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Recent advances in application of edible coatings for temperate fresh/fresh-cut fruits: a review

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ABSTRACT

Purpose: Temperate fruits not only provide essential nutrients but also contribute to the diversity and sustainability of horticultural production systems worldwide. The total production of fruits, increased during the past twenty years. However, postharvest losses of fruits due to spoilage, decay, and physiological deterioration pose a significant challenge to the global food supply chain, which leads to a decline in fruit quantity and quality after harvest. **Findings:** Edible coatings have emerged as a sustainable solution for extending the shelf life of fruits while reducing postharvest losses. The use of edible coatings is not only environmentally friendly but also addresses consumer demands for natural, safe, and healthy food products obtained through minimal processing. A wide array of edible coating materials is available, each possessing unique properties that influence their effectiveness in preserving fruits. The specific composition and application of edible coatings play a crucial role in their effectiveness in inhibiting microbial growth, reducing enzymatic browning, and maintaining the sensory quality of the fruits. **Limitations:** No limitations were found. **Directions for future research:** Future research should focus on exploring and developing new, sustainable, and biodegradable coating materials derived from renewable sources. Additionally, incorporating nanotechnology into edible coatings can enhance their properties, such as improved barrier properties, controlled release of active compounds, and enhanced antimicrobial activity. Continued research and innovation in this area hold significant promise for reducing postharvest losses, improving food security, and promoting sustainable agricultural practices. This review summarizes recent advances in different edible coating materials and their uses in prolonging shelf life and decreasing postharvest losses of important temperate fresh/fresh-cut fruits worldwide.

INTRODUCTION

Fruits are vital in human diet, rich in nutrients. Fruits play a crucial role in human health due to their rich content of essential nutrients and bioactive compounds. They are abundant sources of dietary fiber, antioxidants, phytochemicals, vitamins (such as vitamin C, thiamine, niacin, pyridoxine, folic acid), and minerals, all of which are vital for maintaining optimal health and preventing chronic diseases (Alemu, 2024). The consumption of fruits has been linked to various health benefits, including improved physical and mental health, preventing of non-communicable diseases like cardiovascular disease, diabetes mellitus, and certain cancers, and protection against neurological disorders (Jideani et al., 2021). The antioxidant components in fruits are typically credited for their protective impact.

The demand for fresh produce and fresh-cut fruits has significantly increased in recent years due to consumer preferences for convenient, healthy, and ready-to-eat products (Liyanapathiranage et al., 2023; Firdous et al., 2023). Consumers are attracted to fresh fruits for their freshness, nutritional value, safety, and overall eating experience, driving the growth in this market segment. Various emerging technologies such as active packaging, natural preservatives, and physical treatments have been developed to extend the shelf life of fresh/fresh-cut fruits while maintaining their quality and properties (Palumbo et al., 2022).

Global fruit production is increasing due to the demand of the world population, improving standards of living, and growing health consciousness in fruit consumption. Within a decade, the total production of temperate fruits, berries, citrus and tropical fruits significantly increased (Maringgal et al., 2020). However, postharvest losses of fruits due to spoilage, decay, and physiological deterioration pose a significant challenge to the global food supply chain, which leads to a decline in fruit quantity and quality after harvest. These losses result in economic losses for producers, retailers, and consumers; and contribute to food waste and environmental degradation. Losses can be caused by improper handling and storage, improper packaging, and microbial and fungal infections (Sanches & Repolho, 2022; Moradinezhad & Ranjbar, 2023). It is estimated that about 20-50% of fresh fruit produced losses at different postharvest stages (Nabi et al., 2017).

In recent years, a variety of strategies and methodologies have been established for the management of postharvest losses. One technique that shows potential in decreasing the respiration rate and prolonging the shelf life of fruits is modified atmosphere (Mitcham et al., 2023). The fundamental concept of this approach involves altering the gas composition surrounding the fruit through the manipulation or removal of gases essential for respiration (Moradinezhad et al., 2013). By creating an unsuitable environment, this method hinders the ripening process by modifying the internal gas configuration, decelerating the fruit's metabolic processes, thus retarding senescence and restraining microbial proliferation. Another practical and effective approach is the utilization of low temperatures for fruit preservation immediately postharvest and throughout storage. While maintaining fruits at reduced temperatures can uphold quality over extended periods, it also has the potential to induce chilling injury if storage conditions drop below recommended thresholds (Baloyi et al., 2023). Similar to modified atmosphere techniques, edible coatings serve as a protective layer on the product’s surface to impede gas exchange and halt the ripening process, thereby conserving the quality of the fruits. This methodology has demonstrated efficacy in numerous research investigations (Guimarães et al., 2021).

In this paper, a review of the advances made in the field of coating technology and its impact on the postharvest life of fruits is presented, highlighting the importance of preserving fruits and protecting them from spoilage by using novel techniques. The study will explore different kinds of edible coating materials and their uses in prolonging shelf life and decreasing postharvest losses of important temperate fresh/fresh-cut fruits worldwide.

Edible coatings properties and applications

Edible coatings have emerged as a sustainable solution for extending the shelf life of fruits and vegetables while reducing food waste and postharvest losses. Edible coatings are thin layers of biodegradable natural polymers applied to food surfaces to enhance quality, shelf life, and reduce post-harvest losses (Perez-Vazquez et al., 2023). These coatings, made from polysaccharides (alginate, cellulose, chitosan, gums, pectin, and starch), proteins (gelatin, gluten, and zein), and lipids (fatty acids and waxes), act as a barrier against moisture loss, microbial growth, and oxidation, extending the shelf life of fresh-cut fruits and vegetables (Aaqil et al., 2024). By incorporating essential oils or nanoparticles, edible coatings can further improve physicochemical properties and provide antioxidant or antimicrobial effects (Kanwar et al., 2024). The use of edible coatings is not only environmentally friendly but also addresses consumer demands for natural, safe, and healthy food products obtained through minimal processing. Moreover, coatings present an environmentally sustainable substitute for conventional non-biodegradable packaging substances, thereby facilitating the mitigation of plastic waste and enhancing methods of food preservation (Pandya et al., 2023).

A wide array of edible coating materials is available, each possessing unique properties that influence their effectiveness in preserving fruits. This section provides an overview of various commonly employed edible coating materials, including their properties and applications in fruit preservation.

Chitosan

Chitosan, a biopolymer derived from chitin, is a versatile edible coating material with excellent film-forming and antimicrobial properties. Its cationic nature allows it to interact with the negatively charged cell walls of microorganisms, inhibiting their growth and preventing spoilage. Chitosan coatings also exhibit good barrier properties against gases and moisture, contributing to the preservation of fruit quality. Chitosan, exhibits unique properties such as biocompatibility, biodegradability, and non-toxicity, making it a promising material for various applications (El-Araby et al., 2024). The molecular weight and degree of deacetylation of chitosan play crucial roles in determining its physicochemical and biological characteristics. Chitosan can be sourced from different organisms like crustaceans, fungi, and insects, with commercial production mainly from crustaceans (Hemmamı et al., 2024). Its applications span industries, including healthcare, agriculture, cosmetics, and wastewater treatment, with recent advancements focusing on chitosan derivatives and nanocomposites to enhance its efficiency and broaden its utility (Román-Doval et al., 2023). In the biomedical field, chitosan has been extensively explored for drug delivery systems, tissue regeneration, gene delivery, and vaccination, showcasing its potential in various biomedical applications (El-Araby et al., 2024).

Carboxymethylcellulose (CMC)

Carboxymethylcellulose (CMC), a cellulose derivative, is a water-soluble polysaccharide widely used as a thickener and stabilizer in food applications. It exhibits excellent film-forming properties, forming strong and flexible coatings that can effectively reduce fruit moisture loss. CMC-based coatings also contribute to the preservation of fruit quality by retarding gas exchange and microbial growth. CMC plays a significant role in various food-related applications. Studies have shown that CMC is widely used in the food industry due to its safety approvals by regulatory bodies like the European Food Safety Authority (EFSA) and the Food and Drug Administration (FDA) (Yildirim-Yalcin et al., 2022). CMC is utilized in edible film production, contributing to the recycling of food waste and promoting sustainability and biodegradability in food packaging (Costa et al., 2023). Furthermore, CMC has been incorporated into composite films with nanoparticles like TiO_2 to enhance antimicrobial properties, providing an alternative to traditional antibiotics in combating microbial resistance in food products (Elmehbad et al., 2024). Additionally, CMC has been explored for its potential in agriculture, offering solutions to challenges such as water absorption and fruit preservation postharvest (Yildirim-Yalcin et al., 2022). Overall, CMC's versatility and beneficial properties make it a valuable component in food technology, packaging, and agricultural practices.

Alginate

Alginate, a natural polysaccharide extracted from seaweed, is a widely used edible coating material. It forms strong and flexible films that can effectively reduce moisture loss and retard gas exchange in fruits (Luna-Zapién et al., 2023). Alginate coatings also exhibit good antimicrobial properties, inhibiting the growth of spoilage microorganisms and extending the shelf life of fruits. Alginate-based edible coatings have been extensively studied for their potential in enhancing post-harvest handling of various food commodities. These coatings can improve product quality by reducing mass loss and preserving color (De Simone et al., 2024). Incorporating probiotic *Lactiplantibacillus plantarum* strains into alginate coatings has shown promise in extending the shelf life of fruits like table grapes by controlling harmful microorganisms and reducing decay, thus enhancing safety and quality (De Simone et al., 2024). Additionally, alginate coatings combined with whey protein and curcumin have demonstrated excellent UV barrier properties, reduced water vapor transmission rates, and extended the shelf life of apples by suppressing respiration and moisture loss, ultimately reducing enzymatic browning and weight loss (Botalo et al., 2024). Overall, alginate-based edible coatings offer a versatile and effective solution for improving the post-harvest management and quality of various food products.

Zein

Zein, a protein extracted from corn, is another prominent edible coating material. Its hydrophobic nature makes it suitable for creating water-resistant coatings that can effectively prevent moisture loss from fruits. Zein coatings also exhibit good barrier properties against gases, further contributing to fruit preservation. Additionally, zein's ability to encapsulate bioactive compounds, such as antioxidants, enhances the nutritional value of coated fruits. Zein, has gained attention for its eco-friendly and versatile properties, making it an ideal candidate for edible coatings and films in the food industry (Egea et al., 2022). Studies have shown that zein-based coatings can effectively maintain the quality of fruits like "Granny Smith" apples by reducing weight loss and microbial contamination, thus extending their shelf life (Belay et al., 2023). Additionally, zein coatings have demonstrated good barrier properties against gases, light, and water, along with antimicrobial effects, which can further enhance the preservation of food products. Furthermore, the integration of essential oils with zein in coatings has demonstrated encouraging outcomes in the suppression of microbial proliferation on fruits such as dates, underscoring the potential of zein in food packaging (Salajegheh et al., 2020). Overall, zein-based edible coatings present a sustainable and secure solution for prolonging the shelf life of diverse food products while preserving their safety and quality.

Pectin

Pectin, a naturally occurring polysaccharide extracted from fruits, is a widely used edible coating material. It exhibits excellent film-forming properties, owing to its ability to form gels in the presence of sugars and acids. Pectin-based coatings effectively reduce water loss and retard oxygen permeability, contributing to moisture retention and delayed ripening in fruits. Moreover, pectin's biodegradability and low toxicity make it an attractive choice for food packaging. Pectin-based edible coatings offer a promising solution for preserving food quality by enhancing shelf-life characteristics and providing a protective barrier against moisture loss and gas exchange (Freitas et al., 2021). These coatings, originating from natural polymers such as pectin, can be enhanced with bioactive components like essential oils to boost antioxidant attributes and structural qualities, thereby prolonging the shelf life of fruits and vegetables (Nastasi et al., 2022). By incorporating elements like protein hydrolyzate, pectin films can exhibit enhanced biodegradability, moisture resistance, and antioxidant capacity, making them ideal for food packaging applications (Freitas et al., 2021). Additionally, using pectin in edible coatings can lead to the development of composite materials with improved physicochemical properties, offering a natural and environmentally friendly alternative to traditional food preservation methods (Rohasmizah & Azizah, 2022).

Gums

Gums are complex carbohydrate molecules which have the ability to bind water and form gels at low concentration. These carbohydrates are often associated with proteins and minerals in their structure. Gums are of various types such as seed gums, exudate gums, microbial gums, mucilage gums, seaweeds gums, etc (Barak et al., 2020). Edible coatings made from natural gums like tragacanth, guar gum, almond gum, Arabic gum, and zedo gum have demonstrated encouraging outcomes in the conservation of the characteristics of different types of fruits and vegetables during storage (Zare-Bavani et al., 2024; Yazıcıoğlu, 2023; Rasool et al., 2023; Jahanshahi et al., 2023). These coatings have proven effective in mitigating weight loss, maintaining firmness, and improving color retention, and delay deterioration processes such as proteolysis and microbial growth, ultimately extending the shelf life of coated products. For example, coatings with almond gum have demonstrated superior physicochemical properties compared to synthetic gums, leading to better quality retention in pineapples (Rasool et al., 2023). Additionally, formulations incorporating aloe vera, starch, and Arabic gum have proven effective in prolonging the longevity of bananas by reducing the rate of chlorophyll breakdown and preserving their firmness (Tchinda et al., 2023). Overall, these natural gum-based edible coatings offer a sustainable and efficient solution for improving post-harvest quality and marketability of various perishable products.

Aloe vera gel

Aloe vera gel, extracted from the aloe vera plant, is a natural moisturizer with antimicrobial properties. It is often incorporated into edible coatings to enhance their moisturizing and antimicrobial effects. Aloe vera gel can improve the flexibility and barrier properties of coatings, contributing to better fruit preservation (Ahmed, 2024). Aloe vera gel has been extensively studied for its potential as an edible coating material to enhance food preservation and quality. Research has shown that incorporating aloe vera gel into edible coatings can effectively retard lipid oxidation, improve quality characteristics, and extend the shelf life of various food products, such as apples (Suhartatik & Karyantina, 2023), figs, and tomatoes (Tobing et al., 2024). The combination of aloe vera gel with other materials like chitosan has been found to enhance film-forming abilities, rheological properties, antioxidant effects, and microbial growth inhibition, making it a promising bio-based solution for food packaging and preservation (Tobing et al., 2024). Additionally, using aloe vera gel has shown to increase public awareness and skills in utilizing natural coatings for fruits like strawberries (Álvarez-Barreto et al., 2023), contributing to sustainable food preservation practices.

Essential oils (EOs)

Essential oils (EOs) are volatile aromatic liquids extracted from various parts of aromatic plants, containing compounds like flavonoids, terpenoids, and phenylpropanoids, which contribute to their diverse medicinal properties such as antimicrobial, antioxidant, anti-inflammatory, and antiviral effects (Tiwari et al., 2023; Kahawattage et al., 2023). EOs have gained attention as green alternatives to synthetic chemicals due to their safety and effectiveness in inhibiting the growth of mycotoxigenic fungi and eliminating mycotoxins, making them valuable in food preservation (Tiwari et al., 2023). Essential oil edible coatings have shown significant potential in extending the storage life and enhancing the quality of different horticultural crops. Studies have highlighted the effectiveness of essential oil-based coatings in preserving fruits like mandarins (Liguori et al., 2024) and vegetables (Perez-Vazquez et al., 2023). These coatings, often incorporating oils like oregano, thyme, and cinnamon, exhibit antimicrobial properties that inhibit microbial growth, thereby extending the product's freshness. Essential oil concentrations and types play a crucial role in determining the physicochemical properties of the coatings, affecting factors such as viscosity, color, and transparency (Perez-Vazquez et al., 2023). Overall, essential oil edible coatings offer a natural and effective solution for enhancing food quality and safety.

Calcium chloride ($CaCl_2$)

Calcium chloride ($CaCl_2$), an inorganic salt, is often used in combination with other edible coating materials to enhance their film-forming properties and improve their barrier properties. It interacts with polysaccharides, such as pectin and alginate, to form stronger and more rigid coatings that can effectively reduce moisture loss and retard gas exchange. Calcium chloride plays a significant role in various edible coating applications as highlighted in the provided research contexts. Studies have shown that $CaCl_2$ can be utilized in edible coatings to enhance the quality and shelf life of fruits by inhibiting fungal attacks and maintaining membrane stability (Moradinezhad et al., 2019, 2021; Dorostkar et al., 2022a). Furthermore, the combination of $CaCl_2$ with other ingredients like starch, Arabic gum powder, and garlicin in edible coating agents has been demonstrated to prolong the fresh-keeping period of fruits like *Pyrus bretschneideri* Rehd., showcasing the versatility and effectiveness of $CaCl_2$ in food preservation applications (Araujo et al., 2021). These findings indicate the valuable role of $CaCl_2$ in edible coatings for enhancing food quality, extending shelf life, and improving consumer satisfaction.

Mechanisms of action of edible coatings

Edible coatings function as a protective barrier separating the fruit from its surrounding environment, significantly influencing various physiological and biochemical processes contributing to fruit preservation. These mechanisms are multifaceted and involve a complex interplay of factors that ultimately contribute to extended shelf life, reduced decay, and improved quality attributes.

Moisture retention

Edible coatings are crucial in minimizing moisture loss from fruits during storage. This is primarily achieved through the formation of a semi-permeable barrier that limits the rate of water vapor diffusion from the fruit to the surrounding atmosphere. The coating's ability to retain moisture depends on its composition, thickness, and the relative humidity of the storage environment (Pham et al., 2023). For instance, coatings enriched with polysaccharides like pectin and alginate exhibit excellent moisture-retention properties due to their hydrophilic nature. They form a gel-like matrix that traps water molecules, effectively preventing dehydration. This moisture retention is essential for maintaining fruit turgor, texture, and overall appearance.

Gas exchange regulation

The composition and structure of edible coatings influence the permeability of gases like oxygen and carbon dioxide, which are crucial for respiration and ripening processes in fruits. Some coatings, particularly those based on hydrophobic polymers like zein, act as barriers to oxygen diffusion, slowing respiration rates and delaying ripening (Liyanapathiranage et al., 2023). This controlled gas exchange helps to maintain the desired level of oxygen for fruit respiration while minimizing the accumulation of ethylene, a ripening hormone that accelerates senescence (Sun et al., 2022).

Microbial growth inhibition

Edible coatings can also provide an effective barrier against microbial contamination, a major cause of fruit spoilage. The coating material itself may possess antimicrobial properties, such as chitosan, which exhibits antifungal activity. Moreover, the coating has the ability to establish a hostile environment for microbial growth by changing the pH, oxygen levels, and nutrient composition surrounding the surface of the fruit (Leite et al., 2023). This antimicrobial effect helps to suppress the growth of bacteria, yeasts, and molds, extending the shelf life of fruits and reducing spoilage rates.

Apart from the mechanisms as mentioned earlier, edible coatings can also influence fruit preservation in other ways, including:

Nutrient Enrichment: Certain coatings can be formulated to incorporate beneficial nutrients, such as vitamins or antioxidants, enhancing the nutritional value of the coated fruit.

Antioxidant Activity: Some coating materials, like polyphenols, possess antioxidant properties that protect fruits from oxidative damage, preserving their color, flavor, and nutritional quality.

Sensory Properties: Edible coatings can influence the sensory attributes of fruits, such as their appearance, texture, and flavor, enhancing consumer appeal.

Applications and effectiveness of edible coatings in fruit preservation

Edible coatings have found diverse applications in fruit preservation, targeting various challenges associated with postharvest handling and storage (Liyanapathiranage et al., 2023). Some key applications include:

Shelf life extension: Edible coatings act as a barrier against moisture loss, gas exchange, and microbial invasion, effectively extending the shelf life of fruits by slowing down respiration and delaying ripening. Studies have demonstrated that coatings can significantly reduce the decay rate and extend the storage life of fruits like strawberries, blueberries, apples, and mangoes.

Reduction of decay: Edible coatings can inhibit the growth of microorganisms that cause decay, thus preventing spoilage and preserving the fruit's quality. Coatings containing antimicrobial agents, such as chitosan or essential oils, have been shown to reduce the incidence of fungal infections and bacterial contamination effectively.

Maintenance of quality attributes: Edible coatings can help preserve the sensory quality of fruits by preventing loss of moisture, color, flavor, and texture. They can also reduce the incidence of enzymatic browning, a common problem in fruits like apples and bananas.

The effectiveness of edible coatings in fruit preservation is influenced by several factors, including the type of coating material, the fruit variety, the storage conditions, and the application method (Firdous et al., 2023). Different coating materials exhibit varying degrees of effectiveness depending on their properties. For example, pectin-based coatings are known for their moisture retention and gas barrier properties, while chitosan coatings offer antimicrobial activity (Liyanapathiranage et al., 2023). The effectiveness of coatings can vary depending on the fruit variety. Some fruits are more susceptible to decay or moisture loss than others, requiring specific coatings for optimal protection. Temperature, humidity, and gas composition of the storage environment significantly affect the effectiveness of coatings. Optimal storage conditions can enhance the protective effects of the coatings. The application method can influence the uniformity and thickness of the coating, impacting its effectiveness. Dip coating, spray coating, and brush coating are commonly used methods.

Edible coatings for temperate fruits

Temperate fruits encompass a variety of economically important crops adapted to middle-latitude climates, requiring cold periods for dormancy and exhibiting winter hardiness (Awasthi, 2023). Examples of important temperate fruits include apple, pear, apricot, peach, plum, grape, and strawberry, which are widely cultivated and consumed globally. These fruits not only provide essential nutrients but also contribute to the diversity and sustainability of horticultural production systems worldwide.

This section explores the application of edible coatings on important temperate fruits (pome fruits, stone fruits, and small fruits) especially focusing on the effect of various postharvest coatings on fresh-cut fruits, analyzing their efficacy in inhibiting microbial growth, slowing down deterioration and extending shelf life. The literature that was used in this review obtained from original research and review papers mainly published during 2019 to the Middle of 2024.

Edible coatings for pome fruits

Apple (*Malus domestica*)

Edible coatings are crucial in extending the shelf life and maintaining the quality of apples postharvest. Various studies have examined the effectiveness of different edible coatings on apples, such as CMC, sodium alginate (SA), citric acid (CA), oxalic acid (OA) (Magri et al., 2023), zein, and zein combined with nisin (Belay et al., 2023). Magri et al. (2023) investigated the impact of edible coatings and the combination treatments containing CMC (1%), sodium alginate (1%), citric acid (1%), and oxalic acid (0.5%) on fresh-cut apple. Findings indicated that all the combination treatments enhanced the shelf-life of fresh-cut apple by retarding the qualitative postharvest deterioration, total soluble solids, and titratable acidity. Also, antioxidant activities and bioactive compounds of coated fresh-cut apples significantly increased. These coatings have shown promising results in reducing weight loss, delaying microbial decay, enhancing antioxidant enzyme activities, and regulating respiration rates, thus improving the overall quality and shelf life of the fruit. Additionally, incorporating active oxygen scavengers like ascorbic acid in chitosan-based coatings has been found to delay quality deterioration further and maintain fruit firmness (Wang et al., 2023). Fresh-cut apples are particularly vulnerable to enzymatic browning and microbial deterioration. Edible coatings have proven to be effective in prolonging their shelf life. Research has shown that coatings made from chitosan, pectin, and alginate can significantly curb enzymatic browning and microbial proliferation (Najafi Marghmaleki et al., 2021), resulting in a notable decrease in quality degradation. These coatings can also help retain moisture and maintain firmness, improving overall sensory attributes (Sanchís et al., 2017). Overall, edible coatings present a sustainable and effective method for preserving apples during storage and transportation.

Pear (*Pyrus communis*)

Various studies have investigated the application of edible coatings to enhance the quality and shelf life of pears. Research has shown that using composite coatings like sodium alginate with ginger oil can effectively control physiological and microbiological activities in fresh-cut pears, extending their shelf life significantly (Lamani & Ramaswamy, 2023). Lamani and Ramaswamy (2023) examined the impact of composite alginate and ginger essential oil-based edible coatings on the regulation of physiological and microbiological processes in fresh-cut pear during refrigerated storage. A solution consisting of 2% sodium alginate with 0.5% ginger oil as a natural antimicrobial agent was utilized as the coating material, while a 2% calcium chloride dip was employed for cross-linking and firming purposes. They found that both the coated fruits, with and without ginger oil, exhibited markedly superior preservation of product quality and absence of microbial spoilage for a duration of up to 15 days, in contrast to the control fruits, which experienced spoilage within a week. Additionally, the combination of edible coatings such as alginate or pectin with osmotic dehydration processes has been found to improve mass transfer kinetics, physicochemical parameters, and the retention of optical and mechanical properties in pear cubes (Campanone et al., 2024). In addition, the edible coating based on pectin combined with antibacterial and anti-browning agents effectively preserves fresh-cut pears, thereby improving quality characteristics and extending shelf life (Pleșoianu & Nour, 2022). They found that pectin coating delayed weight loss and improved the firmness of pears. Additionally, incorporating lemon peel essential oil into edible skin coatings made of chitosan and guar gum has been found to reduce weight loss, improve firmness, enhance antioxidant capacity, antibacterial efficiency, and overall acceptability of pears for up to 45 days at 4 ± 2°C (Iftikhar et al., 2022). Pears are known for their delicate texture and susceptibility to browning. Edible coatings, particularly those incorporating antioxidants like vitamin C and polyphenols, have been shown to control browning and microbial growth in fresh-cut pears effectively. Studies have reported that coatings based on chitosan, whey protein, and pectin can effectively extend the shelf life of pears, while maintaining their sensory quality (Mei et al., 2023). These findings highlight the effectiveness of edible coatings in preserving the quality and extending the shelf life of pear and its fresh-cut products.

Some examples regarding recent advances in the formulation and effects of edible coating for fresh/fresh-cut pome fruits are described in Table 1.

Table 1. Recent advances in application and effects of edible coating in temperate fresh/fresh-cut fruits (Pome fruits).

Fresh/fresh-cut fruit	Coating formulation	Outcomes	Reference
Apple	Carboxymethylcellulose, sodium alginate, citric acid, and oxalic acid	Combined coating inhibits flesh browning, maintains lower color changes, and improves antioxidant defense. Improved the shelf life of fresh-cut 'Annurca Rossa del Sud' apples.	(Magri et al., 2023)
Apple	Zein-nisin	Zein coating delayed weight loss on apples till day 21. Zein-nisin coating reduced yeast and mould.	(Belay et al., 2023)
Apple	Chitosan-based edible coating with ascorbic acid	Delayed deterioration, preserved firmness, moisture, and antioxidant enzyme activities in Custard apple.	(Wang et al., 2023)
Apple	Whey protein-based emulsion coating with transglutaminase and sunflower oil	Sunflower oil improves water resistance and mechanical properties. Whey protein-based emulsion coating treatment reduces weight loss and browning in fresh-cut apples.	(Xin et al., 2023)
Apple	Sodium alginate with Eugenia pyriformis leaf extract	Uvaia leaf extract reduced enzymatic browning in fresh-cut apples.	(Maldonado-Silva et al., 2020)
Apple	Nanochitosan	Reduced weight loss and moisture content. Preserved color, vitamin C, and antioxidants.	(Dasgupta & Mitra, 2024)
Pear	Edible coatings (alginate or pectin) combined with osmotic dehydration using glucose solution	Enhanced quality of pear cubes, improved weight reduction, water loss, and mechanical properties.	(Campanone et al., 2024)
Pear	Composite alginate-ginger oil	Extended the shelf-life of fresh-cut pears by controlling physiological and microbiological activities, enhanced product quality and preventing spoilage.	(Lamani & Ramaswamy, 2023)
Pear	Pectin-based edible coating combined with antimicrobials and antibrowning agents	Pectin coating delayed weight loss and improved firmness of fresh-cut pears.	(Pleșoianu & Nour, 2022)
Pear	Guar gum and chitosan-based edible coatings enriched with lemon peel essential oil	Improved pear quality by reducing weight loss, enhancing firmness, antioxidant capacity, and antibacterial efficiency during storage.	(Iftikhar et al., 2022)
Pear	Whey protein-based edible coatings with lemon or lemongrass essential oils	Improved the quality of fresh-cut pears by preserving color, firmness, and sensory attributes during storage at 4°C.	(Galus et al., 2021)
Pear	Edible coating based on carboxymethylcellulose, sodium alginate, oxalic and citric acid	Preserved and improved the antioxidant content, delayed browning, and retarded the senescence.	(Magri et al., 2024)

Edible coatings for stone fruits

Plum (*Prunus domestica*)

Various studies have explored the use of different edible coatings on plum fruit such as chitosan grape-seed-oil nanoemulsion, arrowroot starch films, starch-based materials with whey protein, CMC and pectin-based coatings, and gum arabic coatings (Zsivanovits et al., 2023; Basiak et al., 2022; Panahirad et al., 2020a, b). Zsivanovits et al. (2023) investigated the effect of chitosan grape-seed-oil nanoemulsion on freshly cut plum fruits (var. Stanley). Various properties, including physical, physico-chemical, microbiological, and sensorial aspects, were assessed over a 9-day refrigeration period. By the 4th day, the control samples had already deteriorated in terms of safety and quality. In contrast, the coated samples maintained their quality and safety until the end of the storage duration. While the chitosan-coated fruits exhibited reduced microbiological contamination, those coated with chitosan grape-seed-oil displayed elevated values in terms of sensorial characteristics. Furthermore, the coated samples retained around 80% of their sensorial attributes by the end of the 9th day. These coatings have shown positively affected on parameters like microbiological contamination, sensorial properties, water vapor permeability, firmness, antioxidant capacity, weight loss, and shelf life extension. The coatings have demonstrated abilities to reduce mass loss, delay fruit ripening, preserve firmness, improve total phenolic content, and alleviate shrivel, making them valuable for postharvest maintenance and preservation of plums. Plums are prone to microbial spoilage, mainly due to the presence of yeast and mold. Coatings based on alginate, chitosan, and CMC have been shown to effectively inhibit microbial activity, while also maintaining the firmness and color of the plum fruit (Panahirad et al., 2020a; Riva et al., 2020). Panahirad et al. (2020a) investigated the impact of edible coatings based on CMC and pectin on various characteristics of plum fruit during cold storage, including titratable acidity, firmness, vitamin C, total soluble solids, pH, total phenolics, anthocyanin, flavonoid contents, total antioxidant capacity (DPPH)), peroxidase (POD), polyphenol oxidase (PPO), and polygalacturonase (PG) enzyme activities, as well as weight loss. The findings indicated that the coatings, whether used individually or in combination, had positive effects on most parameters measured, excluding weight loss. These coatings helped maintain firmness, enhance total phenols, anthocyanin, flavonoid contents, antioxidant capacity, and POD activity. Moreover, TSS levels decreased, pH values remained relatively stable, and the coatings slowed down TA and vitamin C losses while reducing enzymatic activities like PPO and PG. Notably, the optimal outcomes for the majority of parameters were observed with 1% CMC or 1.5% Pectin individually, and the combination of 0.5% pectin and 1.5% CMC proved to be the most effective.

Peach (*Prunus persica*)

Research has shown that applying edible coatings such as gum arabic (GA) and polyvinylpyrrolidone (PVP) with salicylic acid (SA) can significantly inhibit degrading enzyme activities, reduce browning symptoms, and minimize tissue breakdown in peaches, extending their shelf life (Taher et al., 2022). Taher et al. (2022) blended GA and PVP with varying concentrations of salicylic acid (SA) (0, 1, and 2 mM) and utilized as a coating on peach fruits to prolong their shelf life. The fruits were then coated and kept at room temperature (26 ± 1 °C) with relative humidity (51 ± 1%) for duration of 10 days. Peach fruit coated with GA/PVP-SA 2 mM exhibited a notable reduction in the activities of degrading enzymes like lipoxygenase (LOX), cellulase (CEL), and pectinase (PT) in comparison to both uncoated and coated fruits throughout the storage period. This led to the maintenance of cell wall compartments, consequently reducing browning symptoms by inhibiting the activities of polyphenol oxidase (PPO) and phenylalanine ammonia-lyase (PAL). Additionally, there was a decrease in lipid peroxidation and ionic permeability. The findings indicate that the application of GA/PVP-SA 2 mM as an edible coating can help minimize fruit tissue breakdown, thereby extending the shelf life of peaches by up to 10 days without any signs of tissue breakdown.

Additionally, coatings based on aloe arborescens and 1-methylcycyclopropene (1-MCP) have been effective in preserving the quality of white flesh peaches by slowing down maturation processes, limiting weight loss, and maintaining sensory characteristics (Sortino et al., 2020). Furthermore, a combination of chitosan and thymol is more effective in preserving peach quality, reducing weight loss, fungal decay, and maintaining firmness, anthocyanin, carotenoid content, and sensory attributes, thus extending the fruit's shelf life (Rahimi et al., 2019). Peaches are highly susceptible to enzymatic browning, which significantly affects their appearance and quality. Edible coatings containing antioxidants, such as vitamin C and polyphenols, effectively controlled browning in fresh-cut peaches. A recent review has also shown that application of different edible coatings can improve moisture retention and reduce microbial growth, contributing to a longer shelf life in fresh peaches (Aaqil et al., 2024). These studies collectively highlight the potential of edible coatings in enhancing the postharvest quality and prolonging the shelf life of peaches.

Sweet cherry (*Prunus avium*)

Recent studies have highlighted the benefits of different edible coatings on sweet cherries. For instance, natural edible coatings containing galbanum gum and cumin essential oil helped maintain phenolic compounds and antioxidants, enhancing the fruit's health-promoting phytochemicals and shelf life (Asghari et al., 2022). The application of edible chitosan coating was effective in maintaining total phenolics, and enhancing antioxidant enzymatic activities in sweet cherries (Hu & Feng, 2022). They examined the impact of applying edible chitosan coating (0.1, 0.3, 0.5, and 0.75% w/v) on the quality, respiration rate, total phenolic content, and anthocyanin changes in postharvest sweet cherry at 10 °C. Findings revealed that the use of chitosan edible coating effectively delayed the progression of postharvest ripening-related parameters, such as color, firmness, and respiration rate. It was recommended that optimal quality and improved antioxidant enzymatic activities in postharvest cherry fruits were achieved by applying an edible chitosan coating of 0.5% for up to 24 days at 10 °C. Using chitosan edible coating could be advantageous in prolonging shelf-life and preserving the quality of sweet cherries. Furthermore, carboxymethyl chitosan-gelatin-based coatings incorporating $CaCl_2$ and ascorbic acid preserved the quality and nutritional characteristics of sweet cherries, reducing decay and improving various parameters like firmness, acidity, and antioxidant capacity (Zhang et al., 2021). Also, in a study an edible nanoemulsion coating of alginate and soybean oil with $CaCl_2$ cross-linker utilized on sweet cherries (Gutiérrez-Jara et al., 2021). The results showed that nanoemulsion and $CaCl_2$ coating increased firmness and nutritional values and reduced fruit cracking by 53%. Edible coatings have been investigated to reduce microbial growth and extend the shelf life of cherries. A recent study has shown that coatings based on chitosan and aloe vera gel, combine with extractions of some medicinal plants can effectively inhibit microbial activity and maintain the nutritional quality of cherries during cold storage (Afonso et al., 2023).

Apricot (*Prunus armeniaca*)

Coatings containing chitosan nanoparticles (CHNPs) have been found to reduce weight loss, decay, and lipid peroxidation in stored apricots, ultimately extending their shelf life (Algarni et al., 2022). The sensory evaluation results showed that there was a significant difference in the overall acceptance scores between the CHNPs-treated samples and the other samples.

They indicated that chitosan nanoparticles treatment improved apricot quality, and extended shelf-life up to 30 days in cold storage and nine days at room temperature (Algarni et al., 2022). Furthermore, coatings with gum arabic have demonstrated effectiveness in preserving the physicochemical characteristics, texture, and antioxidant activity of fresh apricots during refrigerated storage for 12 days (Wani et al., 2019). Dorostkar et al. (2022b) investigated the effect of different postharvest calcium salt treatments on apricot fruit. They found that calcium chloride and calcium nitrate dipping treatments significantly preserved quality and reduced the decay of apricot fruit compared to control samples during cold storage. Also, soybean protein isolate-chitosan edible coating effectively reduces weight loss, maintains firmness, and inhibits pectin degradation in apricots, to enhance their shelf life and quality during storage at 2°C (Zhang et al., 2018). Apricots are susceptible to enzymatic browning and microbial spoilage, leading to a short shelf life for fresh-cut fruits. Edible coatings have been explored as a potential solution to address these issues. Coatings based on pectin, cellulose, bees wax, and alginate have shown promise in controlling microbial growth, extending the shelf life of apricots and maintaining their sensory quality (Kefayatullah & Wahab, 2023). However, among edible coating applied, bees wax 2% treatment had lower decay and chilling injury during 28 days of cold storage at 5 °C. These findings highlight the potential of edible coatings in enhancing the preservation and quality of apricots.

Some examples regarding recent advances in the formulation and effects of edible coating for fresh/fresh-cut stone fruits are described in Table 2.

Table 2. Recent advances in application and effects of edible coating in temperate fresh/fresh-cut fruits (Stone fruits).

Fresh/fresh-cut fruit	Coating formulation	Outcomes	Reference
Plum	Chitosan grape-seed-oil nanoemulsion	Coating enhanced postharvest quality of fresh-cut plums, preserving safety, quality, and sensorial parameters for up to 9 days during refrigerated storage.	(Zsivanovits et al., 2023)
Plum	Wheat starch and wheat starch-whey protein	Enhanced firmness and reduced weight loss.	(Basiak et al., 2022)
Plum	Polysaccharide-based edible coatings, like carboxymethylcellulose and pectin	Enhanceed postharvest quality of plums by preserving firmness, antioxidants, and enzyme activities.	(Panahirad et al., 2020a)
Plum	Pectin-based edible coating	Preserved antioxidative capacity, including ascorbic acid and phenolic compounds, enhanced fruit quality and shelf life.	(Panahirad et al., 2020b)
Plum	Carboxymethylcellulose-based edible coating	Improved plum fruit quality by maintaining firmness, acidity, antioxidants, and enzyme activities, enhancing shelf life and preserving qualitative properties.	(Panahirad et al., 2019)
Peach	Gum Arabic and Polyvinylpyrrolidone with Salicylic Acid	Reduced tissue breakdown, maintained cell wall integrity, and extended shelf life up to 10 days.	(Taher et al., 2022)
Peach	Aloe arborescens edible coating, alone or combined with 1-MCP	Extended the shelf life of white peach fruit by preserving quality attributes and sensory characteristics during storage.	(Sortino et al., 2020)
Peach	Chitosan and thymol essential oil	Maintained peach quality and extended shelf life, Combination had superior preservation effects compared to individual coatings.	(Rahimi et al., 2019)

Peach	Chitosan coatings incorporated with seabuckthorn leaf extract	Increased the antioxidant potential and controlled the browning up to 25 days under refrigerated temperature at 4 °C.	(Rather et al., 2024)
Sweet cherry	Galbanum gum and cumin essential oil	Effectively preserved sweet cherry quality, maintaining phytochemicals and antioxidants, enhancing shelf life and health benefits.	(Asghari et al., 2022)
Sweet cherry	Chitosan	Delayed ripening, maintained quality, and enhanced antioxidant enzymatic activities, extending shelf life.	(Hu & Feng, 2022)
Sweet cherry	Carboxymethyl chitosan-gelatin coating with $CaCl_2$ and ascorbic acid	Improved quality, reduced decay, and maintained nutritional properties of different sweet cherry cultivars during postharvest storage.	(Zhang et al., 2021)
Sweet cherry	Nanoemulsion of alginate and soybean oil with $CaCl_2$ cross-linker	Reduced cracking, enhanced firmness, and maintained quality parameters postharvest.	(Gutiérrez-Jara et al., 2021)
Sweet cherry	Nano-emulsion coatings containing hydroxypropyl methylcellulose (HPMC), beeswax (BW), and essential oils (thyme, cinnamon, clove, and peppermint)	Maintained quality attributes such as TSS, color, weight loss, respiration rate, firmness, total phenolic contents, and sensory evaluations.	(Iqbal et al., 2024)
Sweet cherry	Chitosan and aloe vera gel, combine with extractions of some medicinal plants	Inhibited microbial activity and maintained the nutritional quality of fruit	(Afonso et al., 2023)
Apricot	Chitosan nanoparticles	Improved apricot quality, reduced decay, and extended shelf-life up to 30 days in cold storage and 9 days at room temperature.	(Algarni et al., 2022)
Apricot	Edible coating with gum arabic	Enhanced apricot shelf life and improved physicochemical characteristics, texture, and antioxidant activity during refrigerated storage for 12 days.	(Wani et al., 2019)
Apricot	Soybean protein isolate-chitosan edible coating	Reduced weight loss, maintained firmness, and inhibited pectin degradation in apricots, enhanced shelf life during storage at 2°C.	(Zhang et al., 2018)
Apricot	Coatings based on pectin, cellulose, bees wax, and alginate	Controlled microbial growth, extended the shelf life of apricots and maintained sensory quality	(Kefayatullah & Wahab, 2023)

Edible coatings for small fruits

Strawberry (*Fragaria × ananassa*)

Research has shown that coatings such as chitosan, beeswax, moringa leaf extract, aloe vera gel, ascorbic acid, oxalic acid, Arrayan extract, essential oils, and Carnauba wax can effectively improve the quality and shelf life of strawberries by reducing weight loss, enhancing firmness, decreasing respiration rate and ethylene production, improving biochemical quality parameters, inhibiting microbial growth, and increasing antioxidant activity (Álvarez-Barreto et al., 2023; Shafique et al., 2023; Topno, 2024). Álvarez-Barreto et al. (2023) investigated the impact of different concentrations of Carnauba wax (0, 0.3, and 0.4% w/v) and aloe vera gel (0, 30, and 45% v/v) coatings on the quality and shelf life of strawberry fruit. They found that the treatment with the highest concentration of the two ingredients produced the lowest changes in weight loss, pH and ripeness index, as well as the lowest values of the *Botrytis cinerea* severity index. The coated fruit were not significantly different from uncoated samples and were well and scored acceptable by panelist from an organoleptic viewpoint. Zein nano-fiber film loaded with thyme essential oil significantly decreased weight loss and preserved the anthocyanin content, firmness and color of the strawberries, and reduced decay during cold storage (Ansarifar & Moradinezhad, 2022). Stored fruit in packages containing zein nanofiber significantly lowered microbial load, and maintained the total phenols and antioxidant activity of the strawberries during 15 days of storage at 4 °C (Ansarifar & Moradinezhad, 2021). The effect of essential oil concentrations from tangerine peel incorporated in sodium alginate-based edible coatings on physical properties was investigated (Utami et al., 2023). Sodium alginate-based edible coatings containing different concentrations of essential oil from tangerin peel significantly affected strawberry quality in all parameters including color, hardness, total dissolved solids content, and weight loss during storage at refrigerator temperature (Utami et al., 2023). These coatings have been found to maintain fruit quality, prevent decay and spoilage, and exhibit high consumer acceptance. Strawberries are highly perishable and prone to microbial spoilage and decay. Edible coatings have been widely investigated to extend the shelf life of fresh-cut strawberries. Recent reviews regarding edible coatings based on chitosan and pectin have shown effectiveness in inhibiting microbial growth, reducing moisture loss, extending the shelf life, and maintaining the firmness and color of the strawberries (Moghadas et al., 2024; de Albuquerque Sousa et al., 2024). Using these edible coatings at optimal concentrations, strawberries can be preserved for longer periods, ensuring that this nutrient-rich fruit remains fresh and appealing for consumption.

Grapes (*Vitis vinifera*)

Edible coatings for grapes have been extensively studied for their ability to extend shelf life and maintain quality. Various materials like propolis and aloe vera gel, grape seed tannins, hydroxypropylmethylcellulose, and kappa carrageenan, grape pomace extract combined with polyvinyl alcohol, and a mixture of alginate, galactomannans, cashew gum, and gelatin have been explored (Aljabary, 2024; de Souza et al., 2021; Lo'ay et al., 2021). In the research conducted by de Souza et al. (2021), the effect of edible coatings on the overall physicochemical makeup of phenolic content and antioxidant properties was assessed. The edible coatings, which included alginate (2%), galactomannans (0.5%), cashew gum (0.5%), and gelatin (2.0%), minimized weight loss in grapes while maintaining their hardness and color quality after nine days of storage in comparison to the control group. Furthermore, this formulation enhanced the levels of phenolic compounds, thereby boosting the significant antioxidant capacity of the coated grapes. Chitosan–zinc oxide nanoparticles and essential oil coatings improved grape quality by reducing microbial contamination, enhancing catalase activity, and maintaining the freshness of grapes (Kadi, 2023). These coatings have shown promising results in reducing weight loss, delaying decay, enhancing firmness, and improving antioxidant properties, ultimately extending the storability of grapes. The use of edible coatings not only provides a protective barrier against microbial growth but also offers health benefits and preserves the sensory attributes of the fruit. Fresh grapes are susceptible to microbial growth and dehydration, leading to a short shelf life (Lo'ay et al., 2021). Edible coatings have been studied as a means to enhance the storage stability of grapes. Coatings based on chitosan, pectin, and alginate have shown promise in reducing microbial activity, inhibiting moisture loss, and maintaining the quality of grapes during storage (Moreira et al, 2023). Overall, edible coatings present a novel and effective approach to enhancing the postharvest quality and shelf life of grapes, potentially revolutionizing the fruit preservation industry.

Kiwi fruit (*Actinidia deliciosa*)

Recent studies have explored different edible coating materials and their effects on the quality and preservation of kiwifruit. For instance, CMC and aloe vera gel coatings have shown positive results in improving microbial properties and sensory attributes of fresh-cut kiwi fruit slices, enhancing their overall quality (Nikhil & Topno, 2023). Additionally, incorporating thymol-halloysite nanohybrids into chitosan biopolymer films has demonstrated enhanced antimicrobial and antioxidant activities, leading to prolonged preservation and shelf life of kiwi fruits (Salmas et al., 2022). Furthermore, coatings with mucilage from Opuntia ficus-indica or aloe arborescens have been found to reduce weight loss, microbial spoilage, and improve firmness in fresh-cut kiwifruits, highlighting their potential for shelf-life extension (Sortino et al., 2022). Moreover, nanoemulsion coatings with antioxidant and antimicrobial agents, including alginate, CMC, ascorbic acid, and vanillin, improved the shelf life of fresh cut kiwi slices by delaying decay, weight loss and microbial growth (Manzoor et al., 2021). Innovations like alginate coatings functionalized with hop extracts have also proven effective in preserving the quality and nutraceutical traits of fresh-cut kiwifruit during cold storage, further emphasizing the importance of edible coatings in maintaining fruit freshness and marketability (Carbone et al., 2021). However, Xanthan gum enhanced the shelf life and maintained the quality of fresh-cut kiwi slices compared to alginate- and chitosan-coated treatments (Guroo et al., 2021). Kiwis are known for their delicate texture and susceptibility to enzymatic browning. In general, edible coatings have demonstrated effectiveness as a potential solution to extend the shelf life of fresh-cut kiwis, inhibiting microbial growth and maintaining the quality of fruit.

Some examples regarding recent advances in the formulation and effects of edible coating for fresh/fresh-cut small fruits are described in Table 3.

Table 3. Recent advances in application and effects of edible coating in temperate fresh/fresh-cut fruits (Small fruits).

Fresh/fresh-cut fruit	Coating formulation	Outcomes	Reference
Strawberry	Chitosan and Beeswax	Reduced weight loss and maintained Vitamin C.	(Topno, 2024)
Strawberry	Moringa leaf extract, aloe vera gel, oxalic acid, and ascorbic acid	Improved strawberry quality, reduced weight loss, enhanced firmness, and increased antioxidant content during storage.	(Shafique et al., 2023)
Strawberry	Aloe Vera Gel and Carnauba Wax microparticles	Reduced weight loss, maintained ph, and inhibited *Botrytis cinerea* growth.	(Álvarez-Barreto et al., 2020)
Strawberry	Zein nano-fiber film loaded with thyme essential oil	Decreased weight loss and preserved the anthocyanin content, firmness and color, and reduced decay during cold storage	(Ansarifar & Moradinezhad, 2022)
Grape	Propolis and aloe vera gel	Preserved Thompson Seedless grapes' quality during cold storage, delayed deterioration and potentially extended storability up to 30 days at 5°C.	(Aljabary, 2024)
Grape	Alginate, galactomannans, cashew gum, and gelatin	Enhanced shelf-life of 'Italia' grapes by reduced weight loss, maintained firmness, color, and increased antioxidant properties.	(de Souza et al., 2021)
Grape	Composite coating of pectin, polyphenylene alcohol, and salicylic acid	Improved the quality and shelf life of 'Crimson Seedless' grapes by reducing weight loss, browning, and cell wall damage.	(Lo'ay et al., 2021)
Grape	Chitosan–zinc oxide nanoparticles and essential oil	Improved grape quality by reducing microbial contamination, enhancing catalase activity, and maintaining fruit freshness.	(Kadi, 2023)
Kiwi fruit	Carboxymethyl cellulose and aloe vera gel	Fresh-cut kiwi, with aloe vera gel 30% showing the best results in microbial analyses and sensory attributes.	(Nikhil & Topno, 2023)
Kiwi fruit	Thymol-halloysite nanostructures in chitosan/polyvinyl alcohol gels	Enhanced fruit preservation by improving antimicrobial, antioxidant, mechanical, and barrier properties, extending shelf life.	(Salmas et al., 2020)
Kiwi fruit	Opuntia ficus-indica and aloe arborescens mucilage	Enhanced kiwifruit shelf life by reducing weight loss and microbial spoilage, improving firmness, pectin content, and visual quality.	(Sortino et al., 2022)
Kiwi fruit	Nanoemulsion coatings with antioxidant and antimicrobial agents, including alginate, carboxymethylcellulose, Tween 80, ascorbic acid, and vanillin,	Improved the shelf life of fresh cut kiwi slices by delaying decay and microbial growth.	(Manzoor et al., 2021)
Kiwi fruit	Alginate coatings functionalized with hop extracts	Preserved the quality and nutraceutical traits of fresh-cut kiwifruit during cold storage.	(Carbone et al., 2021)

Future directions and challenges

Incorporating antimicrobial elements, antioxidants, or enzymes into active coatings could provide enhanced protection against microbial spoilage, oxidative decay, and physiological decline. This requires investigating natural and synthetic active components that can be smoothly integrated into the coating structure. It's crucial to ensure that consumers accept edible coatings for successful implementation. However, using edible coatings poses challenges in terms of production, storage, and large-scale usage while maintaining consumer acceptance, food safety, nutrition, and shelf life extension (Kumar et al., 2023). Edible films based on polysaccharides and proteins encounter difficulties with their poor water and gas barrier properties, requiring the addition of plasticizers, emulsifiers, and other components to enhance their mechanical and thermal resistance. Moreover, increased levels of biopolymers and active components like essential oils and plant extracts can negatively influence the flavor of the produce, directly impacting consumer satisfaction. This is also associated with the potential harm of these substances. Lastly, there are minimal safety and regulatory standards regarding the levels of active ingredients in edible coatings. Therefore, it is crucial to raise consumer awareness and establish regulations regarding the benefits of edible coating for both the environment and consumers to address consumer acceptance challenges on a large-scale commercial level.

CONCLUSION

Edible coatings have emerged as a promising strategy for extending the shelf life of temperate fresh/fresh-cut fruits, including apple, pear, plum, peach, cherry, apricot, strawberry, grape, and kiwi. The specific composition and application of these coatings play a crucial role in their effectiveness in inhibiting microbial growth, reducing enzymatic browning, and maintaining the sensory quality of the fruits. Further research is needed to optimize the use of edible coatings for specific fruit types and to develop innovative solutions that address the challenges associated with extending shelf life and maintaining freshness.

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