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Edible coating application and its effects on tropical and citrus fresh/fresh-cut fruits: a review

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ABSTRACT

Purpose: In recent years, tropical and citrus fruits have become increasingly important in global fruit production. However, postharvest fruit loss due to spoilage and decay remains a significant challenge, impacting the global food supply chain. Owing to their perishable nature, horticultural products can experience losses of approximately 20–40% during postharvest handling and storage. **Findings:** Tropical and subtropical fruits are important commodities that play a significant role in human nutrition and health. Citrus fruits, bananas, mangoes, papaya, and pineapples are among the main traded tropical and subtropical fruits worldwide. Edible coatings have emerged as a sustainable solution to extend the shelf life, improve the quality of fruits and reduce postharvest losses. They are environmentally friendly and meet consumer preferences for natural, safe, and healthy food products. The exact composition and application of these coatings are crucial for determining their ability to prevent microbial growth, reduce enzymatic browning, and maintain the sensory properties of fruits. Additionally, incorporating nanotechnology into edible coatings has the potential to enhance their properties, such as improved barrier functions, regulated release of active substances, and increased antimicrobial capabilities. Recent progress regarding the influence of edible coatings is emphasized in this review, demonstrating how they contribute to extending shelf life, maintaining quality, and minimizing postharvest losses of important tropical and citrus fresh/fresh-cut fruits on a global scale. **Limitations:** There were no limitations. **Directions for future research:** Despite their potential, challenges in production, storage, and commercial-scale usage exist, requiring continuous research and innovation. Overall, edible coatings show promise in reducing postharvest losses and promoting sustainable agricultural practices on a global scale.

INTRODUCTION

Tropical and subtropical fruits hold a unique position in agriculture globally. Developing countries are responsible for more than 90% of tropical fruit production. This often means dealing with inadequate infrastructure, unreliable power sources, and relying more on basic storage methods. Furthermore, the supply chain for these fruits is complex and involves various handlers before they reach consumers. These challenges add stress to fruits that are already more perishable than those from temperate climates (Yahia, 2011). Tropical and subtropical fruits are important commodities that play a significant role in human nutrition and health. Citrus fruits, bananas, mangoes, papaya, and pineapples are among the main traded tropical and subtropical fruits. However, açai, lychee, mamey, passion fruit, and jackfruit are some tropical fruits that are consumed less often due to their low commercial production. Unlike highly consumed fruits, these less-consumed tropical fruits are not extensively traded but are cultivated and consumed mainly locally or regionally (Belmonte-Herrera et al., 2022). Certain regions have a long history of incorporating tropical fruits into their diets. Although some people are just beginning to discover tropical fruits, they have been dietary staples for many cultures for generations.

Owing to their perishable nature, horticultural products can experience losses of approximately 20–40% during postharvest handling and storage. Fruit losses globally exhibit concerning statistical trends, with approximately one-third of food produced being lost or wasted along the supply chain, highlighting the significant impact on food security and sustainability (Blanckenberg et al., 2022). In developing countries, postharvest losses for fruits can reach between 40% and 50%, underscoring the challenges faced in reducing these losses (Silveira et al., 2021). Freshly harvested horticultural products quickly lose their freshness, impacting their marketability. Additionally, tropical and subtropical fruits are highly perishable, susceptible to a range of physiological and microbial deterioration processes, and prone to mechanical damage during harvesting, transportation, and storage (Kader, 2013). Thus, the horticultural industry has sought new methods to regulate ripening and extend shelf-life. Common techniques, such as cold storage and modified atmosphere storage, are used to extend the shelf-life of horticultural products. However, most tropical fruits and many subtropical fruits can be stored for only short periods of time (few days to few weeks), whereas certain fruits can be stored for longer periods (such as oranges, some types of table grapes, nuts, and dried fruits) (Kader & Yahia, 2011). The main postharvest issues that impact tropical and subtropical fruits are chilling injury, decay, and insect damage.

Edible coatings have become recognized as a viable solution for prolonging the shelf-life of fruits, thereby reducing food waste and losses incurred postharvest. These coatings, which are composed of biodegradable natural polymers, are applied as thin layers on food surfaces to increase quality, extend shelf-life, and mitigate postharvest losses (Perez-Vazquez et al., 2023). The primary classifications utilized in the production of edible coatings include polysaccharides such as pectin, starch, gums, alginate, chitosan, cellulose, proteins such as gelatin, egg albumin, wheat gluten, zein, whey protein, casein, soy protein, and lipid compounds such as fatty acids and waxes (Aaqil et al., 2024). Through the incorporation of essential oils or nanoparticles, edible coatings can further enhance their physicochemical properties and offer antioxidant or antimicrobial effects (Ansarifar & Moradinezhad, 2022; Moradinezhad et al., 2023; Kanwar et al., 2024). The adoption of edible coatings not only aligns with environmental sustainability but also meets consumer preferences for natural, safe, and minimally processed food products.

In this paper, a review of recent progress (2018-2024) regarding the application of edible coatings and their impact on the postharvest life of main tropical and citrus fruits is presented, highlighting the importance of preserving tropical and citrus fresh/fresh-cut fruits, prolonging shelf life and protecting them from spoilage via novel techniques.

Edible coatings, mechanism of action and applications in the food industry

Edible coatings serve as a protective barrier that separates the fruit from its surrounding environment, playing a significant role in various physiological and biochemical processes that contribute to fruit preservation. These processes involve complex interactions of factors that ultimately lead to prolonged shelf-life, decreased decay, and enhanced quality attributes (Firdous et al., 2023).

Edible coatings play a vital role in preventing moisture loss from fruits during storage by creating a semipermeable barrier that controls the rate of water vapor diffusion from the fruit to the surrounding atmosphere. The ability of a coating to retain moisture is dependent on its composition, thickness, and humidity of the storage environment (Pham et al., 2023). Coatings containing polysaccharides such as pectin and alginate are effective at retaining moisture due to their hydrophilic properties, forming a gel-like structure that prevents dehydration and maintains fruit turgor, texture, and appearance.

The composition and structure of edible coatings impact the permeability of gases such as oxygen and carbon dioxide, which are essential for fruit respiration and ripening processes. Certain coatings, such as those made from hydrophobic polymers such as zein, act as barriers to oxygen diffusion, slowing respiration and delaying ripening processes. This controlled gas exchange helps regulate oxygen levels for respiration while reducing the accumulation of ethylene, a ripening hormone that accelerates fruit senescence (Liyanapathiranage et al., 2023).

Edible coatings also offer an effective defense against microbial contamination, a significant cause of fruit spoilage. Some coating materials, such as chitosan, possess antimicrobial properties that combat fungi. Additionally, coatings can create an unfavorable environment for microbial growth by modifying pH levels, oxygen availability, and nutrient content around the fruit surface (Leite et al., 2023). This antimicrobial action inhibits the proliferation of bacteria, yeasts, and molds, extending fruit shelf-life and decreasing spoilage.

The thin layer of edible coating is designed to be consumed, protecting food from damage during storage. Using standardized ingredients, edible coatings are created to increase food safety, quality, and nutrient content while extending shelf-life and minimizing gas exchange. Various techniques, such as dipping, spraying, brushing, and vacuum impregnation are involved in edible coating technology (Andriani & Handayani, 2023). Nevertheless, when it comes to the application of edible coatings on fruits, the dipping and spraying methods are frequently utilized (Fig. 1). Specific parameters, such as color, firmness, weight loss, and nutritional value, are tailored according to the product type and storage conditions, allowing for precise monitoring.

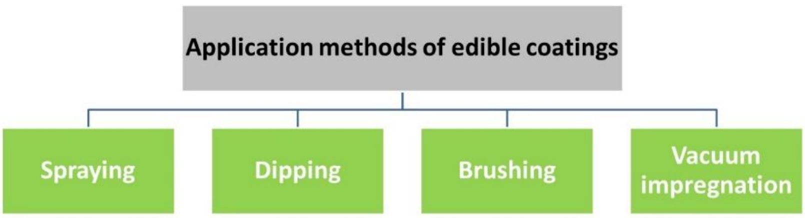

Fig. 1. Different application methods of edible coatings to fresh produce.

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 food preservation, as described in previous reviews (Paidari et al., 2021; Priya et al., 2023; Andriani & Handayani, 2023).

Polysaccharide-based coatings:

- Good gas and aroma barrier
- Poor moisture barrier (due to hydrophilic nature)
- Film-forming capability
- Biodegradable and generally recognized as safe (GRAS)

Examples of polysaccharide-based coatings are as follows:
Starch, used for fruits, vegetables, and baked goods. Reduces respiration rate and maintains firmness. Cellulose derivatives (e.g., methylcellulose, hydroxypropyl methylcellulose), Provide flexible and transparent films; used on confections and fresh produce. Alginate, forms strong gels in the presence of calcium; used on cut fruits, vegetables, and seafood. Pectin, Gel-forming agent used in fruit and candy coatings; helps retain moisture and flavor. Chitosan, exhibits natural antimicrobial properties; applied to meats, fruits, and vegetables to inhibit microbial growth.

Protein-based coatings:

- Excellent oxygen and aroma barrier
- Moderate to poor moisture barrier
- Good mechanical strength and flexibility
- Potential for allergenicity (e.g., soy, milk proteins)

Some examples of protein-based coatings are as follows:
Whey protein, transparent, strong films used on nuts, fruits, and dairy items; excellent oxygen barrier. Casein, forms smooth films for bakery and dairy products; helps maintain freshness. Gelatin, flexible, transparent films with good adhesion; applied to meats and confectioneries. Soy protein, offers good mechanical properties; used for fruits, vegetables, and cereal products. Zein, hydrophobic and moisture resistant; used in nuts, candies, and pharmaceutical coatings.

Lipid-based coatings:

- Excellent moisture barrier
- Poor gas barrier
- Hydrophobic nature
- Often brittle and used in combination with other materials

Examples of lipid-based coatings are:
Waxes, (e.g., beeswax, carnauba wax), commonly used to coat fruits like apples and citrus to reduce water loss and enhance appearance. Fatty acids and glycerides, used to control moisture migration in baked goods and fresh produce. Lecithin and other emulsified lipids, improve distribution and functionality in multilayer systems; used in processed foods and meats.

Composite and multilayer coatings:

- Combine functional benefits of two or more materials
- Enhanced mechanical, barrier, and bioactive properties
- Can be customized for specific applications

Some examples of composite and multilayer coatings are:
Chitosan + beeswax, combines antimicrobial activity with moisture barrier properties; used in seafood and meats. Whey protein + fatty acids, improved oxygen and moisture control; used in cheese and processed foods. Polysaccharide + essential oils, dual function of preservation and sensory enhancement in fruits and vegetables.

Edible coating application and its effects on main tropical and citrus fresh/fresh-cut fruits

Banana (*Musa paradisiaca*)

Bananas are climacteric fruits that are rich in nutrients and have high ethylene production and respiration rates at harvest and postharvest stages (Moradinezhad et al., 2008). The primary causes of banana losses during transportation and storage include mechanical damage, improper transport, improper storage, fruit rot, and improper ripening (Gemechu et al., 2021). Mechanical damage, especially from impact forces during handling, can significantly reduce the quality of bananas, leading to weight loss, firmness reduction, and color changes. Improper transport and storage practices exacerbate these losses, with chilling injuries observed at lower temperatures and accelerated transpiration rates at higher temperatures (Al-Dairi et al., 2023). Additionally, fruit rot due to improper ripening techniques contributes to postharvest losses, emphasizing the need for better management operations, awareness creation, education, and training on proper handling practices to minimize losses in the banana supply chain (Kumar et al., 2018). Various studies have explored the use of edible coatings to increase the shelf-life of bananas. Research has shown that coatings made from carboxymethyl cellulose incorporated with citronella oil can significantly reduce weight loss in bananas during storage (Kamar & Yunihharni, 2023). Additionally, a combination of aloe vera, starch, and Arabic gum has been found to prolong the shelf-life of bananas by slowing chlorophyll degradation, leading to loss of firmness, weight loss, and the synthesis of total soluble solids (Tchinda et al., 2023). Furthermore, the application of carrageenan edible coatings has been shown to reduce weight loss and total soluble solids in bananas, indicating an inhibitory effect on the ripening process (Pamungkas et al., 2023). Similarly, Alhassan and Ndomakaah (2024) reported that a 25% Aloe vera gel coating reduced weight loss, delayed TSS and TA changes, minimized decay and maintained the quality of Lantundan and Cavendish bananas. These findings collectively suggest that utilizing edible coatings, whether incorporating essential oils or natural compounds, can be an effective strategy to prolong the postharvest quality and shelf life of bananas.

Lemon (*Citrus limon*)

Preharvest factors such as production locations, pest attacks, diseases, and harvest methods significantly influence the postharvest losses of citrus fruits such as lemon and lime (Khan et al., 2022). Research has shown that incorporating herbal extracts such as lemongrass, oregano, and cinnamon in edible coatings can effectively prevent water loss, delay oxidative browning, and reduce microbial growth in fruits such as lemons (Nasrin et al., 2023). Moreover, applying chitosan coatings with clove oil to fresh-cut lemon fruits has been found to significantly reduce weight loss, maintain vitamin C content, and increase hardness during storage (Li et al., 2020). Furthermore, the use of irradiated cassava starch as an edible coating on lemons has been shown to reduce weight loss, enhance fruit appearance, and improve chemical constituents such as titratable acidity and ascorbic acid content (Mounir, 2022). Furthermore, Kaur et al. (2022) investigated the impact of beeswax enriched with a sodium nitropride coating on lemon fruit during cold storage. These authors reported that coating significantly reduced weight loss and maintained the high antioxidant activity and quality of the lemon fruit. These findings collectively highlight the diverse approaches and benefits of using edible coatings to improve the storage and quality of lemons.

Lime (*Citrus aurantiifolia*)

Postharvest research on lemon fruit revealed that microbial assessments of lemon fruits during postharvest handling stages reveal an increase in microbial load, especially during transportation, highlighting the need for improved handling practices and the use of new technologies to minimize losses (Makavana et al., 2018). Edible coatings, such as pectin-based coatings and chitosan coatings incorporating plant extracts such as cashew leaves, have been studied for their ability to increase the quality and shelf-life of lime fruits (Maftoonazad & Ramaswamy, 2019). These coatings reduce weight loss; maintain firmness, color, and vitamin C content; and exhibit antimicrobial properties against pathogens such as *Aspergillus niger*, thus improving overall fruit quality and extending storage life (Maftoonazad & Ramaswamy, 2019; Shiekh et al., 2022). Additionally, lime fruits coated with chitosan combined with cashew leaf extracts presented increased antioxidant activities and decreased disease incidence, highlighting the potential of natural antifungal agents in agricultural produce (Shiekh et al., 2022). Moreover, Wijewardane (2022) examined the effects of mixed wax of palm oil, glecerol, sorbitan monooleate, and guar gum edible coatings on lime quality and shelf-life. They reported that compared with the control, mixed coating wax significantly improved the overall quality of lime fruit and reduced decay. When designed correctly, edible coatings can effectively control decay, delay ripening, and enhance the health benefits of fruits such as limes.

Mandarin (*Citrus reticulata*)

The qualitative and quantitative postharvest loss of mandarin, which impacts both fruit quality and marketability, is a significant concern in most production regions. Recent research has shown that edible coatings such as cellulose nanofibers, CMCs, gellan-based edible coatings with oregano essential oil, sodium alginate, ylang-ylang oil, and cellulose nanocrystals exhibit significant antifungal properties, effectively combating pathogens such as *Botrytis cinerea* (Liguori et al., 2024; Nkede et al., 2024). Additionally, incorporating oregano essential oil in edible coatings has been found to minimize weight loss, water loss, and microbial growth, particularly in molds, thereby enhancing the overall preservation of mandarin fruits (Liguori et al., 2024). Wigati et al. (2023) explored how an edible coating made of pregelatinized cornstarch, basic essential oil, and cellulose nanofibers affected mandarin fruit. These findings indicated that the combined use of pregelatinized corn starch and basic essential oils could be enhanced to preserve the quality of mandarin fruit. Additionally, the treatments with cellulose nanofibers showed promise in extending the shelf-life of mandarin fruit. Nasrin et al. (2018) examined the effects of different natural materials, such as liquid paraffin wax, chitosan, and coconut oil, on the postharvest quality of mandarin. They reported that 100% coconut oil reduced weight loss and the respiration rate and improved fruit quality. These findings collectively highlight the potential of edible coatings in enhancing the postharvest quality and safety of mandarin fruits through their antimicrobial and preservation properties.

Mango (*Mangifera indica*)

Mango postharvest losses are a significant concern, mainly due to the susceptibility of mango fruit to pathogens such as *Colletotrichum*, *Aspergillus*, *Alternaria*, and Botrytis, leading to losses ranging from 5–30% of production (Moreno-Hernández et al., 2024). Various methods, including cold storage and edible coatings, help reduce losses and prolong shelf-life. Edible coatings, such as those made from herbal extracts such as palm oil, oregano, and aloe vera combined with gum Arabic, have been proven to enhance the quality and shelf life of mangoes by reducing water loss, controlling ripening, and inhibiting microbial growth (Désiré et al., 2023; Susetyo et al., 2023). Coatings based on cassava starch, coconut fiber, and Garcinia kola oil have also been shown to be effective at preserving mango quality attributes, including reducing weight loss and maintaining firmness and vitamin C content during storage (Désiré et al., 2023). Additionally, coatings using palm oil derivatives have successfully increased the freshness of Arumanis mangoes by suppressing weight loss and controlling respiration rates (Susetyo et al., 2023). Furthermore, a 3% CMC coating has been found to delay maturation, maintain skin color, and enhance the titratable acidity of mangoes during storage, highlighting its potential for quality preservation (Santos et al., 2023). In studies conducted using xanthan gum alone (Prasad et al., 2022) or in combination with pomegranate peel extract (Kumar et al., 2023a), coated mangoes were shown to have a longer shelf life because of the maintenance of quality attributes and the reduction in postharvest characteristics during storage. Zahedi et al. (2019) reported that the addition of chitosan (2%) with ascorbic acid enhanced fruit quality during cold storage, resulting in delayed deterioration. Moradinezhad (2021) examined the effects of different edible coatings and natural materials on the quality and shelf life of fresh-cut mango. The results indicated that the $CaCl_2$- and salicylic acid-coated slices had longer shelf lives, whereas the $CaCl_2$- and ascorbic acid-coated slices had better sensorial properties at the end of two weeks of cold storage. These findings collectively emphasize the significant role of edible coatings in extending the shelf-life and improving the overall quality of mangoes.

Orange (*Citrus sinensis*)

The postharvest loss of orange fruit is related mainly to weight loss, fungal decay, peel disorders, and insect injury. Microbial contamination of orange fruits is usually accelerated in hot weather, especially when the humidity is relatively high. In addition, the high moisture content of fruits favors the active reproduction of various microorganisms, especially during the postharvest period. Green and blue molds are the main spoilage causative agents during storage and are caused by *Penicillium digitatum* and *Penicillium italicum*, respectively (Elbarbary et al., 2023). Therefore, the damage caused by pathogens should be mitigated by appropriate methods to increase and improve resistance to pathogens. Edible coatings are effective and safe ways to improve the appearance quality and prolong the storage life of fruits during postharvest stages by controlling the respiratory process and inhibiting microbial growth on the fruit surface. Some effective coatings for orange are salicylic acid, acetic acid, and CMC (Amiri et al., 2021). Edible coatings extend the shelf-life of oranges by providing a protective layer that helps maintain freshness and quality. Medany et al. (2022) examined the use of pectin and chitosan and different herbal extracts, such as lemongrass, oregano essential oils, and aloe vera gel, to enhance the postharvest preservation of orange fruits. These authors reported that these coatings significantly extended the Washington Navel orange shelf life by reducing the decay rate and weight loss and increasing firmness. Additionally, a study on orange fruits coated with a layer-by-layer (LbL) self-assembled edible coating based on chitosan and CMC demonstrated improved morphological attributes, increased surface brightness and firmness, and reduced weight loss during storage, highlighting the potential of such coatings in maintaining postharvest quality (Niu et al., 2023).

Papaya (*Carica papaya*)

The postharvest loss of papaya is a significant concern that affects fruit quality and market value. Factors contributing to postharvest losses include anthracnose disease caused by *Colletotrichum gloeosporioides*, mechanical damage during handling and transportation, and poor postharvest handling practices (Getnet et al., 2024). Studies have shown that implementing proper postharvest practices, such as the use of edible coatings based on natural compounds such as *Origanum vulgare* L. and *Aloe arborescens*, can help reduce fungal infections and prolong the shelf-life of papaya fruits (Culmone et al., 2023). Various studies have explored the use of edible coatings to increase the shelf-life and quality of papaya fruits. Recent research has focused on the effects of materials such as mung bean starch (Sharma et al., 2024), hydrocolloid CMCs combined with papaya leaf extract (Prasad et al., 2024), chitosan and gelatin blends (Silva et al., 2023), and substances such as Carnauba wax nanoemulsions with *Syzigium aromaticum* and *Mentha spicata* essential oils (Oliveira Filho et al., 2023) on the postharvest quality of papaya. These coatings have shown promising results in maintaining fruit characteristics, reducing weight loss, preserving nutrients such as vitamin C, increasing firmness, and delaying ripening. Kumari and Nikhanj (2022) evaluated the efficacy of different edible coatings for their antimicrobial effects on fresh-cut papaya fruit. They noted that, compared with other edible coatings, pectin was the most effective coating for inhibiting microbial growth. Compared with the control, the application of 1% pectin significantly prolonged the shelf-life of fresh-cut papaya stored at low temperature for six days. Furthermore, nanoemulsion alginate-based edible coatings containing oregano essential oil have potential for enhancing fresh-cut papaya quality and shelf-life by reducing moisture loss and microbial growth (Tabassum et al., 2023). The application of these edible coatings has proven effective in extending the shelf-life of fresh/fresh-cut papaya fruits, making them valuable tools in postharvest management to minimize losses and ensure product quality during storage under ambient conditions.

Pineapple (*Ananas comusus*)

The primary factors contributing to postharvest loss in pineapple production include internal browning, fruit weight loss, and skin dehydration (Chandra et al., 2023). The application of edible coatings to fresh-cut pineapples has been shown to increase their quality and extend their shelf-life. Various studies have explored the use of different edible coatings, such as carrageenan, almond gum, and aloe vera gel-based coatings. Research has demonstrated that carrageenan-chitosan film coating can effectively reduce vitamin C loss and weight loss in sliced pineapples, maintaining their quality (Maulidiyah et al., 2024). Basaglia et al. (2021) explored the influence of an edible chitosan-based coating with the addition of cinnamon essential oil at different concentrations on the quality and shelf life of fresh-cut pineapples stored at 5 °C for 15 days. The best outcomes were achieved with a blend of 2% chitosan and 0.5% cinnamon essential oil, which helped decrease weight loss, inhibited microbial growth, and extended the shelf-life of the fresh-cut produce. Additionally, almond gum exudates have been found to delay changes in color, weight loss, acidity, hardness, and microbial growth in pineapples, highlighting their potential as edible covers for fruit preservation (Rasool et al., 2023). Furthermore, combining edible coating solutions consisting of sodium alginate and sodium isoascorbate with MAP has proven to be highly effective in inhibiting water loss, maintaining firmness, and preserving the overall quality of fresh-cut pineapples during storage at low temperatures (Liao et al., 2023). These findings collectively highlight the significant role of edible coatings in enhancing the storage stability and quality of fresh-cut pineapples.

Some examples of recent advances in the formulation and effects of edible coatings for main tropical and citrus fresh/fresh-cut fruits are described in Table 1.

Table 1. Recent advances in application and effects of edible coating in main tropical and citrus fresh/fresh-cut fruits.

Fresh/fresh-cut fruit	Coating formulation	Outcomes	Reference
Banana	Olive, coconut, and butter oil coatings	Butter oil coating showed the best retention of quality attributes for 12 days.	(Asghar et al., 2024)
Banana	Incorporating citronella oil into CMC edible coating	Enhanced banana fruit quality by reducing weight loss and inhibiting microbial growth during storage.	(Kamar & Yunihharni, 2023)
Banana	A carrageenan-based edible coating, with or without peppermint essential oil	Enhanced banana shelf life by reducing weight loss and total soluble solids, inhibiting the ripening process.	(Pamungkas et al., 2023)
Banana	Aloe vera, starch, and Arabic gum	Improved banana shelf life by reducing chlorophyll degradation, firmness loss, weight loss, and enhancing total soluble solids synthesis.	(Tchinda et al., 2023)
Banana	Corn starch (6%) combined with papaya leaf extract (6%) and/or mint leaf extract (6%)	Extended the shelf life of 'Ney Poovan' bananas up to 9 days by reducing spoilage and maintaining quality.	(Chithra et al., 2022)
Banana	A cellulose nanofiber-based film coating with carboxymethylcellulose and red cabbage extracts	Enhanced the preservation of bananas by reducing respiration, weight loss, browning, and slowing the aging process.	(Kwak et al., 2022)
Banana	Aloe vera gel	25% Aloe vera gel reduced weight loss, delayed TSS and TA changes, and minimized decay.	(Alhassan & Ndomakaah, 2024)
Lemon	Coconut oil and beeswax	Enhance shelf life and quality attributes during storage at low temperatures.	(Nasrin et al., 2023)
Lemon	Irradiated cassava starch at 2% concentration	Enhanced storage ability, reduced weight loss, improved appearance, color, and higher chemical constituents compared to other starch sources.	(Mounir, 2022)
Lemon	Beeswax enriched with sodium nitroprusside	Reduced weight loss and maintained high antioxidant activity and quality.	(Kaur et al., 2022)
Lime	Pectin-based edible coating	Reduced weight loss, maintained color and firmness, and extending shelf-life by slowing respiration rate at different temperatures.	(Maftoonazad & Ramaswamy, 2019)
Lime	Chitosan coating with cashew leaf extracts	Extended lime fruit shelf life by enhancing firmness, color, vitamin C, and antioxidant properties while inhibiting *Aspergillus niger* growth.	(Shiekh et al., 2022)
Lime	Mixed wax of palm oil, glecerol, sorbitan monooleate, (tween 80%), and guar gum	Mixed wax extended lime fruit storage life.	(Wijewardane, 2022)
Mandarin	Gellan-based edible coatings with oregano essential oil	Reducing weight loss, water loss, and inhibiting mold growth.	(Liguori et al., 2024)
Mandarin	Sodium alginate, ylang-ylang oil, and cellulose nanocrystals	Delayed postharvest spoilage of fruit.	(Nkede et al., 2024)
Mandarin	Pregelatinized corn starch, basil essential oil, and cellulose nanofiber	Enhanced quality and prevented quantity loss, extended shelf life.	(Wigati et al., 2023)
Mandarin	Chitosan and alginate	Enhanced shelf life and quality of Kinnow	(Puri & Kumar,

		mandarin by reducing weight loss and maintaining ascorbic acid.	2021)
Mandarin	100% liquid paraffin wax, chitosan (0.5%, 1.0%, 1.5%), and 100% coconut oil	Coconut oil reduced weight loss and respiration rate. Preserved ascorbic acid, TSS and firmness.	(Nasrin et al., 2018)
Mango	Cassava starch, coconut microfiber, and Garcinia kola oil	Preserved mangoes (Kent variety) by reducing weight loss and maintaining physicochemical and sensory properties.	(Désiré et al., 2023)
Mango	Edible coating products based on palm oil derivatives	Extend Arumanis mangoes' freshness by suppressing weight loss, maintaining hardness, and controlling respiration rates for up to 4 weeks.	(Susetyo et al., 2023)
Mango	CMC coating at 20 °C	3% CMC delayed ripening, maintained firmness, acidity, and color, enhanced overall quality during storage.	(Santos et al., 2023)
Mango	Xanthan gum and pomegranate peel extract	Extended the shelf life by maintaining quality attributes and reducing postharvest characteristics during storage.	(Kumar et al., 2023a)
Mango	Xanthan gum	Xanthan gum (0.3%) extended mango shelf life, reduced decay, maintained quality, offering an eco-friendly and effective postharvest preservation method.	(Prasad et al., 2022)
Mango	Chitosan and spermidine	Chitosan (2%) and spermidine (2 mM) enhance quality during cold storage, showing delayed deterioration and improved firmness, water retention, and antioxidant activity.	(Zahedi et al., 2019)
Mango	Calcium chloride, ascorbic acid, salicylic acid, oxalic acid, and citric acid	Ascorbic acid, salicylic acid and oxalic acid maintained antioxidant content. Calcium chloride and salicylic acid treated fresh-cuts had longer shelf life.	(Moradinezhad, 2021)
Orange	Edible coating of nanocurcumin based on carboxymethyl chitosan/polyvinyl alcohol	Extended the shelf life, improving freshness and quality while exhibiting antimicrobial properties.	(Elbarbary et al., 2023)
Orange	A layer-by-layer (LbL) edible coating based on chitosan and CMC	Maintained postharvest quality by enhancing attributes and reducing weight loss during storage.	(Niu et al., 2023)
Orange	Pregelatinized corn starch and basil essential oil in an edible coating with cellulose nanofiber	Improved quality and extend shelf life. Enhanced antimicrobial properties.	(Wigati et al., 2023)
Orange	Chitosan-pectin/emulsion coating with lemon grass and thyme oils	Extended Washington Navel orange shelf life by reducing decay rate, weight loss, and enhancing firmness, vitamin C retention, and microbial properties.	(Medany et al., 2022)
Papaya	Mung bean starch	Enhanced papaya fruit shelf life by maintaining color, reducing weight loss, preserving vitamin C, and delaying firmness loss.	(Sharma et al., 2024)
Papaya	Eco-safe composite edible coating with CMC and papaya leaf extract	Enhanced papaya fruit quality and shelf life under ambient storage conditions, reduced weight loss and decay.	(Prasad et al., 2024)

Papaya	Gelatin and chitosan, especially the layer-by-layer technique	Preserved minimally processed papayas by reducing mass loss, maintaining firmness, and color, extending shelf life.	(Silva et al., 2023)
Papaya	Nanoemulsion-based edible coating	Indicating potential for enhancing papaya quality and shelf life through innovative coating technology.	(Tabassum et al., 2023)
Papaya	Carnauba wax nanoemulsion with *Syzigium aromaticum* and *Mentha spicata* essential oils	Acts as an antimicrobial edible coating, enhancing fruit preservation during postharvest storage.	(Oliveira Filho et al., 2023)
Papaya	Aloe vera gel, ascorbic acid, and chitosan	Enhanced papaya fruit quality and shelf life during storage and transportation, maintaining nutritional parameters.	(Raju et al., 2023)
Papaya	Pectin-coated fresh-cut papaya	Significant microbial inhibition and quality maintenance, extending shelf life by 5-6 days when dipped in 1% w/v pectin for 3 minutes.	(Kumari & Nikhanj, 2022)
Pineapple	Carrageenan on fresh-cut pineapples stored at 5 °C	2.5% Carrageenan maintained quality and extended shelf life, Ozon treatment reduced microbial growth.	(Maulidiyah et al., 2024)
Pineapple	Almond gum	Enhanced fresh-cut pineapple shelf life by delaying color changes, weight loss, acidity, hardness, ascorbic acid loss, and microbial growth.	(Rasool et al., 2023)
Pineapple	Carrageenan-chitosan	Reduced vitamin C loss and weight loss, enhanced fresh-cut preservation.	(Ismillayli et al., 2023)
Pineapple	Edible coatings combined with modified atmosphere packaging	Improved storage quality of fresh-cut pineapples by reducing water loss, enhancing appearance, and inhibiting microbial growth, extending shelf life.	(Liao et al., 2023)
Pineapple	Chitosan and cinnamon essential oil	Extended the shelf life of minimally processed pineapple, reduced weight loss, microbial growth, and maintained firmness and quality.	(Basaglia et al., 2021)

Future directions and challenges

The development of active coatings incorporating antimicrobial elements, antioxidants, or enzymes could offer added defense against microbial spoilage, oxidative decay, and physiological decline. This necessitates the exploration of both natural and synthetic active components that can be seamlessly embedded into the coating structure. Additionally, ensuring consumer acceptance of edible coatings is imperative for their successful integration. However, the use of edible coatings presents certain challenges in terms of production, storage, and commercial-scale usage while ensuring consumer acceptability, food safety, nutrition, and shelf life extension (Kumar et al., 2023b). Polysaccharide- and protein-based edible films face challenges in terms of poor water and gas barrier properties, necessitating the addition of plasticizers, emulsifiers, and other components to improve their mechanical and thermal resistance (Abdullah et al., 2022). In addition, elevated levels of biopolymers and active ingredients such as essential oils and plant extracts might adversely affect the taste of the produce, which directly impacts consumer approval. This is also linked to the potential toxicity of the substances. Finally, very few safety and regulatory guidelines exist regarding the concentrations of active agents in edible coatings. Hence, promoting consumer awareness and regulations concerning the advantages of edible packaging for the environment and consumers is essential for addressing consumer acceptance challenges on a commercial scale (Duguma, 2022).

CONCLUSION

Edible coatings show promise in extending the shelf-life of fresh or fresh-cut fruits from tropical and subtropical regions. The precise formulation and utilization of these coatings are pivotal in determining their efficacy in inhibiting microbial growth, minimizing enzymatic browning, and preserving the sensory attributes of fruits. Further investigations are necessary to refine the application of edible coatings for distinct fruit varieties and devise innovative strategies to address the challenges related to extending shelf-life and preserving freshness. While edible coatings have displayed considerable potential in fruit preservation, various future pathways and obstacles need to be addressed for their widespread acceptance and enhancement. Research efforts should concentrate on discovering and formulating novel, eco-friendly, and biodegradable coating materials sourced from renewable outlets. This encompasses exploring overlooked agricultural residues and delving into the capabilities of biopolymers such as proteins, polysaccharides, and lipids. Moreover, the integration of nanotechnology into edible coatings could augment their characteristics, including heightened barrier properties, regulated release of active agents, and increased antimicrobial efficacy. This entails investigating the application of nanoencapsulation and nanoparticles to increase the efficiency of coatings.

Conflict of interest
The authors declare that they have no conflict of interest.

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