Starch Based Edible Films and Coatings

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Abstract
While packaging is effective in reducing food losses, the increased use of petroleum-based packaging materials negatively impacts the environment. Edible films and coatings are considered a significant alternative in addressing this issue. Starch, due to its abundant presence in nature, biodegradable nature, and cost-effectiveness, is a widely studied biopolymer. However, its mechanical properties and sensitivity to moisture limit its use as a food packaging material. This article compiles the characteristics, production, and recent studies on starch-based edible films and coatings.
Keywords: Edible film and coating, food packaging, starch.

Nişasta Bazlı Yenilebilir Film ve Kaplamalar

Öz
Ambalaj, oluşacak gıda kayıplarının azaltılmasında etkili olurken artan petrol bazlı ambalaj materyalleri çevreyi olumsuz yönde etkilemektedir. Yenilebilir film ve kaplamalar mevcut sorunun çözümünde önemli bir alternatif olarak öngörülmektedir. Nişastanın doğada bol bulunması, biyobozunur özelliği ve ekonomik olması nişastayı en çok çalışılan biyopolimer kılmaktadır. Buna rağmen sahip olduğu mekanik özellikler ve nem duyarlılığı gıda ambalajı olarak kullanımını sınırlamaktadır. Bu makalede, nişasta bazlı yenilebilir film ve kaplamaların özellikleri, üretimleri ve son yıllarda yapılan çalışmalar derlenmiştir.
Anahtar kelimeler: Yenilebilir film ve kaplama, gıda ambalajı, nişasta.

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Introduction

Packaging is a communication tool that prevents biological, microbiological, physical, and chemical deterioration in foods, thereby extending the shelf life of foods, facilitating their use, and providing consumers with essential information about the food (Üçüncü, 2011). In the production of food packaging, plastic, a petroleum-based polymer, is widely used due to its economic benefits and ease of use (Matthews et al., 2021). Approximately 36% of plastic, widely used in various industries, is employed as packaging material, with 86% of it ending up as uncontrolled waste (UNEP, 2022). Environmental pollution caused by the slow decomposition of plastic in nature has been increasing (Dissanayake et al., 2022). Additionally, microplastics resulting from plastic breakdown enter the food chain, leading to various health issues (Zhu et al., 2024). Consequently, there is an increasing interest in edible and biodegradable environmentally friendly materials in recent years with research focusing in that direction (Mohamed et al., 2020).

Starch, a polysaccharide-type polymer, is abundantly found in nature. It is also cost-effective, tasteless, odorless, and biologically safe. Due to these characteristics, starch plays a promising role in replacing plastic (Almasi et al., 2010). This study takes over the chemical structure and properties of starch, as well as the characteristics of edible films derived from starch.

Chemical Structure and Properties of Starch

Starch is a carbohydrate synthesized by plants through photosynthesis to store excess glucose. It is a homopolysaccharide composed of granules. Starch granules, commonly found in seeds, roots, and tubers of plants, exhibit various shapes and sizes, such as spherical, polygonal, oval, or disk-like (Shannon et al., 2009). These granules consist of two biopolymers, namely amylose and amylopectin, arranged in successive order. The glucose units in the amylose polymer are mostly linear with α-(1-4) linkages and minimal branching, whereas in the amylopectin polymer, glucose units are branched network with α-(1-4) and α-(1-6) linkages (Bello-Perez & Agama-Acevedo, 2018). The proportions of these polymers within starch granules vary, influencing the gelatinization, thermal processing, retrogradation, and rheological properties of starch (Karakelle et al., 2020). The amounts of amylose and amylopectin obtained from plants vary, and based on the amylose/amylopectin ratio, starch is categorized as normal, waxy, or resistant starch (Clerici et al., 2019) (Table 1).

Table 1. Amylose and amylopectin contents of starches

Starch	Amylose (%)	Amylopectin (%)
Normal	18-35	70-82
Waxy	<8	92-100
Resistant	≥50	≤50

The detailed process of starch production dates back to around 184 B.C. According to a document written by the Roman Cato, starch was obtained by soaking grains in water for 10 days, followed by pressing and filtering the mixture. The precipitate in the filtrate was then washed, and the resulting sediment was dried in the sun (Shannon et al., 2009). This method sheds light on the traditional extraction method used today. Additionally, the recovery of starch is possible through ultrasonically assisted and supercritical extraction methods. Furthermore, the alkali and acid solutions used in extraction methods contribute to enhancing the purity of the obtained starch (Palacios-Fonseca et al., 2013).

Starch finds applications in various industries such as food, paper, chemistry, and packaging. In the food industry, it is extensively used as a fundamental component or additive in the production and preservation of products. The involvement of starch in the packaging sector is facilitated by edible films and coatings (Vilpoux & Junior, 2022).

Starch-Based Films

Preparation of Starch Films

The production of starch-based films utilizes the gelatinization property of starch, which involves the swelling of starch granules through water absorption under high temperatures. There are two methods for the gelatinization of starch granules: one involves applying heat in the presence of high humidity, while the other is achieved through extrusion under low humidity conditions. Extrusion is a shaping process conducted under high temperature and pressure. The properties of the films obtained from both processes vary depending factors such as the starch composition, plasticizer used in the film solution, polymer, and other additives (Lumdubwong, 2019).

The extrusion method for obtaining starch-based films is a less preferred technique. In recent years, high hydrostatic pressure has been applied as an alternative to heat treatment. Films prepared using high hydrostatic pressure have shown improved mechanical properties, lower water vapor permeability, and enhanced thermal stability (Kim et al., 2018).

Starch Film Properties

Starch is a non-toxic polymer with the ability to form good films. The properties of these films are influenced by the source of plan tor fruit from which the starch is derived (Pajak et al., 2019). Starch-based films are transparent, odorless, tasteless, and exhibit good oxygen barrier properties (Cheng et al., 2022). However, they have inadequate moisture barrier and weak mechanical properties. These unfavorable characteristics in films made from pure starch limit their use as packaging material (Nordin et al., 2020). To address these limitations, plasticizers need to be used and/or different polymer combinations need to be created (Li et al., 2024). Starch films prepared with plasticizers such as glycerol and sorbitol show an increase in water solubility, water vapor permeability, and elongation percentage, whereas the inclusion of mannitol and sorbitol reduces water vapor permeability (Ballesteros-Martinez et al., 2020; Ma et al., 2023). Moreover, films prepared with a combination of glycerol, thymol, and corn starch exhibit a decrease in water vapor permeability and tensile strength, and an increase in elongation at break. Additionally, thymol added to the film combination imparts ultraviolet (UV) light barrier properties (Nordin et al., 2020).

The addition of plant and fruit extracts as fillers to the prepared films improves their mechanical and physical properties (Table 2). The phenolic compounds found in these extracts provide the films with antioxidant and antimicrobial activity (Ali et al., 2019; Menzel et al., 2019). Furthermore, anthocyanins present in some plant extracts add smart packaging features to the films by causing color changes at different pH ranges. This enables the visual assessment of potential quality losses and spoilage in food products (Cheng et al., 2022).

In films created with the addition of various extracts, their properties vary depending on the characteristics of the extract. For example, extracts obtained from plants, fruits, and microalgae confer antioxidant properties to the films. Essential oils, owing to their hydrophobic nature, impart antibacterial properties by disrupting the bacterial cell membrane (Carissimi et al., 2018; Shen et al., 2022).

Table 2. Effect of some extracts and oils used on starch-based films

Type of extract or essential oil	**Components forming the films**	**Effects**	**References**
Basil leaf extract	Polyvinyl alcohol (PVA) + starch + %15 basil extract	Antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus* Low tensile strength	Varghese et al., 2023
Portulaca oleracea extract (POE)	Chitosan + wheat and pea starch (1:1) + glycerol + POE	Increased water vapor permeability Low tensile strength, high elongation at break High antioxidant property	Fan et al., 2023
Rosemary leaf extract	Cassava starch + glycerol + rosemary extract	UV light barrier Antioxidant properties	Piñeros-Hernandez et al., 2017
Rose petal extract	Buckwheat starch + citric acid + rose petal extract	Antioxidant properties UV light barrier Low tensile strength, high elongation at break pH sensitivity	Thakur et al., 2023
Pomegranate peel extract	Taro starch + casein + glycerol + pomegranate peel extract	Antimicrobial activity against *E.coli* and *S.aureus* High thermal stability	More et al., 2022
Honey bee extracts	Starch + glycerol + honey bee extract	Low tensile strength Better structure and mechanical properties in bee bread and propolis extracts	Pajak et al., 2022
Red cabbage extract	Red cabbage extract (RCE) + sweet whey (SW) + glycerol + starch	T2 (64,18% RCE+4,36% SW), T7(50% RCE + 0% SW), T10 (50% RCE +15 SW) films showed higher mechanical and antioxidant; lower humidity and solubility properties	Sanches et al., 2021
Oregano essential oil (OEO)	Dioscorea zingiberensis starch + glycerol + Oregano essential oil	UV light barrier Antioxidant properties 3% oil concentration antimicrobial effect against *Bacillus subtilis, E.coli, S.aureus*	Shen et al., 2022
Orange essential oil	Corn starch + glycerol + orange essential oil	Low tensile strength and elongation at break Antimicrobial activity against *Listeria monocytogenes* and *S. aureus* High water vapor permeability	do Evangelho et al., 2019
Cinnamon essential oil	Cassava starch + glycerol + Tween 80 + cinnamon essential oil	Low tensile strength and high elongation at break High O_2 barrier UV light barrier Low water vapor permeability High thermal stability	Zhou et al., 2021

Starch-Based Edible Films in Food Packaging

Edible films and coatings contribute to preserving the physical and chemical properties of foods, preventing potential quality losses, and extending shelf life by inhibiting pathogenic microbial activation. The selection of the polymer, plasticizer, and other additives used in film production should be tailored to the specific characteristics of each food, and an appropriate film solution should be prepared accordingly (Li et al., 2024).

Additionally, mechanical damages on the surface of foods may increase microbial activation. Therefore, packaging should be resistant to mechanical damages, and edible film surfaces should not crack during storage methods such as refrigeration or freezing. Particularly in the packaging of protein-rich red meats, poultry, fish, and dairy products, a barrier property against potential pathogenic microorganisms should be considered (Üçüncü, 2011).

Edible food packaging should possess certain features depending on the type of food it will be applied to. For example, in the packaging of fresh meats, high oxygen permeability is required to maintin the bright red color of the meat, while low water vapor permeability is necessary to prevent water loss (Sezer & Bozkurt, 2021). For frozen meats, packaging with low oxygen and water vapor permeability is preferred to prevent water loss and lipid oxidation. Since fish is rich in unsaturated fatty acids, measures should be taken to prevent deoxidative spoilage. The packaging used for ripened cheeses should have high water vapor permeability to prevent moisture loss, which can lead to, weight and quality losses. For ripened cheeses to maintain the activities of their flora without quality loss, gas barrier permeability is also required. Different types of cheese have varied characteristics, necessitating different packaging conditions. Semi-hard and soft cheeses require low light, water vapor, and gas barrier properties, while shell-less cheeses require non-water vapor-permeable packaging, and fresh cheeses require packaging with low light, water vapor, and gas permeability (Üçüncü, 2011).

In the packaging of fresh fruits and vegetables, providing an appropriate gas and moisture barrier according to the type of food can prevent weight, taste, and odor losses, as well as inhibit browning reactions (Chettri et al., 2023).

Numerous studies have been conducted on the use of starch-based edible films in various food products (Baek et al., 2019; De Moraes et al., 2020; Mehdizadeh et al., 2020; Carrión et al., 2023; Fan et al., 2023; Abera et al., 2024; Bodana et al., 2024; Da Costa et al., 2024)

In a study conducted by Baek et al. (2019), navy bean starch films containing maki fruit extract were examined for antioxidant properties on salmon samples. The linear increase in antioxidant activity was observed with the increased proportion of maki fruit extract in the film content. Additionally, the film, which created a UV light barrier, prevented lipid oxidation in salmon samples.

De Moraes et al. (2020) prepared antimicrobial films treated with pulsed light, including a starch combination of sodium benzoate, citric acid, and sodium benzoate + citric acid. The antimicrobial properties of the film were examined on sliced cheddar cheese inoculated with *Listeria innocua*. Pulsed light application did not show a strong effect on the film structure. While the concentration of sodium benzoate used in the study did not exhibit antimicrobial effects, citric acid demonstrated its impact.

In a study by Mehdizadeh et al. (2020), chitosan-starch film containing pomegranate peel extract and thyme essential oil was applied to beef and monitored for 21 days at 4 °C. The film showed antimicrobial effects against *Listeria monocytogenes* and prevented lipid oxidation in beef, thereby extending shelf life.

Carrión et al. (2023) applied sodium alginate, nisin, and taro starch-based films to chicken meat inoculated with *L. monocytogenes* and investigated their antimicrobial effects during refrigerated storage. The prepared film exhibited antimicrobial effects against *L. monocytogenes*, extending the shelf life by 15 days compared to the control sample.

In a study by Fan et al. (2023), the potential application of purslane extract, chitosan, and wheat + pea starch-based films in chilled pork was examined. Pork slices of 8x8 cm were stored at 4 ˚C for 16 days. The antioxidant properties imparted to the film due to the extract used in the film solution prevented lipid oxidation in chilled meat, thereby preventing spoilage and extending shelf life.

Abera et al. (2024) created a film combination using starch, chitosan, and glycerol. The solution formed was applied to apples, mangoes, and strawberries. The resulting films extended the shelf life, with apples and mangoes showing an increased shelf life of 28 days and strawberries exceeding 21 days with minimal weight loss.

Bodana et al. (2024) produced jackfruit starch-based films containing pomegranate peel extract to extend the shelf life of white grapes. It was observed that the firmness of white grapes was maintained during storage at room temperature for up to 8 days, with reduced weight loss and acceptable color preservation.

Da Costa et al. (2024) aimed to extend the shelf life of fresh pears by producing k-carrageenan-starch films containing copper oxide particles. The added copper oxide particles provided UV barrier properties to the film, and no quality loss was observed during a 30-day storage period.

Conclusion

In conclusion, the abundance of starch in nature and its ability to form effective films offer promising prospects for it to replace traditional packaging materials. However, its susceptibility to moisture limits its applicability. Nevertheless, films with better physical and mechanical properties have been observed by incorporating plasticizers, polymers, and other additives into the created combinations. The addition of extracts, essential oils, and other bioactive compounds to starch-based films provides antioxidant and antimicrobial properties, turning them into active and intelligent packaging. These films effectively prevent quality losses and microbial activity, leading to extended shelf life in applied food products. Further research is needed to explore the extrusion process in starch-based film production, and combinations of films created from starch obtained from various sources are expected to have a significant impact on the literature.

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Ethical Statement

This study does not present any ethical concerns.

Author Contributions

Investigation: K.Y.B.; Supervision: H.Ç.; Visualization: K.Y.B.; Writing-Original Draft: K.Y.B. Writing- review & Editing: K.Y.B. & H.Ç.

Conflict of Interest

The authors declared that there is no conflict of interest.

Data Availabilty Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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