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RECENT DEVELOPMENTS IN EDIBLE COATINGS FOR FRESH FRUITS AND VEGETABLES

A review

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ABSTRACT

The world population is elevating rapidly, the demand for fruits and vegetables is increasing due to their nutritional value, and the concerns regarding the quality have been amplified. Therefore, the development of various techniques to retain quality attributes, and shelf-life extension of food has become a focal point for researchers and food industries. One of the economical techniques used for the preservation of food is the application of edible coating onto the surface of fresh or minimally processed fruits and vegetables. The foremost advantage of edible coating is that it is eco-friendly. Edible coatings can improve nutritional quality along with the maintenance of physiological attributes of fruits and vegetables. It can also act as a vehicle to carry active components, such as essential oils and spices that also carry antioxidant and antimicrobial properties. The application of nanotechnology for the formulation of edible coating is playing a significant role and aids in the reduction of microbial load on fruits and vegetables. The main aim of this review is to bring up-to-date information regarding various edible coatings used on minimally processed fruits and vegetables – carbohydrates, proteins, lipids, composites, fruit purees, and herb-based edible coatings and their significant effect on the physiological properties of produces. The information will be beneficial for the researchers and scholars to study the various effects of edible coatings on minimally processed fruits and vegetables.

Key words: antimicrobial compounds, edible coatings, fabrication, functional coatings, preservation of fresh fruits and vegetables

INTRODUCTION

Various technologies have been developed in the market to combat the challenge of delivering fresh fruits and vegetables to consumers' plates (Tahir et al. 2019). Edible coating aids in maintaining freshness and enhances the shelf life of fresh or minimally processed fruits and vegetables (Pavlath & Orts 2009; Tahir et al. 2019). An edible coating is defined as a thin layer of edible material covering the food commodity, it is usually applied via dipping the commodity into the coating solution or by spraying. It suppresses moisture loss and preserves the sensory quality of fruits and vegetables. It also helps to make the product more attractive by providing a shiny texture to the waxed surfaces of the fruit (Lin & Zhao 2007; Kang et al. 2013).

Fruits and vegetables have a short shelf life and are highly susceptible to physiological and biochemical damage (Sapper & Chiralt 2018). Previously, synthetic waxes and fungicides were used to protect against degradation of the postharvest shelf life and to extend the shelf life. The major disadvantage of these treatments is their negative impact on health and the environment, which has led to the development of edible coating and films made of naturally occurring biopolymers that have proven to be environmentally and user-friendly materials (Karaca et al. 2014; Jemilakshmi et al. 2020).

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Nowadays researchers are focusing on finding suitable raw materials for edible coatings and films that are ecologically friendly and safe for consumers. Edible coatings can be fabricated using several natural polymers, for example polysaccharides, which include starch, alginate, dextrose, chitosan, cellulose, and pectin (Hassan et al. 2018). These polymers also act as carriers for functional components (Mehyar et al. 2014; Corbo et al. 2015) such as antimicrobials, antioxidants and antibrowning agents, vitamin E, spices, and food stabilizers that can be incorporated into edible coatings (Fagundes et al. 2015).

Farm food is best eaten directly. However, as the demand for nonseasonal fruit and vegetable increases, it is necessary to store food longer (Embuscado & Huber 2009). The system of distributing food from farms to consumers' tables has been improved; therefore the main responsibility of the distributor is to preserve the sensory qualities and freshness of the food. Edible coating aids in reducing product loss during storage and transportation to a noteworthy extent. The deterioration of food production increases to a notable level during storage and transportation, and if appropriate precautions are not taken, the product will be unappealing to consumers; thus, the food industry will face huge losses (Embuscado & Huber 2009). The aim of this review is to provide up-to-date information regarding the application of edible coatings and their significant effects on the physiological properties of fruits and vegetables.

Fabrication and deposition of edible coatings and films

Edible films serve as a conveyance for delivering active components, flavors, drugs, and nutraceuticals (Wongphan & Harnkarnsujarit 2020). These active components are trapped in the biopolymer matrix and remain stable until reaching the consumer's table. Edible films are fabricated from biopolymers using wet and dry processes. The wet process is solvent casting; whereas, the dry process is also known as the extrusion process (Siemann 2005; Suhag et al. 2020). Edible coatings are generally prepared from the substance pertaining to film-forming properties. The raw material for formulating the edible coating must be able to be dispersed and dissolved in the desired solvent, for example water, alcohol and a mixture of solvents in the desired ratio. While preparing edible coating plasticizers, antimicrobial agents, flavor-enhancing substances, vitamins, colors, and spices can also be incorporated (Dhall 2013; Raghav et al. 2016). Plasticizers are blended into the solution of edible coating to increase the mechanical strength (Sothornvit & Krochta 2005) and to provide flexibility to the films and coatings (Hassan et al. 2018). Water acts as a natural plasticizer for edible coatings and films. Glycerol, sorbitol, fatty acids, sucrose, polyethylene glycol (PEG), propylene glycol (PG), and monoglycerides are good options to provide flexibility and plasticizers (Krochta 2002; Sothornvit & Krochta 2005).

Casting method

The casting method or solvent casting method is commonly exercised at the pilot scale. The main steps involved in this method are solubilization of biopolymer into suitable solvent followed by casting into suitable molds and drying (Jensen et al. 2015; Suhag et al. 2020). The casting method provides fewer defects due to its homogenous nature, and the manufacturing method is cost-efficient (Chen et al. 2008; Yang et al. 2011). The method contributes to appreciable optical purity and good transparency (Suhag et al. 2020). The salient disadvantage of casting methods is that proteins and other components get degraded by the use of solvent, the amount of film fabricated is limited, film development is dependent on the temperature and evaporative range, and it is a time-consuming technique. Therefore, it is not recommended for commercial use (Sait & Ma 2009; Fakhouri et al. 2013; Jensen et al. 2015; Suhag et al. 2020).

Extrusion method

The extrusion method (dry process) for the development of edible films is used at a commercial scale. The extrusion process takes place in three different stages: a) feeding stage, b) kneading stage, and c) heating stage. The extrusion process is also referred to as the dry process because the least amount of water or solvent is required during the feeding zone to obtain an optimal result (Peressini et al. 2003; Calderón-Castro et al. 2018). The extrusion method takes a short processing time, least solvent, and low energy expenditure. This method is recommended for commercial purposes, and the final product has high mechanical and optical properties (Raghav et al. 2016). The major drawbacks of using the extrusion method are: its high initial cost, requirements to skilled workers, biopolymer used must be temperature tolerant, and low moisture content (Raghav et al. 2016; Suhag et al. 2020).

Deposition of edible coating

The deposition of the edible coating on the food product depends on the nature and the surface attributes of the food product to be coated (Suhag et al. 2020). Edible coatings can be deposited over the fruits and vegetables by various techniques, such as dipping, spraying, fluidized bed, and panning (Raghav et al. 2016; Suhag et al. 2020). The application of an edible coating by the brushing method has been found to have valuable results on both less perishable vegetables such as beans and extremely perishable fruits such as strawberries and berries (Valverde et al. 2005; Raghav et al. 2016). The dipping process involves the immersion of food products directly into the edible coating solution followed by drying in which the solvent gets evaporated (Andrade et al. 2012; Senturk Parreidt et al. 2018). The spraying technique is the widely used technique for the application of edible coating over food products. Droplets are formed and then distributed over the food surface via nozzles. Air spray atomization, air-assisted airless atomization, and pressure atomization are the major spraying techniques practiced at the industrial scale (Andrade et al. 2012; Valdés et al. 2017). The low density or small size dry particles are usually thinly coated using the fluidized-bed technique. This process is categorized into three types; (i) top spray, (ii) bottom spray, and (iii) rotary fluidized bed. The top-spraying fluidized technique is highly effective in food industries (Suhag et al. 2020). The coating or layering solution is sprinkled onto the rotating bowl in which the product is placed. It is followed by drying of the coating layer (Pandey et al. 2006). Hard panning is the application of a hard shell by continuous treatment with sugar syrup on the surface of the product. Soft panning involves the administration of a mixture of corn syrup and sugar for coating followed by the application of dry sugar. Chocolate panning involves the use of fat-based layers such as cocoa-based or white chocolate (Gesford 2002).

Polysaccharide-based edible coatings and its derivatives

Polysaccharides are widely used for the fabrication of edible coatings and films to enhance the shelf life and quality retention of food products. They are proven to possess good oxygen barrier properties but are hydrophilic in nature; edible coatings derived from polysaccharides lack satisfactory moisture barrier properties (Hassan et al. 2018; Yousuf et al. 2018). Polysaccharide-based edible coatings are colorless and constitute less caloric content and in addition to that can be used to extend the shelf life of food products such as fruits, vegetables, and meat (Hassan et al. 2018). Edible coatings resulting from polysaccharides include cellulose and its derivatives, such as methylcellulose, hydroxypropyl cellulose, hydroxypropyl methyl cellulose, methyl ethyl cellulose, carboxyl methylcellulose, starches (derived from different sources), dextrin, pectin derivatives, pullulan, alginate, chitin, and chitosan-based edible coatings, gums – Arabic gum, guar gum, xanthan gum, carrageenan, and agar (Raghav et al. 2016; Hassan et al. 2018; Yousuf et al. 2018; Salehi 2020). The major advantage of using starch-based coatings is that they are colorless, provide an oil-free exterior, it is readily available, and the cost is low, which makes it a promising polymer for an edible coating (Luchese et al. 2017); thus, it can be used to enhance the shelf life of fruits and vegetables. Starch cannot be used solely for the preparation of edible coating due to its hydrophilic nature, which makes it water-sensitive and decreases water vapor barrier capacity; therefore, plasticizers and emulsifiers are added to improve the flexibility and barrier properties (Cazón et al. 2017). Table 1 summarizes the application of various types of edible coatings on fruits and vegetables.

Protein-based edible coatings and its derivatives

Globular and fibrous proteins happen to be found naturally. Milk protein, that is, casein protein and whey protein, are suitable raw materials for the formulation of edible coatings (Mohamed et al. 2020). Edible coatings and films derived from protein exhibit outstanding barriers against carbon dioxide and oxygen but do not possess great mechanical strength (Yousuf et al. 2018). Almond and walnut oil can be incorporated to enhance the barrier properties (Hassan et al. 2018). Proteins such as soy protein, corn zein, wheat gluten, gelatin are also promising substitutes for protein-based edible films to preserve the quality of products (Hassan et al. 2018; Yousuf et al. 2018). Zein is majorly extracted from corn; it is a raw material for the preparation of edible films and coatings. Protein-based edible coatings derived from zein display significant barriers against moisture, and by the addition of fatty acids, zein coatings can provide a good barrier against water vapor loss (Hassan et al. 2018). Fish protein such as Whitemouth croaker protein isolate along with organoclay Montmorillonite (MMT) demonstrated great potential in extending the shelf life of minimally processed papaya (Cortez-Vega et al. 2014).

Lipid-based edible coatings and its derivatives

Lipids are ideal choices as constituents in edible films and coatings due to the necessity to prevent moisture losses by packaged or nonpackaged food items. Lipids are generally combined with polysaccharides or proteins to improve their functionality in edible films or coatings. The most commonly used lipid compounds in lipid-based edible coatings are neutral lipids, fatty acids, waxes, and resins (Hall 2012; Raghav et al. 2016; Hassan et al. 2018). Coatings derived from paraffin are used to preserve cheese, vegetables, and raw food (Hassan et al. 2018). Fruits and vegetables meant to be stored for a longer time are coated with formulations containing lipids incorporated with antifungal compounds and growth regulators (Hall 2012). Zambrano-Zaragoza et al. (2020) studied the effect of nano-edible coating based on beeswax lipid nanoparticles on strawberries for extending its quality by 21 days of storage at 4 °C. Best results were obtained with 10 $g \cdot L^{-1}$ of beeswax solid nanoparticles dispersion giving the lowest weight loss (6.1%), a decay index of 31%, and loss of firmness of 34%, being an excellent alternative to increase the shelf life of strawberries. Beeswax or stearic–palmitic acids (1 : 1) mixture was blended with gellan gum to form gellan/lipid composite films. The addition of lipids significantly improved the water vapor permeability but lowered the mechanical properties of the films. Beeswax was found to be a better alternative than the stearic-palmitic acids blend (Yang & Paulson 2000).

***Aloe vera*-based edible coatings**

Nowadays *Aloe vera*-based edible coating is emerging in the market demonstrating better results as compared to the traditional edible coatings and health benefits because it also acts as a medicine (Sharma et al. 2019). *Aloe vera* is reported to have 75 nutrients, sugars, anthraquinones, vitamins, minerals, salicylic acid, approximately 200 active compounds and amino acids that show medical properties (Dureja et al. 2005). For this reason, a gel-based on this plant was developed that can be used in the preservation of freshness of fruit freshness (Tripathi & Dubey 2004; Misir et al. 2014).

This gel proves to be a harmless and safe alternative to sulfur dioxide, a synthetic preservative that is widely used all over the globe. The *Aloe vera* gel provides a protective layer against oxygen and moisture transmission from fresh fruits or vegetables and exhibits antibacterial, antiparasitic, antiviral (Misir et al. 2014), and antifungal properties due to which it is capable of inhibiting the microbial deterioration of food. Anthraquinones present in *Aloe vera* inhibit the solute transport in membranes of *Staphylococcus aureus* and *Escherichia coli* strains (Hamman 2008; Lone et al. 2009). It was also reported that *Aloe vera* inhibits the activity of foodborne pathogenic microbes, that is, *Bacillus cereus, Salmonella typhimurium*, *Escherichia coli*, *Klebsiella pneumonia*, etc. (Misir et al. 2014).

Emodin of *Aloe vera* is reported to be effective in inhibiting the activity of gram-positive bacteria (Cock 2008). The gel-based coatings have been proven to counteract moisture loss and retain firmness also, facilitating in maintaining the respiratory rate. It also controls fruit ripening, the maturation rate of vegetables, delay oxidative browning, and microbial growth (Castillo et al. 2010). *Aloe-vera*-gel-coated fruits do not depict a distinct taste and flavor and possess no harm to consumers (Misir et al. 2014). This gel blended with gaur gum for the preservation of Indian jujube (*Ziziphus mauritiana* Lamk) delayed the ripening process, a significant reduction in physiological weight loss, and visual quality retained for a longer period of time, hence, extending shelf life (Mani et al. 2018).

Purees of fruits and vegetable-based edible coatings

The formulation of edible coatings using fruit purees was reported first time in 1996 (McHugh et al. 1996). Fruit purees can be intermixed with biopolymers and active compounds to enhance the shelf life of perishable foods (Galus et al. 2020). One of the studies concluded that the shelf life of minimally processed fresh produces, such as pumpkin, carrot, persimmon, etc., can be extended using papaya puree as an edible coating. The papaya-puree-based edible coating can be added into minimally processed papaya to increase its nutritional values (Rangel-Marrón et al. 2019). The application of edible coatings formulated by blending alginate and acerola puree on acerola fruits showed a decrease in weight loss, ascorbic acid, ripening rate, and the decaying process, hence, extending the shelf life of acerola fruits (Azeredo et al. 2012). Papaya purees can be attained from fruit-processing wastes (Otoni et al. 2014). The composite coating of mango puree, gaur gum, sesame protein, and calcium chloride has been proved to enhance the shelf life of fresh-cut mango. The application of the mentioned coating on fresh-cut mangoes showed a decline in degradation of ascorbic acid, total phenolics content, and carotenoids level in the sample and was helpful in maintaining the firmness, total soluble solids, and sensory attributes of mango (Sharma et al. 2019).

Composite films and coatings

Composite edible coatings are a combination of protein/polysaccharide and lipid providing combined advantages. The water-soluble polymers (hydrocolloids) and lipid-based composite films provide the great water vapor barrier property of lipids and good oxygen and carbon dioxide barrier properties of carbohydrates. Bioactive compounds can be incorporated into composite films and coatings to improve their functionality (Sharma et al. 2019). Polysaccharides and proteins exhibit great mechanical and structural properties but lack good moisture barrier properties that can be overcome by blending lipids with them. The main reason behind the applicability of composite films and coatings is to aggregate the advantages provided by carbohydrates, proteins, and lipids into a single resultant coating or film; in addition to that, aggregating also helps in minimizing the loss of each component (Yousuf et al. 2018).

Nanotechnology-based edible coatings

Nanotechnology aids in the postharvest preservation of fresh produce. The nanosized zinc oxide, silicon, and calcium carbonate were used to enhance the shelf life of fresh produce and reduce the decay rate (Jianglian & Shaoying 2013). The exercise of nanotechnology approaches such as the delivery of active or antimicrobial compounds using encapsulation methods has the potential to confront the issue of microbial-caused decay of fruits and vegetables; hence, it aids in maintaining the food quality attributes (Dhital et al. 2018; Jafarzadeh et al. 2021). Emulsification is a process to deliver advantageous compounds to a liquid solution. This approach is employed to make nano-emulsified edible coatings to convey active compounds onto the fresh produce via edible coatings. The application of citral-based nano-emulsified edible coating onto fresh-cut melons has proved to exhibit antimicrobial properties and extended the shelf life of the product (Arnon-Rips et al. 2019).

The implementation of the nanoencapsulation approach by incorporating curcumin and limonene into liposomes has proved to prolong the shelf life of strawberries, whereas the application of limonene liposomes has been found to have significant control over fungal decay and maintain total phenolic content (Dhital et al. 2017). The application of edible coating enriched with limonene liposomes on strawberries demonstrated positive results by extending the shelf life and reducing the respiration rate of food products (Dhital et al. 2018). The employment of solid–lipid nanoparticles with xanthan gum edible coating to preserve tomatoes exhibited positive results to the overall quality parameter of tomatoes (Miranda-Linares et al. 2018). The use of chitosan incorporated with a nanosilicon dioxide coating has proved to be an effective alternative to preserve the food quality attributes. The chitosan with nanosilicon dioxide onto jujube fruit has shown a positive impact in aspects of quality and shelf life (Yu et al. 2012).

Incorporation of antimicrobial and essential oils into edible coatings

The concentration of phenolic compounds preventing microbial-caused decay is high in spices and herbs (thyme, rosemary, oregano, sage). Essential oils (EOs) are majorly recovered from herbs and spices that have high antioxidant properties; therefore, EOs can be used as natural antioxidants as well as provide antimicrobial protection. Active compounds can be extracted from byproducts of plants – pomegranate peel, olive leaves, etc. (Ganiari et al. 2017). Essential oils extracted from spices are commonly used as natural preservatives (Ju et al. 2019).

In the food industry, EOs are commonly used to provide flavor. Along with it, they obtain antioxidant and antimicrobial functional properties. EOs from bergamot, cinnamon, coriander, clove, eucalyptus, lemon, oregano, rosemary, sage, thyme, and tea tree are commonly used to develop edible coatings/films and provide promising antioxidant, antibacterial, and antifungal properties (Sánchez-González et al. 2011a, b). Carvacrol, thymol, and eugenol are the main components present in basil and thyme oils, which exhibit antioxidant properties (Lee et al. 2005). The EOs of oregano (*Origanum vulgare* L.) exhibit antibacterial properties as it deteriorates Staphylococcus aureus by altering the morphology of its cell surface, which results in loss of cytoplasmic material (de Souza et al. 2010). Oregano EOs repress the synthesis of staphylococcal enterotoxins (de Souza et al. 2010). The EOs also affect the mitochondrial membrane of bacteria (Rasooli et al. 2006). Terpenoid and phenolic compounds are the major components that exhibit antioxidant properties in essential oils. They are extensively used to preserve food (Sánchez-González et al. 2011a, b).

The EOs of tee tree were used as natural antioxidants in food, for example in preserving raspberries (Chanjirakul et al. 2006). The EOs of clove, lemon, eucalyptus, tea tree, roomer, and melissa were used in leafy vegetable produces (Ponce et al. 2004) and as factors preserving color, texture, and firmness, in fruits due to reduced water loss and lower respiration rate (Sánchez-González et al. 2011a). Commercially available oranges coated with *Lippia scaberrima* oil resulted in a reduction in weight loss (du Plooy et al. 2009). The table grapes covered with an edible coating of HPC/chitosan enriched with bergamot oil resulted in a reduction in weight loss (Sánchez-González et al. 2011a). This coating reduced respiration rate in grapes (Sánchez-González et al. 2011a), apples, and melons (Raybaudi-Massilia et al. 2008). Various studies of these authors have shown that the incorporation of EOs into edible coating causes less consumption of oxygen and reduction in carbon dioxide production; the main reason behind this is the lipophilic nature of EO.

Functional edible coatings

Edible coatings are used as the vehicle for the incorporation of bioactive compounds such as antioxidants, probiotics, antimicrobials, and EOs for the improvement of food quality and the creation of functional foods. Bioactive components are present in food in minuscule quantities, and incorporation of these components into a product increases its nutritional value (Tajkarimi et al. 2010; Quirós-Sauceda et al. 2014). Incorporation of N-acetylcysteine and glutathione into edible coatings was found to be effective in preventing browning reactions in fresh-cut pears for a period of 2 weeks without any textural damage (Song et al. 2011). No significant reduction in the number of viable organisms was observed during storage at 5 °C of strawberries coated with encapsulated *Lactobacillus acidophilus* and *Bifidobacterium lactis* in calcium alginate and 2% (w/v) solution. Some researchers have used edible coatings to add flavors to food products. Laohakunjit and Kerdchoechuen (2007) incorporated 25% natural pandan leaf extract into 30% sorbitol-plasticized rice starch for coating of nonaromatic milled rice, resulting in produce with a smell similar to aromatic rice. Another approach is by adding flavor precursors in the coating formulations, which, when coming in contact with the food, may react with food components and produce flavoring compounds. An increase in the concentration of aroma compounds was observed when alginate calcium coatings using linoleic acid and isoleucine was applied on apple wedges (Olivas et al. 2012).

Problems associated with edible coatings

Even though edible coatings have been regarded as means of extending the shelf life of fruits and vegetables, still their commercialization faces many challenges.

The effect of these coatings on sensory properties sometimes affects consumer acceptance. The incorporation of different herbs, spices, antimicrobials, and antioxidants could impart undesirable flavors to the commodities. Criteria for the selection of edible coating are based on respiration and transpiration rates of food and the storage conditions. Since fruits and vegetables differ in respiration rate, gas diffusion, and skin resistance, coating developed for one commodity may not be suitable for another. The thickness of the coating and method of application affect the permeability of pores, thus influencing transport-related properties. Refined mineral oil-based coatings result in anaerobic conditions, causing fruit injury (Moalemiyan et al. 2012). The anaerobic respiration results in fermentation and development of off-flavor detrimental to the sensory quality of the commodity. The application of essential oils in higher concentrations as antimicrobials in edible coatings may adversely affect the aroma of fresh-cut fruits. Azarakhsh et al. (2012) reported that the use of lemongrass oil in alginate-based coating for fresh-cut pineapple decreased the sensory score even when used at a low concentration. Antibrowning agents such as N-acetylcysteine and glutathione, when used in higher concentrations, may result in unpleasant odors (İyidoğan & Bayındırlı 2004). Therefore, minimizing the detrimental changes in sensory attributes can be a potential area of research that can be explored.

Market trend and environmental impact

The quality of living standard is increasing along with the significant demand for fruits and vegetables (Maringgal et al. 2020). The rise in health awareness among people leads to the elevated demand for fruits and vegetables rapidly due to their nutritional value. Fruits and vegetables comprise various nutrients, phenolic compounds, and antioxidants that aid in preventing many deadly diseases (Hassan et al. 2018). The main problem is connected with delivering fresh fruits and vegetables to the plate of consumers due to their perishable nature and high risk of postharvest losses in view of poor handling practices, ripening rate, and microbial contamination. Consumers demand fresh produce and judge that on the basis of visual attributes (Maringgal et al. 2020). The preservation of fruits and vegetables is a worldwide challenge; therefore, edible coatings made from natural sources are influential techniques used to overcome this trouble to some extent. Edible coatings are consumer-friendly as well as eco-friendly. Herbal edible coatings such as *Aloe vera* (Tripathi & Dubey 2004; Misir et al. 2014) provide health benefits and act as nutraceuticals (Raghav et al. 2016) along with the preservation of fresh produce (Maringgal et al. 2020).

CONCLUSION

This review assembles up-to-date information about edible coatings and their application to preserve fruits and vegetables. Edible coatings support retaining the nutritional and sensory attributes of food products. The addition of natural antimicrobial and active ingredients into the coating formulation helps in preservation by exhibiting various properties (antibacterial, antifungal), which results in improved physical and chemical aspects of fruits and vegetables. The present study also discusses the use of edible matrix (carbohydrate/protein/composite/lipid) and its significant effects on the quality of fruits and vegetables. The review indicates that the application of composite-edible coating overcomes the drawback of raw material and delivers significant results. Consumers can choose fresh produce with high nutritional value instead of stale products in the market; therefore, the preservation of semi-perishable produces such as fruits and vegetables has become a center of attraction for food industries. The edible coatings from natural sources (carbohydrates, proteins, and lipids) have come up with convenient results. Edible coatings can act as vehicles to carry nutraceutical components to provide additional health benefits to consumers. The herb-based edible coating also engages the researchers' curiosities and acceptance by consumers. The exploration of a suitable edible coating with respect to the food product is a vital factor that needs to be considered.

Table 1. Edible coating matrix and its significant effects

Food product	Type of fruit	Coating material	Additive	Active component	Method of application of edible coating	Effective concentration	Significant effects	References
Apples	fresh apples	cassava starch + gellan + soy lecithin	glycerol	thyme essential oil	spreading using glove (approximately 1.5 mL per fruit)	8 : 2 (starch : gellan)	prevented water loss in persimmon, showed antifungal properties	Sapper et al. 2019
	fresh-cut apples	cassava starch, carnauba wax and stearic acid	glycerol	cinnamon bark or fennel (0.05% to 0.30% v/v, respectively)	dipping (2 minutes)	0.3% v/v cinnamon bark essential oil into cassava starch (2% and 3% w/v)	good barrier properties along with good mechanical and structural properties, exhibited antioxidant and antimicrobial properties	Chiumarelli & Hubinger 2014
	fresh-cut apples	xanthan gum	propylene glycol	tocopherol nanocapsules	dipping	-	physicochemical properties preserved, activity of PAL and PPO enzymes reduced and reduction in respiration rate observed	Galindo-Pérez et al. 2015
	fresh-cut apples	hsian-tsao leaf gum (dHG) + tapioca starch	glycerol	cinnamon essential oil, ascorbic acid (antibrowning agent), calcium chloride (texture enhancer)	dipping (1 minutes)	1.7% starch, 0.3% dHG, 0.3% glycerol, 0.2% cinnamon essential oil, 1% $CaCl_2$ and 1% ascorbic acid	maintained the quality of food product, shelf life extended, and delayed browning	Pan et al. 2013
	fresh-cut apples	soy protein isolate	glycerol, sodium sorbate	ferulic acid	dipping (10 seconds)	SPI ($30\ g \cdot L^{-1}$) + ferulic acid ($4\ g \cdot L^{-1}$)	controlled enzymatic browning and extended shelf life of fresh-cut apples	Alves et al. 2017
Plums	fresh plums	wheat starch + whey protein isolate (WPI)	glycerol	-	dipping	80–20% (wheat starch and WPI)	shelf-life extension, reduced respiration rate	Basiak et al. 2019
	fresh plums	hydroxypropyl methylcellulose (HPMC) + beeswax (BW)	glycerol, stearic acid, food additives, such as SEP (sodium ethylparaben), SMS (sodium methylparaben) and PS (potassium sorbate)	-	spreading (approximately 300 μL per fruit)	36% beeswax (dry basis), 3 : 1 (HPMC : glycerol) and 5 : 1 (BW : stearic acid)	delayed postharvest ripening, reduced weight, firmness, and color loss and extended shelf life of plums	Gunaydin et al. 2017
	fresh plums	rice starch and carrageenan	glycerol	-	spreading (approximately 0.5 mL per fruit)	-	delayed respiration rate, restricted ethylene production and firmness retained	Thakur et al. 2018
Straw-berries	fresh straw-berries	sodium alginate and pectin		eugenol and citral essential oils	dipping (2 minutes)	alginate 2% + eugenol EO 0.1% and alginate 2% + citral EO 0.15% + eugenol EO 0.10% pectin 2% + eugenol EO 0.1% and pectin 2% + citral EO 0.15%	reduction in microbial load during storage	Guerreiro et al. 2015
	fresh straw-berries	beeswax	-	coconut and sunflower oil	spreading	60 mL coconut oil, 50 mL sunflower oil and 25 g beeswax	good moisture barrier, hence prevented water loss and deactivation of vitamin C, improved appearance, antifungal due to presence of coconut oil	Mladenoska 2012

	fresh straw-berries	chitosan + banana starch	2% citric acid solution and sorbitol	aloe-vera gel	dipping (3 minutes)	final concentration of coating solution; 3% (w/v) starch, 2% (w/v) chitosan and 20% (v/v) aloe-vera gel	reduced decay rate, showed antifungal and antimicrobial properties, decreased in water vapor loss and delayed loss of physicochemical properties during storage	Pinzon et al. 2020
	fresh straw-berries	chitosan	acetic acid	-	dipping (5 minutes)	application of 1% and 1.5% chitosan showed significant positive results	increased in shelf life, inhibited oxidative enzyme activity, i.e., delayed in G-POD and PPO activities and retarded decrease of ascorbic acid, GSH content, and β-1,3-gluconase activity	Wang & Gao 2013
	fresh manda-rins	chitosan, MC, HPMC, CMC	glycerol	-	spreading	first layer CMC (1.5%) and second layer chitosan (1.5%)	firmness and gloss improved and physiological quality of fruits improved	Arnon et al. 2015
Citrus fruit	fresh fruit	chitosan and locust bean gum (LBG)	-	pomegranate peel extract		chitosan (1% w/v) and LBG (0.5% w/v) + 0.361 g dry water pomegranate peel ex-tract (WPPE per mL)	shelf life extended, inhibited green mold development, antifungal in nature	Kharchoufi et al. 2018
	fresh fruit	beeswax	benlate-fungicide	-	-	5% beeswax + 0.5% benlate	extension of shelf life and overall quality improved	Shahid & Abbasi 2011
	fresh cherry tomatoes	quinoa protein + chitosan	-	thymol nanoemulsion	dipping (3 minutes)	1 : 5 w/v quinoa flour and distill water + 10% thymol nanoemulsion	antifungal in nature inhibited the growth of *Botrytis cinerea*	Robledo et al. 2018
Cherry toma-toes and toma-toes	cold stored cherry tomatoes	hydroxypropyl methyl cellulose (HPMC) and beeswax (BW) (HPMC-lipid edible compo-site emulsion)	glycerol, 2% sodium benzoate and oleic acid	-	dipping (30 seconds)	-	inhibited the growth of *A. alternata*, reduction in the black spots, respiration rate and weight loss, controlled the postharvest quality of food, decreased water loss, and food looked glossy	Fagundes et al. 2015
	fresh tomatoes	pectin + corn flour + beet-root powder	glycerol		dipping		delayed respiration rate, retained biochemical quality, decreased in weight loss and decaying rate	Sucheta et al. 2019
	fresh peaches	chitosan	chlorogenic acid	-	-	1 : 1 (chitosan : chlorogenic acid) showed highest antioxidant activity	exhibited strong antioxidant activities and results promised to maintain firmness, ascorbic acid content, SSC and TA when stored at 20 °C for 8 days	Jiao et al. 2019
Peaches	fresh-cut peaches	-	-	green tea, *Posidonia oceanica* (PO)	dipping	-	controlled microbial spoilage and made food product look attractive for consumers	Piva et al. 2017
	fresh fruit	sodium alginate	-	rhubarb extract	dipping	1% (w/v) sodium alginate + 0.05% rhubarb extract	control degradation caused by *Penicillium expansum*, exhibited antifungal properties and maintained physiological quality parameters	Li et al. 2019
Button mush-rooms	fresh	tragacanth gum		*Satureja khuzistanica* essential oil		100–1000 ppm of *Satureja khuzistanica* essential oil	maintenance of 92.4% tissue firmness, and reduction in microorganism counts, such as yeasts and molds and *Pseudomonas*, compared to uncoated samples	Nasiri et al. 2018

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