

# ***Progress in Research on Materials, Preparation Processes, and Applications of Degradable Food Preservation Films***

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**Abstract:** With the improvement of living standards, the application of degradable materials in the food industry has garnered widespread attention as these materials address the dual needs of environmental protection and food preservation. This paper aims to explore degradable food preservation films to mitigate the environmental impact of food preservation and promote green and sustainable development in the food industry. The properties, classifications, and application scenarios of degradable food materials are summarized, and the preparation processes of degradable food preservation films are introduced. Additionally, the application of degradable food materials in food preservation is discussed in detail. While considering both environmental protection and preservation effectiveness, this paper also analyzes potential issues in using degradable materials for food preservation film preparation and proposes future directions for degradable materials in food preservation, providing valuable insights for the development of the food preservation and environmental protection industries.

**Keywords:** Degradable materials, Food preservation film, Preparation process, Research progress

## **1. Introduction**

The improvement of living standards has led to increasing public attention on food health[1], and green materials have become a popular research topic. Degradable food materials, as environmentally friendly options, exhibit characteristics of biodegradability and resource renewability, and are non-toxic and harmless to food itself, making them highly suitable for manufacturing food preservation films. Deng Weiling proposed a biodegradable packaging material, bioORMOCER, for food packaging[2], which, due to its biodegradability, antibacterial properties, and high barrier performance, can effectively reduce environmental pollution and CO<sub>2</sub> emissions[3]. However, this research does not address the application of various food-grade materials within degradable materials. In his study on the application of degradable materials in food packaging design, Fan Meng explored the environmental benefits of degradable food materials but did not cover properties such as antibacterial activity, gas barrier, and moisture resistance, which are beneficial for food preservation[4]. At present, research specifically focused on multifunctional degradable food preservation materials remains limited. Wu Xianghan et al. studied antibacterial functional degradable preservation packaging, which can slow the reduction in banana pulp firmness, maintain pulp texture, and extend storage time[5], but did not explore its applicability across various types of

food. This paper examines the properties and applications of different degradable food-grade materials and the superior properties of degradable food preservation films to provide insights for the future development of degradable food preservation films.

## **2. Progress in Research on the Preparation Materials, Processes, and Applications of Degradable Food Preservation Films**

### **2.1. Starch-Based Materials**

Starch consists of two types: amylose and amylopectin. Amylose has an unbranched helical structure, while amylopectin consists of 24–30 glucose residues linked end-to-end by  $\alpha$ -1,4-glycosidic bonds with branches connected by  $\alpha$ -1,6-glycosidic bonds. Amylose contains hundreds of glucose units, while amylopectin contains thousands. Amylose accounts for 20%–26% of natural starch and is water-soluble, whereas the remainder is amylopectin, which has lower solubility[6]. Different sources of starch vary in amylose content, gelatinization characteristics, and the rheological properties of starch gels[7]. Under certain conditions, starch is prone to gelatinization and retrogradation, with swelling capabilities and several chemical properties similar to glucose.

Starch-based materials are innovative, modified, biodegradable, and environmentally friendly materials, primarily blended with plasticizers, cross-linking agents, and polymers like polyvinyl chloride (PVC), polyethylene (PE), and polyvinylidene chloride (PVDC) to produce biodegradable films[8]. Starch-based degradable films are fully degradable and do not cause environmental pollution. They are lighter than traditional plastic and serve as a novel type of packaging film. Additionally, combining starch-based films with antibacterial agents or other composite materials can enhance and modify their antibacterial properties. When applied as a coating for fruits and vegetables, the film forms a protective layer on the surface, providing a barrier against oxygen, water, and microorganisms. This helps inhibit the physiological processes of the produce, protect against microbial infection, and slow down aging, thereby extending shelf life[9]. However, starch-based degradable films also have certain disadvantages, including poor heat and water resistance. They tend to lose their original mechanical properties in humid environments and may deform at high temperatures, limiting their applications in specific conditions.

### **2.2. Polysaccharide Materials**

Currently, common polysaccharides used in fruit preservation films include sodium alginate, chitosan, carrageenan, and pullulan. Chitosan is derived from the deacetylation of natural polysaccharide chitin and exhibits properties such as biodegradability, biocompatibility, and good film-forming ability[10]. Sodium alginate, a natural polyanionic polysaccharide obtained from brown algae cell walls, has the stability, solubility, viscosity, and safety required for pharmaceutical excipients[11]. Sodium alginate can be made into various gel-based foods, maintaining a stable gel form without liquid separation or shrinkage, making it suitable for frozen and imitation foods. Carrageenan, a sulfated anionic polysaccharide, enhances protein functionality and can partially prevent protein aggregation, thus improving protein functionality. It is also commonly used as a stabilizer to control the texture of dairy fluids[12]. The environmental friendliness of polysaccharides primarily lies in their biodegradability; they are renewable, biodegradable, highly adsorptive, and possess antibacterial and antioxidant properties. These characteristics make polysaccharides an environmentally friendly material, helping reduce environmental pollution and promote ecological balance.

In bio-based packaging materials such as polysaccharides, incorporating antibacterial agents capable of inhibiting or killing pathogenic and spoilage microorganisms responsible for food contamination is a significant research focus in active food packaging technology. However, due to the poor stability of polysaccharides, natural polysaccharides often require chemical or physical

modification based on specific applications to optimize their functional properties and enhance their use in fruit preservation films. Common modification methods for polysaccharide-based preservation films include homogenization of the film matrix with antibacterial agents, solubilization treatment for hydrophobic antibacterial agents, and immobilization treatment for self-aggregating antibacterial agents. Additionally, combining trehalose and pullulan to prepare composite films can benefit from the stabilizing effect of trehalose on active substances and the film-forming ability of pullulan[13].

### 2.3. Cellulose-Based Materials

Cellulose is composed of D-pyran glucose units (anhydroglucose) and is classified into two types: water-soluble dietary fiber and insoluble dietary fiber. Its industrial production primarily involves cooking plant materials with sulfite or alkaline solutions to remove lignin, while laboratory methods use acid to dissolve pulp, removing lignin and hemicellulose. Cellulose can be chemically or biologically converted into bioethanol and various chemicals such as glucose, hydroxymethylfurfural, levulinic acid, and levulinic acid esters. Due to its abundant sources and broad application value, cellulose is considered an important and promising resource[14]. Common modification methods for cellulose are categorized into physical, chemical, and biological modifications, with chemical modification being the most common. Chemical modifications include oxidation, esterification, etherification, and grafting[15].

Cellulose has excellent biodegradability and good processing properties, making it widely used as a raw material for preparing degradable bio-based composite films, particularly for food storage preservation films. Cellulose can also be combined with materials such as tea polyphenols and polyethylene glycol to create antibacterial composite films that effectively prevent food spoilage. Hemicellulose films, known for their gas barrier properties, can effectively prevent packaged items from coming into contact with oxygen in the air, thereby avoiding oxidative spoilage, and are widely used in making food preservation films[16].

### 2.4. Polylactic Acid (PLA) Materials

Polylactic acid (PLA) is a new bio-based and renewable degradable material made from starch extracted from renewable plant resources such as corn and cassava. The starch is saccharified to produce glucose, which is then fermented with specific strains to obtain high-purity lactic acid, followed by chemical synthesis to produce PLA with a specific molecular weight. The main methods of PLA preparation include direct polycondensation, a two-step process, and reactive extrusion for high molecular weight PLA, with direct polycondensation of lactic acid being the most developed method. Cellulose, extracted from plants like cottonseed husks and corn stalks, contributes to a pollution-free production process and provides benefits such as high strength and low density, enabling the preparation of 100% degradable PLA-based composites, making PLA an ideal green polymer material[17].

Common PLA preservation films include PLA breathable films, PLA antibacterial films, and PLA degradable films. Using a non-solvent phase separation method, a series of PLA breathable films with varying N-methylpyrrolidone (NMP) content can be prepared. Compared to conventional preservation films, PLA breathable films can extend the shelf life of fruits and vegetables by 2–3 days and meat products by 3 days. By blending PLA with chitosan, tea polyphenols, magnesium oxide, and silver as antibacterial agents, a series of PLA antibacterial films can be prepared. Compared to conventional preservation films, PLA antibacterial films can generally extend the shelf life by 5 days. By blending PLA with starch, polyethylene glycol, and sodium carboxymethyl cellulose in different proportions and combinations, four types of PLA composite films can be produced, each exhibiting a higher degradation rate than pure PLA films[18].

### 3. Preparation Process of Degradable Food Preservation Films

#### 3.1. Overview of Preparation Process

The production of preservation films mainly includes the following steps:

- **Ingredient Preparation and Mixing:** According to production requirements, various raw materials (including suitable degradable materials such as chitosan, modified starch, corn fiber, etc.) and polyvinyl alcohol are weighed in specific proportions. The raw materials are placed into a mixer and blended thoroughly to ensure an accurate composition ratio.
- **Heating, Melting, and Extrusion:** The blended raw materials are heated until they reach a molten state, giving them the required fluidity. The molten materials are then extruded through a screw mechanism and passed through a mold to form a film.
- **Blowing and Stretching:** Using a blowing device, the extruded film is inflated to form a bubble, increasing the film's thickness and stability. It is then longitudinally stretched to enhance its length, width, and mechanical properties.
- **Cooling and Cutting:** The stretched film is cooled and set into a stable shape using a cooling device. It is then cut into specific lengths to produce preservation films of standardized dimensions.

Due to the low heat resistance of many food-grade materials, strict control of heating temperature and extrusion pressure is required during the production process to prevent material degradation. Cooling and solidification are crucial steps in the film production process. Typically, the film is rapidly cooled and solidified using a cooling roller, where temperature and speed must be precisely controlled. Alternatively, a composite film solution can be placed in an ultrasonic cleaner for degassing, poured onto a flat glass surface for even coating, left to cool, and then placed in a thermostatic oven for several hours to form the film. Once formed, the film is peeled off and set aside for use[19].

The methods for preparing degradable food preservation films include calendering, casting, solution, and blending.

Calendering is a common method for producing food preservation films. The specific process involves heating the polymer material to a certain temperature, then using a calendering machine to press it into a film of specified thickness. This method is widely used due to its simplicity and high production efficiency. However, because it requires high pressure and high temperatures, it places significant demands on equipment, and the waste generated is difficult to recycle, potentially impacting the environment.

The solution method involves mixing the polymer material with an appropriate amount of solvent, stirring the mixture at a specific temperature to create a homogeneous solution. Once the solution is uniform, parameters such as temperature and viscosity are adjusted so that the mixture forms a gel film in the mold, followed by curing and solvent removal, ultimately yielding a food preservation film. This method is relatively flexible, allowing the adjustment of parameters such as the type and ratio of solvents to meet specific needs.

Adding certain substances to the solution can enhance the performance of the preservation film. For example, incorporating a suitable amount of natamycin in the solution can help control post-harvest diseases in fruits and vegetables. Natamycin is a natural antimicrobial agent that specifically inhibits the growth and reproduction of fungi such as yeast and *Aspergillus niger*, requiring only a small amount to be effective. Combining multiple antimicrobial agents can increase the film's antibacterial properties and expand its range of antimicrobial effects. By adding varying amounts of glycerol, polyvinyl alcohol, and nano-TiO<sub>2</sub>, the mechanical properties of the preservation film can be adjusted to provide excellent tensile strength and elongation at break, allowing customization based on the characteristics of different food materials[20].

## **4. Application Scope of Degradable Food Preservation Films**

### **4.1. Preservation of Vegetables and Fruits**

Degradable food preservation films are not only easy to degrade but also inhibit the respiration of vegetables, helping retain moisture and better slow down the decline in fruit firmness, thus maintaining the texture and achieving preservation effects for vegetables. They are widely used in the food industry.

Microorganisms are a primary cause of spoilage in fruits and vegetables. While chemically synthesized fungicides can inhibit bacterial growth to some extent, they may cause resistance and pose health risks to humans. Studies have shown that, under the same preservation time and conditions, bananas stored in degradable preservation films exhibit fewer spots and less browning of the peel compared to those stored in conventional commercial preservation bags. This indicates that degradable preservation films have a certain inhibitory effect on the growth of pathogens. Thus, developing more antibacterial degradable food preservation films is a current trend[21].

### **4.2. Meat and Seafood**

Meat products are not only delicious but also nutritionally rich, popular with consumers for their high protein and quality fat content. However, these characteristics also make them an ideal medium for microbial growth. Packaging conditions and the composition of gases around meat significantly impact the structure of spoilage microbial communities; for example, *Pseudomonas*, *Acinetobacter*, and *Moraxella* species are considered the dominant spoilage bacteria under aerobic storage conditions at different temperatures [22]. Using degradable food preservation films can effectively isolate external microorganisms and extend the shelf life of meat products. Incorporating antibacterial materials into these films can further prolong the shelf life of meat. In fresh meat, myoglobin is oxidized in the presence of oxygen to form oxymyoglobin, which gives the meat a bright red color. During canning sterilization and heating, oxymyoglobin undergoes protein denaturation, and the iron in the heme of myoglobin changes from ferrous to ferric state at temperatures above 75°C, resulting in the formation of metmyoglobin with a grayish-brown color [23]. Degradable food preservation films can effectively prevent meat from coming into contact with air, helping to maintain the color of meat products.

## **5. Conclusion**

Materials suitable for preparing degradable food preservation films include starch-based materials, polysaccharides, cellulose-based materials, and polylactic acid (PLA) materials. These materials are fully degradable and environmentally friendly. By adding certain modifiers, films with enhanced properties, such as high gas barrier films or antibacterial films, can be produced. The preparation process for preservation films includes four main steps: ingredient preparation and mixing, heating and melting followed by extrusion, film blowing and stretching, and cooling and cutting. Since food materials have limited heat resistance and low compression resistance, careful control of heating temperature and extrusion pressure is required during production to avoid film failure. Degradable food preservation films are already widely used in the food industry, primarily for packaging perishable items like fruits, vegetables, meat, and seafood. These films provide excellent preservation effects, extending the shelf life of these foods. Degradable food preservation films are a current research focus and development trend, with more multifunctional degradable films expected to be developed in the future. These innovations will better protect food health and environmental safety, and their applications are likely to expand across more fields.

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