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Review Article

A Review on Enhancing Quality and Shelf-Life of Fruits and Vegetables by Edible Coating

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Abstract

Edible coating is an eco-friendly method employed across a diverse range of products to effectively regulate oxidation, gas exchange, and moisture transfer. In addition to providing an extra layer of protection, edible coatings have the same effect on internal gas composition as modified atmosphere storage technique. Several active chemicals can be added to the polymer matrix and consumed with the meal, improving safety or even nutritional and sensory qualities. This highlights a key advantage of employing edible films and coatings. The application of various edible coatings, including composites, proteins, lipids, and polysaccharides, on fresh produce serves to not only prolong its shelf-life but also enhance its overall quality. This also covers the most recent developments on the use of nutraceuticals, texture enhancers and antimicrobials aiming to elevate the functional properties and quality of fresh-cut fruits and vegetables.

Keywords: Edible Coating; Safety; Quality; Protection; Shelf-Life

Introduction

Edible coating is a thin layer of material applied to the surface of fruit either as an enhancement or alternative to naturally occurring waxy protective coatings, with the purpose of providing a barrier to moisture, oxygen, and solute movement thereby preserving the quality and freshness of the fruit. About 30-40% loss of fruits and vegetables takes places from harvest to consumption by several factors, including improper infrastructure, subpar transportation, limited knowledge in handling, market inefficiencies, and technological gaps. A highly effective post-harvest management technique for handling fresh fruits in volve the application of edible coatings. Edible coating is an environmental friendly sustainable technology utilized across various items, which plays a crucial role in controlling gas exchange, moisture transfer and oxidation processes. By changing the composition of the inside gas, it provides an extra layer of protection and have the same effect as modified atmosphere storage. These coatings create a semi-permeable barrier to gas exchange and water vapor, which reduce weight loss aiding in minimization of postharvest losses.

Mechanism of edible coating

The mechanism of edible coating involves several key processes that enhance the preservation of food products, particularly fruits and vegetables. These coatings serve as barriers against moisture and gas transfer leading to an extension of shelf-life and maintaining quality (Table 1). Edible coatings control the transfer of water vapor, oxygen, and carbon dioxide, which are crucial for maintaining the freshness of food products (Figure 1) [1]. Various application methods, such as dipping and spraying, are employed to coat food products, tailored to the specific characteristics of the food and desired outcomes [2]. Innovative technologies, including high hydrostatic pressure and ultrasound, are being explored to improve the properties of edible coatings [3]. While edible coatings present a sustainable alternative to traditional packaging, challenges remain in achieving optimal barrier properties and consumer acceptance. Further research is essential to enhance their effectiveness and integration into food systems.

Coating	Food Matrix	Active Agent	Effect	Reference
Pectin (2%) + glycerol combined with MAP	Nectraine (*Prunus persica* L. cv. Babygold)	–	Textures, colour and hygienic quality improved (3°C, 7days)	[4]
Multilayered alignate (1%)-β-CD-trans (2%)/pectin (2%) Calcium lactate	Watermelon (*C.lanatus*)	trans-cinnamaldehyde encapsulated in β-Cyclodextrins	Antimicrobial activity maintaining, quality and sensory attributes enhanced (4°C, 9days)	[5]
Osmotic dehydration (with 0.5% calcium lactate) + pectin coating (1%)	Ripe melon (*Cucumis melon* cv. inodorus)	–	Reduction of respiration rate, maintaining sensory properties and quality parameters (5°C, 80%RH, 14days)	[6]
Multi-layered chitosan (2%)-β-CD-trans (1%)/pectin (1%) $CaCl_2$	Watermelon (*C.lanatus*)	trans-cinnamaldehyde encapsulated in β-Cyclodextrins	Enhanced Antimicrobial activity, maintaining quality and sensory attributes (4°C, 12days)	[5]
Pectin (3%), sorbitol, beeswax	Mango (cv. Atauflo)	–	Reduction of physiological changes, respiration rates and weight loss (15days, room temperature)	[7]
Low methoxylpectin (2%), glycerol, sunfloweroil, $CaCl_2$	Melon (*Cucumis melon* L.)	–	Antioxidant properties, maintaining quality attributes (4°C, 15days)	[8]
Pectin (3%), sorbitol, beeswax	Avocado	–	Reduction of firmness, colour, respiration rates and moisture loss (10°C, 1month)	[9]
Pectin (2%), glycerol, $CaCl_2$	Pear (*Pyrus communis* L.)	*N* – acetylcysteine Gluathoine	Antibrowning, antimicrobial, antioxidant maintaining sensory	[10]

Table 1: Effect of edible coating on fruits and vegetables.

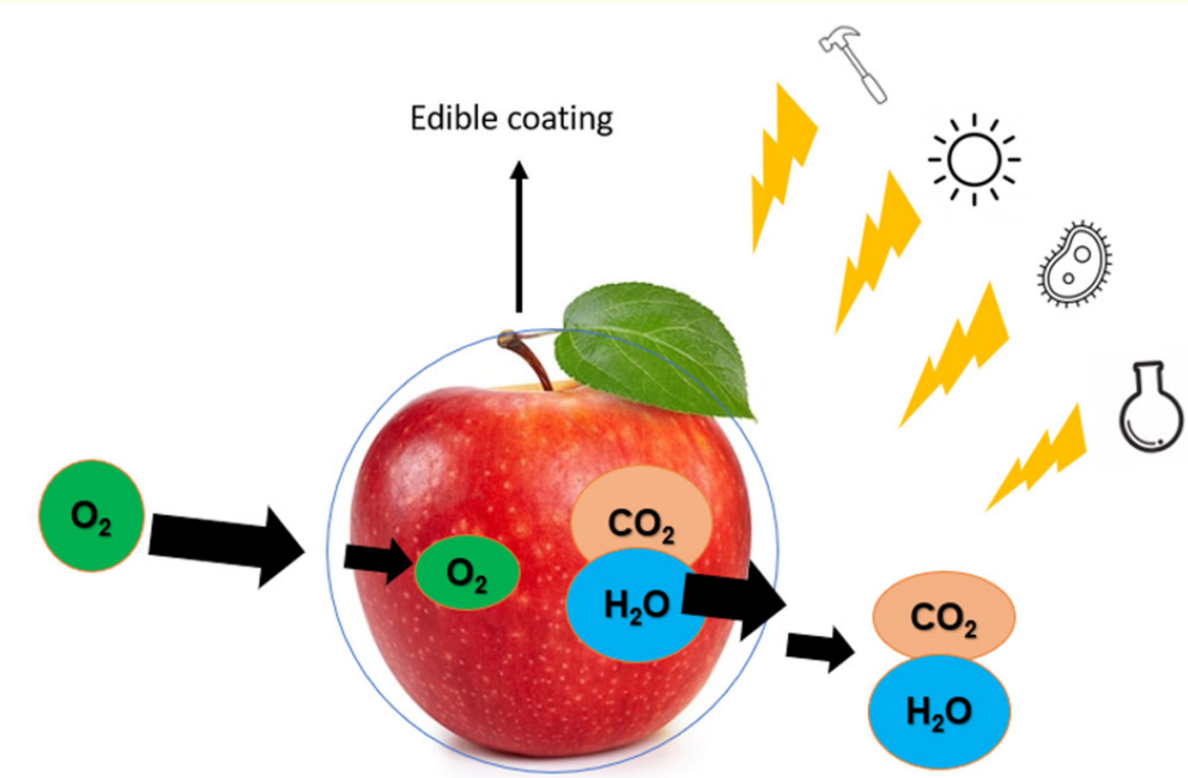

Figure 1: Mechanism of edible coating.

Coating effect on quality of fruits and vegetables

Firmness

Three distinct coatings sodium alginate (Al), pectin (Pe), and sodium alginate plus pectin (Al + Pe) were applied on blueberry. The data showed an increase in samples firmness by the application of Al, Pe, and Al + Pe compared to uncoated samples after 14-day storage period at 4°C. The coated blueberries had more intense blue hue and were generally less light than the control samples due to alterations in their surface reflection characteristics [11]. Additionally, a study revealed that firmness loss was reduced significantly by *Aloe vera* coating treatment compared to control fruits of sweet cherry. In sweet cherries, softening is influenced by the increased activities of polygalacturonase, β-galactosidase, and pectin methylesteras [12]. Semperfresh™ coating applied at varying concentrations (10 and 20g/l) on sweet cherries stored in cold conditions (0°C; RH 95-98%) had higher firmness than cherries stored at ambient temperature (30 ± 3°C; RH:40-50%). The retention of firmness is mainly due to strong effect of low temperature. As the concentration of Semperfresh coating increased, the firmness also increased. Retention of firmness is achieved by retarding insoluble protopectin degradation to more pectin and pectic acid. During fruit ripening, pectin esterase and polygalactronase activities increased depolymerization or shortening of the chain length of pectin substances [13].

Total soluble solids, titratable acidity and ascorbic acid

In the evaluation of Kinnow Mandarin with various coating materials tested and compared against uncoated fruit (control), carboxymethyl cellulose (CMC) 1%, 5% gum arabic (GA), 1% persian gum (PG), 0.5% beeswax (BW), 1% carnauba wax (CA) (w/v), and commercial wax were applied as coatings and stored for three weeks at 5°C and 90-95% relative humidity. The outcome demonstrated that, as compared to control, all coatings could lessen weight loss. The samples with CMC treatment exhibited the highest TSS/TA. Weight loss, TSS, and TA increased along with a decrease in firmness as storage duration increased. Only PG and CMC coatings showed signs of glossiness; still their performance lagged behind that of commercial wax coatings. The best coating utilized in this study, according to the findings was PG [14]. Pectin at two concentrations (0.5 and 1%) in essential oil derived from lemon and orange peels were coated on strawberry fruits. Following a one-minute immersion of the strawberry fruit in the coating solution, the fruits were stored at a temperature of 5°C and a relative humidity of 75 ± 1%. The results showed that all evaluated variables exhibited an increased trend with an increase in storage duration. Pectin (1.0%) containing lemon essential oil had the longest shelf-life (24 days), with a 12-day increase over the control. This showed that coated treatment was responsible for the high amount of soluble solids. Therefore, the application of edible coatings containing essential oils could be an effective strategy for enhancing the postharvest quality of strawberries [15]. Effect of coating on cucumber storability at 23°C and 40% RH (display cabinet) and 12°C and 85% RH (cold room) were ascertained by monitoring the physiological and quality parameters. At both temperatures, the covering significantly decreased respiratory rate and weight loss. The coating prolonged the cucumber fruits storage life under both storage settings and decreased the loss of colour, firmness, total soluble solids, and chlorophyll [16]. Coatings with shellac (14.3g/100 ml water), Semperfresh™ (1.0g/100 ml water) and carboxy methyl chitosan (2.0g/100 mL water) were applied to Huanghua pear cultivar in cold storage (4°C). After 60 days of storage, levels of ascorbic acid, titratable acidity and total soluble solids significantly dropped across all treatments of pear. Pears coated with shellac exhibited notably elevated amounts of ascorbic acid, titratable acidity and total soluble solids when compared with the control samples. During storage, respiration consumes fruit substrates such as soluble solids and organic acids. Due to its lower gas permeability compared to other coatings, shellac coating effectively suppressed respiration rates, thus extending the overall storage life of pears by delaying metabolic activities [17]. Green tomatoes coated with 3% pectin (dipped for 5 min) resulted the best in retaining ascorbic acid, titratable acidity and total sugars of 9.96%, 0.41%, 11.2% respectively, compared to 1% and 5% pectin coated tomatoes and extended shelf-life to 4 weeks when stored at 30 ± 0.2°C. During storage, 3% pectin coated tomatoes showed no decay and no quality loss and enhanced the shelf-life [18]. Increase in Semperfresh™ concentrations increased the acidity of sweet cherry. The loss of ascorbic acid was successfully decreased by Semperfresh™ coatings under both ambient (30°C) and cold storage (0°C) conditions with 40–50% relative humidity and 95–98% relative humidity, respectively. Due to the sucrose polyester coatings, low oxygen permeability decreased enzyme activity and arrested ascorbic acid from oxidizing thereby ascorbic acid loss in coated cherries was reduced. The ascorbic acid loss was greatly decreased by the low temperature. Semperfresh™ displayed the highest increase in total sugars and the lowest starch content [13].

Weight loss

Freshly harvested Rambutan coated with pectin, either with or without trans-cinnamaldehyde (TCIN) were taken and stored at 10°C or 20°C along with control stored at 20°C. Three concentrations of TCIN were added to a pectin solution to create coatings with 0.05%, 0.1%, and 0.2% TCIN, in order to determine the optimal formulation for the coatings. The weight loss observed in the fruits treated with 0.1% TCIN coating was significantly lower than both the control and fruits treated with 0.2% TCIN coating, after being stored at 20°C for 6 days [19]. The application of a coating comprising of 2% apple pectin and 1% glycerol yielded a mere 3.673% reduction in weight over a period of 20 days, in contrast to a weight loss of 5.718% observed with a 0.7% sorbitol formulation, thereby suggesting a notable efficacy in moisture preservation [20]. The lime fruits that were coated with pectin solution demonstrated a reduced weight loss when compared to the control samples, exhibiting losses of 2%, 4%, and 17% after a 8-day storage duration at temperatures of 10°C, 15°C, 20°C respectively, in contrast to the losses of 6%, 10%, and 24% observed in the uncoated fruits [21]. Following a period of seven days of storage of Ataulfo Mango fruits, the control fruits experienced a reduction of approximately 7.9% in their weight, while the mango fruits that underwent treatments with pectin, sorbitol and monoglyceride exhibited weight losses of 7.7%, 6.4%, and 5.8%, respectively, by the end of seven-day storage period. These fruits subsequently continued to experience weight loss reaching 12.8%, 12.2%, and 11.2% respectively, by the thirteenth day [7].

Respiration and ethylene production

Pre-established coating measured the impact of pectin-based coating on the kinetics of quality change in preserved lime fruits. The lime fruits were stored at predetermined temperatures (10–25°C) and the respiration rate of coated samples was limited to 40, 32 and 106 mL CO_2/(kg·h) after 11, 25, and 32 days at the storage temperatures, whereas that of control samples reached 79, 35, and 7 mL CO_2/(kg·h) after 7 days at 25°C and 22 days at 15 and 10°C, respectively. After eight days of storage at 10, 15, and 20°C, the control fruits lost 6%, 10%, and 24% of their weight respectively, whereas coated fruits lost 2%, 4%, and 17% of their weight, on an average [21]. Strawberries were coated with chitosan in acetic acid, glycerol 0.2g, tween-80 0.2g and beewax coatings with tween-80. The beewax coating controlled 20% of the gas exchange as CO_2 and O_2 has different permeability between fruits and environments. It resulted in better preservation on beeswax coatings that reduced respiration rate of strawberries [22]. The shelf-life of Ataulfo Mangoes increased and the related physiological alterations reduced with the application of a pectin-based coating. The coating decreased respiration rate exchange of O_2 and CO_2 postponed ethylene production and response, limiting transpiration, thereby minimizing weight loss during storage due to water evaporation. The formulation must be adjusted to achieve a balance between gas and water vapor transfer, which will rely on the fruit or vegetable cultivar particularly the respiration rate in order to avoid and receive the best outcomes [23]. Breadfruit stored at low temperature of 13°C doubled the shelf-life for about 10 days. Softening of fruit is delayed by coatings at both ambient and 13°C by reducing internal O_2 and CO_2 concentration. One fifth of CO_2 production was reduced when the fruits were stored at 13°C compared to ambient temperature storage [24].

Coating effect on antioxidant property

Edible coating made of pectin on plum fruits had the ability to withstand oxidation and extended the shelf-life for 8 days at 19.2°C and 65% relative humidity. Applying glycerol (0.3% w/v) as a plasticizer, three different pectin solutions (0.5, 1, and 1.5%) were applied to plum fruits alongside with control. The result showed that the edible pectin coating significantly preserved the levels of ascorbic acid, anthocyanin and flavonoid levels, and antioxidant capacity of the plum fruits. Furthermore, the enzyme activity in the fruit coating had a considerable impact on the preservation of these beneficial compounds [25]. Moreover, an edible film comprising pectin and cinnamon leaf essential oil enhanced the antioxidant levels and inhibited bacterial growth in fresh-cut peaches when applied at the concentration of 0.0, 7.3, 15.7 and 36.1 oilg/l. Antioxidant capability increased with additional oil concentration; the only materials exhibiting inhibitory zones against *E. coli, Staphylococcus aureus, and Listeria monocytogenes* were the films containing 36.1g/l. These finding showed that the freshness of fresh-cut peaches can be preserved by creating an edible film made of pectin with cinnamon leaf oil [26].

Coating effect on Shelf-life

The efficacy of pectin extracted from mango fruit peels as an edible coating to enhance the shelf-life of fresh mangoes was systematically assessed. A variety of pectin-based formulations were synthesized and subsequently applied to freshly harvested mangoes. Both coated and uncoated mangoes were preserved at ambient temperature (25-27°C) and in cold environment (8-10°C). Cumulatively, the findings of Philippine Center for Postharvest Development and Mechanization (PhilMech) indicated that 2-4% pure PhilMech mango pectin exhibited significant potential in prolonging the shelf-life of fresh mangoes. This treatment conferred a protective period of 12 days for mangoes stored under ambient conditions, in contrast to the 6 days observed for uncoated mangoes and those treated with alternative pectin formulations. Similarly, this specific formulation provided a protective duration of 24 days for mangoes when kept under cold conditions, as opposed to the 9 days shelf-life observed for uncoated fruits [27]. The postharvest shelf-life of the avocado cultivar 'Quintal' was prolonged, and the ripening process deferred by a minimum duration of 8 days, through the application of a coating specifically formulated with rice flour, pectin, sorbitol, potassium sorbate and nanofibers derived from cellulosic rice skin [28]. The primary aim of the study was to assess the preservation of 'Prata Anã' bananas (*Musa* spp.) that have been treated with coatings composed of cassava starch and pectin during ambient temperature storage. The bananas were selected, thoroughly washed, and subsequently coated with starch and pectin solutions at varying concentrations of 0 (control), 2, 5, and 8%, and stored at a controlled temperature of 25 ± 3°C for a duration of 12 days. The concentrations 5 and 8% of both coatings stood out in the preservation of some fruit quality attributes such as color, firmness, and total soluble solids. Considering the cost/benefit ratio, the use of starch-based coatings found to be more appropriate [29]. Lime fruits subjected to immersion in a pectin coating emulsion, subsequently undergo surface desiccation, cooling, and assessment, following varying durations of storage at specified temperatures 10–25°C.The permissible shelf-life of lime fruits was determined to be 8, 25, and 32 days at temperatures of 25, 15, and 10°C respectively for the control samples, while the coated limes exhibited shelf-life of 13, 32, and 40 days [21]. The edible coating was formulated for sapota utilizing the polysaccharide pectin at a concentration of 3%, glycerol at 2.5%, polyvinyl alcohol at 1.25%, and citric acid at 1%, after which the sapota fruits were coated via the dipping technique. Both the control and the coated fruits were stored under ambient conditions at a temperature of 30 ± 3°C. The shelf life of the coated sapota fruits prolonged to a duration of 11 days, whereas the control fruits remained in an edible condition only until the sixth day during storage at room temperature [30]. Postharvest characteristics of tangerines coated with varying concentrations of pectin during storage at a regulated temperature of 22°C ± 0.1 were evaluated. The fruits exhibiting predominantly green coloration (approximately 90% of the surface) were classified into four distinct groups: uncoated fruits and fruits coated with pectin solutions at concentrations of 4g/100g, 6g/100 ml, and 8g/100 ml. Overall, the tangerines subjected to different pectin concentrations maintained their greenness for 15 days, a characteristic that is highly valued by consumers [31].

Future prospects

The future of edible coatings lies in advancing sustainability, functionality, and innovation to address global food preservation challenges. These coatings are expected to incorporate bioactive compounds such as natural antimicrobials, antioxidants, and probiotics to enhance food safety and nutritional value. Emphasis on eco-friendly materials derived from renewable sources, including polysaccharides, proteins, and agricultural by-products, align with sustainability goals. Smart and active coatings with responsive properties or integrated sensors could monitor food freshness or release active agents based on environmental changes. Advances in nanotechnology will enable the development of uniform coatings and controlled release systems for bioactive compounds improving preservation efficiency. Additionally, scalable and cost-effective production methods are essential for commercial viability, supported by digital tools like AI for optimization of formulation and blockchain for traceability. Overall, edible coatings play a pivotal role in reducing food waste, enhancing food quality meeting the demands of a sustainable food system.

Conclusion

By adding specific functional and bioactive substances into the polymetric matrix, edible coating can be transformed into active system which improves the nutritional value and sensory quality, safety, and consumer health of coated fruits. With regard to controlling the quality of fresh horticultural produce, new generation edible coatings incorporating active ingredients particularly antimicrobials, antioxidants, texture modifiers, nutrients, *etc*., are considered as the most promising methods. Recently, innovative edible coatings derived from sustainable and biodegradable materials have been suggested for use on various fruits and vegetables to extend the shelf life. These edible coatings offer numerous advantages, including biodegradability, cost-effectiveness and most importantly, serving as effective carriers for various bioactive compounds.

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