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A review

Enhancing shelf life of fresh fruits by the application of different edible coatings

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Abstract
Fruits have short shelf life due to their perishable nature. The demand for fruits is high in the market due to their rich nutritional value and health benefits and the preservation of fruits is a big challenge for the world. Due to post-harvest loss nearly 30% of horticultural commodities get lost due to less shelf life to minimize this loss various techniques have been developed among them edible coatings became more popular and effective method in recent decades because it replaces the natural outermost cuticle layer of fruits which gets lost after harvesting from tree and washing during post-harvest handling and also act as a barrier for reducing atmosphere gases exchange like CO_2 & O_2%, respiration & senescence rate and gives glossy look to the fruits after applying with edible coatings extends shelf life, reduce water and moisture loss, delayed the ripening process and also prevent microbial growth specifically in fresh fruits. The review covers different types of edible coatings and their effect on enhancing the quality and shelf life of different fruit crops.

Keywords: Edible coatings**,** fruits, shelf life, harvesting

Introduction

Fruits are used frequently by humans and play important role in human diet balance and health and they fulfil the average requirement of essential nutrients, antioxidants, minerals, bioflavonoids, dietary fibres and flavour compounds by taking them on daily basis. But fruits are extremely perishable as they contain 80–90% of water by weight (Alao SE, 2000). Post-harvest treatments are used to reduce the loss of moisture from the surface of fruits through evaporation, transpiration, respiration and metabolic activities within the fruits especially respiration and the effect of decay-causing microorganisms (Malik, 1994).

The external factors like atmospheric components such as oxygen, carbon dioxide, ethylene ratios, temperature and stress factors while the internal factors include cultivars, species and its growth stage. The contamination of fruits and vegetable flesh can occur from skin increasing the fruit's spoilage leading to biochemical deterioration such as browning, off flavour and texture breakdown, decreasing the quality of the fruits and risk the consumers due to the presence of pathogenic microorganisms (Harris *et al*. 2003) [21]. Fruit texture, quality, colour, appearance, flavour, nutritional value and microbial activity are the important quality factors of fresh produce that contribute to the marketability of fruits. These quality factors are measured by plant variety, ripening stage, maturity stage, pre-harvest and post-harvest conditions (Lin and Zhao, 2007) [32]. The post-harvest losses of fruits is a serious problem because it rapidly deteriorates during handling, transport and storage. Edible coating over fruits is used to improve their quality and shelf life (Kumar *et al.* 2014) [28]. Many post-harvest techniques have been developed to enhance the shelf life of fruits. Among them, edible coatings are rising as a new method for increasing the shelf life and improving the quality of fruit and also act as an alternate method for synthetic fungicides coatings as consumers show more preference for the eco-friendly method because of more health-conscious and demand fresh fruits. Edible coatings prevent loss of moisture and firmness. They control maturation, development and respiratory rate and also prevents oxidative browning and decreases the growth of microorganisms in fruits. The decreased metabolic activity provided by edible coatings has also been known to retard softening changes (Conforti and Zinck, 2002; Zhou *et al*. 2011) [13, 63], which result from the loss of turgor pressure and degradation of cell walls, contributing to a decrease in fruit brittleness and firmness (Zhou *et al*., 2008) [64]. Many edible coatings are usually made from materials such as polysaccharides, proteins and lipids; the polysaccharides used in edible coatings are starches and modified starches, chitosan, alginates, gums, cellulose derivatives and Pectins (Krochta & Johnson, 1997) [27]. The functionality of coating is greatly influenced by the physical and chemical characteristics of polymer (Sothornvit 2000). These can also be eaten safely as part of the product and do not add unfavourable properties to the foodstuff and they store the quality of fruits by forming a barrier between fruit surface and atmosphere which stops gaseous exchange and decrease the ripening and moisture loss and hence fruits can keep their odour and essence (Olivas G. I. *et al*, 2008) [40].

Edible Coating

History

The technique of using edible coatings for fruits is not a new method it has been used for many centuries. In China, the use of edible coating was started in the 12th century (Krochta and Mulder-Johnston, 1997) [27]. Lemons and oranges were earlier used for a wax coating to maintain their quality for longer periods (Guilbert, S. and Biquet, B.). Even though the Chinese did not recognize its full potential and reported that non-wax coated fruits were stored for a lesser time than waxed coated fruits. In 1922 waxing on fruits was invented and the first time was commercially applied on fruits (CPMA, 2014) [14].

Definition

The edible coating is defined as are thin layers of edible material which can be consumed applied to the fruit surfaces as a substitute for natural protective waxy coatings that extends the storage life of fresh fruits without anaerobic conditions and reduce the decay without affecting the quality of the produce. Edible coatings derived from various sources are enlisted in the below figure.

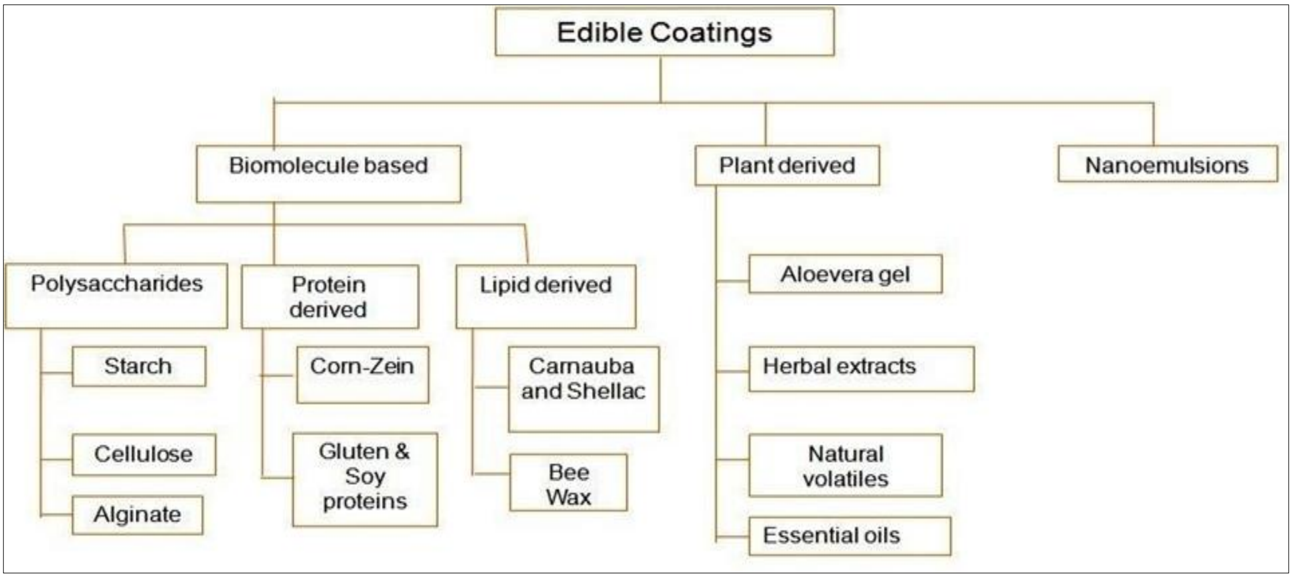

Fig 1: Edible coatings derived from various sources

Literature related to different types of edible coatings and their effect on fruit crops

Polysaccharide based edible coating

The most commonly used edible coatings for fruits and vegetables are polysaccharide-based and they include starch, cellulose, alginate which are derived from plant species. These coatings act as a partial barrier for gases exchange, also reduce water loss and slow down ripening and senescence.

The application of polysaccharide-based edible coatings enriched with antimicrobials and antioxidants has been proved to be efficacious in preserving fruit quality during storage. Alginate, chitosan and pullulan are often used as a polysaccharide-based edible coating due to their capacity to form rigid and stable gels (Gurreiro *et al.* 2016) [19]. The reported positive result for improving shelf life of plum fruit by using alone or combination of different polysaccharide-based edible coating. It was observed that application of 1% carboxymethylcellulose and pectin@1.5%+1.5% CMC and 0.5% showed the best result in reducing nutrient loss and improved total phenolics, flavonoids and anthocyanins, vitamin-c, POD activity and also reduces enzymatic activity such as polygalacturonase and polyphenol oxidase. (Panahirad *et al*. 2020) [43].

Cellulose-based-edible coatings

These are the type of polysaccharides most abundantly available natural polymer on earth but these types of coatings have poor water and gas barrier properties. generally, derivatives of polysaccharides are hydrophilic so they have very low mechanical properties as edible coatings. Some of the cellulose-based edible coatings commercially used are carboxymethylcellulose (CMC), hydroxypropyl methylcellulose (HPMC), methylcellulose, hydroxypropyl cellulose (HPC).

Khodaei *et al.* (2021) [25] in their experiment found that Tragacanth gum and Carboxymethyl cellulose coated strawberries exhibited the lowest weight loss (3.65%) and decay (32.66%) at day 16 of storage, respectively. Edible coatings reduced the rate of deterioration in ascorbic acid, total phenolics, and anthocyanins in fruit over time. Zillo *et al.* (2018) [62] reported from his experiment that the use of edible coating based on a combination of carboxymethyl cellulose and essential oil was proved to be good to extend the shelf life of papayas and also maintained the post-harvest characteristics. It was observed that methyl cellulose-based edible coatings shows a positive result on strawberry for increasing shelf life and decreasing the senescence and the addition coatings reduced moulds infections, colour change and weight loss of strawberry (Nadim, Z. *et al*, 2014).

Starch-based edible films

Starch is easily available and inexpensive complex storage polysaccharides found in cereals, legumes, tubers vegetables, like cassava, potato, rice, banana, corn etc. Starch-based coatings act as a semipermeable barrier for carbon dioxide and oxygen exchange and are biodegradable.

It was observed that a combination of cassava starch and citric acid combination coatings applied for fresh-cut mango was efficient in storing colour parameters and slowing down the quality deterioration, reducing the fruit respiration rate and inhibiting the characteristic during storage (Chiumarelli *et al*. 2010) [11]. A study from his report revealed that edible coating based on starch 3%, carrageenan 1.5% and Fatty Acid Esters 2% improves the shelf life of plum and maintains overall quality during fruit storage and can be commercialized as a new edible coating (Thakur, R. *et al*. 2018). It was found that the formulation containing 0.25% of chitosan and 0.5% of cassava starch showed the most favourable results as it presented a post-harvest shelf life of 3 days more than the control fruits and lower rates of CO_2 production, showing that this coating decreased the rate of the respiratory processes of mango, without compromising the proper ripening of the fruit (Camatari *et al.* 2018) [8]. Pullulan is an extracellular polysaccharide of starch that is edible and biodegradable. Pullulan films are colourless, odourless, and tasteless and show high O_2 barrier properties. Pullulan coating has been applied for preserving strawberries and kiwi fruits (Diab 2001) [16].

Alginate-based edible coatings

Alginate is naturally extracted from brown seaweed belongs to the Phaeophyceae family and it's a polysaccharide. Alginate act as a good barrier for water vapour and moisture (G.L. Robertson, 2009) [48].

Four different cultivars of plum treated with 1or3% of alginate edible coating were effective in delaying acidity and weight losses, colour changes and softening and also in preventing ethylene production for four cultivars, especially when used 3% alginate (Valero, D *et al*. 2013) [59]. The U.S. Food and Drug Administration (FDA) classifies food grade sodium alginate as GRAS (generally regarded as safe) substance in Title 21 of the Code for Federal Regulations (CFR) and lists its usage as an emulsifier, stabilizer, thickener, and gelling agent (U. S. Food & Drug administration-2018) [58]. Sodium alginate coating enriched with essential oils showed greater antimicrobial and anti-browning activities during fruits storage and has significant effects on weight loss and shelf life of fruits. It enhances the security of many fresh and fresh-cut fruits and minimally processed fruits. Sodium alginate incorporated in essential oils forms a barrier and reduce exchange between the environment and fruits and carry different natural antimicrobial agents to maintain characteristics and improve shelf life (Wang *et al*. 2020). It was found that, after 7 days of storage at 4°C, lowest values of weight loss (0.33%), microbial load (2.95 log CFU/g), electrolyte leakage (35.5%) and highest rates of lightness (96.11) and antioxidant capacity (11.03 mmol Fe^{2+}/Kg) were detected when the alginate-based coating formulation enriched with both citric acid and ascorbic acid compounds (Marghmaleki *et al*. 2021) [33].

Table 1: Application of Polysaccharide based coatings on Fruits

Fruits	Coating types	Effect on fruits	Reference
Guava	Potato Starch	Did not affect the pH, titratable acidity, and sugars, soluble and total pectin, firmness, and values of chlorophyll a and b	Boas *et al*. 2005 [7]
	Cellulose	Slowed softening, but fruits did not develop as much colour, had lower soluble solids, and were more prone to surface blackening	McGuire and Hallman, 1995
Banana	Gum Arabic and Chitosan	Delayed colour development and reduced the rate of respiration and ethylene evolution, maintaining the overall quality	Maqbool *et al*. 2011
Pineapple	Chitosan	Extends the shelf-life	Talens *et al*. 2012 [55]
	Sodium alginate and gellan gum	Control weight loss, preserve flesh firmness and slow the respiration rate at 10±1 °C and 65% RH	Azarakhsh *et al*. 2012 [3]
	Alginate	Helped to retain internal liquids	Montero-Calderon *et al*. 2008 [35]
Apple	Carboxymethyl cellulose (CMC)	Delayed browning more effectively when was applied in an edible coating than in an aqueous solution	Baldwin *et al*. 1996 [5]
Grapes	HPMC (Hydroxypropyl-methylcellulose)	It slowed down weight losses and controlled the oxygen consumption, had a better microbial safety	Pastor *et al*. 2011 [44]
Melon	Alginate	Inhibited the microbial growth and reduced up to 3.1 log CFU/g after 30 days of storage	Raybaudi-Massilia *et al*. 2008 [47]
Pear	Methylcellulose	Prolonged shelf-life by retarding browning	Olivas *et al*.2003
	Alginate, gellan	Prevented browning for 2 weeks	Oms-Oliu *et al*.2008 [41]

Protein-Based Edible Coating

Protein-based edible coatings are extracted from plants and animals. The animal-based protein is collagen, egg albumen etc. The plant-based protein edible coating material is whey protein, milk protein casein, gluten (from wheat), zein (from maize), soy protein etc.

Shown positive result when Zein based edible coatings were used for apple and very effective in maintaining the overall quality of fruit is good and is comparable to a commercial shellac coating (Bai *et al*. 2003 and Lee *et al*. 2003) [4, 29]. Protein-based edible coatings are brittle and susceptible to cracking. Protein-based edible coating shows poor water barrier properties (Mohamoud and Savello 1992) [34]. The Persian lime treated with soya protein-based edible coating including some anti-microbial compounds shows effectiveness in controlling the infestation of blue mould, decreases water loss and thus maintains colour (González-Estrada *et al*. 2017) [17].

Table 2: Application of Protein-based coatings on Fruits

Fruits	Coating types	Effect on fruits	Reference
Apple	Calcium caseinate and whey protein	Delayed browning	Tien *et al.* 2001 [57]
	Whey protein concentrate + beeswax	Reduced surface browning	Perez-Gago *et al.* 2006 [45]
Mango	Galactomannans+collagen	Effective in less O_2 consumption and CO_2 production	Lima *et al.* 2010 [31]
Cherry	Gelatine film	Lowest moisture loss	Lim *et al.* 2011 [30]
	Zein	Accelerated ripening and fungal deterioration	Carvalho-Filho *et al.* 2006 [9]
	Soy protein isolate (SPI)	Decrease the acidity	Lim *et al.* 2011 [30]
Kiwifruit	Whey protein concentrate and rice Bran oil	Preserved the colour, firmness, taste, and the overall acceptability of the fruits, slow down the increase of acidity and weight loss	Hassani *et al.* 2012

Lipid-Based Edible Coating

Edible lipids are neutral lipids, waxes and resin which are traditional coating materials for fresh produce and provide effective moisture barrier properties and also improve surface appearance (Hernandez, 2006; Morillon, 2002) [23, 36]. Lipid-based edible coatings were been used for many years for enhancing the shelf life of fruits due to their excellent barrier properties and giving things to fruits which improve the market value of produce. The most commonly used materials are beeswax, carnauba wax, paraffin wax, and vegetable oil or mineral.

Proved that based on his results of physical, chemical and sensory parameters, that edible coating containing coconut oil-beeswax (90:10 and 80:20) or only coconut oil coating of lemons and kept in MAP shown a great effect to increase the shelf life maintaining quality during ambient storage (Nasrin, T. A. *et al*. 2020) [37]. The lipid-based coating gives a greasy surface and undesirable organoleptic properties such as waxy taste and lipid rancidity (Robertson, 2009) [48]. Revealed that based on the study 0.5% shellac as an edible coating in combination with cinnamon essential oil were effective in controlling green mould decay, weight loss and can maintain ascorbic acid content, firmness and both qualitative and quantitive parameters of 'Thomson navel' orange fruit during storage. (Khorram, F. & Ramezanian, A. 2020) [26]. The edible coating based on carnauba wax on pear fruit reduced internal O_2 concentration and friction discolouration and improved shelf life. (Amarante *et al*. 2001) [2].

Table 3: Application of Lipid based coatings on Fruits

Fruits	Coating types	Effect on fruits	Reference
Mango	Carnauba Wax	Effective in retarding fruit ripening, retaining fruit firmness, and improving fruit quality attributes including levels of fatty acids and aroma volatiles.	Dang, 2008 [15]
	Semperfresh and A. vera gel (1:1 or 100%)	Slightly delayed fruit ripening but reduced fruit aroma volatile development	Dang, 2008 [15]
Apple	Wax, oil	Increased the shelf life.	Sabir *et al*. 2004
	Candelilla Wax	Prolongs and improves the shelf life, excellent antifungal barrier inhibiting the growth of natural Phytophatogenic fungal strains and slow weight loss.	Ochoa *et al.* 2011 [38]
Banana	Semperfresh	Extended the green life, delayed ripening	Chukwu *et al.* 1995 [12]
Pomegranate	Oil + starch	Reduced softening of arils, weight loss and % of the browning index, loss of vitamin C.	Oz and Ulukanli, 2012 [42]
Guava	Palm oil	Resisted the leaching effects	Suhaila-Md *et al*. 1992 [54]
	Waxol	Best fruit quality, better organoleptic properties, increased shelf life, highest acidity and TSS under the treatment with 6 to 9%	Jagadeesh and Rokhade, 1998 [24]
Huanghua pears	shellac	Retaining texture (especially for brittleness); also maintained higher POD activity and lower activities of cell wall hydrolases such as PE, PG, and cellulose.	Zhou *et al*. 2011 [63]

Other plant-based edible coatings

Herbal based edible coatings

It's a new technique of edible coating made up of herbs or a combination of other edible coatings and herbs. They are non-toxic and safe. Herbal coatings are usually obtained from aloe vera gel, tulsi, neem, lemongrass, rosemary and turmeric. Among these aloe vera gel is very effective in enhancing the shelf life of fruit crops like mangoes, strawberries, apples, nectarines, cherries, peaches, plum, tomatoes and table grapes, papaya.

Studied the application of edible coating based on aloe vera gel on pineapple fruit and seen that its very effective in reducing the ripening process, weight loss besides delayed ascorbic acid, softening and also maintaining the quality of fruit during post-harvest storage. (Adetunji C.O. *et al*. 2002) [1]. Aloe vera gel is used as an edible coating for fruit and vegetables. It has antifungal properties (Saks 1995) [49].

Aloe vera gel-based edible coatings prevent moisture loss and retain firmness, decreases respiration rate, delays oxidative browning and reduce the growth of microorganisms in table grapes (Valverde 2005) [60]. Papaya treated with 1.5% aloe vera was effective in enhancing shelf life and maintained colour& improved physical changes during storage (Sharmin *et al.* 2016) [51]. 20% aloe vera gel coated on guava fruits was a very effective post-harvest treatment that maintained fruit quality and reduced spoilage during storage and improved consumer acceptability (Sood M. 2019) [52]. Sogvar *et al.* (2016) studied the impact of an edible coating such as aloe vera with ascorbic acid on strawberries. Their study suggested that coating reduced weight loss and inhibited the growth of mesophilic yeast and moulds. This coating enhanced the shelf life of strawberries. Chauhan *et al.* (2014) [10] studied the effect of Aloe vera gel edible coating on green grapes, according to their study coating reduced weight loss, browning, cracking and also inhibited the growth of bacteria and fungi in berries.

Essential oils based edible coatings

The ginger essential oil, lemongrass, turmeric neem extract, clove bud oil, mint oil, other essential oil extracted from spices and other plant originated compounds can be used as a coating or used in the packaging films for improving the shelf life of fruits.

Results from his studies reported that the use of edible coating based on essential oil of lemon 0.2% and essential oil of orange 0.1% for red raspberry were effective in controlling mould and yeast growth after 15 days of storage increased the shelf life without changing any quality parameters of raspberry. (Gomes, M. D. S. 2017) [18].

Observed that from his research edible coating based on 5% cinnamon essential oil was very effective in extending the shelf life of coated apples and inhibiting the growth of fungus and maintained physiochemical characteristics during storage period for 2 months@ 5 °C (Rashid, Z. *et al*. 2020) [46]. The impact of composite coating comprised of xanthan gum, olive oil and antioxidants on table grapes was studied by Baraiya *et al*. (2016) [6]. The study concluded that this coating reduced weight loss, slow down respiration rate and delayed firmness. The shelf life of grapes was extended by this coating.

Conclusion

Edible coating alone or as carries of many additives and safest, non-toxic, environment friendly and eaten with fruits. Edible coatings are alternatives for synthetic and plastic films. Coatings show promise as environment-friendly quarantine treatments. Most coating materials are produced from renewable, edible resources and can even be manufactured from waste products that represent disposal problems for other industries.

Edible coatings are a very effective post-harvest technique for enhancing the shelf life of fruit crops by reducing moisture and water loss, preventing microbial growth and also delaying the ripening process, especially in fresh fruits. Reduces post-harvest losses during storage.

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