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Extending Fruit Freshness through Edible Coatings: A Review

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Abstract

Fruits and vegetables, vital for daily nutrition, have seen a rise in demand due to their rich content of vitamins, minerals, antioxidants, and dietary fibers. However, these perishables face challenges from both abiotic and biotic factors, leading to spoilage and biochemical deterioration, which can compromise quality and safety. Postharvest losses are significant, especially in developing countries, often reaching 20-30%. Cold storage is essential but insufficient alone, necessitating additional postharvest technologies to maintain quality. Respiration rates, particularly in climacteric fruits, increase during ripening, marking senescence. Minimizing respiration and ethylene production is crucial for prolonging shelf life. Edible films and coatings have emerged as an effective solution, creating a barrier that reduces respiration, transpiration, and senescence while potentially incorporating nutrients and bio-preservatives. The quality of fruits and vegetables is multifaceted, encompassing appearance, texture, flavor, nutritional value, and safety, which can change during storage and commercialization due to environmental interactions. Edible coatings, made from natural, biodegradable polymers like proteins, carbohydrates, and lipids, offer a promising alternative to synthetic materials. These coatings can prolong shelf life by modifying the gaseous environment, reducing respiration and ethylene biosynthesis, and filling surface cracks. Edible coatings have shown effectiveness in preserving quality attributes such as texture, flavor, and nutritional content across various fruits. Research highlights their role in maintaining antioxidants, phenolics, and pigments, as well as regulating physicochemical properties. Different application methods (dipping, brushing, spraying) and composite blends enhance the coatings' effectiveness. Studies demonstrate the potential of coatings to reduce decay, delay ripening, and improve appearance while incorporating functional benefits like antioxidants. The development of edible coatings continues to focus on enhancing mechanical, barrier, and sensory properties, making them a viable solution for extending the shelf life and quality of fresh produce.

Key words: Fruits, Freshness, Edible coatings, Nutritional value, Shelf life

Fruits and vegetables, crucial components of daily nutrition, have witnessed increased demand in recent years from a significant portion of the population. They serve as rich sources of vitamins, essential minerals, antioxidants, bio-flavonoids, dietary fibers, and flavor compounds. However, they are susceptible to both abiotic and biotic adversities. Furthermore, contamination of their flesh can occur from the skin, exacerbating spoilage and leading to biochemical deterioration such as browning, off-flavor, and texture breakdown. This compromises the quality of fruits and vegetables and poses risks to consumers due to the presence of pathogenic microorganisms [1]. The postharvest loss of fresh fruits and vegetables is estimated to be 20–30%, which poses a significant challenge for economies reliant on agriculture. This issue is widespread in developing countries, where huge post-harvest losses occur during handling, transport, and storage. Given the perishable nature of these products, cold storage is essential to slow down ripening-related changes such as ethylene production, softening, pigment alteration, respiration rate, acidity fluctuations, and weight loss. However, cold storage alone is insufficient to maintain optimal quality during transportation and marketing, often resulting in severe chilling injuries. Thus, the adoption of appropriate postharvest technologies, in conjunction with cold storage, is crucial [2-6].

Respiration plays a crucial role in the postharvest longevity of fruits. In most fruits, respiration rates increase sharply during ripening, especially in climacteric fruits, marking the onset of senescence and deterioration. To prolong postharvest life and delay ripening, it's essential to minimize the respiration rate. Ethylene, produced by ripening fruits, accelerates the ripening process further. Therefore, understanding the factors affecting respiration and ripening rates is vital for developing effective postharvest technologies. Recently, edible films have emerged as a solution to extend the shelf life of fruits and vegetables. This eco-friendly technology wraps the film tightly around the fruit, reducing respiration and transpiration, thus slowing down senescence. Studies indicate that these films can incorporate nutrients or preservatives and offer various functional benefits. With a growing demand for natural foods, bio preservatives are being integrated into these films, enhancing their wholesomeness for consumers. The quality of a food product relies on its organoleptic, nutritional,

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and hygienic characteristics, which may undergo changes during storage and commercialization. These alterations primarily stem from the interactions between the food and its environment [7]. Quality is inherently subjective, varying across consumer demographics such as nationality, age, and dietary preferences; what's pertinent to some may not be to others [8]. Nonetheless, there exists a consensus that attributes like visual appearance, texture, flavor, absence of defects, nutritional content, and, more recently, safety (in terms of chemical and microbiological contamination) collectively define the quality.

Table 1 Major quality attributes of fresh fruits and vegetables [9]

Quality factor	Primary concerns
Appearance (visual)	Size
	Shape and form
	Color, intensity, uniformity
	Gloss
	Defect
Texture (mouth-feel)	Firmness / Softness
	Crispness
	Juiciness
	Toughness (Fibrousness)
Flavor (taste, aroma)	Sweetness
	Acidity
	Astringency
	Bitterness
	Volatile compounds
Nutritional value	Vitamins
	Minerals
Safety	Toxic substances
	Chemical contaminants
	Microbial contamination

Edible coatings

Edible packaging, comprising thin layers or sheets of edible polymers, serves as a protective barrier against the external environment, thus prolonging the shelf life of food products [10-11]. Common food components such as proteins, carbohydrates, and lipids can be utilized to create these films. Typically, lipids aid in reducing water transmission, polysaccharides regulate oxygen and gas transmission, and protein films offer mechanical stability. These materials can be employed individually or in composite blends, ensuring they do not compromise food flavor. When developing films for foods like fresh fruits and vegetables, the primary goal is to maintain the transmission rates of gases and liquids consistent with those in their natural states. Since the chemical structures of the three major components differ significantly, each contributes distinct attributes to the overall properties of the film. These researches mainly focused on developing edible coatings and improving their properties to apply the main desired features of usual synthetic materials, such as high mechanical strength, lightness, softness, water resistance and transparency. One of the alternatives to plastics, are edible biopolymers including proteins, polysaccharides and lipids [12-15]. Edible coatings and formulations are made from edible polymers that are abundantly available in nature, ecofriendly, nontoxic, biodegradable, and can be consumed along with the food product [16-17]. The mode of action for shelf-life extension of fresh produce is attributed to the creation of a semi permeable protective layer around fruit and vegetable surface by modifying the gaseous environment (O_2 and CO_2) that helps in reduction of respiration rate, ethylene biosynthesis, and ultimately delays the ripening-associated biochemical changes. Moreover, coating of fruit or vegetable fills the cracks on the pericarp of fruit, which results in closing of stomata and lenticels leading to a delay in the development of physiological disorders such as reduction in weight loss [18-21]. The more important application of edible films and coatings until now, and particularly since the 1930s, concerns the use of an emulsion made of waxes and oil in water that was spread on fruits to improve their appearance, such as their shininess, color, softening, onset of mealiness, carriage of fungicides, and to better control their ripening and to retard water loss [22-23]. Edible films have been widely used since then on whole fruits like orange, grapefruit, lemon, apple, and pear, mainly with the purpose of reducing water loss, with waxes being the most commonly employed materials [24-26].

Table 2 Potentials and requirements for edible coatings adapted from [25]

Potential uses of edible coatings	Produce a modified atmosphere in the fruit
	Reduce decay
	Delay ripening of climacteric fruits
	Reduce water loss
	Delay color changes
	Improve appearance
	Reduce aroma loss
	Reduce exchange of humidity between fruit pieces
	Carriers of antioxidants and texture enhancers
	Carriers of volatile precursors Impart color and flavor
	Carriers of nutraceuticals
Requirements for edible coatings	Stability under high relative humidity GRAS (generally recognized as safe) components
	Good water vapor barrier
	Efficient oxygen and carbon dioxide barrier
	Good mechanical properties
	Adhesion to the fruit
	Colorless and tasteless1
	Pleasant to taste
	Physico-chemical and microbial stability Reasonable cost

Characterizations of edible coatings

Edible coatings play a crucial role in maintaining the phytonutrients (such as antioxidants, phenolics, and pigments) and regulating the physicochemical properties (including respiration rate, weight loss, total dissolved solids, and pH) of fruits for extended periods [27]. It's imperative that these coatings do not alter the sensory attributes of the fruit [28], underscoring the need for careful formulation during development. Additionally, these coatings should effectively manage gas exchange to prevent fruit fermentation and the development of undesirable off-flavors [29]. To address these requirements, mixtures of different components can be employed in the production of edible coatings, enhancing their physicochemical characteristics and mitigating the limitations of individual components [30]. The function and performance of edible coating mainly depends on its mechanical, barrier and colour properties, which control the gas transfer and moisture loss of fruits and vegetables [31].

Applying methods of edible coating

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

a) Dipping
b) Brushing
c) Extrusion
d) Spraying
e) Solvent casting

Application of edible coatings on fruits for shelf-life extension and management of the quality

The ecological awareness of consumers, as well as the prevention and/or reduction of postharvest loss, are of great concern for the food processing industry, due to this research has been directed towards the search for edible and innovative materials, which also if they are safe for the consumer, they form a barrier that can protect the food from microorganism's establishment. In addition, these films and coatings can delay moisture loss, are good barriers to oxygen and can maintain food quality [32]. Furthermore, a study made by Sun *et al.* [33] compared the shelf-life effect of three bio-based nanomaterial coatings from chitin, cellulose, and chitosan that were applied on kiwi, avocado, strawberry, banana, nectarine, and apricot. Both wood nanocrystals as well as chitosan nanofibers presented the best antifungal activity. Moreover, color changes and weight loss of the coated strawberries decreased by half compared to the control samples. Coatings at 1% of sodium alginate applied on strawberry fruits (*Fragaria* × *ananassa*) in postharvest state, have been shown to have a beneficial effect on the anthocyanin content present during storage, where untreated fruits showed a total decrease in the content of cyanidine-3-o-glucoside, the main bioactive compounds associated with the red color of the fruit, which did not maintain its stability after a period of 15 days unlike coated fruits, which kept the anthocyanin content stable during the same period of time [34]. Studies in mandarin (*Citrus reticulata*) under storage conditions, showed that the application of coatings based on 1% of chitosan with coconut oil added, had an effect on the content of ascorbic acid in fruit, maintaining stability in a 63.39% and 71.36% over a period of 16 days at room temperature, while the uncoated fruits maintained the content of ascorbic acid only at 45.56% at the end of the same period, in the same way, an improvement in the stability of the bioactive compounds was reported associated to the flavor and aroma of the fruits with coating, this due to the formation of controlled atmospheres that allow the reduction of the oxidative processes and of maturation improving the integrity of the phytochemical profile of the fruit [35]. Coatings of extracts of guava leaf (20%) and lemon (15%), demonstrated a positive effect on banana fruits (*Musa sapientum* L.) at the postharvest stage, reducing changes in color and content of vitamin C compared to untreated fruits during storage [36]. The application of Carboxymethyl cellulose, low methoxyl pectin, Persian gum, and tragacanth gum had a positive effect in the preservation of in ascorbic acid, total phenolics, and anthocyanins in coated fruit during 16 days of storage [37].

Kumar and Thakur [38] analyzed the effect of the use of active packaging on pear fruits, the authors reported low water losses, good values of firmness and content of TSS; the resulting quality of fruit according to their sensory evaluation test led to a high consumer acceptance. In a recent study, Galus *et al.* [39] applied on fresh-cut pear fruits coatings based on whey protein amended with essential oils (lemon and lemongrass), the results were promising by obtaining a high acceptability and the maintenance of polyphenols and flavonoids content. In another study, chitosan and gum Ghatti were applied on grapes, the results showed that the phenolic acids content were significantly retained, at the end of storage high concentrations of delphinidin, cyanidin, pelargonidin and malvidin were reported [40]. In a study on effect of agar agar-based coating on minimally processed cloves it was observed that filamentous fungus and aerobic measophilic were inhibited and the coating resulted in reduction of respiration rate of clove [41].

Dipping mango fruit in carboxymethyl cellulose (CMC) improved the visual quality and delay firmness loss was studied by Plotto *et al.* [42]. The study conducted by Tanada Palmu *et al.* [43], Maftoonazad *et al.* [44] stated that methyl cellulose edible coating slowed down respiration rate, prevented firmness loss and color of avocados and the wheat gluten coating enhanced the shelf life of strawberries and also maintained the quality. It also reduced weight loss and maintained the firmness of strawberries. Durango *et al.* [45], Hernandez Mumz *et al.* [46], Martmez Romero *et al.* [47] suggested that edible coating improve the quality of fruits. First study concluded that the starch chitosan edible coating used on minimally processed carrot controlled the growth of mesophilic aerobes, yeast, molds and psychrotrops. Second study concluded that chitosan combined with calcium gluconate edible coating increase the shelf life of strawberries by reducing respiration activity, delaying ripening and reducing fruit decay due to senescence. Third study concluded that Aloe vera based edible coating maintained sweet cherry quality and safety during postharvest treatment. Aloe vera coating reduce respiration rate, weight loss and color change and decreased softening and ripening of strawberries. It also decreased microbial populations. Application of chitosan coating delayed the decrease in anthocyanin content, increase in PPO activity and changes in colour index as well as reduction in eating quality decrease in concentrations of total soluble solids and titratable acidity and partially inhibited decay. In addition, treatment with chitosan coating was potential for shelf-life extension at ambient temperature when litchi fruits were removed from cold storage [48]. Jiang and Li [49] studied the effects of chitosan coating in extending postharvest life of longan fruits as well as investigated the maintenance of their quality. Their study revealed that the application of chitosan coating reduced respiration rate and weight loss, delayed the increase in PPO activity and the changes in colour and eating quality and partially inhibited decay of fruit during storage. Furthermore, increasing the concentration of chitosan coating enhanced the beneficial effects of chitosan on postharvest life and quality of the fruit. Sharmin *et al.* [50] studied the effects of *aloe vera* gel coating on storage behaviour of papaya at room temperature (29 °C-31 °C). Among the physico-chemical parameters, colour, physical changes, total weight loss and TSS contents increased significantly, whereas moisture content, vitamin C and titratable acidity decreased during storage. The overall results showed the superiority of 1.5% *aloe vera* gel coating in extending the shelf-life of papaya up to 15 days compared to that of 0.5%, 1% *aloe vera* gel coating and control papaya.

CONCLUSION

Edible coatings are used from many years for storage of Fruits and Vegetables in food industry. Different coating materials are used for coating such as hydrocolloids, waxes, protein. Researchers have produced new edible coatings; it is safe and environment friendly and safely eaten with Fruits and Vegetables. According to this review, Edible Coatings extends shelf life, reduce water and moisture loss, delayed ripening process and also prevent microbial growth specifically in fresh fruits and vegetables. Edible coatings and films based on natural hydrocolloids provide an additional protection for fresh or blanched fruits and vegetables. Natural gum edible coatings provide a promising approach for enhancing quality and prolonging shelf life of fruits and vegetables. Moreover, the edible coatings and film can become a very promising method that could be applied for delivering bioactive compounds in order to increase bioavailability. Despite the various and clear research in this field and due to very specific coating technology applied for different fruit and/or vegetables, with different proposed aims (starting from improving shelf life to preserving a high nutritional value or increasing certain nutritional features of the products) the subject is of permanent topicality and experiments are absolutely necessary starting from the known data.

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