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Edible coatings as carriers of food additives on fresh-cut fruits and vegetables

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Abstract

Purpose of review: This article reviews the incorporation of food additives into edible coatings for preserving and extending the shelf-life of fresh-cut fruits and vegetables.

Findings: During minimal processing operations such as peeling, cutting, shredding, coring, etc, the integrity of fruit and vegetable tissues is altered. Cell wall breakdown after mechanical operations induces in the plant tissues degenerative physiology and biochemical changes such as enzymatic browning, texture softening, water loss, and production of undesirable flavours and odours due to microbial growth. Therefore, the control of these deleterious effects is critical to maintaining the quality and safety of fresh-cut fruits and vegetables. A promising alternative to dipping treatments is the application of food additives such as antioxidant, antimicrobial and antisoftening agents, in addition to nutraceutical substances that can be effectively incorporated into edible coatings based on protein, lipid or polysaccharides matrices. Studies have demonstrated that these coatings, which support additives and bioactive compounds, can enhance, maintain and prolong fresh-cut product quality and safety.

Limitations/implications: Some food additives have a significant impact on the sensory attributes (taste, aroma and colour) of fresh cut-fruits and vegetables when effective concentrations are incorporated into edible coatings.

Directions for future research: Further research should be focused on a commercial scale, since most studies on food applications have been conducted at the laboratory scale. More studies are necessary to understand the interactions among food additives and coating materials when new edible coatings are used, in addition to its effect on sensory attributes.

Keywords: edible coating; fruits and vegetables; antimicrobial; antioxidant; antisoftening; nutraceutical

Abbreviations

PPO	Polyphenol Oxidase
WPC	Whey Protein Concentrate

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Introduction

Fresh-cut fruits and vegetables are highly nutritious but highly perishable (short shelf-life), because they are living tissues that continue to carry out their physiology and biochemistry processes after cutting, slicing, trimming, coring or shredding [1]. Once the skin of the fruit or vegetable is removed or altered in size, a release of nutrients, ions and other cellular components, caused by cell wall breakdown during processing, can accelerate the enzymatic reactions, produce undesirable volatile compounds, microbial growth, colour change, texture change, weight loss and respiration rate if they are not adequately processed or stored [2–4].

Although, low temperature (<5ºC), modified atmosphere packaging and dipping of aqueous solutions containing antimicrobials and antioxidants are the most practical and common ways to settle these problems and prolong the shelf-life of fresh-cut products, edible coatings have emerged as a new method of preservation and an alternative to the more traditional methods. Edible coatings can also extend shelf-life and enhance the quality of fresh-cut fruits and vegetables, and protect them from harmful environmental effects [5**]. In addition, they have advantages over others methodologies because they act as moisture and gas barriers, can serve as carriers of flavourings, vitamins and minerals, in addition to other food grade additives such as antimicrobial, antibrowning or antisoftening agents for controlling microbial growth, preserving the colour, moisture and texture [6]. Furthermore, edible coatings are environmentally friendly because they are made from natural biodegradable materials.

The purpose of this review is to revise significant findings and studies performed on the effectiveness of edible coatings as carriers of food additives, as well as their effects on the shelf-life and sensory attributes of fresh-cut fruits and vegetables.

Food additives incorporated into edible coatings

Table 1 shows food additives such as antimicrobial, antioxidant, antisoftening and nutraceutical substances incorporated in foods through edible coatings for improving quality, safety, functionality and shelf-life of fresh-cut fruits and vegetables. Each of these substances is studied in the following sections of this review.

Antimicrobial agents

Fruits and vegetables may become contaminated with pathogenic and spoilage microorganisms in the field through contact with polluted soil, dust and irrigation water, as well as by inadequate handling at harvest [7]. Hence, postharvest processing of fresh produce into fresh-cut products through mechanical operations may increase the risk of microbial growth and contamination, because release of plant cellular fluids by breaking of the natural exterior barrier of produce can provide a nutritive medium in which pathogens and spoilage microorganisms can survive or grow [8]. Therefore, antimicrobial agents used during postharvest processing are essential for controlling the microbiological safety and quality, and prolonging the shelf-life of fresh-cut fruits and vegetables.

Several studies have demonstrated that antimicrobials such as essential oils, organic acids, polysaccharides and spices, incorporated into edible coatings, have been effective in controlling pathogenic and spoilage microorganisms in different fresh-cut products. In this context, Rojas-Graü *et al*. [9] studied the antimicrobial effect of essential oils of lemongrass (1 and 1.5%), oregano (0.1 and 0.5%) and vanillin (0.3 and 0.6%) incorporated into coating forming solutions based on alginate and apple puree against the naturally occurring microorganisms (psycrophilic aerobic microorganisms, moulds and yeasts) and inoculated *Listeria innocua* on fresh-cut apples. The authors found that all the antimicrobials used significantly inhibited the native flora during 21 days of storage at 4ºC, with lemongrass and oregano oils being more effective against *L. innocua* than vanillin. Similarly, Raybaudi-Massilia *et al.* [10] reported significant reduction (3–5 log cycles) of the inoculated *Salmonella enterica* var. Enteritidis population in pieces of melon when an edible coating based on alginate containing malic acid (2.5%), alone or in combination with essential oils of cinnamon, palmarose or lemongrass at 0.3 and 0.7% or their actives compounds eugenol, geraniol and citral at 0.5%, were applied. Inhibition of the native flora by more than 21 days of storage was also observed at 5ºC. Similar results were found by Raybaudi-Massilia *et al.* [11], who evaluated the antimicrobial effect of an edible coating based on alginate with incorporated malic acid (2.5%), alone or in combination with essential oils of cinnamon bark, clove or lemongrass at 0.3 and 0.7% or their actives compounds cynnamaldehyde, eugenol or citral at 0.5%, applied over fresh-cut apples and found an important reduction in the inoculated population of *Escherichia coli* O157:H7 (4 log cycles) after 30 days of refrigerated storage (5ºC), as well as an inhibition of the native flora by more than 30 days.

On the other hand, Chien *et al.* [12] reported inhibition of total microorganism growth (5.53; 5.41; 5.30 log CFU/g) in fresh-cut mango coated with an edible coating based on chitosan (0.5; 1; 2%) and stored for 7 days at 6ºC in comparison with the control (6.41 log CFU/g). Nonetheless, a higher effectiveness was observed by González-Aguilar *et al.* [13], who reported a reduction (by 2.8 log CFU/g) of mesophilic aerobic microorganisms to undetectable levels after 14 days of storage at 5ºC in fresh-cut papayas coated with an edible coating based on chitosan of low molecular weight (2%) and medium molecular weight (1 and 2%). The authors also found that populations of moulds and yeasts were also inhibited. The differences found between these studies could be due to the fruit type and initial microbial load.

Sangsuwan *et al.* [14] studied the effectiveness of an edible coating based on chitosan/methyl cellulose with and without vanillin on fresh-cut melon and pineapple inoculated with *E. coli* and *Saccharomyces cerevisiae* and stored at 10ºC for 8 days. They observed that the inoculated level of *E. coli* (5.18 CFU/piece) significantly decreased to undetectable levels throughout storage in coated fresh-cut melon in comparison with the control sample. In addition, the researchers found that the inoculated level of *S. cerevisiae* decreased slightly in coated fresh-cut melon, whereas in coated fresh-cut pineapple it significantly decreased in comparison with the control samples (uncoated fresh-cut melon and pineapple). They also reported that the effectiveness of the edible coating increased when vanillin was incorporated. Likewise, Durango *et al.* [15] controlled the growth of mesophilic aerobes, yeasts and moulds, and psychrotrophs of minimally-processed carrots during the first 5 days of storage at 15ºC using yam starch edible coating containing chitosan (0.5 and 1.5%). Olivas *et al.* [16] inhibited the microbial growth of mesophilic and psychrotropic bacteria, and moulds and

Table 1. Main food additives incorporated into edible coatings to maintain and extend quality and safety of fresh-cut products.

Edible coating material	Food additives			
	Antimicrobial	**Antioxidant**	**Antisoftening**	**Nutraceutical**
Alginate	Essential oils Malic acid Potassium sorbate Vanillin	Calcium chloride N-Acetyl-Cysteine Glutathione	Calcium lactate Calcium chloride	Probiotic
Apple Puree	Essential oils Vanillin	Ascorbic acid Citric acid	Calcium chloride	-
Cellulose derivatives	Potassium sorbate Sodium benzoate *Trans*-cynnamaldehyde vanillin	Ascorbic acid TBHQ*	Calcium chloride	-
Carrageenan	-	Ascorbic acid Citric acid Cysteine Oxalic acid	Calcium chloride	-
Caseinate	*Trans*-cynnamaldehyde	-	Calcium chloride	Calcium Vitamin E
Chitosan	Chitosan Vanillin	Chitosan	-	Calcium Zinc Vitamin E
Gellan	-	Ascorbic acid N-Acetyl-Cysteine Glutathione	Calcium chloride	Probiotic
Maltodextrin	-	Ascorbic acid	-	-
Pectin	*Trans*-cynnamaldehyde	N-Acetyl-Cysteine Glutathione	Calcium chloride	-
Starch	Chitosan	-	-	-
Soy Protein	Potassium sorbate Sodium benzoate	Ascorbic acid TBHQ*	Calcium chloride	-
Xanthan gum	-	-	-	Calcium Vitamin E
Whey Protein	*Trans*-cynnamaldehyde	Ascorbic acid Citric acid Oxalic acid Cysteine 4-Hexylresorcinol	Calcium chloride	Calcium Vitamin E

*TBHQ: *ter*-butyl-hydro-quinone

yeasts in apple slices coated with an alginate edible coating containing 0.05% potassium sorbate during 8 days of storage at 5ºC. On the other hand, Caillet *et al.* [17] reduced the microbial populations of *L. innocua* inoculated on peeled minicarrots by more than 1 log cycle after 21 days at 4ºC using *trans*-cynnamaldehyde (0.025%) incorporated into a casein-based edible coating. However, when coated samples were irradiated at 0.25 kGy a reduction of *L. innocua* to undetected levels was observed.

Antioxidant agents

Colour is of special importance in fresh-cut fruits and vegetables, since oxidation and enzymatic browning take place quickly upon contact with oxygen, leading to discolouration [5**]. Browning phenomena in fresh-cut products are caused when, after mechanical operations (cutting, slicing, coring, shredding, etc) during processing, enzymes, which are released from wounded tissues, come in contact with phenolic components to give dark coloured pigments [18*]. Such phenomenon is caused by the action of a group of enzymes called polyphenol oxidases (PPOs), which can oxidise the phenolic substrates to *o*-quinones in presence of oxygen [19**].

Application of antioxidants as dipping treatments after peeling or cutting is the most common way to control browning of fresh-cut fruits. Nonetheless, the application of antioxidant agents incorporated into edible coatings has proven to be a good alternative, since this technology can ensure the inhibition of browning, avoid ascorbic acid or vitamin C loss, and extend the shelf-life of fresh-cut fruits and vegetables [20**].

Baldwin *et al.* [21] reported that ascorbic acid (0.5%) and *ter*-butyl-hydro-quinone (0.2%) had a better effect on the inhibition of browning in fresh-cut apples and potatoes throughout storage when it was incorporated into an edible coating based on carboxy-methyl cellulose or soy protein than when it was used in an aqueous dipping solution after 14 days at 4ºC. Both methods were effective during the first day of storage, but samples coated with the edible coating prevented browning appearance for a longer time than those samples dipped in an aqueous solution alone. In the same way, Brancoli and Barbosa-Cánovas [22] achieved a decrease in surface browning of apple slices during 21 days storage at 4ºC using maltodextrin and methyl-cellulose-based coatings containing ascorbic acid (1%). Likewise, Lee *et al.* [23] delayed the browning of fresh-cut apples using antibrowning agents such as ascorbic (1%), citric (1%), oxalic (0.05%) acid or their combinations incorporated into edible coatings based on carrageenan or whey protein concentrate (WPC). These authors observed inhibition of enzymatic browning in fresh-cut apples during 14 days storage at 3ºC. In addition, all edible coating treatments resulted in higher sensory scores (positive effect) than non-coated apples for all the quality factors tested.

In another study, McHugh and Senesi [24] achieved a delay of browning in fresh-cut apples coated with an apple puree-based edible coating containing ascorbic acid (1.5%) or citric acid (1.5%) after 12 days of storage at 5ºC. A similar result was also obtained by Pérez-Gago *et al.* [25], who observed reduced browning of fresh-cut apples with ascorbic acid (1%), cysteine (0.5%), or 4-hexyl-resorcinol (0.02%) incorporated into an edible coating based on WPC for at least 14 days of storage at 4ºC, the first two being the most effective treatments. On the other hand, Rojas-Graü *et al.* [26, 27] inhibited the browning in fresh-cut apples using edible coatings based on alginate or gellan with the addition of glutathione (up to 2%) or N-acetylcysteine (up to 2%), or their combination. These authors indicated that a concentration of 1% each of the antibrowning agents was needed to maintain the colour of cut apples. Similar results were also obtained by Oms-Oliu *et al.* [28], who achieved browning inhibition of fresh-cut "Flor de invierno" pears for 14 days at 4ºC using N-acetyl-cysteine (0.75%) and glutathione (0.75%) incorporated into edible coatings based on alginate, gellan or pectin. Bico *et al.* [29] also extended the browning of fresh-cut bananas using ascorbic acid and cysteine at 0.75% incorporated into an edible coating based on carrageenan during 5 days of storage at 5ºC. Olivas *et al.* [16] delayed development of browning in apple slices during 8 days of storage at 5ºC after applying alginate coatings containing calcium chloride (10%). Calcium chloride is an anti-browning agent known to inhibit PPO by interaction of the chloride ion with copper at the PPO active site [30].

Discolouration of fresh-cut vegetables has also been investigated. Pen and Jiang [31] evaluated the effect of applying an edible chitosan coating on the colour changes of fresh-cut Chinese water chestnut, and found that the discolouration associated with enzymatic activity such as phenylalanine ammonia lyase, PPO and peroxidase were delayed by the application of the coating. These authors reported shelf-life extension and quality preservation of fresh-cut Chinese water chestnut for 9 days at 4ºC, depending on the concentration of chitosan applied (0.5, 1 and 2%) in the coating.

Antisoftening agents

Softening is mainly caused by the action of pectinolytic and proteolytic enzymes produced by the breakdown of cell wall of plant tissues during mechanical operations [32*]. Moreover, these enzymes could affect the morphology, cell wall-middle lamella structure, cell turgor, water content, and biochemical components [33]. Pectinase enzymes such as pectin methylesterase and polygalacturonase are responsible for texture losses in plant tissues. Polygalacturonase hydrolyses the α-1,4-glucosidic bond between anhydrogalacturonic acid units, resulting in texture degradation due to hydrolysis of the pectin polymers. On the other hand, pectin methylesterase hydrolyses the methyl ester bonds of pectin to give pectic acid and methanol [32*].

In general, calcium treatments help to improve firmness of fruit tissue by reacting with pectic acid present in the cell wall to form calcium pectate, which strengthens the molecular bonding between constituents of the cell wall, thus delaying senescence and controlling physiological disorders in fruits and vegetables [34].

Raybaudi-Massilia *et al.* [10, 11] demonstrated that the incorporation of calcium lactate (2%) into an alginate-edible coating maintained the firmness of fresh-cut apples and melons during 3 weeks at 5ºC. Oms-Oliu *et al.* [28, 35] and Rojas-Graü *et al.* [9, 26, 27] observed that fresh-cut melons, pears, and apples coated with alginate-, gellan-, pectin- or apple-puree edible coatings containing calcium chloride (2%) outstandingly maintained their initial firmness during refrigerated storage (4ºC) from 2 to 3 weeks. A similar effect was achieved by Olivas *et al.* [16] who preserved the firmness of apple slices stored at 5ºC for 10 days by using an alginate edible coating containing calcium chloride (10%). Tapia *et al.* [4] improved the firmness of fresh-cut papaya with the addition of calcium chloride (2%) into alginate- and gellan-edible coating during the period studied (8 days at 4ºC). Coatings based on other polysaccharides or proteins, such as carrageenan or WPC, containing calcium chloride (1%) have been also used to maintain firmness of fresh-cut apple and banana slices at refrigerated temperature [23, 29].

Nutraceuticals

The incorporation of nutraceuticals into edible coatings and films to fortify and enhance the nutritional value of foods has been investigated in different contexts. Mei and Zhao [36] investigated calcium caseinate and whey protein isolate films prepared to contain 5 or 10% Gluconal-Cal, a mixture of calcium lactate and gluconate, or 0.1 or 0.2% α-tocopheryl acetate, respectively. Park and Zao [37] evaluated functionality of chitosan-based films containing a high concentration of calcium (Gluconal-Cal), 5-20% Zn lactate, vitamin E (5–20% α-tocopheryl acetate) and acetylated monoglyceride. Both authors concluded that milk protein and chitosan films may be used as carriers for nutraceuticals. These types of films may be used for wrapping or coating to enhance the nutritional value of foods, fruits and vegetables among them. The concentration the nutraceutical added to the films must be carefully selected to meet the required water barrier and mechanical properties of the films depending on their specific applications. Mei *et al.* [38] used xanthan gum coating as a carrier of calcium (calcium lactate at 5%) and vitamin E (α-tocopheryl acetate at 0.2%) for covering peeled baby carrots. The authors indicated that calcium and vitamin E contents of the coated samples, per serving (85 g), increased from 2.6% to 6.6%, and from 0 to about 67% of the Dietary Reference Intakes values, respectively. In addition, they found that edible coatings improved the desirable surface colour of carrots without significant effects on the taste, texture and fresh aroma.

Edible coatings can provide an excellent vehicle to further enhance the health benefit of products like berry fruits where the lack of some important nutraceuticals, such as vitamin E and calcium may be compensated for by incorporating them into the coatings [39**]. Hernández-Muñoz *et al.* [40] treated strawberries (*Fragaria* x *ananassa* Duch.) either with 1% calcium gluconate dips, 1.5% chitosan coatings or with a coating formulation containing 1.5% chitosan + 1% calcium gluconate and stored at 20°C for up to 4 days. The amount of calcium retained by strawberries was greater than that obtained with calcium dips alone, resulting in increased nutritional value of the strawberries: the chitosan-coated strawberries retained more calcium gluconate (3,079 g/kg dry matter) than strawberries dipped in calcium solutions (2,340 g/kg). Zao [39**] discusses several aspects of applying edible coatings on the surface of berry fruits, reviewing the research conducted by the author and his colleagues on the development of edible coatings and their demonstrations on a broad range of berry fruits, including strawberries, raspberries, hardy kiwifruits and blueberries. As an example, in one of his works with Han *et al.,* [41], the authors used chitosan-based edible coatings to extend the shelf-life and enhance the nutritional value of strawberries (*Fragaria* × *ananassa*) and red raspberries (*Rubus ideaus*) stored at either 2°C and 88% relative humidity (RH) for 3 weeks or −23°C up to 6 months. The authors studied three chitosan-based coatings (chitosan, chitosan containing 5% Gluconal® CAL, and chitosan containing 0.2% DL-α-tocopheryl acetate). Chitosan-based coatings containing calcium or Vitamin E significantly increased the content of these nutrients in both fresh and frozen fruits. One hundred grams of coated fruits contained about 34–59 mg of calcium, or 1.7–7.7 mg of Vitamin E depending on the type of fruit and the time of storage, while uncoated fruits contained only 19–21 mg of calcium or 0.25–1.15 mg of Vitamin E. The coatings also significantly decreased decay incidence and weight loss, and delayed the change in colour, pH and titratable acidity of strawberries and red raspberries during cold storage, indicating that the high concentrations of calcium or Vitamin E into chitosan-based coatings did not alter their anti-fungal and moisture barrier properties.

Edible coatings that carry vitamins and minerals when applied onto fresh-cut fruits can convert them into functional foods. Tapia *et al.* [4] reported that the addition of ascorbic acid to the alginate edible coating helped to preserve the natural vitamin C content in fresh-cut papaya preserving its nutritional value. Developing edible coatings to carry high concentrations of nutraceuticals for nutritionally fortified foods can also be considered as an important way to confer functional characteristics to coated foods. In this context, potential health benefits and biological functions offered by bifidobacteria in humans, like intestinal production of lactic and acetic acids, inhibition of pathogens, reduction of colon cancer risks, reduction of cholesterol in serum, improved calcium absorption, and activation of the immune system [42, 43] were considered for coating formulations that could carry this probiotic organism. Thus, Tapia *et al.* [44] managed to incorporate viable *Bifidobacterium lactis Bb12* into alginate and gellan film-forming solutions to coat fresh-cut apples and papayas, and evaluated the effectiveness of such edible coatings to carry and support the probiotic culture**.** The authors reported that populations > 10^6 CFU/g of the microorganism were maintained during 10 days of refrigerated storage. Tapia *et al.* [45] confirmed these results when developing a novel functional fresh-cut product of papaya (*Carica papaya* L.) c.v Maradol elaborated by pulsed vacuum impregnation with isotonic solutions containing calcium, zinc, ascorbic and folic acid, and oligofructose. Vacuum-impregnated fruit cylinders were coated with alginate or gellan-based edible films transporting viable bifidobacteria. Results showed the potential of these coatings to serve as vehicles of micronutrients and other bioactive compounds, like probiotics for fruit fortification, since viable bifidobacteria were incorporated into the gellan and alginate coatings in concentrations > than 10^7 CUF/g. These counts remained constant indicating the viability of the organisms during the 12 day period studied. Cells dispersed well in the coating, demonstrating the feasibility of these polysaccharide coatings to carry and support viable probiotics on a non ferment product like fresh-cut fruit. Olivas and Barbosa-Cánovas [46*] present a thorough and comprehensive review of edible films and coatings for fruits and vegetables and Martín-Belloso *et al*., [47**] on delivery of flavour and active ingredients using edible films and coatings.

Conclusions

Even if very good results are obtained on enhancing overall quality, browning and softening, shelf-life extension, control of decay, and nutraceutical benefits with a number of diverse additives and bioactive compounds incorporated into edible coatings designed for fresh-cut fruits and vegetables, sensory implications may be the major drawback for commercial and final use. Thus, the use of some antibrowning agents can yield unpleasant odours when high concentrations of sulphur-containing compounds such as cysteine, N-acetyl-cysteine, and reduced glutathione are proposed as an alternative to ascorbic acid. The use of essential oils as antimicrobial agents may produce undesirable sensory modifications in fresh-cut fruits when effective concentrations are used. Many nutraceutical compounds can impair flavour and lead to rejection of the product by consumers. It becomes clear that more studies are required in order to develop edible coatings with adequate sensory performance. More studies are also needed for a better understanding of the interactions among food additives and coating materials.

Reference

Papers of interest have been highlighted as:
*Marginal importance
**Essential reading

1 Watada AE, Ko NP and Minott DA. Factors affecting quality of fresh-cut horticultural products. Postharvest Biology and Technology 1996: 9:115–125.

2 Baldwin EA, Nisperos-Carriedo MO and Baker RA. Use of edible coatings to preserve quality of lightly (and slightly) processed products. Critical Reviews in Food Science and Nutrition 1995: 35(6):509–552.

3 Balla C and Farkas J. Minimally processed fruits and fruit products and their microbiological safety. In: Handbook of fruits and fruit processing. Edited by Hui YH, Barta J, Cano MP, Gusek T, Sidhu JS and Sinha N. Ames, Iowa: Blackwell Publishing; 2006: pp. 115–128.

4 Tapia MS, Rojas-Grau MA, Carmona A, Rodriguez FJ, Soliva-Fortuny R and Martín-Belloso O. Use of alginate and gellan-based coatings for improving barrier, texture and nutritional properties of fresh-cut papaya. Food Hydrocolloids 2008: 22:1493–1503.

5 Lin D and Zhao Z. Innovations in the development and application of edible coatings for fresh and minimally processed fruits and vegetables. Comprehensive Reviews in Food Science and Food Safety 2007: 6:60–75.

**This review concise all about edible coating applied to fresh-cut fruits and vegetables

6 Olivas GI and Barbosa-Cánovas GV. Edible coatings for fresh-cut fruits. Critical Reviews in Food Science and Nutrition 2005: 45(7-8):657–670.

7 Raybaudi-Massilia RM and Mosqueda-Melgar J. Factors affecting the incidence of pathogenic micro-organisms of fresh-cut produce. Stewart Postharvest Review 2009: 4:1–8.

8 USFDA [U.S. Food and Drug Administration]. Guide for industry: Guide to minimize microbial food safety hazards of fresh-cut fruits and vegetables. February 2008. [http://www.cfsan.fda.gov/~dms/prodgui4.html#ch4].

9 Rojas-Graü MA, Raybaudi-Massilia RM, Soliva-Fortuny RC, Avena-Bustillos RJ, McHugh TH and Martín-Belloso O. Apple puree-alginate edible coating as carrier of antimicrobial agents to prolong shelf life of fresh-cut apples. Postharvest Biology and Technology 2007: 45:254–264.

10 Raybaudi-Massilia RM, Mosqueda-Melgar J and Martín-Belloso O. Edible alginate-based coating as carrier of antimicrobials to improve shelf life and safety of fresh-cut melon. International Journal of Food Microbiology 2008: 121:313–327.

11 Raybaudi-Massilia RM, Rojas-Graü MA, Mosqueda-Melgar J and Martín-Belloso O. Comparative study on essential oils incorporated into an alginate-based edible coating to assure the safety and quality of fresh-cut Fuji apples. Journal of Food Protection 2008: 71:1150–1161.

12 Chien PJ, Sheu F and Yang FH. Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. Journal of Food Engineering 2007: 78:225–229.

13 González-Aguilar GA, Valenzuela-Soto E, Lizardi-Mendoza J, Goycoolea F, Martínez-Tellez MA, Villegas-Ochoa MA, Monroy-García IN and Ayala-Zavala JF. Effect of chitosan coating in preventing deterioration and preserving the quality of fresh-cut papaya “Maradol”. Journal of the Science of Food and Agriculture 2009: 89:15–23.

14 Sangsuwan J, Rattanapanone N and Rachtanapun P. Effect of chitosan/methyl cellulose films on microbial and quality characteristics of fresh-cut cantaloupe and pineapple. Postharvest Biology and Technology 2008: 49:403–410.

15 Durango AM, Soares NFF and Andrade NJ. Microbiological evaluation of an edible antimicrobial coating on minimally processed carrots. Food Control 2006: 17(5):336–341.

16 Olivas GI, Mattinson DS and Barbosa-Cánovas GV. Alginate coatings for preservation of minimally processed ‘Gala’ apples. Postharvest Biology and Technology 2007: 45(1):89–96.

17 Caillet S, Millete M, Salmiéri S and Lacroix M. Combined effects of antimicrobial coating, modified atmosphere packaging, and gamma irradiation on *Listeria innocua* present in ready-to-use carrots (*Daucus carota*). Journal of Food Protection 2006: 69(1):80–85.

18 Ahvenainen R. Improving the shelf life of minimally processed fruit and vegetables. Trends in Food Science and Technology 1996: 7:179–187.

* This overview contains good information about the minimal processing of fresh-cut fruit and vegetables.

19 Friedman, M. Food browning and its prevention: Overview. Journal of Agricultural and Food Chemistry 1996: 44(3):631–652.

** Excellent review concerning to antibrowning processes in fresh-cut fruits during processing.

20 Rojas-Graü MA, Soliva-Fortuny RC and Martín-Belloso O. Edible coatings to incorporate active ingredients to fresh-cut fruits: a review. Trends in Food Science and Technology 2009: 20:438–447.

**The authors made an excellent review on edible coating as carriers of food additives in fresh-cut fruits.

21 Baldwin EA, Nisperos MO, Chen X and Hagenmaier RD. Improving storage life of cut apple and potato with edible coating. Postharvest Biology and Technology 1996: 9(2):151–163.

22 Brancoli N and Barbosa-Cánovas GV. Quality changes during refrigerated storage of packaged apple slices treated with polysaccharide films. In: Innovations in food processing. Edited by Barbosa-Cánovas GV and Gould GW. Pennsylvania: Technomic Publishing Co; 2000: pp. 243–254.

23 Lee JY, Park HJ, Lee CY and Choi WY. Extending shelf-life of minimally processed apples with edible coatings and antibrowning agents. Lebensmittel Wissenschaft und Technologie 2003: 36:323–329.

24 McHugh TH and Senesi E. Apple wraps: a novel method to improve the quality and extend the shelf life of fresh-cut apples. Journal of Food Science 2000: 65:480–485.

25 Pérez-Gago MB, Serra M and Del Río MA. Color change of fresh-cut apples coated with whey protein concentrate-based edible coatings. Postharvest Biology and Technology 2006: 39:84–92.

26 Rojas-Graü MA, Tapia MS, Rodríguez FJ, Carmona AJ and Martín-Belloso O. Alginate and gellan based edible coatings as support of antibrowning agents applied on fresh-cut Fuji apple. Food Hydrocolloids 2007: 21:118–127.

27 Rojas-Graü MA, Tapia MS and Martín-Belloso O. Using polysaccharide-based edible coatings to maintain quality of fresh-cut Fuji apples. Lebensmittel Wissenschaft und Technologie 2008: 41:139–147.

28 Oms-Oliu G, Soliva-Fortuny R and Martín-Belloso O. Edible coatings with antibrowning agents to maintain sensory quality and antioxidant properties of fresh-cut pears. Postharvest Biology and Technology 2008: 50:87–94.

29 Bico SLS, Raposo MFJ, Morais RMSC and Morais, AMMB. Combined effects of chemical dip and/or carrageenan coating and/or controlled atmosphere on quality of fresh-cut banana. Food Control 2009: 20:508–514.

30 García E and Barret DM. 2002. Preservative treatments for fresh cut fruits and vegetables. In: Fresh-Cut Fruits and Vegetables. Edited by Lamikanra O. Florida, CRC, Press; 2002: pp. 267–304.

31 Pen LT and Jiang YM. Effects of chitosan coating on shelf life and quality of fresh-cut Chinese water chestnut. Lebensmittel Wissenschaft und Technologie 2003: 36:359–364.

32 Martín-Belloso O, Soliva-Fortuny R and Oms-Oliu G. Fresh-cut fruits. In: Handbook of fruits and fruit processing. Edited by Hui YH, Barta J, Cano MP, Gusek T, Sidhu JS and Sinha N. Ames, Iowa: Blackwell Publishing; 2006: pp 129–144.

* This overview contain an excellent information about the physiologic and biochemical changes occurred during mechanical operations.

33 Harker FR, Redgwell RJ, Hallett IC, Murray SH and Carter G. Texture of fresh fruit, Horticulture Review 1997: 20:121–224.

34 Soliva-Fortuny RC and Martín-Belloso O. New advances in extending the shelf life of fresh-cut fruits: a review. Trends in Food Science and Technology 2003: 14:341–353.

35 Oms-Oliu G, Soliva-Fortuny R and Martín-Belloso O. Using polysaccharide-based edible coatings to enhance quality and antioxidant properties of fresh-cut melon. Lebensmittel Wissenschaft und Technologie 2008: 41:1862–1870.

36 Mei Y and Zhao Y. Barrier and mechanical properties of milk protein-based edible films containing nutraceuticals. Journal of Agricultural and Food Chemistry 2003: 7:1914–1918.

37 Park SI and Zhao Y. Incorporation of high concentration of mineral or vitamin into chitosan -based films. Journal of Agricultural Food Chemistry 2004: 52:1933–1939.

38 Mei Y, Zhao Y, Yang J and Furr H.C. Using edible coating to enhance nutritional and sensory qualities of baby carrots: Journal of Food Science 2002: 67:5:1964–1968.

39 Zhao Y. Edible Coatings for enhancing quality and health benefits of berry fruits. In: Flavor and Health Benefits of Small Fruits. Chapter 18. Edited by: ACS Symposium Series, Vol. 1035 2010; pp 281–292.

** Excellent review on the concept of development of edible coatings, its applications and their demonstrations on a broad range of berry fruits.

40 Hernández-Muñoz P, Almenar E, Ocio, MJ and Gavara R. Effect of calcium dips and chitosan coatings on postharvest life of strawberries (*Fragaria* × *ananassa*). Postharvest Biology and Technology 2006: 39:247–253.

41 Han C, Zhao Y, Leonard SW and Traber MG. Edible coatings to improve storability and enhance nutritional value of fresh and frozen strawberries (*Fragari*a × *ananassa*) and raspberries (*Rubus ideaus*). Postharvest Biology and Technology 2004: 33:1:167–178.

42 Mitsuoka T. Bifidobacteria and their role in human health. Journal of Industrial Microbiology and biotechnology 1990: 6:263–267.

43 Gibson GR and Roberfroid MB. Dietary modulation of the human colonic microbiota: introducing the concept of probiotics. Journal of Nutrition 1995: 125:1401–1412.

44 Tapia MS, Rojas-Graü MA, Rodríguez FJ, Ramírez J, Carmona A and Martín-Belloso O. Alginate- and gellan based edible films for probiotic coatings on fresh-cut fruits. Journal of Food Science 2007: 72:E190–E196.

45 Tapia MS, Olaizola C, Carmona A, Martín-Belloso O. and Reynes MA. Novel functional fresh-cut product of papaya (*Carica papaya* L.) c.v Maradol using vacuum impregnation and edible coatings. ISHS Acta Horticultural. III International Symposium on Human Health Effects of Fruits and Vegetables: FAVHEALTH 2009–2010. In press.

46 Olivas GI and Barbosa-Cánovas GV. Edible films and coatings for fruits and vegetables. In: Edible films and coatings for food applications. Edited by embuscado ME and Huber KC. London, Springer Dordrecht Heidelberg; 2009: pp 211–244.

*Authors carried out a full and comprehensive review on edible films and coatings for fruits and vegetables.

47 Martín-Belloso O, Rojas-Graü MA and Soliva-Fortuny R. Delivery of flavor and active ingredients using edible films and coatings. In: Edible films and coatings for food applications. Edited by Embuscado ME and Huber KC. Springer Dordrecht Heidelberg; 2009: pp 295–314.

**Excellent review on edible films and coatings as carriers of flavour and active ingredients in foods with deep insights on fruits and vegetables.