms a semi- permeable barrier, reduces dehydration and oxidative stress	Glycerol and other biopolymer	Fresh and minimally processed fruit products [31]
Chitosan	Antimicrobial, moisture barrier, extends shelf life	Other natural or synthetic polymers, plasticizers, nanofillers, natural plant extracts, and essential oils (bioactive agents)	Edible films and coatings for meat [32]
Alginate	Reduces moisture loss, prevents lipid oxidation, controls respiration rate	Other polymers and plasticizers	Coated vegetables [33]
Carrageenan	Reduce the air content of the product.	Glycerol and other polymers	Coating material for fruits [34]
Xanthan gum	Provides barrier to moisture and gases, stabilizes food structure	Suspending and thickening agent	Edible coating of fresh-cut fruits and meat [35]
Pullulan	Enhances barrier to oxygen and aroma compounds, provides glossy appearance [36]	Other biopolymers, active agents, and additive plasticizers [18]	Coating material for fruits and bakery materials [18]

3.1. Protein

Proteins, with their diverse monomer composition, possess unique structures and functions. Their strong intermolecular forces make them more effective than polysaccharides and lipids for specific coating and packaging needs. Protein films offer better barrier properties (due to organized hydrogen bonds) than polysaccharide and lipid films. However, their susceptibility to moisture limits their practical application. Protein-based coatings are inherently hydrophilic but can be chemically modified to improve their functional properties [37]. Protein-based edible films are valued for their water solubility, emulsifying action, and nutritional benefits. Although they offer good mechanical strength, their effectiveness in preventing moisture transfer is a drawback that might require additional measures depending on the intended use. The addition of various oils can improve their barrier and appearance [38].

Collagen is the top-selling edible protein film, widely used in the meat industry as a replacement for natural gut in sausage casings. This abundant, non-toxic fibrous protein, which forms the structural framework of animal tissues like skin, bones, and tendons (making up about 30% of body mass), is an excellent material for biomaterials. Notably, dried collagen films are highly effective oxygen barriers, but their oxygen permeability sharply increase as higher humidity [39].

Gelatin, a biocompatible, low-cost, and nontoxic protein derived from collagen through partial hydrolysis. Its capacity to effectively encapsulate food ingredients with low moisture content makes it particularly potential in biodegradable film application. Gelatine-based edible film frequently modified to improve their resistance to water vapor and overall functionality [18]

Whey protein stands out as a highly observed material for creating edible films. It show considerable potential for edible film application. It effectively act as oxygen, scents, and flavors barrier. Its low water absorbtion capability, leading to good moisture barrier properties. Further modifications are required to enhance the strength and overall characteristics of these films, particularly through the incorporation of other substances like polysaccharides [42].

Egg yolk contains important lipids, including egg yolk lecithin, which is mainly made up of phosphatidylcholine and phosphatidylethanolamine. The protein-rich residue left after extracting lipids from egg yolk granules, which is significantly altered, presents an opportunity for the production of edible films [43].

Recent innovations in edible film of proteins illustrated in Table 2.

Table 2. Protein-based edible film

Type of Protein	Characteristic	Additional materials	Aplications
Collagen	Good mechanical properties and oxygen barrier in dry environments [39]	Plasticizers that are water soluble) [39]	Edible films and coatings for fruits and vegetables [39]
Gelatin	Biodegradable, improve barrier properties [42]	Plasticizer (gliserol). [43] and chitosan [44]	Edible films for meats, fruits, and vegetables [43]
Whey protein	An excellent barrier properties against oxygen and aromas when the humidity is low [45]	Esssential oils (cinnamon, lemon, bergamot, tea tree or anise) [38], Lipid (olive oil), polyethylenglycol (PEG) [45], and Gliserol [46]	Edible film for fruits [38]
Egg yolk	Its abundant lecithin, fatty acids, and vitamin reducing flocculation, preventing aggregation, then enhancing the physical stability of the emulsion [47]	Chitosan and curcumin [47]	Edible film for fresh meat [47]
Gluten	Wheat gluten has an isoelectric point (IP) below pH 5.5. The cohesiveness and elasticity of gluten are enabled by disulfide bonds between its protein molecules [37]	Urea, egg white protein, pectin, Tartaric acid, Beeswax and gliserol [37]	Edible film for fruits [37]

3.2. Composite

The combination of biopolymers that used to synthesize edible films is called a composite film. In general, composite films combine proteins with polysaccharides or other polymers to enhance the mechanical properties of edible films. Additionally, combining multiple polymers can improve the film's barrier properties and physical characteristics [20]. Composite films are also considered multi-component materials that integrating hydrophobic and hydrophilic components. Hydrophobic components, such as lipids, help reduce moisture migration but have poor mechanical properties. Therefore, hydrophilic components like proteins and polysaccharides are added to improve the mechanical strength and surface structure of the film. Composite films can take the form of layered films or emulsions containing edible film-forming materials. Emulsion-based composite films provide better film structure than layered films, while layered films offer better drying time [13].

Recent innovations in edible film of composites illustrated in Table 3.

Table 3. Composite-based edible film

Type of composite	Characteristics	Additional materials	Application	Ref.
Sodium alginate - nanocellulose	The edible film degrades within 16 days, has a thickness of 0.0432 mm, a tensile strength of 45.90 MPa, and an elongation break at 19.10%.	Moringa oleifera leaf extract as an antioxidant	Edible oil packaging	[48]
Pectin – xanthan gum	Thickness of 0.07 mm – 0.11 mm, a tensile strength of 3.91 – 8.55 MPa, a moisture content of 24.30% – 26.69%, and a homogeneous surface with some visible particles.	Glycerol as plasticizer and grape essential oil as an antioxidant	Edible film food packaging	[49]
Starch – Carboxymethyl cellulose	Thickness of approximately 0.02 mm – 0.045 mm, a density of 0.0035 – 0.0152 g/mm^3, a semi-crystalline structure, and degrades within 15 days.	Glycerol as plasticizer	Packing salmon fillet	[50]
Gelatin – persian gum	Water content of 5.91% - 9.55%, a density of 1.25 - 1.35 gr/mm3, a thickness of 0.088 - 0.104 mm, a tensile strength of 1.38 - 2.17 MPa, and an elongation of 8.65% - 9.55%.	Glycerol as plasticizer	Food packaging	[51]
Chitosan – guar gum	Compact surface structure with few cracks, a thickness of 0.10 – 0.16 mm, a water content of 9.7% - 13.1%, a tensile strength of 35.74 – 69.42 MPa, and an elongation of 9.69% - 15.56%.	Roselle calyx extract as an antioxidant and ZnO – NPs as an antibacterial	Food packaging	[52]
Gelatin – hydroxypropyl methyl cellulose - sodium carboxymethyl cellulose	Thickness of 0.17 – 0.19 nm, water content of 6.95% - 11.71%, tensile strength of 4.37 MPa – 16.39 MPa, is in the form of a gel film with a crosslinking structure, and has thermal resistance at 320℃.	Glycerol as a plasticizer	Food packaging	[53]
Starch - gelatin	Thickness ranging from 0.06 – 0.086 mm, tensile strength ranging from 0.62 – 11.9 MPa, elongation ranging from 0.23% - 6.44%, and water vapor transmission rate of 11.41 – 20.03 gr/m^2.h.	Glycerol as a plasticizer	Food packaging	[54]
Collagen – sodium alginate	Flexible structure, it degrades for 20 days.	Glycerol chitosan, and pomegranate peel powder	Edible packaging material	[14]

3. Food Packaging Challenges

Food packaging plays a critical role in preserving quality, ensuring safety, extending shelf life, and enhancing consumer convenience. Despite its importance, the field faces several challenges related to production processes, evolving consumer expectations, environmental sustainability, and regulatory compliance [10].

Options for sustainable materials that close to commercial plastic standard are limited. Effective packaging materials must serve as barriers against moisture, light, oxygen, and microbial contamination to prevent spoilage. It is required to further understanding of food properties. In addition to functional requirements, packaging design must respond to growing consumer demand for convenience, aesthetics, and sustainability. This necessitates innovations such as transparent films that convey freshness and resealable, lightweight formats that reduce material usage. However, the adoption of such technologies remains limited by cost considerations, posing a barrier for some manufacturers [40].

Economic feasibility is a critical factor in the adoption of sustainable packaging solutions, as such alternatives are often associated with higher costs. These increased production costs are frequently reflected in retail pricing, potentially reducing the competitiveness of eco-friendly products in price-sensitive markets [41].

In addition to economic barriers, regulatory constraints play a pivotal role in shaping packaging innovation. It can push the commercialization of edible film from laboratory observations. For instance, the Indonesian government has no focused on specific requirement for biodegradability food packaging, then environmental concerns are not encouraged. It can delay the commercialization of new eco-friendly materials.

4. Conclusions

Various materials derived from nature have been investigated for their potential to make edible films and improve food packaging. Some of the biopolymers used are derived from polysaccharides, proteins, and composite forms. Edible films made from these biopolymers have their own characteristics including mechanical properties and physical properties. The addition of additives such as plasticizers, antioxidants, and antibacterials improve and support edible films that meet the standards. Further researches related to optimization and exploration of new material sources is essential to support the progress of the environmentally friendly food packaging sector.

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