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Edible coatings: A promising technology for shelf life extension in fruits and vegetables

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Abstract

Fruits and vegetables are in high demand these days due to their nutritious value. Because they are perishable, fruits and vegetables have a limited shelf life. Insects, microbes, pre-harvest and post-harvest circumstances, transportation and preservation all have an impact on or cause harm to about 30% of fruits and vegetables. Fruit and vegetable preservation is a major global concern. An efficient way to address this issue is using edible coating. Edible coatings have been identified as one of the safest and most dependable methods for preserving fruits and vegetables because of their film-forming capabilities, antibacterial qualities, biodegradability and biochemical characteristics. These efficiently block water vapor, moisture, CO₂ and O₂. It reacts well to the biochemical (enzymes that break down cell walls), physiological (respiration rate, ethylene evolution rate) and physical (firmness, glossiness, appearance and moisture retention) properties. Therefore, the safest, non-toxic and most environmentally friendly way to increase the shelf life of fruit and vegetable harvests is to apply an edible coating.

Keywords: Edible coating, fruits, vegetables, coating types, shelf life and postharvest

Introduction

Fruits and vegetables are extremely perishable because they comprise 80-90% water by weight. Without cuticle, the water rapidly starts to evaporate, shortening the product's shelf life. Between harvest and consumption, fresh fruits and vegetables experience significant losses in both quality and quantity. Temperature, stressors and atmospheric composition such O₂, CO₂ and ethylene ratios are examples of external determinants of loss, whereas species, cultivar and growth stage are examples of internal factors (Kluge *et al.*, 2002) [28]. Furthermore, the skin of fruits and vegetables can contaminate their flesh, increasing their susceptibility to spoilage and biochemical deterioration, including browning, loss of flavour and breakdown of texture. This lowers the quality of the fruits and vegetables and increases the risk to consumers due to the presence of pathogenic microorganisms. Covering fresh-cut food with safe, edible, biodegradable and biocompatible polymers, also referred to as edible coatings, is one possible method for maintaining quality and extending shelf life.

In addition to or in place of natural protective waxy coatings, edible coatings are thin layers of edible substance that are put to the product's surface to prevent moisture, oxygen and solute migration. They are brushed, sprayed or dipped directly onto the food surface to provide a changed environment (McHugh and Senesi, 2000) [36]. It should be generally regarded as safe (GRAS) (Krochta and Mulder-Johnston, 1997) [31] approved by FDA and must conform to the regulations that apply to the food product concerned (Guilbert *et al.*, 1996) [15]. An ideal coating is one that can decrease decay without compromising the quality of fresh fruits and vegetables and prolong their shelf life without creating anaerobiosis. In addition to being environmental-friendly, edible coatings or films extend the shelf life of fruits and vegetables. The primary goal of edible coating for fruits and vegetables is to enhance the natural barrier, if it is already there and to replenish it when handling and washing have partially destroyed or changed it. Additionally, the fact that this edible covering can be consumed with fruits and vegetables is one of its most significant features (Baldwin *et al.*, 1994) [10]. Moreover, another important advantage of edible coating is the reduction of synthetic packaging waste because these coatings are composed of

biodegradable raw material. In fact, the development and application of edible coatings to extend the shelf life and enhance the quality of fresh food has drawn more attention during the past 20 years. However, industrialization is still in its early stages. Thus, the main goal of this article is to review on edible coatings for fresh fruits and vegetables focusing on the history, properties, classification and different methods of using, pro and cons of edible coating to reduce postharvest loss of fruits and vegetables occurring at different stages of the supply chain to enhance food and nutrition security.

History of Edible Coatings

The first edible fruit coating was made of wax. In the 12th and 13th centuries, the Chinese coated oranges and lemons with wax (Hardenburg, 1967) ^[19]. The Chinese discovered that fruits with wax coatings could be kept for longer than fruits without, despite their ignorance that edible coatings actually slowed down respiratory gas exchange. Hot-melt paraffin waxes started to be sold commercially in the 1930s as edible coverings for fresh fruits like pears and apples. According to Erbil *et al.* (1986) ^[11], applying wax emulsions to peach surfaces reduced oxygen and water vapor transmission, lowering respiration rate and extending fruit shelf life. According to Nisperos-Carriedo *et al.* (1990) ^[40] and Baldwin *et al.* (1995) ^[6], cellulose and oils or waxes had comparable impacts on tropical fruit's ability to stay fresh and avoid spoiling. Other materials that could be utilized to cover, generate and alter the internal gas composition of fruits and vegetables for short-term storage have been the subject of numerous attempts. A nonphytotoxic, tasteless, odourless edible covering that effectively extends the shelf life of fruits and vegetables was described by Lowings and Cutts in 1982. This coating material is a blend of sodium carboxymethyl cellulose, mono and di-glycerides and sucrose fatty acid esters (SFAE). In the beginning, SFAE was created as an emulsifier. On the other hand, SFAE coating delays the ripening of fruits. SFAE mixtures have been commercially available since 1980's for coating fruits and vegetables under the trade names "TAL Pro-long" and "Semper fresh" (Park *et al.*, 1996) ^[42]. According to Park *et al.* (1994) ^[41], applying a zein coating to the tomato's surface caused its colour to be delayed.

Definition

A thin covering of material that is safe to eat and acts as a barrier against oxygen, external microorganisms, moisture and food solute movement is known as an edible coating. A semi-permeable barrier is included in edible coatings with the goal of extending shelf life by lowering respiration, oxidative reaction rates, gas exchange, moisture and solute migration and physiological disorders in fresh cut fruits (Park *et al.*, 1999) ^[16]. Pavlath and Orts (2009) ^[1] state that a variety of materials were employed to coat and wrap different fruits and vegetables in order to increase their shelf life. This coating, whether or not it is removed, is regarded as edible. Fruits and vegetables are given a glossy appearance by edible films or coatings. In general, edible coatings are less than 0.3 mm thick. Its primary function is to extend the shelf life of processed or fresh fruits and vegetables while shielding them from environmental and postharvest harm. The edible coatings are utilized as a nutraceutical and as a carrier for antioxidants and texture enhancers. Edible coatings should be stable and widely

accepted as safe when exposed to high relative humidity. The majority of edible coatings and films are colourless, odourless and tasteless; they should also have high mechanical qualities. Edible coatings are effective in keeping out gases and moisture.

Properties of edible coatings

Molecular structure, as opposed to molecular size and chemical composition, is the primary determinant of edible coating qualities. Particular specifications for edible coatings and films are (Arvanitoyannis and Gorris, 1999) ^[4]:

- The coating should be water-resistant so that it remains intact and covers a product adequately, when applied.
- It shouldn't accumulate too much carbon dioxide or deplete oxygen. Around a commodity, oxygen must be present at least 1-3% to prevent a transition from aerobic to anaerobic respiration.
- It should reduce water vapor permeability.
- It should improve appearance, maintain structural integrity, improve mechanical handling properties, carry active agents (antioxidants, vitamins, etc.) and retain volatile flavour compounds.
- It should melt above 40 °C without decomposition.
- It should be easily emulsifiable, non-sticky or should not be tacky and have efficient drying performance.
- It should never interfere with the quality of fresh fruit or vegetable and not impart undesirable order (Akhtar *et al.*, 2015) ^[2].
- It should have low viscosity and be economical.
- It should be translucent to opaque but not like glass and capable to tolerate slight pressure.

Edible Coating Applied on Different Fruits and Vegetables

About half of fresh product deteriorates during harvest, processing, transit and storage, making fresh fruits and vegetables extremely perishable. In order to deal with this problem, edible coatings are crucial. Freshly cut and entire fruits and vegetables are coated with edible coatings (Youssef *et al.*, 2015) ^[57]. Fruits and vegetables which has been coated are:

- **Fruits:** Apple, Cherry, Orange, Mango, Lemon, Papaya, Guava, Strawberry, Grapefruit, Peach etc. and fresh-cut Apple, fresh-cut Peach, fresh-cut Pear etc.
- **Vegetables:** Tomato, Capsicum, Cucumber, Cantaloupe and minimally processed Carrot, fresh-cut Potato, fresh-cut Cabbage, fresh-cut Tomato slices, fresh-cut Onion, Lettuce.

Classification of edible coatings

Materials with the ability to form films can be used to create edible coatings. A solvent, such as water, alcohol, a combination of water and alcohol or a combination of other solvents, must be used to disperse and dissolve the film materials during manufacture. This procedure allows for the addition of plasticizers, antimicrobials, minerals, vitamins, colours or flavours. Hydrophobic groups, such as lipid-based or wax-based and hydrocolloids or hydrophilic groups, such as polysaccharide-based, protein-based or a combination of both groups, are used in edible coatings to enhance their functionality (Warriner *et al.*, 2009) ^[55]. Edible coatings are natural and not created chemically. When compared to other synthetic coatings, the primary benefits of edible coating are its cost-effectiveness, non-

toxicity and edibility (Prasad and Batra, 2015) ^[44]. The edible coatings are mainly divided into three classes; these are following- (Donhowe and Fennema, 1993) ^[9].

1. **Hydrocolloids:** *e.g.*, polysaccharides, proteins and alginate.
2. **Lipids:** *e.g.*, fatty acids, acryl glycerides and waxes.
3. **Composites:** *e.g.*, protein/protein, polysaccharides/protein, lipid/polysaccharides.

1. Hydrocolloids

Hydrocolloids are hydrophilic polymers that can be derived from synthetic, microbial, vegetable or animal sources. Alginate, carrageenan, pectin, carboxymethyl cellulose, xanthan gum and gum Arabic are examples of poly electrolytes that contain hydroxyl groups. These days, a variety of coating forming solutions, including hydrocolloids, are used to coat and regulate the colour, texture, flavour and shelf life of fruits and vegetables (Williams and Phillips, 2000) ^[56]. The main purpose of all hydrocolloids, which are generally partially or totally soluble in water, is to enhance the viscosity of the aqueous phase (continuous phase) or the thickness of the gelling agent. Because of this stabilizing effect, they function as an emulsifier. There are two classes of hydrocolloids: polysaccharide-based and Protein-based

Polysaccharide based edible coatings

Many types of polysaccharides can be used to create edible coatings. The most widely accessible polymers are derived from agricultural and marine plants and animals (Dhall, 2013) ^[45]. Chitosan, starch, alginate, cellulose, pullulan, carrageenan, gellan gum and others are the most often used polysaccharides for the edible covering of fruits and vegetables. Edible coatings based on polysaccharides are water soluble and have weak moisture barrier qualities. However, its O₂ permeability is only relatively poor. In order to lower their respiration rate, edible coatings based on polysaccharides are typically placed on fresh and minimally processed fruits and vegetables by creating a modified atmosphere. Its enhanced handling capacity for additives and mechanical handling properties (Bai and Plotto, 2012) ^[5]. A range of food coatings are made crispier, harder, more compact, thicker, more sticky and more viscous by polysaccharides. Because polysaccharides are composed of polymer chains with superior gas barrier qualities, they provide a desired modified environment that prolongs the shelf life of fruits and vegetables without creating anaerobic conditions. These coatings are given below-

Cellulose Derivative

The most common natural polymer on Earth is cellulose, which is a nearly linear polymer of anhydro glucose. Anhydro glucose is highly crystalline form, which is resistant to breakdown in aqueous conditions, is caused by the extremely close packing of its polymer chains. Cellulose can be made more soluble in water by swelling its structure with alkali and then reacting with methyl chloride, propylene oxide or chloroacetic acid to produce carboxymethyl cellulose (CMC), methyl cellulose (MC), hydroxypropyl methyl cellulose (HPMC) or hydroxyl propyl cellulose (HPC). Generally, odourless and tasteless, methyl cellulose, HPMC, HPC and CMC films are translucent, flexible and moderately strong. They are also resistant to oil and fats, water soluble and only moderately permeable to

moisture and oxygen transfer (Krochta and Mulder-Johnston, 1997) ^[31]. The molecular weight of cellulose determines the mechanical and barrier qualities of cellulose-based films; the higher the molecular weight, the better the properties (Krochta *et al.*, 1993) ^[32]. Methyl cellulose is most resistant to water and is lowest hydrophilic cellulose derivative (Kester and Fennema, 1986) ^[27]; however, the water vapor permeability of cellulose ether (CE) film is still relatively high. Although several cellulose derivatives have good film-forming qualities, their cost prohibits their widespread application.

Starch Derivatives

The storage polysaccharide found in cereals, legumes and tubers, starch is a plentiful and renewable raw resource that may be used in a wide range of industrial processes. Anhydro glucose units make up the polymeric carbohydrate known as starch. This substance is not consistent and the majority of starches contain two different kinds of glucose polymers: amylose, which is a straight chain glucose polymer and amylopectin, which is a branched glucose polymer (Rodriguez *et al.*, 2006) ^[50]. Because they are inexpensive, renewable and have strong mechanical qualities, they have been used to create biodegradable films that can either completely or partially replace plastic polymers. Corn starch, for instance, is a great source of amylose for coating and film making (Mark *et al.*, 1966) ^[34]. The physical properties of corn starch-based films and coatings are similar to those of plastic films and coatings; they are non-toxic, tasteless, odourless and colourless. It is semi-permeable to carbon dioxide and oxygen and physiologically absorbing.

Chitosan

Chitosan is an edible polymer that comes from chitin. Animal shells from crustaceans are the primary source of chitin. After cellulose, chitosan is the most widely used natural, non-toxic substance for creating edible coatings (Shahidi *et al.*, 1999) ^[51]. Without the addition of any kind of additive or antioxidant, chitosan has good properties, including a good O₂ barrier, CO₂ permeation and antibacterial activity against microorganisms. Chitosan's mechanical qualities are good. Chitosan has a very high viscosity, just like natural gums. Chitosan extends the shelf life of fruits and vegetables and is composed of clear and transparent coatings. Typically, its coating is cohesive, glossy, smooth and free of surface fissures.

Gums

Gums are mostly made of sugars and polysaccharides. Because of their texture, gums are utilized to make edible coatings for fruits and vegetables. Generally, gums are divided into three parts- a. Exudate gums (*e.g.*, gum Arabic) b. Extractive gums (*e.g.*, guar gum) c. Microbial fermentation gums (*e.g.*, xanthan gum). Water dissolves gums. Through a fermentation process and microbial extraction, xanthan gums are made. Because of its high viscosity, it spreads quickly in both hot and cold water. Guar gum, xanthan gum and Arabic gum are used to create uniform coats with strong adherence in wet batters. Mesquite gum exhibits excellent water barrier properties when a small amount of lipid is added to produce a coating (Mei *et al.*, 2006) ^[37].

Alginate and Carrageenan

Brown seaweed, a member of the Pheophyceae family, is the source of alginate, which is frequently utilized as sodium alginate. Alginic acid salts are found in alginate. Alginate contains monomers of D-mannuronic acid and L-guluronic acid in a linear chain copolymer. Alginate has a superior moisture and water vapor barrier (Robertson, 2009) ^[49]. Alginate has a number of advantageous qualities, such as decreased shrinkage, moisture retention and food colour and odour. Because of their hydrophilic nature, strong edible coatings or films formed of alginate have a low water resistance. A water-soluble polymer belonging to the Rhodophyceae family, carrageenan is a sulphated polysaccharide that is isolated from the cell walls of several red seaweeds. A linear chain of partly sulphated galactans, which can form coatings or films, is present in it. During a moderate drying process, carrageenan coatings or films create a gelation mechanism that results in a three-dimensional network formed by the double helical polysaccharide and a solid coating or film following solvent evaporation. (Karbowski *et al.*, 2006) ^[25].

Pectin

Fruits and vegetables naturally contain pectin, a class of carbohydrates generated from plants. Pectin works well for fruits and vegetables with low moisture content, however it is not a good moisture barrier. This group of acidic polysaccharides is diverse. It is frequently found in apple pomace and citrus fruit peel. High Methoxy Pectin or HMP, is a great pectin chemical for creating high-quality films and coatings. A flexible film and coating were produced by the combination of high amylose starch and citrus pectin. At 180 °C, they remain stable; the pectin dissolves in polyvinyl alcohol (Fang and Hanna, 2000) ^[12].

Protein-Based Edible Coating

Animals and plants are the sources of protein-based edible coatings. Casein, whey protein, zein (from maize), gluten (from wheat), soy protein and other plant-based proteins are edible coating materials; collagen and egg albumen are examples of animal-based proteins. Although protein-based edible coatings are strong and have good barrier qualities for oxygen, oil and scent, they are ineffective at keeping moisture out. Its densely packed hydrogen bonded structure is the cause of its exceptional oxygen barrier property. At low relative humidity, protein-based edible coatings have strong O₂ barrier qualities. Although protein-based coatings have good organoleptic and mechanical qualities, their hydrophilic nature makes them poor barriers to water vapor (Krochta, 2002) ^[30].

Casein

All casein species are present in micelles, which are the form of casein, a milk protein. Due to its amphipathic structure and hydrophilic and hydrophobic ends, casein is frequently employed in emulsion preparation. The most prevalent casein product is caseinate, which dissolves readily in water. Due to its ease of formation, casein might be employed primarily for edible coatings.

Corn Zein

Zein proteins are synthesized from corn gluten flour and come from maize. Zein protein dissolves in alcohol and glycol esters but is immiscible in water. Zein protein is sticky, binding and film and coating-producing qualities

(Raghav *et al.*, 2016) ^[47]. Zein protein from corn is useful in preventing colour change, hardness and weight loss. It also extends the shelf life of fruits and vegetables and has a strong O₂ barrier. Compared to other edible coatings and wrapping films, corn-zein coatings and films have an exceptional water vapor barrier that is approximately 800 times higher.

Whey Protein

A byproduct of making cheese, whey protein is especially high in β -lactoglobulin. When properly processed, whey proteins (20% of total milk proteins) form flexible yet brittle films (Kaya and Kaya, 2000) ^[26]. They have been thoroughly studied as edible coatings and have a comparatively high nutritional content. If combined with gelatin, whey protein can be easily processed and has some potential as an outer film; however, appropriate modification techniques can be created to lessen moisture sensitivity (Claus, 2000) ^[8].

Soy Protein

Compared to cereal grains, which have a protein concentration of 8-15%, soybeans have a substantially greater protein content (38-44%). Both surface film formation on heated soymilk and film production from solutions of soy protein isolate (SPI) are methods for producing edible films based on soy protein (Gennadios and Weller, 1992) ^[14]. Both soymilk and SPI can be made into films by heating film solutions, which breaks down the protein structure, cleaves native disulfide bonds and reveals sulfhydryl and hydrophobic groups. The production of soy protein film structure is thought to be influenced by the creation of new disulfide, hydrophobic and hydrogen bonds during film drying (Subirade *et al.*, 1998) ^[52].

Lipid based edible coatings

Edible coverings based on lipids have been used for many years to preserve fruits and vegetables. They give meals a glossy, shiny appearance. Carnauba wax, beeswax, paraffin wax and mineral or vegetable oil are the most widely used lipid-based coating compounds. Lipids have a good ability to block water (Morillon *et al.*, 2002) ^[39]. In comparison to other lipid-based and non-lipid coatings, wax coatings have excellent moisture barrier qualities. Because of their greasiness, thickness and rancid flavour, coatings made of oil, fat and wax are difficult to apply to the surface of fruits and vegetables (Robertson, 2009) ^[49]. The barrier qualities of coating materials are enhanced by the combination of proteins, lipids and polysaccharides. According to Galus and Kadzińska (2015) ^[13], lipid combinations can effectively enhance the hydrophilic nature of materials based on polysaccharides and proteins. The most popular lipid-based coatings are covered in further detail.

Wax and Oil-Based Coatings

Mineral oil, paraffin wax, candelilla wax, beeswax, carnauba wax and polyethylene wax are all included in this coating. The distillate fraction of crude petroleum is used to make paraffin wax, which is a mixture of solid hydrocarbons produced by ethylene catalytic polymerization and can be applied to raw cheese and fruits. The leaves of the palm tree (*Copernicia cerifera*) are the source of carnauba wax, which has a very high melting point and is added to other waxes to give them more shine and toughness. While candelilla wax comes from the candelilla plant, beeswax is produced by honeybees. The oxidation of

polyethylene, a petroleum by-product, yields polyethylene wax. The main application for polyethylene wax is the creation of emulsion coatings. Lastly, liquid paraffin and naphthenic hydrocarbon combine to form mineral oil (Hernandez, 1994)^[21] and commonly used for coating fruits and vegetables and as a food release agent (Hernandez, 1991)^[20]. Waxes are used to enhance the surface appearance of a variety of fruits and vegetables and to act as barrier films against gas and moisture. When placed in thin layers, they are regarded as edible, but when put in thick layers, they must be removed before consumption (certain cheeses). The most effective edible substances that provide a barrier against humidity are waxes, particularly paraffin, carnauba, candelilla and bee wax. There are three categories of waxes: Vegetable waxes (carnauba wax, candelilla wax, bayberry wax, rosin wood wax, sugarcane wax, palm wax, esparto wax, cotton seedwax and rice bran wax), animal waxes (bee wax, spermaceti wax, shellac wax, lanolin wax and Chinese bug wax) and mineral and synthetic waxes (Montan, paraffin, ozocerite, synthetic and microcrystalline waxes)

Resins and Rosins

Both wood rosin and coumarone indene, which are used to coat citrus fruits, are examples of rosins and resins found in edible coatings. The bug *Laccifer lacca* secretes a substance called shellac resin, which dissolves in both alcohols and alkaline solutions. Since shellac is only allowed as an indirect food additive in food coatings and adhesives, it is not a generally recognized as safe (GRAS) ingredient. Its

primary application is in pharmaceutical coating. After volatiles are extracted from the crude resin, leftovers known as rosins are produced from the pine tree's oleoresins. The main purpose of rosins and resins was to add high gloss. Compared to citrus fruits coated with wax, those coated with shellac and wood resin often have higher internal CO₂, lower internal O₂ and higher ethanol content (Hagenmaier and Baker, 1993)^[17]. Additionally, shellac and wood resin-based treatments have a tendency to make postharvest pitting more common (Petracek *et al.*, 1998)^[43].

Emulsions

The application of emulsion coatings based on wax is a relatively recent concept. These emulsion coatings don't provide a product a glossy finish, but they do offer good moisture-blocking qualities. Glycerol and fatty acid derivatives are used as emulsifiers in several of these wax emulsions. These commercially available emulsifiers include polyglycerols and polystearates (Hernandez, 1991)^[20].

Composites Based Edible Coating

Proteins, polysaccharides and lipid-based materials are combined to create composites, also known as multicomponent films and coatings. This is utilized to increase edible coatings and films' mechanical strength, moisture resistance and gas barrier qualities. According to Han *et al.*, (2005)^[18], composites are divided into two categories: Bilayer composites and Conglomerates

Table 1: Effect of different edible coatings on fruits and vegetables

Edible coatings	Fruits/vegetables	Results	Reference
Chitosan	Broccoli	Enhance broccoli's nutritional value and quality while lowering yellowing symptoms and enhancing its pleasing sensory appeal.	Fang <i>et al.</i> , 2022 ^[58]
	Bell pepper	For post-harvest quality, it has a 5-day shelf life at 20 ± 2 °C and physicochemical characteristics are preserved during cold storage.	Hernández-López <i>et al.</i> , 2022 ^[59]
	Japanese pear	Increase shelf life and create a well-balanced aerobic-anaerobic metabolic control mechanism.	Hira <i>et al.</i> , 2021 ^[60]
Pectin	Star fruit	Prolongs shelf life and keeps physicochemical properties for over 14 days.	Shuaimi <i>et al.</i> , 2021 ^[61]
Xanthan gum	Fresh lotus root (<i>N. nucifera</i>)	Effective at preventing bacterial growth, it prolongs the shelf life of lotus root and fresh cuts after harvest.	Lara <i>et al.</i> , 2020 ^[62]
Zein	Melon	On the surface of the undamaged melon skin, the flexible film can be applied as an antimicrobial coating to suppress some of the main harmful bacteria.	Boyaci <i>et al.</i> , 2019 ^[63]
Gelatin	Persimmon	Reduce weight loss, slow down fruit deterioration during storage and reduced TSS, high firmness, pH and another natural covering technique that needs work.	Kingwascharapong <i>et al.</i> , 2020 ^[64]
Glycerol	Walnuts	Lessen lip oxidation or rancidity and stop a from growing <i>A. flavus</i> fungus, enhance nutritional value and prolong walnuts' shelf life.	Shaukat <i>et al.</i> , 2023 ^[65]
Carnauba wax	Tomato	Preserving quality, preventing spoiling, increasing fruit luster, extending shelf life, influencing gas permeability or the creation of carbon dioxide and oxygen, influencing colour and preventing weight loss.	Miranda <i>et al.</i> , 2022 ^[66]
Fatty acid	Cucumber	Prolongs the shelf life of fresh cucumbers and lowers their respiration and water loss.	Rux <i>et al.</i> , 2023 ^[69]
Loquat leaf extract + Alginate (lipid/polysaccharidic)	Nanfeng Tangerine	Citrus fruit preservation, postharvest spoiling rate reduction, fruit respiration delay, delayed nutrient degradation of nanfeng tangerines during cold storage and increased non-enzymatic antioxidants are all potential benefits of the green composite coating including plants.	Zhang <i>et al.</i> , 2022 ^[67]
Polysaccharides/ lipids (Carboxymethyl cellulose (CMC) + Cardamom essential oil)	Tomato	When fresh tomatoes are stored at a temperature of 25 ± 2 °C, the nanoemulsion layer reduces weight loss (7.32 ± 2.4%), hardness (1.3 times), total dissolved solids and acidity of tomatoes that can be titrated. It also increases antioxidant enzymes and reduces oxidative stress for 15 days.	Das <i>et al.</i> , 2022 ^[68]

Applying Methods of Edible Coatings

Edible coatings should be applied on fruits and vegetables by different methods. These methods are:

1. Dipping

The most popular technique for covering fruits and vegetables with tasty substances is dipping. Because of its efficacy and convenience of use, it is regarded as the most straightforward and widely used method (Alemu *et al.*, 2025) [3]. The dipping method's primary benefit is that it guarantees even and thorough coating of the food's surface. In order to enable the coating to adhere uniformly and create a consistent layer around the entire product, the produce is completely submerged in the coating solution for a certain amount of time (Ju *et al.*, 2019) [24]. Following the dipping process and drying of the residual layer, the food item is either air dried at ambient temperature or dried with a specialized drier.

2. Spraying

This technique uses an atomizer to spray the coating solution onto the meal, dispersing the liquid under high pressure into tiny droplets that are usually between micrometers and nanometers in size. The rheological characteristics of the coating solution, such as temperature, viscosity and surface tension, have a significant impact on spray coating efficacy. Spraying technology enables uniform coating with uniform thickness and multi-layer applications like interlayer solutions (Martín *et al.*, 2009) [35].

3. Layer by Layer Method

Layer-by-layer methods control coating characteristics and operation more precisely by layering polyelectrolytes with opposing charges. This process produces multilayer films that may increase edible coating's effectiveness. For polysaccharides and charged polyelectrolytes that can form hydrogen and covalent bonds, the application of the multilayer coating technique to improve the compactness of the coating layers during postharvest fruit storage has been recorded. When using the multi-layer coating technique to increase the coating's tightness, polysaccharides and charged polyelectrolyte showed effectiveness in fruit preservation (Kocira *et al.*, 2021) [29].

Effect of edible coatings

Effect on external appearance and glossiness

An essential component of the horticultural product is its external look. One of the main causes of the destruction of the natural wax coating and bruising injuries during packing and transportation processes is the rough physical handling of fruits during the postharvest period. The edible coating provides a physical barrier between the outside of the product and the fruit surface, ultimately preserving postharvest quality. When compared to gellan gum coatings, Javanmard (2011) [23] found that whey protein concentrate exhibits a high rate of glossiness, taste and colour with minimal weight loss.

Effect on fruit firmness and softening

By avoiding excessive transpiration and respiration, which directly reduce store reserves, edible coating maintains firmness. By reducing the activity of enzymes that break down cell walls and postponing ripening, edible coating directly affects fruit firmness (Momin *et al.*, 2021) [38]. Since

calcium is known to have a direct impact on fruit firmness, adding calcium to the edible coating also shown a high level of effectiveness in boosting fruit firmness.

Effect on weight loss of fruits

Farmers' profits are determined by the weight of their horticultural products. The primary cause of a product's weight loss is transpiration, which is influenced by the variation in water vapor pressure between the fruit and the atmosphere. Edible coatings act as an extra layer of protection between the fruit's surface and the air, which allows transpiration to happen. The physiology of harvested commodities is affected both directly and indirectly by an edible covering. Tesfay (2017) [53] revealed that coating avocado fruits (Hass and Geem kinds) with 1% carboxyl methylcellulose, moringa leaf and seed extract reduced respiration, ethylene generation and increased firmness over the course of storage.

Ethylene production and respiration

By preventing oxygen from entering the fruit, the edible covering lowers the respiration rate and regulates the synthesis of ethylene. As a result, the fruit's shelf life nearly doubles and they stay firm, fresh and nutrient-dense for longer. The amount, kind and natural coating of fruits will all influence how much internal modified atmosphere (O₂ and CO₂) is formed.

Biochemical parameters

Edible coatings affect the biochemical components *i.e.*, titratable acidity, total soluble solids and ascorbic acid that determine the fruit's flavour and shelf life, both directly and indirectly, in addition to physical and physiological alterations. Hosseini (2018) [22] found that kumquats coated with chitosan coatings containing tarragon and/or savoury essential oils had good sensory acceptability, reduced weight loss and a positive impact on vitamin C maintenance.

Total phenolic and antioxidants

The resistance to several postharvest quality maintaining agents is increased when these chemicals are present. The overall phenolic content of harvested horticultural commodities has the same impact as antioxidants and edible coatings have the power to change or raise antioxidant levels. Li (2017) [33] observed positive effects on fruit quality and highest relative activities of antioxidants enzymes in chitosan based strawberry fruits over alginate and pullulan coatings.

Lipid peroxidation and enzymatic activities

The activity of enzymes linked to the cell wall is influenced by edible coating. Enzymes that play a significant part in peel browning and cell wall disintegration, such as polyphenol oxidase, phenylalanine ammonia lyase and malondialdehyde, have been shown to have this impact. Additionally, edible coatings control the lipid peroxidation process, which breaks down cell walls and produces free radicals, both of which have an impact on postharvest quality.

Advantages of edible coating

- Reduce the loss of firmness and weight.
- The healthy elements found in edible coatings can be eaten with fruits and vegetables

- Edible coatings help preserve the quality of fruits and vegetables during storage by better retaining their acids, colour, flavour and sugar.
- Reduce waste and packaging made of polymers.

Disadvantages of edible coating

- Certain edible coatings have hygroscopic properties, which promote microbial growth.
- Good gas barrier properties in edible coatings cause anaerobic respiration, which interferes with fruits and vegetable's natural ripening process.
- A thick layer can obstruct oxygen flow and cause unpleasant flavours to develop.

Conclusion

The most cutting-edge method of food packaging is edible coating. In the packaging business, edible coating technology has been shown to reduce waste resources. Both natural and synthetic ingredients that are edible are used to make these coatings. Starch, protein, fat, wax and oils are the primary structural elements and they have favourable gelation qualities. The use of edible coatings extends the shelf life of fruits and vegetables while maintaining their freshness and nutritional value. Coatings have demonstrated promise as environmentally friendly quarantine measures. The majority of coating materials are derived from edible, renewable resources; some are even derived from waste materials that present disposal challenges for other sectors. Particularly in fruits and vegetables, edible coatings extend shelf life, reduce moisture and water loss, postpone ripening and inhibit microbial growth. As a result, it will be possible to produce edible films and coatings that are less costly and hazardous, giving consumers access to more wholesome, long-lasting meals. As a result, edible coatings are less expensive to preserve than other methods or low temperatures. The review found that by controlling and minimizing postharvest waste and prolonging the shelf life of fruits and vegetables, edible coatings play a significant role in enhancing food and nutrition security.

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