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REVIEW

Application of edible coatings on fresh and minimally processed vegetables: a review

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ABSTRACT

World population is increasing and expected to reach around 10.5 billion by 2050. To fulfil the requirement of future generations, food supplies need to increase. Increased production, improved distribution, and reduced losses can improve availability and accessibility of food. With the help of innovative postharvest technologies, agricultural industries are meeting production and intercontinental distribution demands of fresh produce. A critical component of ensuring global food security is reduction in postharvest food losses. Use of edible coating is a novel approach to improve the quality of food for consumer acceptance. Edible coatings are an eco-friendly technique, which slows deterioration of vegetables by controlling gas exchange, moisture transfer, and oxidation. Major advantage of these coatings is to improve nutritional and sensory quality of food by incorporating active ingredients into the polymer matrix that are consumed with food products. The aim of this review is to update information about edible coating on minimally processed and fresh vegetables, focusing on the composition, active ingredients, antimicrobial concentration and their effect on ripening rate, phytonutrients retention and shelf-life. This information will be helpful for processors to select the best coating material and its effective concentration for different fresh and minimal processed vegetables.

KEYWORDS
Edible coating; phytonutrients; postharvest; shelf-life enhancement

Fresh vegetables are extremely perishable and more susceptible to postharvest spoilage due to high moisture content (80%–90%) limiting storage period and marketing life and causing economic loss (Zhang and Quantick, 1998). It has been estimated that 20%–25% of the harvested vegetables are spoiled by postharvest pathogens while handling in developed countries and the situation is more severe in developing countries due to inadequate transportation infrastructure and storage facilities (Sharma et al., 2009). Sustainable food systems maintain food quality and improve safety by reducing postharvest loss. Deterioration of fresh produce occurs gradually during storage and its cumulative effect renders food

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unacceptable to consumers. The major problem that most of food industries are evidencing is loss of food quality during storage which ultimately leads to increased waste. Packing, and packaging methods, help maintain, and extend, shelf-life of fresh produce. Impact of temperature and relative humidity management on produce influences quality during transit and storage. In modern food systems, advanced packaging techniques, including controlled atmosphere packaging, edible coatings and modified atmosphere packaging, play roles in maintaining product freshness and quality during storage. Among these, edible coating is non-pollutant and economic. Edible coatings may be defined as thin layers of edible material, which coat food and serve as a barrier between food material and their surrounding environment during handling, processing, and storage. Edible coatings have natural biocide and antimicrobial activity so that they delay food deterioration and enhance safety (Cha and Chinnan, 2004). Edible food coatings were used to reduce water loss, but current formulations, based on new functional edible coatings, have broadened their applications (de Jesús Avena-Bustillos et al., 1994). Edible coatings are made up of the biological materials: hydrocolloids (polysaccharides and proteins), lipids, and composite coatings. Generally, biopolymer-based films are good gas barriers, but provide poor moisture migration resistance. In comparison, lipid-based films act as good moisture barriers, but have poor mechanical strength and present little gas transfer resistance. Composite coating has been mostly used in fresh produce to provide efficient barrier properties (Figure 1) to both air and moisture (Mohammad Fayaz et al., 2009). The effect of coating solution on vegetables depends on the coating polymer, temperature, alkalinity, thickness, and state of the produce (Park et al., 1994).

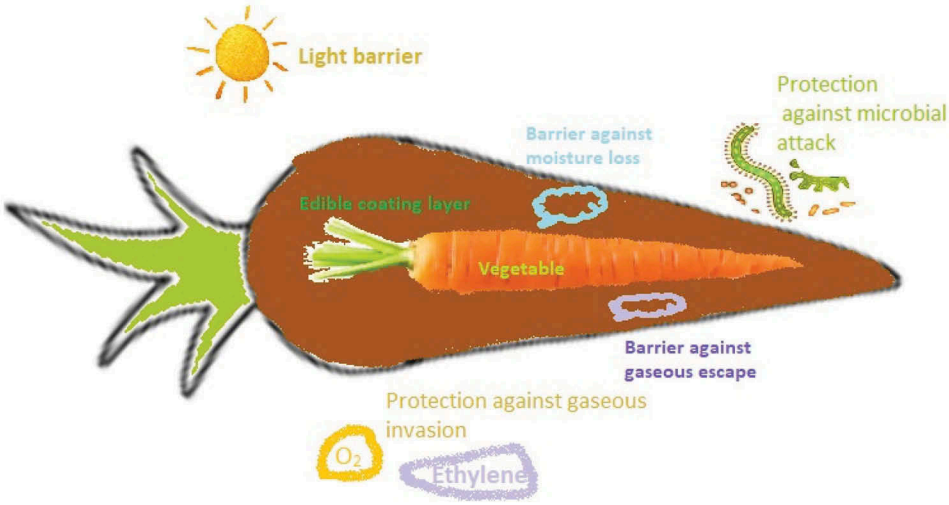

Figure 1. Edible coatings as protective and preservative barriers for vegetables.

Factors affecting the shelf-life of vegetables

Decay of fresh vegetables starts from point of harvest resulting in degradation of quality and quantity. Quality loss affects nutrient composition, edibility, and acceptability of the product; quantity loss refers to the amount of product lost (Arah et al., 2015). Improper handling, inadequate humidity, sun light, temperature, and ethylene exposure affect shelf-life of the vegetables.

Handling practices

The quality of vegetables can be maintained, but not improved, after harvesting, therefore, it is necessary to harvest vegetables at the proper stage of maturity. Improper handling of vegetables during harvesting may lead to skin bruises, breaks, spots, rots and decay, providing favorable conditions for microbial growth. Mechanical injury can lead to increased water loss and respiration rate, decreasing shelf-life of vegetables. Mutari and Debbie (2011) observed that rough handling of tomatoes leads to destruction of fruit cell wall, which reduced marketability and shelf-life. According to Ahvenainen (1996), poor handling practices (raw material, safety aspects) during processing of vegetables can deterioration in color, texture, and aroma.

Microbial decay

Microbial decay is a factor responsible for postharvest loss in vegetables due to direct exposure to contaminating microorganisms through soil, dust, water and postharvest processing equipment (Nigro and Ippolito, 2016). Spoilage microorganisms produce extracellular lytic enzymes that degrade the cell wall polymer leading to the release of intracellular constituents, which provide favorable conditions for the growth of other microorganisms. Minimally processed vegetables offer a favorable environment for microbial growth due to the amount of surface exposed to the environment. The bacteria *Pseudomonas* and *Erwinia* are predominant microorganisms in minimally processed vegetables responsible for qualitative and quantitative loss (Ahvenainen, 1996). Edible coating incorporated with antimicrobial agents such as essential oils, sodium benzoate, and enterocins provides an effective barrier to pathogenic microbes and prevents economic loss.

Environmental factors

Type and amount of light, temperature, and humidity (from harvesting to storage) play roles in maintaining shelf-life of fresh produce. Light intensity and light quality regulate the quality of vegetables (Makus and Lester, 2002). High temperature accelerates the metabolic rate of vegetables, which leads to reducing the shelf-life. Improper temperature leads to water loss, flavor loss,

and deteriorated quality of vegetables (Paull, 1999). Mostly, low temperature is used to increase shelf-life of vegetables. Low-humidity storage leads to shrinkage in vegetables while high-humidity causes microbial growth over the surface. Improper temperature storage accelerates the metabolic rate of tomatoes resulting in reduction of shelf-life (Mutari and Debbie, 2011).

Ethylene

As a ripening hormone, even in small concentrations of ethylene adversely affect growth, development and shelf-life of vegetables (Saltveit, 1999). In climacteric crops, presence of ethylene increases the rate of ripening affecting storage life (Hussen, 2014). Ethylene is produced from methionine via 1-aminocyclopropane-1-carboxylic acid by a highly regulated metabolic pathway and key enzymes involved were 1-aminocyclopropane-1-carboxylic acid synthase and 1-aminocyclopropane-1-carboxylic acid oxidase. Biosynthesis of ethylene can be controlled by maintaining low temperature, creating an oxygen deficit environment, increasing CO_2 concentration and blocking ethylene generating sites (Mohapatra et al., 2013). When more surface area is exposed to the environment, increasing ethylene production, the result is softening of tissues, which reduce consumer acceptability. Application of an edible coating acts as a barrier between the product surface and environment and provides insulation of ethylene delaying senescence processes.

Techniques used to increase shelf-life of fresh and minimal processed vegetables

To enhance shelf-life and quality of products edible coatings, modified atmosphere packaging (MAP) and controlled atmosphere packaging (CAP) are used (Mohapatra et al., 2013). Respiration rate in vegetables can be reduced by MAP, delaying senescence (Drake et al., 1987). The shelf-life of vegetables can be extended using CAP by lowering oxygen and increasing carbon-dioxide at low temperature. The MAP technique is used to extend shelf-life of whole vegetables. This technique cannot be used with fresh-cut products due to short handling period (Watada et al., 1996). An edible coating can be used to extend shelf-life of minimally processed and fresh vegetables. Edible coatings consisting of natural, biodegradable, substances are most acceptable due to their non-pollutant nature (Debeaufort et al., 2010).

Edible coatings

When applied as a thin layer of edible materials such as polysaccharide, protein and lipids act as a barrier between food and the surrounding environment. These coatings reduce decay without affecting product

quality and extend shelf-life without causing anaerobiosis. They act as barriers to moisture and gas and retard the ripening rate of vegetables by controlling respiration rate. Edible coatings also improve functional properties by incorporating components such as antimicrobial compounds, antioxidants, minerals, and vitamins (Cha and Chinnan, 2004). The materials are applied by brushing, dipping or spraying the coating solution on the food surface (McHugh and Senesi, 2000). There are three categories of edible coatings according to the nature of the components used for the preparation of coating solution. Hydrocolloids include alginates, proteins, and polysaccharides; lipids containing acylglycerols, fatty acids or waxes; and composites prepared by combining substances from the other two categories. Hydrocolloids and lipids, are generally used in combination as hydrocolloids are a poor moisture barrier and lipids are a poor gas barrier. Combination of both improves structural integrity and characteristic functionality (Tharanathan, 2003). Antimicrobial additives, antimicrobial compounds and emulsifiers can be added to improve their properties (Valencia-Chamorro et al., 2011a).

Hydrocolloids coating

Hydrocolloids are water soluble polymers obtained from plants, animals or microbial sources in pure state as with starch or cellulose, or chemically modified such as chitosan. Polysaccharide coatings modify the internal atmosphere, reducing respiration and metabolic reaction of vegetables (Lin and Zhao, 2007). Some polysaccharides used as edible coating are chitosan, gums, cellulose, and starch. Chitosan, produced by deacetylation of chitin (obtained from shrimp, crab, and crawfish shells waste), under alkaline conditions, is a cationic polysaccharide (Zhang and Quantick, 1998). Due to its functional properties of antimicrobial activity, antioxidant activity, film-forming ability, texturizing and binding properties, it is a widely used coating material (Benjakul et al., 2003). Chitosan as a coating agent has various roles on vegetables (Table 1). Chitosan can slow down the growth of certain rotting fungi including *Colletotrichum musae, Lasiodiplodia theobromae* and *Fusarium* spp. (Win et al., 2007) and *Botrytis cinerea* (El Ghaouth et al., 1997). Delayed ripening, reduced ethylene production, delayed changes in color pH and titratable acidity (TA) has been observed in chitosan coated produce (Table 1).

Gums are polysaccharides that have wide application as a coating material due to texturizing properties. Different effects of using gums on fresh vegetables have been reported (Table 1). Use of gum Arabic on green tomatoes delayed ripening as well as maintaining firmness; and increasing soluble solids and ascorbic acid concentrations, and TA, and enhancing color and reducing microbial decay compared to uncoated tomato fruit (Ali et al., 2010).

Table 1. Polysaccharide-based edible coatings incorporated with functional ingredients for improving the quality of fresh and cut vegetables.

Product	Coating matrix	Antimicrobial agent	Conc. of antimicrobial compound	Test condition	Target microorganism	Effects of coating matrix	Antimicrobial activity	Reference
Tomato and Cucumber	Guar gum (1% w/v) or Pea starch (4% w/v) glycerol (0.5% w/v)	Potassium sorbate (KS)	1.0% (w/v)	4°C in sterile plastic bag	Yeast and mould	Prolonged shelflife. Greater antifungal effect of (KS[a] + Pea starch) than (KS + Guar gum).	Antifungal	Mehyar et al., 2014
Radish shreds	Chitosan (CH)[a] (0.2%) Chitosan lactate	_[b]	_	10°C for 10 days packed in LDPE pouches	Bacteria, yeast and mould	Decrease in weight loss, Vitamin C loss and respiration rate. Minimal change in TA and SS. Increase in phenolic content and antioxidant activity.	Antimicrobial	Pushkala et al., 2013
Carrot shred	Chitosan (0.2%)	_	_	10°C for 10 days Packed in LDPE pouches	Bacteria, yeast and mould	Reduction in weight loss and respiration rate. Minimum changes in TA, pH and TSS content. Higher phenolic content and antioxidant activity than control. Better retention of color and sensory qualities.	Antimicrobial	Pushkala et al., 2012
Tomato	Chitosan (1.5%), Tween 80 (0.1%)	_	_	10°C	_	Prevention from fungal decay, extended shelf life, delayed ripening, decreased weight loss.	Antifungal	García et al., 2014
Tomato	Chitosan, *N,O*-carboxymethyl chitosan (2%)	_	_	25-30°C	_	High TA. Less red pigmentation.	_	Benhabiles et al., 2013
Tomato	Gum Arabic (5–20%)			20°C RH-80–90%	_	10% gum arabic delayed fruit ripening and ethylene production. Antioxidant activity was maintained for longer time.	_	Ali et al., 2013

(*Continued*)

Table 1. (Continued).

Product	Coating matrix	Antimicrobial agent	Conc. of antimicrobial compound	Test condition	Target microorganism	Effects of coating matrix	Antimicrobial activity	Reference
Button Mushroom	Tragacanth Gum (TG)	*Satureja khuzistanica* essential oil (SEO)	100, 500 and 1000 ppm (ppm = mg·L^{-1})	4 ± 1°C for 16 days	Yeast, mold and *Pseudomonas*	Coating solution (TG + SEO) maintained 92.4% cap firmness and decreased browning index by 57.1%. Controlled growth of microorganisms due to coating solution. High level of total phenolics (85.6%) and ascorbic acid (71.8%) accumulation in coated samples compared to control.	Antimicrobial	Nasiri et al., 2018
Tomato	Gelatinized Mango kernel starch (4%), Glycerol and sorbitol as plasticizers	_	_	25°C, 60% RH for 20 days	Fungi	Delayed fruit ripening, reduced weight loss, restricted change in SS concentration, titratable acidity, ascorbic acid content, firmness and decay percent compare to uncoated sample.	Antimicrobial	Nawab et al., 2017
Capsicum	Chitosan and alginate	Pomegranate peel extract (PPE)	1%	10°C, RH-90–95% for 25 days	*Colletotrichum gloeosporioides* (ITCC5123)	Retention of physiological loss in weight, firmness, color and ascorbic acid in coated samples compared to control. Restricted loss in total chlorophyll compared to control.	Antifungal	Nair et al., 2018
Cucumber slices	Chitosan (2%)	Carvacrol essential oil and Pulsed light	4, 8 and 12 J/cm^2	_	*Escherichia coli* ATCC26	Synergistic effect due to combination of antimicrobial agents with 12 J·cm^{-2} pulsed light.	Antimicrobial	Taştan et al., 2017

[a]CMC = Carboxymethyl cellulose; CH = Chitosan; TA = Titratable acidity; SS = Soluble solids; TSS = Total soluble solids; LDPE = Low density polyethylene
[b] "_" = Information not available.

Cellulose, a water permeable polysaccharide is composed of D-glucose units. Derivatives of cellulose such as carboxy methyl cellulose (CMC), methyl cellulose (MC), hydroxypropyl cellulose (HPC) or hydroxypropyl methyl cellulose (HPMC) are used for the preparation of edible-coating films (Murray, 2000) and have different effects on vegetables (Table 1).

Starch as granules in seed endosperm and plant tubers as amylopectin and amylose molecules carbohydrate reserves (Walstra, 2002). Starch has been used in the production of biodegradable films to partially, or completely, replace plastic polymer because of its low cost and renewability (Xu et al., 2005). Starch films are transparent, or translucent, and brittle under ambient conditions in the presence of water (Myllärinen et al., 2002). Their application is limited due to poor mechanical strength. Starch-based edible films generally require a plasticizer to overcome brittleness. Most commonly used plasticizers in starch films are glycerol and sorbitol (Mali et al., 2005).

Edible film-forming proteins are obtained from animals (collagen, gelatine, whey proteins, casein, and egg albumin) and plants [soy bean (*Glycine max* L. Merr), corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), cottonseed (*Gossypium hirsutum* L.), and wheat (*Triticum* spp.)]. They possess good gas barrier and have better mechanical properties than polysaccharide films, but due to their hydrophilic nature, similar to polysaccharide coating, protein films exhibit poor moisture barrier properties (Gennadios, 2002).

Gelatin is formed by thermal denaturation of collagen obtained as a meat industry by product from animal skin and bones and fish skins. Due to presence of high amino acid content in mammalian gelatin, it possesses better thermal stability and physical properties than fish gelatins (Gómez-Guillén et al., 2007). The film-forming ability of gelatin is directly related to the molecular weight; higher molecular weight gelatin has better film quality (Ledward, 2000).

Whey protein is a thin left-over liquid obtained during cheese formation after precipitation of casein protein. It is dried to form whey protein concentrate (WPC), protein content ranging from 25 to 80%, or whey protein isolate having protein content > 90% (Ennis and Mulvihill, 2000). Edible films formed by whey proteins are transparent, flexible, colorless and flavorless, with a poor moisture barrier. Protein-based films have a good aroma barrier (Miller and Krochta, 1997), and low permeability to oxygen (Hong and Krochta, 2006).

Egg albumin is a good source of protein for coating and film formation. More than 50% of egg white is egg albumen, which contains four free sulfhydryl groups. In egg white, film-forming ability is due to the presence of random coil polypeptides and inter- and intramolecular S-S bond and SH group (Guérin-Dubiard and Audic, 2007).

Soybean is a good source of protein, 38%–44% content, which is higher than protein content of cereal grains (8%–15%). Edible film from soybean can be prepared by using soybean milk or isolated soybean protein. For the

preparation of edible film using soybean, native disulphide bonds are disrupted by exposing the film-forming solution to heat and a new bond is formed (new disulphide, hydrogen bond, and hydrophobic bond) during drying (Dhall, 2013).

Zein protein is a prolamin protein obtained from endosperm of corn (*Zea mays* L). It is immiscible in water and dissolves in aqueous alcohol and glycol esters. Film formed by this protein has good moisture and gas barrier properties and is effective in preventing color change, firmness and weight loss of fresh produce (Raghav et al., 2016).

Wheat protein (gluten) is used for film formation due to its cohesiveness and elasticity. Addition of cross linking agents improves internal binding of the film and enhances its tensile strength (Dhall, 2013).

Lipid-based coatings

Application of lipids as a coating solution has a good moisture barrier but poor gas barrier because of presence of microscopic pores and high solubility and diffusivity (Banker, 1966). Lipid compounds include glycerides, waxes and resins (Hernandez, 1994). Acetylated monoglycerides, beeswax, carnauba wax, mineral oil, paraffin wax, vegetable oil, and surfactants have wide application as coating materials (Dhall, 2013). Lipid-based coating has good compatibility with other coating agents and high-barrier properties in comparison to polysaccharides and protein-based coatings. Lipid-based coatings cause undesirable organoleptic properties due to greasy surface and lipid rancidity (Lin and Zhao, 2007).

Composite coatings

Composite, or multi-component films, have combined benefits of lipid and hydrocolloid components; the lipid component provides a good water vapor barrier and the hydrocolloid component offer a selective barrier to oxygen and carbon dioxide (Baldwin et al., 1995). The effect of composite coatings in combination with other functional ingredients vary (Table 2). Commercially available composite coatings with CMC (carboxymethyl cellulose) are available (Nisperos-Carriedo et al., 1991).

Additives

Edible coating base materials (hydrocolloids, lipids) are combined with certain additives (emulsifiers, antimicrobial agents, and antioxidants) to obtain desired properties (Guilbert et al., 1995). These additives improve film strength and prevent the food product from spoilage. Some additives used are:

Plasticizers

Good elasticity and flexibility with high toughness and low brittleness is a prerequisite for edible films and coatings to prevent cracking during handling and storage (Barreto et al., 2003). The flexibility of edible films modified with plasticizers of low molecular weight (non-volatile) are normally incorporated to hydrocolloid film-forming solutions (Myllärinen et al., 2002). The amount of these plasticizers ranges from 10% to 60%, depending on the hydrocolloid. The most widely used plasticizers includes propylene glycol (Jagannath et al., 2006), glycerol (Myllärinen et al., 2002), polyethylene glycol (Bourtoom, 2008), oligosaccharides such as sucrose (Veiga-Santos et al., 2007), sorbitol (Cerqueira et al., 2009) and water. Plasticizers change barrier properties of films by increasing gas permeability or decreasing tensile strength (Mali et al., 2005).

Emulsifiers

These materials are added to coating solutions to improve wettability and to apply a uniform coating. Addition of surfactant or emulsifiers increase the ability of the film to suppress ripening. Tween 80 is a commonly used emulsifier in edible coating preparations (Nisperos and Baldwin, 1990). Chauhan et al. (2015) used oleic acid as and emulsifier with de-waxed and bleached shellac and Aloe vera gel-based coating and found there was no excessive drip loss and drying time.

Antimicrobial agents

Microbial decay is a major cause for postharvest loss. Addition of antimicrobial agents retards or slows down the growth of these rotting microbes and increases shelf-life of fresh produce. The most commonly used antimicrobials in edible films, or coatings, are potassium sorbate, sodium benzoate, sorbic acid, trisodium phosphate, lactic acid, lauric acid, pediocin, nisin, lacticin, ethylene diamine tetra acetic acid (EDTA), chitosan, green tea powder, grape seed extract, spices/essential oils or their components, thiosulfonates, imazali, conalbumin, isothiocyannates, benomyl, silver, and enzymes. The enzymes lysozyme, lactoperoxidases, and glucose oxidase are used as antimicrobial agents in coating solutions but due to lack of stability (at different pH and temperature) they have very narrow application (Mohammad Fayaz et al., 2009). Antimicrobial agents from plant sources are recommended to increase consumer acceptance.

Effect of edible coating on different properties of vegetables

Phenolics and flavonoids

Vegetables are a good source of phenolics and flavonoids and contribute to the diet as antioxidants, reducing the risk of several diseases. These compounds are secondary metabolites in plants with the ability to protect human body tissues against oxidative attacks (Romanazzi et al., 2002). During maturity, these compounds decrease due to metabolic rate of vegetables. Edible coatings produce an abiotic challenge to fresh produce, modifying the metabolism and affecting production of secondary metabolites. Under challenge, phenylalanine ammonia lyase (PAL) activity is enhanced, which leads to the accumulation of phenolic compounds. Frusciante et al. (2007) showed that low O_2 and high CO_2 concentrations increase phenolics production due to oxidative challenge during storage of fresh cut melons. Edible coating is an effective technique to modify internal atmosphere of vegetables to slow metabolic processes. A coating solution containing 10% gum arabic helps maintain the phenolic content for a longer period than uncoated tomato fruit (Ali et al., 2013). Loss of phenolics in uncoated tissues was due to senescence and breakdown of cell structure. Edible coating effectively delayed senescence by controlling the metabolic rate, retaining phenolics for a longer storage period.

Antioxidants

Antioxidant activity in vegetables is due to the presence of phenolics, flavonoids, lycopene, carotenoids, and glucosinolates (Kaur and Kapoor, 2001). As ripening occurs, these compounds are degraded, and the antioxidant activity decreases. With application of coatings, respiration rate can be slowed, and antioxidant activity can be maintained for a longer storage period. Antioxidant activity in tomatoes is retained longer when coated with 10% gum arabic, as the ripening process is retarded by delaying biochemical and physiological changes (Ali et al., 2013). Similar results were observed for raddish and carrot shred when coated with chitosan (0.2%) compared to uncoated tissue with the same storage conditions (Pushkala et al., 2012, 2013).

Color or pigments

Color is an important indicator of ripening which determines quality and consumer acceptability. During ripening chlorophyll is degraded and formation of other pigments including lycopene and anthocyanins occurs (Petriccione et al., 2015). Edible coating slows ripening rate, delaying color change compared to uncoated tissue (Ali et al., 2013). Chitosan coating delayed the color change in tomatoes better than in controls by slowing respiration rate (Abebe et al., 2017).

Physicochemical properties

Weight loss

Fresh vegetables are highly susceptible to weight loss. The main reason behind weight loss is vapor pressure gradient and respiration, which causes wilting and shrivelling resulting in low- market value and acceptability by consumers (Ali et al., 2010). Edible coatings act as a barrier to water loss to the atmosphere by maintaining high relative humidity in the tissue atmosphere and reducing moisture loss (Olivas et al., 2003). Similar results have been observed by various other workers for reduction in weight loss by edible coating (Tables 1 and 2).

Respiration rate

A factor contributing to postharvest loss is respiration rate. Edible coatings have a potential to decrease respiration rate by creating an internal modified atmosphere providing a barrier to oxygen and carbon dioxide (González-Aguilar et al., 2009). The lipophilic nature of essential oils increases resistance of coatings to gas diffusion. Addition of lipophilic additives improves barrier properties of coatings and decreases respiration rate.

Titratable acidity

Major contributors for TA in tomatoes are citric acid, malic acid and glutamic acid. TA decreases during ripening or maturity as these organic acids act as a substrate for respiration. Edible coatings effectively delay decrement of TA by slowing the respiration rate. Contradictory results of increased TA over time were reported (De Souza et al., 1999). This increment of TA was due to anaerobic respiration (elevation in CO_2 concentration and reduction in O_2 concentration) caused by a thick coating which affected the glycolytic enzyme system, resulting in a build-up of acids (De Souza et al., 1999). Changes in TA depend upon type of coating, cultivars and storage condition (Fagundes et al., 2014).

Total soluble solids

The total soluble solids (TSS) of vegetables increase during storage due to breakdown of starch into soluble sugars or hydrolysis of cell walls. Edible coating slows the breakdown of complex sugars into simple sugars by controlling respiration rate. Delayed change in TSS occurs compared to uncoated tissue. Tomatoes coated with rice starch-based coating had lower TSS compared to uncoated samples during storage (Das et al., 2013).

Table 2. Composite edible coating for improving quality and extended shelf-life of fresh and cut vegetables.

Vegetable	Coating matrix	Antimicrobial agent	Conc. of antimicrobial compound	Test condition	Target microorganism	Effects of coating matrix	Antimicrobial activity	Reference
Tomato	Soy protein isolate (4%), carboxy-methyl- cellulose (CMC) (0.2%), oleic acid (1%)	Sodium benzoate and ascorbic acid	0.1 and 0.4%	Temp: 35 ± 3°C RH[a]: 70 ± 5%	_[b]	Shelf-life of coated fruit was enhanced at ambient conditions. The pH, TSS, total sugar and reducing sugar increased gradually while acidity and vitamin content decreased as storage period lengthened.	_	Nandane and Jain, 2011
Cherry tomato	HPMC (5% (w/w), beeswax (30% db), tween 80.	Sodium methyl paraben, sodium ethyl paraben and sodium benzoate.	2%	21 days at 5°C followed by 4 days at 20°C	*Alternaria alternata*	Reduced *Alternaria* black spot compared to uncoated. Sodium benzoate was most effective. Black spot prevalence was 100% after 21 days at 20°C, indicating the effect of coating solution decreased with increased temperature and time. No significant difference in TA, pH and fruit firmness. b*, h° value was maintained.	Antifungal	Fagundes et al., 2015
Cherry tomato fruit	HPMC 5% (w/w), beeswax 30% (db), Tween 80(1.5%), glycerol.	Sodium propionate, potassium carbonate, ammonium phosphate and ammonium carbonate.	2%	15 days at 5°C followed by 7days at 20°C.	*Botrytis cinerea*	Significant reduction in gray mold development. Sodium propionate was most effective. Disease incidence was 100% after 15 days at 20°C, indicating the effect of coating solution decreased with increased temperature and time. At 20°C Ammonium carbonate coating was most effective in controlling weight loss and fruit firmness. Color, respiration rate, sensory flavor and fruit appearance not affected by antifungal coatings.	Antifungal	Fagundes et al., 2014

(*Continued*)

Table 2. (Continued).

Vegetable	Coating matrix	Antimicrobial agent	Conc. of antimicrobial compound	Test condition	Target microorganism	Effects of coating matrix	Antimicrobial activity	Reference
Green chillies	Shellac 5% (w/w), PVA 3%, oleic acid 0.1%, Tween 80, starch 0.25%, EDTA 0.1%, sodium alginate 0.5%.	_	_	12 days at 26 ± 2°C with 68 ± 4% RH	_	Decreased weight loss. Maintained color. Shellac-sodium alginate was most effective.	-	Chitravathi et al., 2014
Shredded	Cabbage	Acid electrolysed water, Tween 80	Carvacrol essential oil	1%	Stored in the refrigerator (7° C ± 3°C) for 2 days until cabbage turned brown in Ziploc bags.	*Escherichia coli* ATCC25922, *Pichia Pastoris* GS115	3 log reduction in microbial growth	
	Antimicrobial	Sow et al., 2017						

[a]TA = Titratable acidity; TSS = Total soluble solids; HPMC = Hydroxypropyl methylcellulose; PPO = Polyphenol oxidase; POD = Peroxidase; RH = Relative humidity; Temp = Temperature.
[b] "_" Information not available.

pH

The pH is the equilibrium measure of hydrogen ion concentration. Organic acids provide most of the hydrogen ions which normally decrease with ripening, producing an increase in pH (Dávila-Aviña et al., 2014). Edible coating did not affect the pH during storage period.

Textural properties

Texture is an important property of vegetables. It is the appearance that indicates freshness. Textural changes occur along with ripening. Pectic enzyme degrades pectin to protopectin resulting in loss of firmness. Texture enhancers incorporated in edible coating can minimize loss of firmness.

Microbiological analysis

Vegetables contain high water amounts and postharvest decay by microorganisms are common. In minimally processed vegetables, large surface area is exposed to the environment with high nutrients, providing a perfect platform for growth of microorganisms. Coating solutions incorporated with antimicrobial agents (essential oil, plant extracted antimicrobial agents) effectively control the growth of bacteria and fungi and contribute to increased shelf-life. The hydrocolloid chitosan act as a natural antimicrobial compound and inhibit growth of microbes. Growth of *Alternaria alternate* was effectively retarded by chitosan coating in tomatoes.

Conclusion and future prospects

Prevention of postharvest loss is a concern for the food processing industry. Edible coating is an alternative for traditionally used plastic packaging, which are not easily degradable and cause environmental pollution. Functional edible coatings have been developed which modify the internal environment of vegetables and add value to the product. In fresh and minimal processed vegetables, these edible coatings retain the phytochemical (antioxidants, phenolics, color) and physicochemical (weight loss, respiration rate, pH, and TSS) properties for a longer period. Edible coatings or films reduce preservation cost compared to other methods.

More emphasis should be given on use of nanotechnology for delivering bioactive compounds to increase bioavailability, through edible coatings or films. More research is required for determination of effects of these active ingredients to the sensory, mechanical, functional and shelf-life of the food product. Hydrocolloids and lipids used as base material can be replaced with more economic and region base availability. As edible coating is more laborious

to use, new techniques are needed to reduce labor cost. Emphasis should be given to designing edible coating or films, which can be used for broad spectrum food products and can improve their functional properties beyond shelf-life.

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