

REVIEW ARTICLE

Natural Coatings for Shelf-Life Enhancement and Quality Maintenance of Fresh Fruits and Vegetables - A Review

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ABSTRACT

The ever increasing demand for fresh fruits and vegetables challenges the researchers and industry to develop advanced methods for maintaining food quality and enhancing shelf life. The consumers around the globe demand chemical free fresh fruits and vegetables with high quality, nutritional value and extended shelf life. The application of edible films and coatings to fruits and vegetables represents an environment friendly approach to solve this problem. The use of edible coatings helps to reduce or eliminate the risk of adulteration thereby, present food in a hygienic and aesthetically attractive way. The strategy behind the use of coatings is combination of food chemistry and preservation technology. This review covers various types of edible coatings and their effects on the overall quality of whole and fresh cut fruits and vegetables providing an understanding of main functions and beneficial effects of each type of coating.

Key words: aloe vera, cellulose, essential oils, herbal extract, lipid, nanoemulsion, starch

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INTRODUCTION

Fruits and vegetables are highly perishable commodities, because these contain high amount of water content. Once these are harvested or detached from mother plants, water quickly evaporates, resulting in shrivelling, loss of quality and poor shelf life of product. Flaccidity, wilting, shrivelling and decay are some of the major problems that occur during postharvest handling of fruits and vegetables that ultimately prioritize their marketability and consumer preference (Lerdthanangkul and Krochta, 1996). Majorly, postharvest losses are caused by weight loss, fungal diseases, physiological disorders and pests. In order to maintain freshness and quality, the fruits and vegetables must be handled carefully. The application of edible coatings and films on fruits and vegetables, in addition to temperature and relative humidity management, has received attention worldwide for improvement of postharvest shelf life. Edible coatings on fruits serve either as gas or moisture barriers. These help in reducing the moisture loss, and/or reducing oxygen uptake of fruit from the environment and thus slowing down the respiration. In addition these coatings serve as a carrier for food additives like antioxidants or antimicrobials that reduce the decay without affecting quality of the food. The use of edible coatings on fruits is a century old technique. In the early 12th Century, oranges and lemons already used to be coated with wax in order to maintain their quality for longer periods of time.

Food appearance remains the most required attribute, strongly affecting the consumer decision to buy it or not. In addition, food texture is also a fundamental feature in determining product acceptability. Both appearance and texture of a fruit or vegetable tissue strictly depends on genetic, environmental, postharvest handling and storage factors. Now-a-days consumers have become more health conscious and demand fresh fruits and vegetables, which have driven researchers to develop eco-

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friendly coatings and packaging technology for prolonging the shelf-life of these products. Therefore, the precise knowledge of the processes leading to the appearance and textural modifications is of crucial importance in developing effective approaches to manage above said factors that improves quality and shelf-life of these products.

Chemical fungicides are the primary means for controlling postharvest fungal decay of fruits and vegetables. An attempt in reduction of postharvest loss of tomato fruit caused by *Phytophthora infestans* was taken, where certain fungicidal coatings are discussed (Ghatak et al., 2015). There are two major obstacles in continuous use of fungicides; public concern regarding fungicidal residues in crops, and proliferation of pathogen resistance (Tripathi and Dubey, 2004). Food safety is one of the major issues related to fresh fruits and vegetables. The development of natural crop protective products as alternatives to synthetic fungicides is currently in the spotlight. The use of natural and biodegradable coatings might be a good alternative to synthetic fungicides, which in turn fulfills the consumer requirements for more natural and healthy foods. Protective edible coatings and waxes are applied as part of the post-harvest treatment to fresh fruits and vegetables for their preservation. Beniam and Bower (2017) found that waxing, GA3 and micro-perforated bags are promising means of controlling papaya postharvest loss. Also, the increased shelf-life with no change in quality of the fruits even stored within poor infrastructure conditions. On a similar work, Adewoyin (2017) reported for longer shelf life (30 days) for pepper fruits packaged in the aluminium-foil than those packaged in perforated polyethylene bags (21 days) and nonperforated polyethylene bags (15 days). The main goal of this article is to compile and update the information available on plant based natural coatings as an effective preservative aiming at the safety, quality and functionality of fresh fruits and vegetables. Being biodegradable in nature, these edible coatings provide a perfect alternative to the plastic packaging commonly prevailing in the market.

Definition of edible coating

Edible coating is defined as are thin layers of edible material applied to the product surfaces as a replacement for natural protective waxy coatings that extends the storage life of fresh fruits without anaerobic conditions and reduces the decay without affecting the quality of the produce. These coatings allow that exchange of gases along with other features that maintain freshness, flavor, aroma, texture and nutritional value. Edible coatings derived from various sources are enlisted in Figure 1.

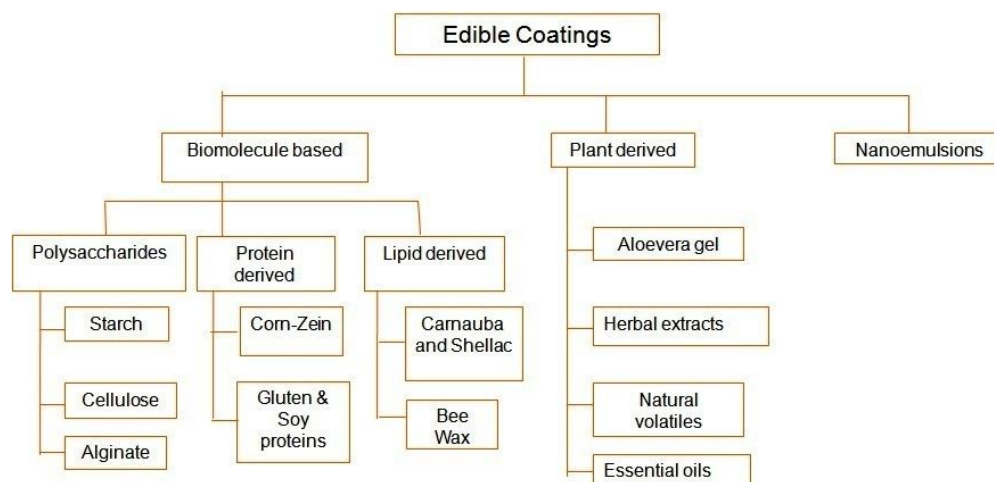


Fig. 1: Edible coatings derived from various sources

NEED OF EDIBLE COATINGS

Edible coatings offer a number of advantages over synthetic coatings. Some are mentioned below:

- Edible films and coatings act as barrier to gases and moisture that creates modified atmosphere within the fruit and which, in turn, extends the shelf life and retains the quality of fresh fruits and vegetables.
- These also act as a barrier against microbial invasion and hence contribute towards hygiene.
- Several active ingredients such as anti-browning agents, colorants, flavors, nutrients, spices can be incorporated into the polymer matrix and consumed along with the fruits, thus enhancing safety or even nutritional and sensory attributes.
- The edible coatings help in the reduction of synthetic packaging waste, because of their biodegradable nature.

Edible coatings based on biomolecules

Edible coatings can be prepared from biomolecules such as polysaccharides, proteins and lipids. These can either be applied as thin film to form wraps or pouches, or as coatings on food. The edible coatings approved by Food Safety and Standard Authority of India (FSSAI) are Shellac wax, Carnauba wax and Bees wax (FSSAI, 2006). Coatings derived from different type of biomolecules are discussed below.

POLYSACCHARIDES

Polysaccharides are highly stable, safe, not-toxic and biodegradable macromolecules among four major biomolecules. Starch and starch derivatives, cellulose derivatives, alginate, carrageenan, chitosan, pectin, and several gums are the main polysaccharides that can be included in edible coating formulations. Some of the important applications of the polysaccharide based coatings have been summarized in the Table 1.

Starch

Starch, a storage polysaccharide from cereals, legumes and tubers is most commonly used in the formulation of edible coatings and films, because of its inexpensiveness, abundance, biodegradability and easy utility. Starch based films are moderate gas barriers. These weak interactions make starch-based films with poor mechanical properties. The starch from different sources preserved the quality of coated strawberries significantly in terms of colour, weight loss and firmness (Garcia et al., 1998). Application of starch solutions on to apples imparted high gloss at the beginning of storage. However, a large decline in gloss during storage was observed, though the firmness, internal oxygen and carbon dioxide concentrations of starch-coated apples had values similar to shellac coated apples. The edible coating of cassava starch with or without the calcium lactate was able to reduce weight loss in fresh cut pineapple (Bierhals et al., 2011), while the edible coating of same starch with or without potassium sorbate dropped off the respiration rate in fresh cut strawberries (Garcia et al., 2010). Minimally processed pummelo (*Citrus Maxima* Merr.), coated with starch-based coatings (derived from cassava and rice) had a lower weight loss of 4.8–7.7% compared to the non-coated minimally processed pummel (Kerdchoechuen et al., 2011). Moreover, the combination of citric acid dipping and cassava starch or sodium alginate edible coatings was able to delay the quality deterioration of fresh-cut mangoes (Chiumarelli et al., 2011). Although, the citric acid increased the weight loss of the product, resulting into a partial dehydration of the vegetable tissue, but the use of cassava starch and alginate coatings in combination was able to hinder this undesirable effect of citric acid, presenting a lower weight loss than the uncoated samples.

Cellulose

Cellulose is the most abundant natural polymer on earth. It is difficult to use as a coating, because of its water-insolubility and highly associated crystalline structure. However, some commercially available derivatives of cellulose such as carboxy methyl cellulose (CMC), methyl cellulose (MC), hydroxyl propyl cellulose (HPC), and hydroxyl propyl methyl cellulose (HPMC), can overcome limitations associated with native form. In a comparison between MC, HPC and CMC coatings applied to the shelled

pecan nuts, CMC was found to be the best coating material for this application (Baldwin and Wood 2006) as it imparted sheen and delayed rancidity; however firmness was not preserved. Further, MC has been used to lower respiration rates of avocados and to preserve their green colour and firmness during storage (Maftoonazad and Ramaswamy, 2005). Carboxymethyl cellulose has been widely used as coating on fruits. Some coating formulations containing CMC are already in the market, such as Tal Pro-long™ and Semperfresh™. Tal Pro-long™ (or Pro-long) is composed to sucrose polyesters of fatty acids and the sodium salt of CMC. Semperfresh™ is made of sucrose esters of fatty acids, sodium salt of CMC, and mono and diglycerides. These coatings have been shown to retard ripening of fruits. Quality of cherries coated with Semperfresh™ can be preserved for longer periods by reducing weight loss, preserving firmness and skin colour. Another cellulose product in the market is, Nature Seal™, composed of cellulose derivatives, but without sucrose fatty acid esters. A combination of Nature Seal™ and soy protein coatings carrying anti-browning agents and preservatives also prolonged shelf life of cut apples for 1 week at 4°C temperature (Baldwin et al., 1996). More than twenty years ago, edible coatings based on cellulose gums effectively delayed ripening in some climacteric fruits like mango, papaya, and banana and significantly reduced the enzymatic browning of sliced mushrooms (Nisperos-Carriedo et al., 1991).

Table 1: Application of natural coatings on fresh fruits and vegetables

Composition Film	Additive	Produce	Results	References
Chitosan	Lemongrass oil	Green bell pepper	Anthracnose control was observed along with preservation of quality attributes	Ali et al 2015
Alginate	Ascorbic acid / Citric acid	Fresh-cut Mango	In fresh-cut mango, the addition of these antioxidants contributed not only to colour retention, but also to the antioxidant potential of fresh-cut mangoes. According to the results, it is possible to store fresh-cut Kent mango for 12 days at 4°C, without any detrimental effects on nutritional and physicochemical quality	Robles-Sánchez et al. (2013)
Cassava starch	Citric acid	Fresh-cut Mango	This combination delayed the quality deterioration of fresh-cut mangoes, decreasing the fruit respiration rate and inhibiting the characteristic during storage.	Chiumarelli et al. (2010)
Alginate, gellan or pectin	N-cetylcysteine Glutathione	Fresh-cut Pears	Significantly reduced vitamin C loss occurred for fresh-cut pears during more than one week. The total phenolic content was higher in samples containing the antioxidants than in the non-treated samples.	Oms-Oliu et al. (2008a)
Pectin	Cinnamon leaf oil	Fresh-cut Peach	The radical scavenging activity increased significantly ($p < 0.05$) as the added oil concentration rose. The coating treatments significantly affected ($p < 0.05$) the total phenolic and flavonoid content as well as the antioxidant capacity of fresh-cut peach	Ayala-Zavala et al. (2013)
Pectin	Cinnamon leaf oil	Table grapes	Cinnamon leaf oil incorporated into pectin coatings significantly increased the antioxidant capacity of grapes.	Melgarejo-Flores et al. (2013)
Rice starch	Coconut oil	Tomatoes	Lipid addition to the starch film significantly controlled the ripening of tomatoes.	Das et al. (2013)
Cassava starch	Cinnamon bark essential oil	Fuji apple slices	The coating containing cinnamon bark essential oil showed higher total phenols concentration and antioxidant activity than the other.	Oriani et al. (2014)

Alginate

Alginate, the sodium salt of alginic acid is isolated from brown seaweed. Alginate forms strong films with translucent and glossy look. Alginate-Ca²⁺ coatings have been used successfully to prolong shelf life of fresh-cut Gala apples without causing fermentation due to undesirable anaerobic respiration. These coatings minimized weight loss and browning, and preserved

firmness during storage. Alginate coatings prevented water loss from fresh-cut papaya (Tapia et al. 2007), pear (Oms-Oliu et al., 2008a) and melon (Oms-Oliu et al., 2008b).

PROTEINS

Proteins have received great attention for their capability of forming edible films and these coatings include corn-zein, wheat gluten (WG), soy protein, whey protein, casein, collagen/gelatin, pea protein, rice bran protein, cotton seed protein, peanut protein, and keratin. Casein based edible coatings are attractive for food applications due to their high nutritional quality, excellent sensory properties, and strong potential for providing food products with adequate protection against their surrounding environment. In general, these films have good barrier properties to gas, though their water barrier properties are generally poor (Gennadios et al., 1994). Proteins generally used as coatings for fruits and vegetables are as under:

Corn-zein

Zein is a natural corn protein produced from corn gluten meal, which is insoluble in water, but soluble in aqueous alcohol, glycols and glycol esters (Martin-Polo, 1995). It is composed of prolamines found within corn endosperm. It has good film-forming, binding and adhesive properties. It provides a good barrier to oxygen. Zein coatings delayed colour change, weight loss and softening without ethanol production in tomato (Park et al. 1994). These coatings supplemented with vegetable oils, citric acid and antioxidants also prevented rancidity of nuts and inhibited moisture transfer from fruits (Andres, 1984). Apples coated with zein solutions experienced decrease in respiration rate, whereas pears had an increased respiration rate as compared to uncoated controls (Park et al., 1996). Nevertheless, zein coatings delay weight loss in both apples and pears during storage. Corn-zein protein has been used as a good renewable and biodegradable material for formation of packaging films, coatings and plastics applications (Shukla and Cheryan, 2001).

Gluten and soy proteins

Gluten is the main storage protein in wheat and corn. Gluten films present good barrier properties against oxygen and carbon dioxide, but exhibit relatively high water vapour permeability (WVP) (Gennadios and Weller, 1990). The fortification of Nature Seal™ coating with soy protein improved its properties and when applied on sliced apples and potatoes, it reduced the permeability to oxygen and water vapour. In addition, the effectiveness of soy protein coatings has also been reported in reducing oxidative browning and moisture loss of cut apples and potatoes during their storage at 4°C (Shon and Choi, 2011).

LIPIDS

Lipids based coatings generally have good barrier properties against moisture, since it has very low affinity for water. Edible lipids used to develop edible coatings are: beeswax, candelilla wax, carnauba wax, triglycerides, acetylated monoglycerides, fatty acids, fatty alcohols, and sucrose fatty acid esters. Lipid coatings and films are mainly used for their hydrophobic properties, representing a good barrier to moisture loss. This factor is extremely important as a large number of studies deal with the use of coatings on fresh fruits and vegetables to control their desiccation. Besides preventing water loss, lipid-based coatings have been used to reduce respiration, thereby, extending shelf life and improving the appearance by generating a shine on fruits and vegetables. In contrast, the hydrophobic characteristics of lipids form thicker and more brittle films. Consequently, these must be associated with film forming agents such as proteins or cellulose derivatives.

Coating sliced apples with a carbohydrate/ lipid bilayer film reduced water loss by 12 to 14 times during storage when compared with uncoated sliced apple in similar storage conditions (Wong et al., 1994). The edible coatings supplemented with citric acid acted as a gas barrier, decreased the respiration rate and delayed the browning of mango pieces during storage and consequently retained the carotenoids. Common coatings of this category are described below.

Carnauba and shellac wax

Carnauba is a natural plant wax and is GRAS (generally recognized as safe). It is available in micro emulsion form, relatively permeable to gases, and quite glossy. Loss of gloss during storage and relatively high gas permeability are the primary problems with this wax, which does not effectively delay ripening (Baldwin et al., 1999). However, it displays excellent barrier to water vapours and it can be combined with shellac to create a coating of moderate permeability to gases and low permeability to water vapours. Natural Shine™ 8000 (carnauba wax) is used to reduce oxygen transfer inside and water vapour outside of the fruit, while shellac is used to give a glossy appearance. Johnfresh™ is composed of both carnauba and shellac waxes.

Shellac and carnauba wax are often used commercially as a coating for apples and citrus fruits to improve their glossy appearance, prevent water loss, thereby preventing shrivelling, increasing marketability, and maintaining their quality through delayed ripening and senescence. Shellac has further problems with whitening, or “blushing” as it is referred to in the industry, where the water condenses on coated fruits after their removal from cold storage. Nevertheless, shellac is recognized as one of the shiniest coatings available, and was found to improve appearance of apples. In a report, shellac coatings increased the subsequent sales of red and green apple cultivars, such as Delicious and Granny Smith, respectively (Bai et al., 2003a).

Beeswax

Beeswax can be used as a composite film. Beeswax was added to pea starch films and it was observed that the thickness of pea starch coating significantly increased with fortification of beeswax (Han et al., 2006). Beeswax has been used in composite coatings in combination with WPI, WPC and HMPC to preserve intact fruits such as plums (Perez-Gago et al., 2003). In most cases, weight loss was not checked with beeswax, with the exception of coated plums and persimmon pieces. The impact of some protein and lipid based natural coatings on fruit quality has been summarized in Table 2.

Table 2 Effect of different natural coatings on fruit quality

Coatings	Fruits	Results	References
Carrageenan	Strawberry	Preserved better firmness	Ribeiro et al. (2007)
Aloe vera gel and water 1:3	Cherry	Delayed WL and firmness loss	Martínez-Romero et al. (2006)
Cactus-mucilage	Strawberry	Increased shelf life	Del-Valle et al. (2005)
Semperfresh™ 10 and 20g/L	Cherry	Effectively reduced WL, and preserved firmness, AA, TA and C. Increased Shelf life by 21% at 30°C and 26% at 0°.	Quezada-Gallo et al. (2005)
Shellac, candelilla shellac-carnauba	Apple	Caused anaerobic respiration on Braeburn and Granny Smith apples. This research recommends shellac for “Delicious”. Carnauba-shellac for “Braeburn” and “Fuji” apples	Han et al. (2006)
Zein	Apple	Overall good quality. Comparable to a commercial shellac coating	Bai et al. (2003b)
HPMC + Beeswax or shellac	Plum	Increased lipid content decreased weight loss. Firmness unaffected after short term storage at 20°C, but affected in prolonged storage.	Perez-Gago et al. (2003)
Carnauba wax	Pear	Decreased friction discoloration and internal O ₂ concentration in pear	Amarante et al. (2001)
Soy protein + pullulan + stearic acid	Kiwifruit	Retarded softening of kiwifruit	Xu et al. (2001)
Cellulose, Nature Seal 2020 hydroxypropyl-cellulose Carnauba Tropical Fruit Coating 213 TFC	Mango	Both coatings created modified atmospheres, reduced decay, and improved appearance. Polysaccharide coating delayed ripening and increased concentration of flavor volatiles. Carnauba coating reduced WL	Baldwin et al. (1999)

OTHER PLANT BASED EDIBLE COATINGS

Aloevera gel

Bio-preservation is a novel food preservation method defined for extension of shelf life and enhanced safety of foods by the use of natural or controlled microbiota and/or antimicrobial compounds (Ananou et al., 2007). In postharvest technology, extending the storage life of fruits and vegetables by utilizing plant-based products have been practiced for a long time. Recently, the uses of plant-based products have been started in fresh fruits and vegetables as bio-preservatives. Aloevera gel is one of the promising bio-preservative, which has a great potential to become a common use for most fresh fruits and vegetables. Since ancient times, Aloevera has been used as an herbal remedy for regeneration and rejuvenation of human skin in China, Japan and India. Owing to its antimicrobial properties, the gel has been tested for few fresh fruits by a postharvest researcher from Spain since 2005. They registered that Aloevera extracts suppressed/retarded postharvest quality losses in 'Crimson Seedless' grapes (Castillo et al., 2010). Furthermore, Aloevera extracts were reported to be useful for 'Artic Snow' nectarines (Ahmed et al., 2009) for declining quality losses after harvest. Aloevera gel is applied to most fruits and vegetables as an edible coating. Edible coatings have a variety of favourable effects on fruits such as imparting a glossy appearance, better colour, weight loss retardation and prolonging storage/shelf life by preventing microbial spoilage (Ahmed et al., 2009).

Aloevera gel (100%) has been used to preserve papaya fruit at room temperature 25°C-29°C and 82-84% RH and it was reported that uncoated papaya showed 22.5% loss in weight, whereas the weight losses of coated fruit was 7.93% (Brishti et al., 2013). In another study, table grapes coated with Aloe gel registered significantly lower weight loss as compared to uncoated fruits (Tripathi and Dubey, 2004). Apart from these, Aloevera gel coating has also been effective in controlling water loss from commodities such as sweet cherry (Martinez-Romero et al., 2006). This positive effect in terms of reduction in moisture loss may be due to the hygroscopic properties of Aloe gel that allow the formation of water barrier between the fruit and the surrounding environment, thus, preventing its external transferences (Morillon et al., 2002). Its use offers an option to film packaging owing to its environment friendly characteristic.

Interestingly, the Aloevera gel coating was effective in controlling microbial growth of 'Crimson' table grape without incorporation of other antimicrobial compounds such as garlic oil, potassium sorbate and nicin to increase the activity (Ali et al., 2016). In case of Aloevera coated papaya fruits, no disease symptoms were observed until 1 week after of the storage period. At the end of the storage period, 100% disease incidence was observed in uncoated fruits, whereas for Aloe gel coated fruits disease incidence was only 27% (Brishti et al., 2013). This was due to the anti-microbial potentiality of coated materials.

Aloe treatment significantly reduced the firmness losses of table grapes during cold storage (1°C, 95% RH), whereas losses of >50% were detected in control grapes after 21 days of cold storage plus 4 days at 20°C (Nunan et al., 1998). Papaya treated with 100% Aloe gel and control fruits presented similar initial pulp firmness values during the storage period of eight days at 25°C-29°C and 82-84% RH. At the end of the storage, control fruits decayed and the coated fruits were slightly soft but did not differ significantly (Brishti et al., 2013). This indicated that the ripening of coated fruits was delayed by delaying softening. Aloevera gel has been proved to maintain the texture of fruits efficiently.

Herbal extracts

The fruit is normally exposed to large number of micro organisms, which may be soil born, air born or may be introduced from the surface of plant. The spoilage of the fruits during post-harvest storage is due to infection of these micro organisms, which gain entry through stomatal openings, lenticels, growth cracks or surface injuries. Several plant extracts or plant products have broad spectrum antimicrobial properties. They can be recognized as bio-preservatives having no harmful effects on human

health. Therefore herbal extracts are promising for use on fruits to enhance the shelf life. They are safe and non-toxic. Their application is simple and do not lose their efficacy at normal storage temperature. The use of herbal extracts has opened a new avenue for the control of spoilage. The extracts of garlic and ginger @ 10% concentration were inhibitory for most of bacterial and fungal isolates except for *Rhizopus* and *Aspergillus* (Shivpuri et al., 1997). The tulsi leaf extracts containing polyamine biosynthesis inhibitor blocked ornithine decarboxylase pathway, which could be exploited to control fruit rots (Patil et al., 1992). Spraying of tomato fruits with 10% garlic and ginger extract retarded spoilage. Significantly lower physiological loss in weight (PLW) percentage was recorded in the tomato fruits sprayed with 10% garlic extract followed by spray of 10% ginger extract. The use of natural antimicrobials such as herbal extracts has enhanced the shelf-life of fresh-cut tomatoes, maintaining or increasing the contents of lycopene, ascorbic acid and total phenolic compounds (Ayala-Zavala et al., 2008). Application of garlic and ginger extracts can enhance the shelf life of tomato and this low cost technology can be better utilized for preservation of raw tomatoes.

The extracts of many herbal plants showed antimicrobial activity. The antifungal activity of fresh juice and aqueous extracts of turmeric and ginger against the fungi *Aspergillus niger* and *Penicillium digitatum* has been reported (Kapoor, 1997). The effect of natural plant products has also been reported on storage rot of mangoes, where the fruits dipped in the plant extracts showed reduction in the diseases incidence (Hasabnis and Souza, 1988).

Azadiractin, an active compound in neem oil, strengthens the pectin molecules with the elimination of the chances of removal of methyl group from the α -galactouronic acid residue of pectin. Thus, it helps in lowering the breakdown of pectin molecules during storage (Kleeberg, 1996). Among GA3, plant extract, castor oil and neem oil studied on storage behaviour of mango (*Mangifera indica*) cv. Langra, neem oil (10%) minimized physiological loss in weight as compared to other treatments and controls (Singh et al., 2000). In comparison to castor oil and neem oil, the neem leaf extract was found to be the best in retaining most of the biochemical characteristics of juicy fruits (Singh et al., 2003).

Natural volatiles

Natural volatile compounds such as methyl jasmonate, ethanol, tea tree oil, and garlic oil were applied on fresh-cut tomato stored at 5°C for 15 days. Ethanol combined with methyl jasmonate was more effective in suppressing microbial proliferation than each single compound. In addition, this combination preserved firmness and colour better than the other antimicrobial preservatives. Moreover, methyl jasmonate let it retain the higher content of lycopene, ascorbic acid and phenolic compounds. The effect of lemon grass, oregano oil and vanillin incorporated in apple puree-alginate edible coating was investigated on the shelf-life of fresh-cut "Fuji" apples (Rojas-Grau et al., 2007). During 21 days of storage at 4°C, the coating with vanillin (0.3% w/w) was the most effective in terms of sensory quality. All the other studied antimicrobial coatings significantly inhibited growth of psychrophilic aerobes, yeasts, and moulds.

Methyl jasmonate (MeJA), a major derivative of the plant hormone, jasmonic acid, plays a critical role in inducing resistance to fungal pathogens. Methyl jasmonate (MeJA), a naturally occurring compound, plays important roles in plant growth and development, fruit ripening, and responses to environmental stresses (Creeman and Mullet, 1997). It has been reported that MeJA treatment could effectively suppress post-harvest diseases of various fruits including loquat (Cao et al., 2008). In addition, it has been reported that a postharvest MeJA treatment maintained higher levels of bioactive compounds and enhanced antioxidant capacity in berry fruits including blackberries, raspberries and strawberries (Kaituo et al., 2009). MeJA, already classified by the U.S. Food and Drug Administration as a Generally Recognized as Safe (GRAS) substance, it may have potential commercial applications in postharvest treatments for maintaining the quality by reducing decay and enhancing antioxidant activity.

MeJA was discovered as a sweet-smelling compound in flower extracts of *Jasminium grandiflorum* L. After its discovery in

jasmine flowers, JA was also isolated from a pathogenic fungus, *Lasiodiplodia theobromae* (Aldridge et al., 1971). The biological activity of MeJA, extracted from *Artemisia absinthium* L., was reported nearly 10 years later (Ueda and Kato, 1980). Some research on MeJA in horticultural uses has focused on pre-harvest and post-harvest treatments to protect against microbial development on harvested tissue. Pathogen growth on celery (*Apium graveolens* L.) and pepper (*Capsicum annuum* L.) was reduced by treatment with MeJA (Buta and Moline, 1998). MeJA applied to cut pineapple (*Ananas comosus* Merr.) as a vapour or a dip, reduced softening and microbiological load after 6 and 12 d storage (Martinze-Ferrer and Harper, 2005), respectively. Peach fruit treated with volatile MeJA slowed down the decay and maintained higher quality than untreated fruit 8 d after treatment (Jin et al., 2006). MeJA applied as a dip ($\leq 25 \mu\text{M}$) or gas ($\leq 100 \mu\text{M}$) to avocado (*Persea americana* Mill.), grapefruit, or pepper fruit prior to chilling reduced chilling injury (Fung et al., 2004). In addition, MeJA has been shown to reduce decay and maintain the postharvest quality of papayas (Gonzalez-Aguilar et al., 2003).

Essential oils

Essential oils and phenolics of plant origin are antioxidants that have century's old use in Indian cuisines. Growing awareness on Indian food and its beneficial effects on human health have promoted the use of spices in the food system. Lately, significant research is being conducted on the spices and the essential oils derived from these like vanillin. To explicit their antioxidant properties, the essential oils derived from spices and other plant derived compounds can be used as coating or supplemented in the packaging films for enhancing the storage life as well as adsorbing off orders. These compounds have been included in the list of generally recognized as safe (GRAS) compounds by FDA (Serrano et al. 2005). Though, these plant derivatives are regarded as safe and can be used in place of chemical agents, their commercial viability is yet to be chalked out.

The use of plant extracts could be a useful alternative to synthetic fungicides in the management of rot fungi during post harvest handling of fruits and vegetables. A new approach to the control of postharvest pathogens, while maintaining fruit quality, has been implemented by the application of essential oils. This approach eliminates the need for synthetic fungicides, thereby complying with consumer preferences, organic requirements and reducing environmental pollution (Du Plooy et al., 2009). Moreover, essential oils of *Verbena officinalis* and *Origanum vulgare* inhibited infection by the first two fungi and only by *P. citrophthora*, respectively.

The antimicrobial activity of essential oils is attributed to the presence of compounds with characteristic chemical structures, in particular to the presence of hydrophilic functional groups, such as hydroxyl groups of phenolic components and/or lipophilicity of some essential oil components (Dorman and Deans, 2000). Usually, the compounds with phenolic groups as oils of clove, oregano, rosemary, thyme, sage and vanillin are the most effective. These are more inhibitory against Gram-positive than Gram-negative bacteria (Marino et al., 2001).

The effect of malic acid and essential oils of cinnamon, palmarosa and lemongrass as natural antimicrobial substances incorporated into an alginate-based edible coating was studied on the shelf-life of fresh-cut melon. The coating containing malic acid was effective in improving the shelf-life of fresh-cut melon from both the microbiological and physicochemical points of view in comparison with non-coated fresh-cut melon samples. The incorporation of the essential oils or their active compounds into the coating prolonged the microbiological shelf-life by more than 21 days in some cases, probably due to an enhanced antimicrobial effect of malic acid and the essential oils. However, some physicochemical characteristics, such as firmness, colour, and also some sensory quality attributes were adversely affected, causing a significant reduction in shelf-life of fresh-cut melon (Raybaudi-Massilia et al., 2008). The essential oil of *Thymus vulgaris* controlled fruit rot caused by *Botrytis cinerea*, *Phytophthora citrophthora*, and *Rhizopus stolonifer*, but was ineffective against *Penicillium italicum* (Camele et al., 2010). An edible pectin film enriched with the essential oil of cinnamon leaves has been proved to increase the antioxidant status and reduce the bacterial growth in fresh-cut peach (Ayala-Zavala et al., 2013).

Carvone is a natural terpenoid found in many essential oils. It is abundantly found in the oil of caraway (*Carum carvi*) seeds. Besides, suppressing sprouting in storage, it exhibits fungicidal activity against decay of potato tubers (Hartmans et al., 1995). Menthol is another organic compound found in peppermint or other mint oils which is effective in controlling several diseases of fruits during storage. Blue mould rot of oranges was effectively controlled with essential oils of *Metha arvensis*, *Ocimum canum* and *Zingiber officinale*, suggesting a synergistic effect between the components (Tripathi, 2001). When fruits and vegetables are treated with menthol, the pathogen cannot easily develop resistance and as a result, it confers protection from decay during postharvest storage.

Nanoemulsions

Another environment friendly approach is the use of nanoemulsions. A nanoemulsion is defined as conventional emulsion with particle size varying between 1 and 100 nm. The entrapment of naturally occurring substances with functional properties, into nanoemulsions is enabling the development of edible coatings with antimicrobial properties and hence proves better than conventional emulsions.

Fresh-cut fuji apples when preserved, using nanoemulsion-based coatings developed by using alginate, Tween 80, and lemongrass oil (as antimicrobial) proves much better than their conventional emulsions. Similar observations were obtained with lemongrass oil nanoemulsion-based coatings which resulted in reduction of *E. coli* growth more rapidly in a greater extent than conventional emulsions. On the other hand, although the natural microbiota was significantly controlled on fresh-cut apples for two weeks using lemongrass oil coatings at the lowest assayed concentration (0.1% v/v), however the quality attributes were barely affected (Salvia-Trujillo et al., 2015). In a another study comparison of nanoemulsions and conventional emulsions with lemongrass oil, Tween 20 and chitosan was done to analyze their impact on the shelf life of grape berries. In this case also, Nanoemulsion-based coatings exhibited higher *Salmonella* inactivation, and controlled the spoilage microbiota growth efficiently in comparison to conventional emulsions. Further, sensorial analyses indicated equal acceptance of uncoated grape berries as well as those coated with nanoemulsions (Oh et al., 2017).

During cold storage studies of the shelf life of rucola leaves, it was found that the shelf life was prolonged for 7 days using edible coatings formed with nanoemulsions prepared by combination of lipophilic and hydrophilic combined surfactants (glycerol monooleate and Tween 20) with lemon oil and water added to a chitosan solution. Nanoemulsion-based coatings exhibited better shelf life than lemon oil or chitosan coatings alone (Sessa et al., 2015). Similarly, carvacrol incorporated nanoemulsions with modified chitosan solutions completely inhibited *Escherichia coli* growth on fresh green beans over 11 days of cold storage (Severino et al., 2015).

Conclusion and future prospective

To effectively extend the shelf life of fruit and vegetable, natural or edible coatings are relatively convenient and safe alternatives to their synthetic analogues. Most fruits and vegetables require protection against decay or spoilage during storage. Consumers demand fresh and safe natural commodities. This drives the researchers for finding out postharvest techniques to improve shelf life, quality and safety without causing nutritional and organoleptic losses. Therefore, the natural compounds are gaining a great importance in research and industry, due to their potential to provide quality and safety benefits, with reduced side effects on human health. The numerous studies have demonstrated that natural compounds are well suited to be utilized as preservatives in fresh fruits and vegetables and could be often valid alternatives to synthetic compounds. In order to promote the application of natural active compounds further at industrial level, some factors are of striking importance. First of all it is necessary to have a good understanding of the mechanism, by which antibacterial agents operate. The information and evidence for many natural compounds are scanty. The mechanism of action by which antimicrobials can control microorganisms needs to be studied for their better applications. In the specific case of essential

oils, despite their great potential, their use in food preservation remains limited mainly due to their intense aroma and toxicity problems. Several authors have reported changes in the organoleptic properties of the food, when these oils are used.

Another limitation involves environmental concerns about the use of plastic materials as coatings. Replacement of plastic films with edible or biodegradable materials is desirable from an environmental perspective. An upcoming approach in this sector is the advent of polysaccharide or essential oil based nanoemulsions along with incorporation of bioactive principles or encapsulated nanocoatings which can curb microbes as well. Moreover, more specific ISO standards are also necessary to assess the legal aspects to set out the definition, the general rules for their use, the requirements for labeling and the maximum levels authorized.

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