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Advancements in edible films and coatings for prolonging the freshness of fruits

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Abstract

This study provides an overview of the latest developments in edible films and coatings as effective solutions for extending the shelf life of fresh fruits. The perishability of fruits poses challenges for the food industry, resulting in substantial economic losses and food waste. Conventional packaging methods have limitations in preserving fruit quality and delaying spoilage. Edible films and coatings offer a promising alternative by creating a protective barrier that helps maintain fruit freshness through mechanisms such as moisture regulation, gas exchange control, and antimicrobial properties. This abstract summarizes the key findings from recent research on edible films and coatings for fruit preservation. It highlights the diverse materials and techniques used in their formulation and application, including biopolymers, composite films, and active packaging systems. Furthermore, it discusses the potential benefits, challenges, and future directions of edible films and coatings for extending the shelf life of fresh fruits. The review underscores that edible films and coatings have the potential to significantly enhance fruit quality, prolong shelf life, and reduce food waste. This paper contributes to the understanding of emerging technologies in the field of fruit preservation and provides valuable insights for industry professionals, researchers, and consumers seeking sustainable and efficient fruit packaging solutions.

Keywords: Biopolymers, composite films, and active packaging systems

1. Introduction

The interest in and research effort surrounding edible packaging has expanded as a result of rising consumer demand for convenient, stable, and safe meals as well as awareness of the detrimental environmental effects of non-biodegradable packaging waste. An edible film or coating is any kind of thin material that is used to enrobe (i.e., coat or wrap) different foods in order to extend the shelf life of the product, may be consumed alongside food with or without further removal, and acts as a barrier to moisture, oxygen, and solute movement for the food (Rhim *et al*., 2007) [47]. There is a difference between edible coatings and edible films, even though the terms are frequently used interchangeably. Coatings are created directly onto food surfaces, whereas edible films are made separately and then applied to food surfaces. It is not new to use edible coatings to maintain the quality of fruits and vegetables. Wax was first applied to oranges and lemons in China in the 12th century to prolong their shelf life. Some fresh citrus fruits, apples, and cucumbers have been coated with edible substances for a long time in order to preserve quality and increase shelf life (Baldwin *et al*., 1996; Li and Barth, 1998) [6, 35].

2. Properties of edible coating

An ideal edible material used for coating fruits or vegetables should be free from any poisonous, allergic, or non-digestible component and should be easily made, environmentally benign, and commercially viable. (Janjarasskul & Krochta, M., 2010) [28] According to Janjarasskul & Krochta, M. (2010) [28], the coating material should offer structural and microbiological surface stability, good adhesive properties, semi-permeability, and should maintain or improve aesthetics and sensory qualities (appearance, taste, etc.) of the product. In order to maintain the proper moisture content, it should control water migration into and out of the fruit during handling and transit to minimise mechanical damage. It ought to offer defence against microbial growth, pest infestation, and other forms of spoiling (Falguera *et al*., 2011) [18].

3. Different types of coatings

Depending on the type of substance they are made from, edible films and coatings can be

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categorised. Each chemical class has particular advantages, disadvantages, and capabilities for coating application. According to Li and Barth (1998) [35] and Dhall (2013) [11], the ingredients used to create edible films can be divided into three groups: hydrocolloids (such as proteins, polysaccharides, and alginate), lipids (such as fatty acids, acylglycerol, and waxes), and composites.

3.1.1 Films and coatings made of polysaccharides

According to Boundless (2013) [7], polysaccharides are long-chain biopolymers made of repeating mono- or disaccharide units that are joined by glycosidic linkages. Polysaccharide films, which are hydrophilic by nature and offer an excellent barrier to CO2 and O2, slow down respiration and fruit ripening (Janjarasskul & Krochta, 2010) [28]. Contrarily, their polarity dictates how sensitive they are to moisture and how poor a barrier they are to water vapour, which may alter their functional qualities (Park *et al.*, 1995; Janjarasskul *et al.*, 2010) [40, 28]. Among the polysaccharides utilised for edible films or coatings include chitosan, exudate gums, starch derivatives, pectin derivatives, seaweed extracts, and cellulose (Janjarasskul & Krochta, 2010) [28].

a) Cellulose and its derivatives

Cellulose is the most prevalent natural polymer on earth and is made up of repeating D-glucose units connected by ß-1, 4 glycosidic bonds, making it one of the most important raw materials for the preparation of edible films along with starch (Peressini *et al.*, 2003) [42]. It is insoluble in water due to the tightly packed polymer chains and extremely crystalline structure. According to IBryan 1972; Janjarasskul and Krochta, 2010) [8, 28], treating cellulose with alkali can make it more water-soluble and cause the structure to swell. This is followed by a reaction with chloroacetic acid, methyl chloride, or propylene oxide to produce carboxymethyl cellulose (CMC), methyl cellulose (MC), hydroxypropyl cellulose (HPMC), or hydroxypropyl cellulose (HPC). According to Krochta and DeMulder-Johnston (1997) [33], all four of these films have good film-forming properties that contribute to fruit preservation. Avocados have an MC coating to delay softening and lower respiration rates (Peressini *et al.*, 2003) [42]. Some fruits and vegetables have edible coatings consisting of HPMC, CMC, HPC & MC to act as barriers against the transmission of oxygen, oil, or moisture (Vargas *et al.*, 2006) [56].

b) Alginates

A source of dietary fibre, alginate is an indigestible substance made by brown seaweed that has special colloidal properties such thickening, stabilising, and gelling (Rhim *et al.*, 2007) [47]. Alginates are hydrophilic by nature, which results in edible films that have low water resistance. Alginate films' characteristics have also been discovered to be improved by substances like modified starches, oligosaccharides, or simple sugars (Cha and Chinnan, 2004) [9]. Due to their colloidal characteristics and the capacity to react with multivalent metal cations to generate solid gels or insoluble polymers, alginate biopolymers are particularly well suited for edible films and food coatings (King 1983; Rhim 2004) [32, 46]. Pine apple cuts (Azarakhsh, 2012) [2], water melon cuts (Poverenov *et al.*, 2014) [45], and fresh cut Fuji apple cuts (Rojas-Grau, *et al.*, 2008) [48] have all been given longer shelf lives by coatings made of alginates and gellan.

c) Edible films made of starch

Because starch is inexpensive, renewable, and has high mechanical qualities, it has been utilised to create biodegradable films that can replace plastic polymers in part or totally (Xu *et al.*, 2005) [61]. Corn starch, which has a high amylose content, is a useful source for the creation of films. According to Shamekh *et al.* (2002) [50], the starch-based films are transparent or translucent, tasteless, and colourless. Because starch-based films are naturally brittle, plasticizers like glycerol and sorbitol are typically added to address this issue (Mali *et al.*, 2002) [36]. Amylose has a significant impact on the weight loss, colour, and firmness of coated strawberries, according to Garcia *et al.* (1998a) [20], who compared the quality of strawberries coated with starch from different sources (corn starch - 25% amylose; potato starch - 23% amylose; high amylose corn starch - 50% amylose; high-amylose corn starch - 65% amylose). Compared to other treatments, strawberries coated with 50% and 65% high-amylose starches best kept their quality characteristics. Starch is therefore not the best choice when working with minimally processed high-water activity commodities because starch films are hydrophilic and their properties will change with fluctuations in relative humidity, for example, their barrier properties decrease with increasing relative humidity (Peressini *et al.*, 2003; Zhang & Han, 2006) [42, 62]. Apples were coated with starch solutions by Bai *et al.* in 2002 [4], and they noticed a high shine at the start of storage. They did, however, notice a significant loss of gloss after storage (Bai *et al.*, 2002) [4].

d) Chitosan and chitin

Next to cellulose, which is mostly present in the exoskeleton of crustaceans and the cell walls of fungi, chitin is the most prevalent naturally occurring non-toxic biopolymer (Park *et al.*, 1996) [41]. Clear, robust, flexible, and good oxygen barriers are characteristics of films made from aqueous chitosan (Sandford, 1989; Kaplan *et al.*, 1993) [49, 31]. Chitosan films often resist water transfer but tend to be resistant to fat and oil. According to El *et al.* (1991a) [16]; Cha and Chinnan (2004) [9], chitosan coatings are frequently used on fruit and vegetable items, such as strawberries, cucumbers, and bell peppers, as an antibacterial coating and as a gas barrier on apples, pears, peaches, and plums. Chitosan has a drawback in that it is extremely sensitive to moisture. Chitosan was also applied to litchi, delaying the decline in anthocyanin concentration and boosting PPO activity (Jiang *et al.*, 2005) [29]. Fruit coatings made of composite coatings including chitosan and chitin are an excellent alternative (Srinivasa *et al.*, 2002) [51]. Chitosan coatings containing oleic acid demonstrated good water retention capabilities on coated strawberries, while N, O-carboxymethyl chitosan films kept apples held in cold storage in fresh condition for longer than 6 months (Vargas *et al.*, 2006; Cha and Chinnan, 2004) [56, 9].

3.1.2 Proteins-based coatings and films

Numerous proteins have been shown to exhibit film-forming capabilities, including casein, whey protein, gelatin/collagen, fibrinogen, soy protein, wheat gluten, maize zein, and egg albumen. Protein-based films offer barriers against oxygen and carbon dioxide while adhering effectively to hydrophilic surfaces (Baldwin *et al.*, 1995b) [5]. However, they do not obstruct water diffusion.

a) Gelatin

Gelatin is a completely animal-based food ingredient that is created by gently heating collagen in either an acidic or alkaline environment. According to the findings of many investigations, gelatin dips greatly increased the oxidative and colour stability of the treated items. Gelatin-starch coatings were applied to avocados by Aguilar-Mendez *et al*. (2008), who discovered that this increased the fruit's postharvest shelf life. Gol and Rao (2013) [23] shown in another investigation that the zein and gelatin coatings might postpone the ripening of mango fruit. Despite these achievements, gelatin lacks strength and needs to be dried in order to make films that are more resilient.

b) Whey proteins

A lot of research has been done on the use of whey protein as a covering for various meals, including whole and hardly processed fruits and vegetables. Whey protein has been proven to produce a flexible, translucent film with excellent oxygen and aroma barrier qualities at low relative humidity levels (McHugh and Krochta 1994; Miller and Krochta 1997) [38, 33, 39]. Due to the antioxidant impact of amino acids, whey protein-based coatings have been shown to be more successful than HPMC-based coatings in preventing the enzymatic browning of golden delicious apple slices (McHugh & Krochta, 1994) [38]. According to Perez-Gago *et al*. (2005a) [43], adding anti-browning chemicals to whey protein coatings, along with suitable storage conditions, could dramatically increase the shelf life of fresh-cut apples.

c) Wheat Gluten

Wheat dough has integrity because of the cohesive and elastic properties of gluten, which also helps to produce films. Wheat gluten aqueous ethanol solution can be dried to create edible films (Day, 2001) [13]. To increase the flexibility of gluten films, a plasticizer, such as glycerin, must be added (Gennadios and Weller, 1992) [22]. Glutaraldehyde or heat curing can be used to alter the characteristics of wheat gluten films (Wittaya, 2012) [59]. Similar results were found by Gontard *et al*. (1994) [24] by combining wheat gluten proteins with a diacetyl tartaric ester of monoglycerides, which effectively reduced water vapour permeability, increased strength, and maintained transparency. In one of the studies conducted by Tanada-Palmu & Grosso (2005) [54] on refrigerated strawberries, wheat gluten coating were very effective in controlling the weight loss and retention of firmness.

d) Soy protein

Either surface film formation on heated soymilk or film production from solutions of soy protein isolate (SPI) can result in edible films made of soy protein (Gennadios and Weller, 1990) [21]. It has been researched (Rhim *et al*., 2007; Gennadios and Weller, 1992; Bai *et al*., 2003b; Stuchell and Krochta, 1994; Kunte *et al*., 1997) [47, 22, 3, 53, 34] how soy protein is used to build films or coatings on food products. By using soy protein, the Nature SealTM covering on sliced apples and potatoes minimises its permeability to oxygen and water vapour (Baldwin *et al*., 1996) [6].

e) Zein Protein

Zein has excellent film forming capabilities, making it a good choice for making biodegradable films. Because the films are fragile, they need plasticizer to make them more flexible (Martinez- Romero *et al*., 2007) [37]. When compared to other edible films, zein protein-based films have pretty good water vapour barriers that can be improved by adding fatty acids or using a cross-linking agent (Guilbert *et al*., 1996) [25]. According to Park *et al*. (1996) [41], zein coatings promote weight loss in both apples and pears during storage. Zein coatings cause a decrease in the respiration rate in apples while increasing the respiration rate in pears when compared to uncoated controls. For Gala apples, a 10% zein and 10% propylene glycol coating formulation was created and dissolved in aqueous alcohol (Chakraverty *et al*., 2001) [10].

3.1.3. Lipid-based edible coatings and films

Due to their low polarity, lipids, unlike other biomolecules, are unable to create self-supporting, cohesive films; as a result, they are used in composite films to act as a moisture barrier (Martnez- Romero *et al*., 2007) [37]. Saturated long-chain fatty acids coatings possess good water vapour barrier properties because they produce a more densely packed structure and have less mobility than unsaturated short-chain fatty acids (Kamper and Fennema, 1984) [30]. The properties of lipids to form films and coatings generally depend on the characteristics of the lipid component, such as its physical state, degree of saturation or chain length of fatty acids (Debeaufort & Voilley, 2009) [14].

a) Shellac and Carnuba Wax

Natural plant wax known as carnuba is regarded as GRAS. It is highly glossy and relatively gas permeable in micro emulsion form. Carnauba wax's gloss loss during storage and relatively high gas permeability are its principal drawbacks (Bai *et al*., 2002) [4]. When mixed with shellac wax, it creates a coating that has a low permeability to water vapour and a moderate permeability to gases, making it an excellent barrier to water vapour. The majority of delectable apples sold in U.S. markets have a shellac or shellac and carnauba wax coating (Day, 1989) [12]. Unfortunately, both substances have non-food applications; shellac, in particular, has issues with limited gas permeability, which can delay fruit ripening and result in anaerobic conditions. Alleyne and Hagenmaier created an apple-specific candelilla-shellac covering in 2002 and studied gloss, hardness, fruit respiration, ethanol, weight loss, and flavour. They come to the conclusion that the 34% shellac candelilla formulation is competitive with the currently available commercial carnauba-based apple coating products. Nevertheless, shellac is regarded as one of the shinest coats on the market and has been shown to enhance apple beauty. In one of the studies done by Bai, *et al*. (2003a), it was discovered that shellac coats increased sales of red and green apple cultivars. The Food and Drug Administration (FDA) has granted shellac GRAS designation, which denotes that it is generally regarded as safe for use in foods (Casalena, 2010) [57].

b) Beeswax

To protect fruits like plums and those with little processing, like apple slices and persimmon pieces, beeswax has been employed in composite coatings along with WPI, WPC, and HMPC (Perez-Gago *et al*., 2005a) [43]. With the exception of coated plum and persimmon pieces, weight loss was generally not stopped by beeswax (Perez-Gago *et al*., 2005b) [44].

3.1.4 Composite films

Edible coatings and films typically combine lipids, proteins, and polysaccharides. To increase the permeability or mechanical qualities, composite films are mostly made. The primary benefit of these films is that they can be used as an emulsion, suspension, or solution in a typical solvent. Based on the findings of Kamper and Fennema (1984) [30], other scholars have investigated the creation of composite films in great detail. For instance, soy protein isolate and gelatin; soy protein isolate and polylactic acid; gelatin and fatty acid; etc.

3.1.5 Other Coatings and Films

Other substances, such as pullulan, gellan, aloe vera, cactus-mucilage, and fruit puree, have been used to create coatings for fruits. Cherry and grape quality preservation has been investigated in relation to aloe vera coatings (Valverde *et al*., 2005) [55]. Strawberry quality has been preserved using cactus mucilage film, and coatings containing a combination of fruit puree and hydrocolloid have also been utilised (Del-Valle *et al*., 2005) [15]. To maintain the quality of the apple slices, an alginate apple puree coating was utilised (Valverde *et al*., 2005) [55].

3.1.6 Film and coating additives

Anti-browning substances, antibacterial agents, texture enhancers, minerals, probiotics, and flavours have all been widely employed as additives in films and coatings. However, the principal additives used in formulations to enhance the mechanical properties of films and coatings are plasticizers. Without plasticizers, the majority of films and coatings are brittle (Xu and Sun, 2001) [60]. Polyols like glycerol, sorbitol, and polyethylene glycol are often used plasticizers, along with disaccharides like sucrose and monosaccharides like fructose, glucose, and mannose (Sothornvit and Krochta, 2005; Zhang and Han, 2006) [52, 62].

4. Future development

Despite the enormous advantages of employing edible coatings, there are still very few commercial uses for this technology across a wide range. Improvements still need to be made to the mechanical, barrier, and water resistance of biopolymer films. In addition to consumer acceptance of the coating, final cost is a major consideration. The impact of coatings and films on the metabolites of fruits is another significant problem.

5.Conclusion

New packaging technologies have been developed and innovated as a result of shifting consumer demands. The market for smart packaging will expand as a result of increased worries about food safety and health, rising food prices, and better purchasing power. Additionally, innovative systems will raise the quality of the product, increase food safety and security, and thereby lower the volume of retailer and consumer complaints.

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