Review Article

Gelatin, chitosan, and beeswax based edible packaging for food product: a review

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ABSTRACT

The widespread use of petroleum-based plastic packaging as food packaging has raised many concerns regarding the negative impact on the environment. The increase of public awareness on environmental problems and the importance of food safety has encouraged a lot of research regarding the development of environmentally friendly food packaging that is safe for food products, such as edible packaging. Gelatin, chitosan, and beeswax have attracted attention in edible packaging research due to their biodegradability and good film-forming characteristics. Chitosan and beeswax have also been reported to have antimicrobial properties that can improve the functional properties of edible packaging. Various studies have been carried out to obtain alternative packaging from a combination of these materials. This article reviews the potential application of edible packaging made from gelatin, chitosan, beeswax and their composites as packaging for food products.

Keywords: Edible packaging, Gelatin, Nanochitosan, Beeswax

1. INTRODUCTION

Packaging is an important factor in food product safety. Packaging functions as a protector of food products from external factors such as gas/air, water, chemicals, microorganisms and other foreign objects which can cause a decrease in product quality [1][2]. Ideal food packaging must have several key characteristics, such as protecting food products for a long time, being easy to use and carry, cheap, and not causing waste [3]. Plastic packaging made from petroleum is the closest type of packaging to these ideal properties. Apart from that, other advantages of plastic packaging include flexibility in shape, light in weight, good barrier properties, transparency, and mechanical properties [4][5].

Plastic packaging is still the most widely used packaging for food products [1]. Globally, the production of plastic packaging is estimated to reach 320 million tons per year

[6]. The massive use of petroleum-based plastics has raised concerns due to the environmental issues it causes. This is due to petroleum-based plastic packaging are difficult to decompose naturally and trigger the accumulation of carbon dioxide and methane gas in nature [7]. The environmental problems caused by single-use plastic packaging have led to the need in research on the development of environmentally friendly packaging.

The environmentally friendly packaging, such as edible packaging, has received a lot of attention in the food packaging industry. The differences between edible packaging and conventional plastic packaging are the constituent materials. Edible packaging is made from biopolymers such as proteins, polysaccharides, and lipids, while plastic packaging is made from synthetic polymers such as polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC). The advantages of using biopolymers compared to synthetic polymers is that biopolymers are safe for food products and extracted from renewable resources [8][9].

Gelatin, chitosan, and beeswax are among the types of materials that are widely used as ingredients for edible packaging. While chitosan and gelatin are used as materials for edible packaging because of their good film-forming abilities, beeswax is widely used as material for edible packaging because it has good moisture barrier capabilities and hydrophobic properties [10][11]. Several studies have also reported that chitosan and beeswax have antimicrobial properties which can improve the functional properties of packaging and prevent deterioration in the quality of the packaged food products [3][12]. This paper will discuss the use of gelatin, chitosan, beeswax, and their composites as edible packaging materials and their impact on the food.

2. EDIBLE PACKAGING

The design for developing edible packaging was initially inspired by fruit and vegetable skins [13]. The use of edible packaging as food packaging has been around for several centuries. China has historically known the technique of preserving citrus fruit by coating the surface with wax since the 12th century [14]. The making of edible films from boiled soybean juice which was then dried were also recorded in the early 15th century in Japan [15].

Edible packaging can be interpreted as packaging that has biodegradable properties, is safe for food products, and safe for human consumption [16][17]. Biodegradable packaging is defined as packaging that can be decomposed and destroyed through natural processes [18]. Apart from the high level of public concern about environmental issues caused by plastic waste, the high level of public awareness and the need for food safety has also encouraged the development of edible packaging in the food industry [17]. Edible packaging is also considered to have economic efficiency because it can maintain quality and extend the shelf life of food products [19]. Although edible packaging is generally not intended as a complete replacement for traditional packaging, the combination of the use of edible packaging with non-edible secondary packaging can increase the protection of the food product being packaged [20].

Based on the form and application, edible packaging can be grouped into two, namely edible coating and edible film. Edible coating is defined as packaging in the form of a thin layer that is generally formed and applied directly to the surface of the food product which functions as a coating, while edible film is packaging in the form of a thin sheet which is processed separately and is generally applied as packaging, pouches, bags, capsules and casings [16][20][21]. In general, there are two methods for making edible film, namely solution casting and extrusion. Solution casting is the most widely used method of making edible film. This method is carried out by evaporating the film solution at a certain temperature and time until a film is formed. The extrusion method is generally used to produce commercial plastic packaging [22]. This method is carried out by adding dry materials to the feeding zone which will then be compressed using a revolving screw and given heat treatment and formed into a film with an extruder [23]. The difference between edible film and other edible coatings is the method of application to food. Edible film is applied to food by wrapping it around the product, while edible coating can be applied directly to the food surface using several methods, such as dipping, spraying, brushing, panning, and fluidized bed processing method [24].

The dipping and spraying method are most often used in applying edible coating. The dipping method is carried out by immersing the product in an edible coating solution for some time, while the spraying method is carried out by changing the solution into droplets through a spraying technique so that the solution covers the surface of the food product [24]. The application of edible coatings and edible films to food products also has different main purposes. Edible film functions to protect food products from mass transfer (water vapor, gas and solutes) which aims to improve product quality and extend the storage period [25]. Edible coatings, on the other hand, function as carriers for additional ingredients such as anti-browning, antimicrobial and antioxidant agents, colorings, flavors, and seasonings, thereby aiming to increase the organoleptic value of the product [1][17].

3. EDIBLE PACKAGING MATERIALS

The main requirements for a material to be used in making edible packaging include that the material must be safe for consumption and can form good layers and films. Therefore, edible packaging is generally made from biopolymers, where the polymers are generally extracted from plant or animal parts [24][26]. Apart from being safe for consumption and having good film-forming capabilities, the use of biopolymers as basic materials for edible packaging has great potential for developing packaging with functional properties that can guarantee food safety [27][28].

Using biopolymers as ingredients for edible packaging has several advantages and disadvantages compared to using synthetic polymers. The advantages of using biopolymers for edible packaging include that biopolymer come from renewable resources, are safe for consumption, can be degraded naturally, have environmentally safe characteristics, are non-toxic, and have quite good mechanical properties, while the disadvantages of using biopolymers include the high production costs is still quite expensive compared to using synthetic polymers [29][30]. The use of biopolymers as ingredients for edible packaging also has a positive impact on the utilization of waste food products because some polymers are extracted from by-products from plantations, livestock, and fisheries such as bones. shell, to hump [31].

Based on the ingredients used, edible packaging is grouped into three categories, namely hydrocolloid (protein and polysaccharide), lipid, and composite (a combination of hydrocolloid and lipid). Each of these materials has several unique properties as materials for making edible packaging. The selection of materials that will be used in edible packaging usually depends on the type of food that will be packaged, because each product has its own need of protection and there are differences in the properties of each polymer [32][33]. Polysaccharides generally have good oxygen barrier properties but poor moisture barrier properties [18]. Protein has good mechanical strength and promising nutritional value. Lipids have low water vapor permeability, hydrophobicity, and good moisture barrier properties but have poor mechanical strength and quite high oxygen permeability [34]. In contrast to the hydrophobic nature of lipids, polysaccharides and proteins have hydrophilic properties, causing low moisture resistance and barrier properties [16].

Apart from being composed of biopolymers, edible packaging also generally has the addition of plasticizers. The function of this plasticizer is to maintain the integrity of film and coating packaging which is still fragile due to extensive interactions between polymer chains [31]. Edible packaging can also include the addition of active compounds. The addition of this active compound can function to increase the shelf life, quality and safety of food by inhibiting oxidation and the growth of microorganisms that cause food spoilage [35]. The addition of active compounds to edible packaging compared to food products directly is considered more effective [36]. This is because the addition of this active compound is able to maintain the activity of the active compound for a longer time due to its periodic release on the surface of the product. The effect of applying edible packaging made from gelatin, chitosan, and beeswax can be seen in Table 2.

3.1 Gelatin

Gelatin is a natural water-soluble protein obtained through the hydrolysis process of the fibrous protein collagen which is generally found in skin, bones and white fiber tissue and tendons of animals through an acid or alkaline process [37][38]. Gelatin can be produced from mammals, fish and insects [39]. Gelatin which is commonly commercialized generally comes from pork by-products and has been popularly produced since the 1930s [40]. Apart from being obtained from mammals, gelatin can also be obtained from marine by-products. The development of marine-based gelatin could also be an alternative for several religious groups, such as Jews and Muslims, who cannot consume pork-based products. However, one of the weaknesses of gelatin derived from marine by-products is that it has less stable rheological properties compared to gelatin obtained from mammalian sources [41].

Gelatin has a wide range of uses, from the food industry, pharmaceuticals, photography, to packaging [22]. The properties of gelatin are generally influenced by the characteristics of the collagen used and the extraction process [40]. Based on the production method used, gelatin can be classified into two types, namely type A and type B. Type A gelatin is gelatin that has an isoelectronic point at pH 8-9 obtained through an acid process, while type B gelatin is gelatin that has an isoelectronic point. at pH 4-5 obtained through an alkaline process [38][42].

Gelatin has the ability to form a physical gel. This gel-forming ability is obtained from the activity of rearranging the protein structure, namely breaking down the triple helix structure of collagen into single-chain molecules [40]. The availability of gelatin and its good mechanical qualities made gelatin frequently used as edible packaging material [23]. In general, making gelatin-based edible packaging has advantages in terms of biodegradability, polymerization, hygroscopic, flexibility, strong gas barrier properties, and low cost, while the disadvantages are its water vapor permeability properties and poor mechanical properties, which limits its application as food packaging [22][43]. The more gelatin concentration added to edible packaging, the greater the film thickness and improved mechanical properties, but will worsen water vapor permeability [44]. The advantages and disadvantages of using gelatin as a basic packaging material edible can be seen in Table 1.

Gelatin has been used together with chitosan as an edible coating ingredient to reduce color deterioration in meat [40]. The combination of gelatin and chitosan in edible packaging is also reported to exhibit antioxidant properties [21]. The addition of essential oils to gelatin and chitosan-based edible packaging has also been proven to have good antimicrobial activity and can extend the shelf life of fish fillets [45]. The addition of additives and agents in edible packaging can help improve the packaging properties. The development of active packaging also received a lot of attention because the incorporated of specific component in the packaging polymers has result in the enhance of physical, chemical, or biological properties and change the interaction within the package, product, and/or space within the food packaging [8]. The effect of applying gelatin-based edible packaging on the food products it is packaged in can be seen in Table 2.

3.2 Chitosan

Chitosan is a compound derived from the deacetylation process of chitin through a hydrolysis process using strong acids or bases, which is often contained in the exoskeletons of marine animals such as shrimp and crabs [46]. Although in general chitosan is mostly obtained from the exoskeletons of aquatic crustaceans, chitosan can also be obtained from groups of insects and fungi [47]. The abundance of these resources makes chitin and chitosan the biopolymers that are most widely available in nature after cellulose. Chemically, chitosan is composed of the monomer (1-4)-linked 2-amino-2-deoxy- β-D-glucose [3]. Chitosan has a solid phase in semi-crystalline form and is generally soluble in organic acids such as acetic, citric, formic, lactic, malic, or tartaric [48].

The process of producing chitosan from chitin goes through three main stages, namely deproteination, demineralization, and deacetylation. The purpose of demineralization is to remove minerals contained in raw materials. Generally, the material used in this stage is acid. Deproteinization is carried out to remove protein residues that are still present in the raw material, the materials used are generally alkaline. The conversion of chitin to chitosan occurs in the deacetylation process where in this process the group ($COCH_3$) is released from the chitin structure which can be carried out through alkaline or enzymatic processes [49].

Chitosan has very wide range of uses in the biomedical, pharmaceutical, and food sectors. The great potential for the use of chitosan is because chitosan has non-antigenic, non-toxic, biodegradable, biocompatible, and biofunctional properties, with film-forming capabilities and antimicrobial properties [50]. The functional properties of chitosan are caused by the presence of amine groups [3]. The good film-forming properties of chitosan make it very potential as a material for making edible packaging. Edible packaging made from chitosan is also reported to show good mechanical properties, has good strength and toughness, does not tear easily, and has antimicrobial properties [43]. Packaging made from chitosan is reported to have good mechanical, permeability to CO_2 and O_2, and antimicrobial properties [48].

The antimicrobial activity of chitosan is reported to be effective against yeast, mold and bacteria [88]. The antimicrobial effectiveness of chitosan as a food packaging material can be influenced by various parameters, such as the degree of deacetylation, concentration, exposure period, molecular weight, pH, temperature, and type of test organism [50]. According to Riaz [51], chitosan is able to prevent the growth of various types of fungi and bacteria and is generally very good at preventing the growth of gram-positive bacteria. The antimicrobial properties of chitosan are caused by the interaction between the amino group ($-NH_3$) in chitosan which is positively charged with a negatively charged carboxylic group (-COO-) in the bacterial cell wall [52]. The interaction between these two charged ions will cause damage to microorganisms, resulting in the inhibition of microbial polygalacturonase secretion [53]. Another opinion states that the antimicrobial mechanism of action of chitosan is due to chitosan's ability to form a protective layer such as cellophane on the surface of food products so that it is able to prevent bacterial contamination and is able to inhibit gas exchange between food products and the environment which can prevent bacterial growth [54].

Currently, the use of chitosan in the packaging industry is being developed in nano form. Nanochitosan is a form of physical modification by reducing the size of chitosan particles to nano size. The making of nanochitosan can be done using various methods, including the method of beads-mill and ionic gelation [55][56]. Methods for producing nanochitosan vary, depending on the desired characteristics, such as particle size, chemical and thermal stability of the particles, kinetic profile, and residual toxicity [56]. The ionic gelation method is the method most widely used in making nanochitosan because the process is relatively simple, namely by adding sodium tripolyphosphate (Na TPP) solution to the chitosan solution and then homogenizing it by constant stirring [55]. The utilization of nanochitosan in making edible films is generally used as an antimicrobial agent and filler. Nano chitosan also can be produced through beads milling process [89].

Reducing the size of chitosan particles to nanoscale as a material *nanofiller* Packaging is believed to be able to increase the properties of the packaging surface area by creating an interfacial area between the nanofiller with a biopolymer matrix. The large distance between these interfacial areas can facilitate the movement of molecules so that it can improve the thermal, barrier, and mechanical characteristics of the packaging [57]. The effect of applying edible packaging made from chitosan can be seen in Table 2.

3.3 Beeswax

Beeswax is generally produced by worker honey bee species *Apis mellifera* and *Apis cerana* [12]. Beeswax is a complex chemical mixture of free fatty acids, hydrocarbons, free fatty alcohols, and monoesters secreted from the beeswax glands [58][59]. The use of beeswax as a coating has been widely applied in the food industry. This is because beeswax has the characteristics of being waterproof, moisture resistant, antioxidant properties, and able to release active ingredients [60]. As an edible packaging material, beeswax is also reported to have good water vapor permeability properties

The hydrophobic nature of natural lipids makes edible film packaging made from beeswax have good water vapor permeability [18]. Beeswax is also reported to have antimicrobial properties. The antimicrobial effect of beeswax is caused by the presence of propolis, which is a sticky substance that bees use to cover holes and cracks in the nest [61]. This propolis is obtained from the resin that bees obtain when collecting pollen from plants [62]. The advantage of beeswax as a raw material is because it is a lipid compound *food grade*, its availability throughout the year, its utilization is still limited, and the price is relatively cheap. Beeswax has anti-inflammatory, wound healing, antioxidant, and antimicrobial activities [12]. Beeswax is also considered suitable as a packaging material *edible* because it has hydrophobic properties that function to inhibit water vapor. However, edible packaging made from beeswax is reported to have poor optical properties and fragile [25][80].

The addition of beeswax to the chitosan edible coating was reported to be able to inhibit the rate of respiration and transpiration, as well as suppress weight loss in guava fruit [63]. The combination of beeswax and chitosan is also able to maintain the firmness and skin color of sapodilla fruit [64]. Edible film beeswax able to extend the shelf life of Naem fermented sausage without major changes in color change, low lipid oxidation, and is able to suppress microbial growth for up to 15 days [65]. The effect of applying beeswax to food products can be seen in Table 2.

3.4 Composite Edible Films and Coatings

Currently, the development of edible packaging is starting to focus on composite films or multi-component films to take advantage of the superior properties of individual materials and minimize their disadvantages [25]. This is because the use of just one type of biopolymer as a material for making edible packaging can generally produce several unfavorable packaging properties [27]. For example, edible films composed of chitosan alone generally have poor mechanical and water vapor barrier properties, and edible films composed of gelatin alone generally have poor mechanical and thermal properties [66][67]. Combining two or more different polymers as materials for making edible packaging can improve the properties of the resulting packaging [25]. The combination of two different polymers is called a composite [68].

The effect of combining two different types of polymers has been proven to be able to improve several properties of edible packaging. Edible packaging based on gelatin alone is reported to have almost no antibacterial effect [69]. However, when gelatin-based edible packaging is combined with other substances such as chitosan, essential oils, and silver nanoparticles, the antimicrobial effect of edible packaging can increase [38]. The addition of gelatin to chitosan edible films shows an increase in firmness and carbon dioxide barrier properties [70]. Gelatin-chitosan edible films show a relatively flat and homogeneous surface, and have excellent physical properties [71][72]. The addition of chitosan to edible coating beeswax shows an increase in texture, retention of color, visual appearance, and antimicrobial activity [64]. The addition of beeswax to chitosan edible film can reduce water vapor permeability [64].

5. CONCLUSION

Currently, the development of edible packaging is driven by the great demand for environmentally friendly and safe packaging for food products. Gelatin, chitosan and beeswax are natural ingredients that have great potential as the materials for producing edible packaging because they are safe to consumed and come from renewable resources. The good mechanical properties of gelatin, the antimicrobial ability of chitosan, and the good water vapor properties of beeswax are good characteristics in making edible packaging. The combination of these materials with additional materials is expected to produce composite edible packaging with the best protection for food products.

Table 1. Advantages and Disadvantages of Gelatin, Chitosan, and Beeswax as Edible Packaging Materials

Material	Advantage	Disadvantage
Gelatin	Good film-forming ability [22] Water-binding ability and emulsifying tendency [73]	Fragile under specific drying condition [74] Weak water vapor barrier property [76]
Chitosan	Good antibacterial properties [75] Good gas barrier properties [77] Produce transparent film [43]	Poor flexibility and extensibility [78] Possibility to cause allergies [64]
Beeswax	Good hydrophobicity [79] Good water vapor permeability [18]	Poor optical properties [80] Fragile, lack of homogeneity, and presence of holes and crack on coating surface [25]
Gelatin-Chitosan	Good optical properties [27] Good surface morphology dan good inhibitory effect (>80%) against spoilage bacteria growth [72]	Poor water vapor permeability [67][81]

Table 2. Effect of Gelatin, Chitosan, and Beeswax Based Edible Packaging on Food

Film/Coating Biopolymer-Based Material	Packaged Food and Storage Condition	Reported Effects	Reference
Beeswax and Chitosan Coating	Crystal Guava (*Psidium guajava L. Var. Crystals*)	Beeswax coating (4%) gives the best effect on fruit quality based on weight loss, texture, color, taste, and aroma parameter.	[63]
Gelatin-Beeswax and Gelatin-Chitosan-Nanochitin	Jelly Candy (*Kappaphycus alvarezii*)	Gelatin-Chitosan-Nanochitin gives the best effect on the candy quality based on microbial activity, appearance and aroma properties	[82]
Chitosan and Beeswax Coating	Strawberry	Combination of Chitosan 2% and Beeswax 4% gives the best	[83]

		effect on fruit quality based on weight loss, water content, and microbial activity.	
Beeswax Film	Naem fermented sausage	Low lipid oxidation, few color changes, fewer microbial growth	[65]
Chitosan Film	Sea bream (*Sparus aurata*) fillets vacym packed at 4 ± 1 ℃ for 20 days	Inhibited the spoilage bacteria Good quality indication during storage especially the TVB-N value	[85]
Gelatin-Propolis extract Film	Rainbow trout (*Oncorhynchus mykiss*) fillets stored at 4 ± 1℃ for 10 days	The addition of garlic peel extract enhanced in antimicrobial and antioxidant properties, good sensory results	[85]
Chitosan-Gelatin Film	Alaskan Pollock Sausages	Inhibited microbial growth in the sausages during storage (until 42 days)	[86]
Chitosan-Beeswax Coating	Sapodilla (*Achras zapota*) fruit	Slowed down microbial population growth over the period of 17 days, slowed down weight loss, retain firmness and skin colour	[87]
Chitosan-beeswax coating	Strawberry	Decreasing the senescence and weight loss, good protective effect of the overall fruit quality	[64]

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Author have declared that no competing interest exist.

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