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A systematic review on plant-based edible coatings for quality improvement and extended postharvest life of fresh fruits and vegetables

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ABSTRACT

Purpose: Use plant-based edible coatings (PBECs) for maintaining quality of fresh fruits and vegetables (FFVs) are trending upward. Compared to modified atmosphere packaging they eliminate the use of non-biodegradable polyethylene films. Therefore, the present study aimed to bring a comprehensive systematic review of the published literature on plant- based edible coatings (PBECs) for quality maintenance and extension of postharvest life FFVs. **Findings:** The results revealed that PBECs are a better alternative to other protective films and packaging materials that utilize non-biodegradable polyethylene films or inorganic chemicals which pose negative impact on both consumers and environment. A wide range of ingredients including biopolymers, leaf extracts, plant waxes, essential oils, and plant byproducts have been intensively researched for their potential applications in the development of edible coatings. The coating treatments significantly retarded the rates of respiration and ethylene emission, activated antioxidative defense mechanisms, suppressed cell wall degrading enzymes, and retarded colour deterioration; all of which led to protecting the biochemical and organoleptic properties of FFVs. **Limitations:** Food items, when coated with some of the edible coatings, alterations of flavour and degradation of their properties upon exposure to light, oxygen & high temperature have been noted. Further, poor stability of the developed emulsion resulting inconsistencies in their effectiveness have been reported. **Conclusions:** In conclusion, PBECs could be considered as promising eco and consumer friendly strategy for maintaining and extending the postharvest life of FFVs. **Future trends:** It seems imperative to focus more on the development of composite coatings to enrich nutraceutical attributes of FFVs. Improving the efficacy of mode of action of the developed formulae alongside enhancing its stabilization and prevention of alterations in flavour when coated are critically important.

INTRODUCTION

Roughly one-third (30-40%) of global fresh fruits and vegetables (FFVs) are thrown away from production to consumption because their quality has dropped below an acceptance limit. On the other hand, nearly one billion people are chronically under-nourished and suffer from nutritional deficiencies (Porat et al., 2018). Today, food security is severely threatened due to climate change, lack of arable lands, and water scarcity. In this context, minimizing postharvest losses should be one of the leading strategies all around the world for ensuring food security of the burgeoning population. Minimizing postharvest losses is more sustainable and environmentally sounds than increasing production areas to compensate for these losses. While it may be impossible and uneconomical to eliminate postharvest losses totally, it is possible to reduce them at least by 50%. For that it is necessary to integrate correct postharvest management practices into supply chains and thereby curtail postharvest losses of FFVs.

There is an increasing trend to use plant-based edible coatings (PBECs) for maintaining quality of FFVs as they are both consumer and eco-friendly. Compared to modified atmosphere packaging they are relatively cheap, utilize the space in packing cartons & shipping containers effectively, and eliminate the use of non-biodegradable polyethylene plastic films (Firdous et al., 2023). Edible coatings are defined as thin layers (0.050 - 0.250 mm thickness) of edible material applied to the product surface in addition to or as a replacement for natural protective waxy coatings. They provide a barrier to moisture, oxygen, and solute movement for food (Dhall, 2013). As a result, they retard the rate of water loss, cellular respiration, thus hinders the rate of ripening and subsequent tissue senescence. Additionally, these coatings contribute to suppress the growth of pathogenic organisms and development of physiological disorders (Murmu & Mishra, 2017; Moradinezhad & Ranjbar, 2023), increase the aesthetic appearance of the produce by shining, hiding minor scars, and helping retain the commodity freshness. Moreover, they prevent the loss of volatile flavor compounds from the food while establishing mechanical protection.

Edible coatings are generally applied to the food material in liquid state. The major components of edible coating are polysaccharides, proteins and lipids. When developing new formulae currently, the researchers pay more attention to their consumer safety thus a diverse array of functional compounds are integrated. Figure 1 is a summary of compounds used to develop edible coating formulae.

The efficiency of the developed new formula depends on several factors namely;

- the nature of the coating ingredients and their concentrations
- the application method (dipping, spreading either manually or mechanically, spraying, etc)
- the uniformity of wetting and spreading on the surface and on the adhesion, cohesion, and durability
- The capability to act as barriers against water or oils permeation, and gas or vapor transmission.

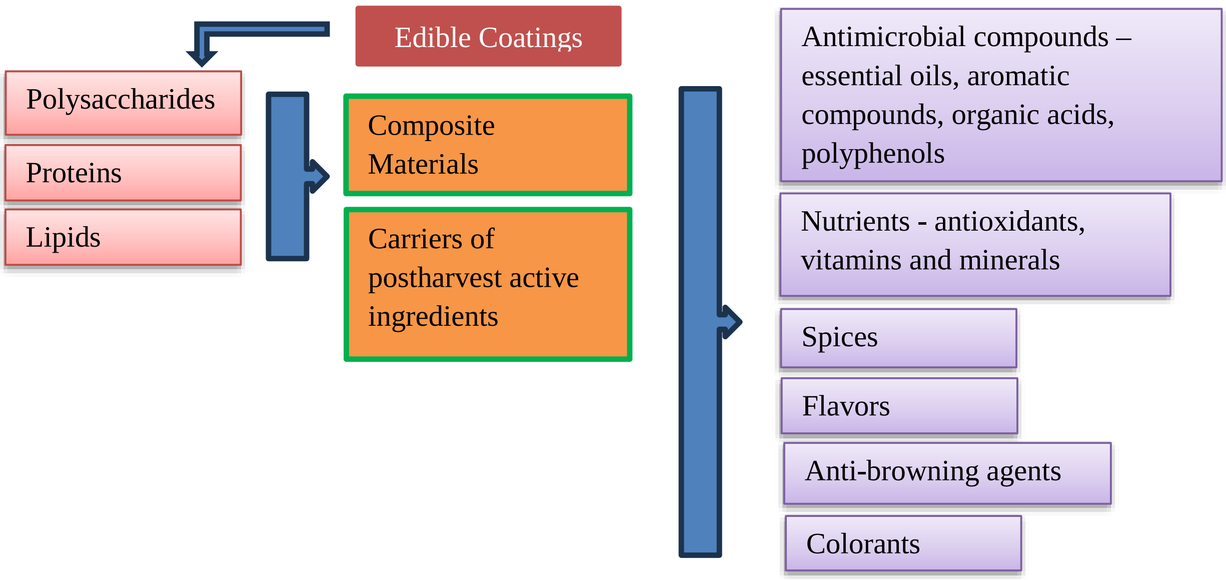

Fig. 1. Major components and additives used in edible coatings.

This study aimed to bring a comprehensive systematic review of the published literature from January 2013 to January 2024 on PBECs for quality improvement and extending the postharvest life of FFVs. Moreover, this review endeavored to depict the current key innovation areas in PBECs and to identify any knowledge gaps and inconsistencies in research that may necessitate further investigation.

MATERIALS AND METHODS

Eligibility criteria and sources of information

In this review we focused on the use of PBECs for improvements of postharvest quality and shelf-life of intact FFVs. Research articles published in Science Citation Indexed Journals during January 2013 to January 2024 were referred. They were retrieved from the Web of Science (https://clarivate.com/webofsciencegroup/solutions/web-of-science/) core collection. The major keywords used were "plant based edible coatings" "fruits" & "vegetables", "by-product utilization", "quality & shelf-life". In addition, to seek innovative fields of studies in PBECs, the keywords "active and/or functional ingredients of plant origin" were used.

Study selection and data collection process

Articles available on application of PBECs published in English were included in this study. Coatings applied on animal products such as fish, meat and minimally processed or fresh cut products were excluded. Moreover, research papers that reflect the content of nanocomposite coatings, nanoemulsions or nanoencapsulation were excluded because of the emerging controversial issue on potential of inducing toxic effects at cellular level in the human body. For instance, according to Evans et al. (2017) exposure to nanomaterials can have unanticipated effects on the overall functionality of the cellular system, and the fidelity of cell division and DNA replication. DNA damage has been linked to cellular exposure to some nanomaterials, resulting in genome rearrangements, single and double-stranded breaks, as well as inter/intra-strand breaks (Onyeaka et al., 2022). Further, edible coatings developed purely by animal-based extractions and/or synthetic inorganic compounds were excluded too. Hence, edible coatings developed by plant extracts such as starches, proteins, gums, waxes, essential oils, and plant byproducts were included. Documents that report studies reflecting improvements of film properties but not reporting their performance after evaluating the developed formula on shelf life of FFVs were excluded.

The retrieved documents were screened in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, and they are comprised of following four stages i.e. (i) identifying articles to be reviewed (ii) screening the studies for review, (iii) figuring which studies are eligible, and (iv) selecting which studies to include in the systematic review. A total of 1893 (n= 1893) articles were identified. Articles published more than 10 years ago, studies that do not focus on plant-based compounds as the primary subject, studies that did not evaluate the developed coating formulation on intact FFVs for its postharvest performance were excluded. Further, book chapters, conference abstracts, proceedings, case studies and articles published in non-English were excluded. Following the application of exclusion criteria, 1788 (n= 1788) documents were removed. Subsequently, 105 (n=105) articles underwent further full-text screening. Utilizing the Mendeley reference manager to eliminate duplicates (n=21) and excluding irrelevant content (n=34), a total of 50 (n=50) documents were considered suitable for inclusion in this systematic review and the process followed is shown in Figure 2.

RESULTS AND DISCUSSION

Numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage are given via a flowchart in Figure 2.

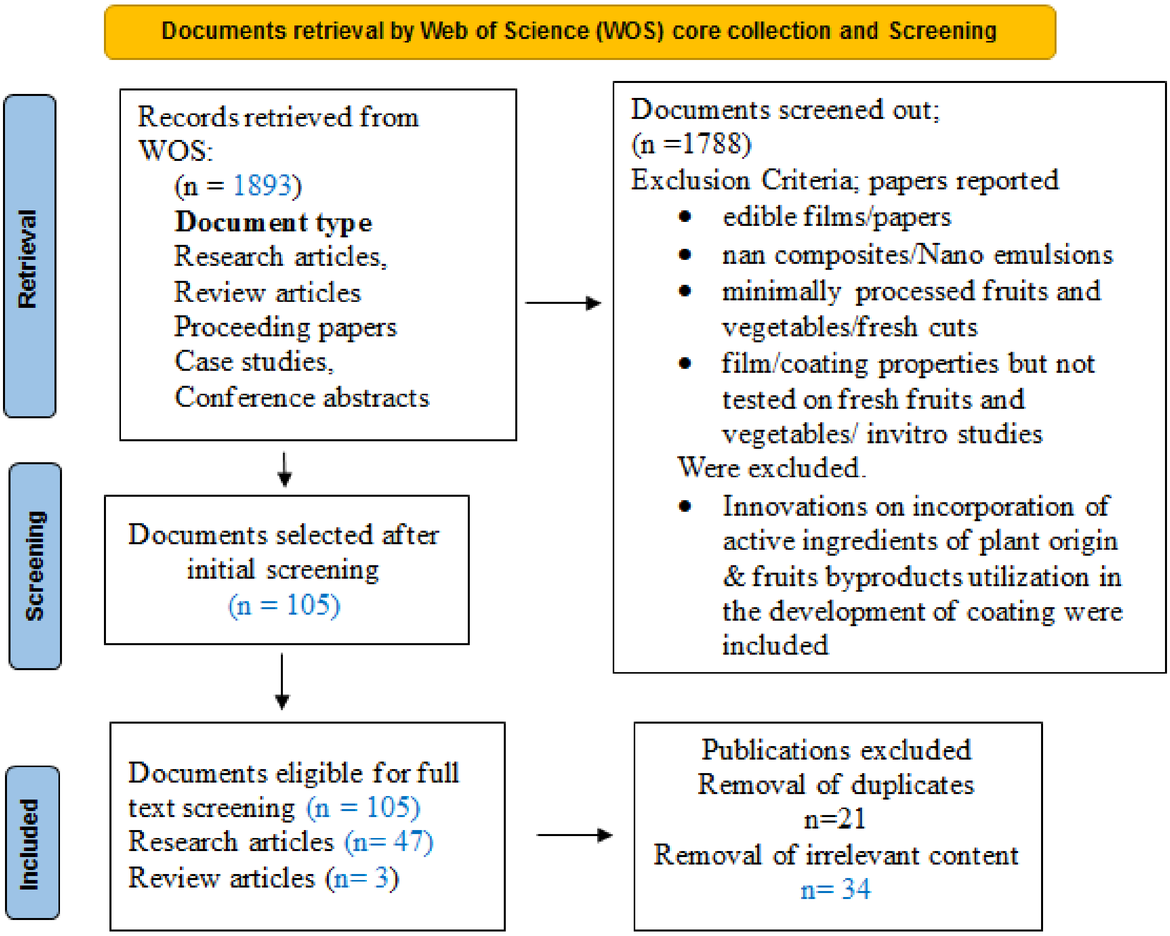

Fig. 2. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flowchart.

Polysaccharides and protein based edible coatings

Starches

Effect of application of edible coatings with 3% corn starch (CS), 1% gum Arabic (GA) and 1% lyophilized fish myofibrillar proteins (LMP) on postharvest quality of guava cv. Cortibel was investigated by Pereira et al. (2021). Three sprays were made on each fruit, with 8 mL of the coating solution at 40°C, with an interval of 1 min between them. After treatment fruits were stored at 24 ± 0.21°C, 64 ± 1.15% RH. The CS and LMP delayed the fruit ripening compared to the control and GA, examined by the color. After 7 days of storage, the coated fruits remained green, which was different from the control that lost this color by 3rd day of storage. A lower weight loss and a higher firmness were shown by fruit treated with LMP and CS during the storage which contributed positively to slowdown the rate of deterioration of guavas.

Thakur et al. (2018) studied the use of rice starch (RS), carrageenan (car) and fatty acid esters (FAEs) composite materials for fruit coating applications. Film solution (starch 3%, car 1.5% and FAEs 2%) was applied manually on plum (*Prunus salicina*) fruit and their impact on physiology and shelf life were evaluated during storage at 20 °C, 55 ± 5% RH for 3 weeks. RS composite coating was shown to be effective in reducing both weight loss and respiration rate and inhibiting the endogenous ethylene production compared to the uncoated control fruit.

Effect of flaxseed (*Linum usitatissimum* L.) and fenugreek (*Trigonella foenumgraecum* L.) polysaccharide-based edible coatings on postharvest quality of apple Cv. Kala Kulu has been studied by Rashid et al. (2020). Fruits were dipped for one min in respective coating solutions and stored at 20 ± 5 ºC, 80-85% RH. From the response optimization analysis, a combination of 2.5 g fenugreek and 1.5 g flaxseed polysaccharide-based coating was predicted to give desirable effects for all response variables. The findings proved that optimized fenugreek and flaxseed polysaccharide based edible coating could retain the quality of apple by minimizing weight loss, retarding the rate of reduction in firmness, TSS, TA, & pH through the mechanism of delaying respiration rate and ethylene production.

Khodaei et al. (2021) evaluated the effect of edible coatings of Persian gum (PG - 4% w/v), low methoxyl pectin (LMP - 2% w/v), carboxy methyl cellulose (CMC - 1% w/v), and tragacanth gum (TG - 0.6% w/v) on extending the shelf-life of fresh strawberries. Freshly harvested strawberries were dipped in respective coating solutions for 30 s which then packed in polyethylene terephthalate (PET) clamshell containers and stored in refrigerator (4 ˚C and 80% RH) for evaluation of their physicochemical properties for 16 days. The TG and CMC coated strawberries exhibited the lowest weight loss (3.65%) and decay (32.66%) on day 16 of storage, respectively. Edible coatings reduced the rate of deterioration in ascorbic acid, total phenolics, and anthocyanins in fruit over time. However, no significant difference observed between the coated and untreated strawberries in firmness and color characterization during storage. Coatings improved the sensorial attributes of the fruit during storage of which CMC coated strawberries exhibited the highest score.

Alginate

Alginate is a polysaccharide extracted from brown seaweeds of the Phaeophyceae class via alkaline extraction, followed by precipitation with either sodium or calcium chloride. It is composed of D-mannuronic acid and -L-guluronic acid and widely used in edible coatings. The U.S. Food and Drug Administration (FDA) classifies food-grade sodium alginate as generally regarded as safe (GRAS) and lists its usage as an emulsifier, stabilizer, thickener, and gelling agent. The European Commission (EC) lists alginic acid and its salts (E400–E404) as authorized food additives.

Three concentrations of freshly prepared coating solutions of sodium alginate (1, 2, and 3% w/v) have been evaluated on postharvest performance of mango cv. Mahali harvested at mature green stage (Rastegar et al., 2019). The fruits were immersed for 5 min in the respective coating formulations and placed as a single row in plastic crates which then stored at 15 ± 1°C, 85 ± 1% RH. Quality characteristics including acidity, ascorbic acid content and peel colour were not affected by the alginate treatments. In contrast, treatment with 3% alginate significantly reduced weight loss and maintained higher firmness (2-fold), total phenols (1.3-fold), and flavonoids content (1.7-fold), compared with the control. Higher antioxidant capacity was observed in 3% alginate treatments than the control.

Gum Arabic

Gum Arabic (GA), also known as Arabic gum is one of the biopolymers acquired from the branches and stems of Acacia trees (*Acacia spp*.). It is comprised of rhamnose, galactose, arabinose, and glucuronic acid with Ca, Mg, and K ions. It is commercially utilized as a food additive, because of its film shaping, emulsification, and encapsulation attributes. El-Gioushy et al. (2022) investigated the effects of edible coatings based on GA with cactus pear, moringa, and henna leaf extracts (10% GA; 10% GA + 10% moringa leaves extract; 10% GA + 10% cactus pear stems extract; and 10% GA + 3% henna leaves extract) on the storability and shelf life of guava (*Psidium guajava* cv. Maamoura). Fruit dipped for 2.5 min in respective coating solutions was stored in cold room (7±1 ^{o}C, 90 ± 5% RH) for 24 days. The combined treatments of 10% GA + 10% moringa leaf extract were the most effective coating for fresh guava which reduced weight loss, decay and *Rhizopus* rot infection (%), while also increasing marketable percentage, and delaying fruit softening. The treatment significantly retained total chlorophyll content, maintained vitamin C, acidity and TSS compared with untreated fruits during the cold-storage period.

In a study conducted by Tahir et al. (2018) revealed that GA (10 and 15% w/v) coatings maintained the total contents of phenolic, anthocyanin and TSS of strawberries (*Fragaria ananassa*) stored at 4±1^{o}C for 10 days. The treatment significantly ($p < .05$) retarded the increase in polyphenol oxidase (PPO) activity, reduced the weight loss, and completely inhibited the fungal infections. Out of the doses examined, 15% GA edible coating retained color, firmness, and increased antioxidant activity along with higher organoleptic quality compared to the control.

Shakir et al. (2022) investigated the effect of 10% GA, 0.5% CMC, and 10% GA+0.5% CMC coating formulations on postharvest quality attributes of tomato cv. Sahil F1 Hybrid harvested at turning stage of maturity. After the treatments, fruit were packed in clamshell PET boxes and stored for 20 days at 20 ◦C, 90±2% RH. Application of biocomposite hydrocolloid coating (10% GA+0.5% CMC) reduced the physiological weight loss, respiration rate, ethylene production, decay percentage and stress markers viz. malondialdehyde (MDA) and hydrogen peroxide (H_2O_2). It also inhibited the degradation of bioactive compounds (phenolics, ascorbic acid, and lycopene), retarded the rate of change of color, organic acids and soluble sugars. The composite treatment upregulated enzymatic reactive oxygen species (ROS) scavenging mechanism in tomato fruit more than GA or CMC alone coatings. Moreover, biocomposite coating delayed senescence by reducing activity of cell wall degrading enzymes and maintaining cell wall fractions.

Murmu and Mishra (2017) studied edible coating formulations based on GA (0 - 15 g/100 mL), sodium caseinate (SC) (0 - 2 g/ 100 mL) and Tulsi extract (TE) (0 - 5 mL/100 mL) on quality of guava stored at 28 ± 2 °C for 7 days. It was found that coating formulation containing GA concentration < 5 g/100 mL were too thin to slow down respiration, ripening, senescence, and mold growth whereas, those with GA concentration > 12 g/100 mL resulted in too thick coating resulting in high rate of O_2 consumption, CO_2 evolution, water loss, higher firmness and adversely affected the overall acceptability of guava following 7 days of storage at 28 °C. The optimized coating formulation was 5 g/100 mL GA, 1 g/100 mL SC and 2.5 mL/100 mL Tulsi extract. Guava coated with the optimized formulation registered no mold growth and had a higher overall acceptability.

Khaliq et al. (2016) studied Mango (*Mangifera indica* L. cv. Choke Anan) dipped for 3 min in 10% GA and 3% calcium chloride (CA) alone or in combination was evaluated on physiological and biochemical quality attributes during storage at 6 °C, 90% RH for 28 days + 5 days at 25 °C. The combined treatment of 10% GA and 3% CA significantly alleviated chilling injury, reduced MDA content and electrolyte leakage compared to the control fruit. This treatment reduced the increase in H_2O_2 content, superoxide anion production rate and enhanced DPPH radical scavenging activity. Furthermore, 10% GA alone or in combination with 3% CA effectively inhibited the loss of total phenolic content and ascorbic acid. The result of transmission electron microscopy confirmed that treated fruit-maintained cell membrane integrity as a result of enhanced antioxidant defense system, thereby reducing oxidative damage and postharvest deterioration of treated mangoes.

Persian gum

Persian gum is an exudate polysaccharide from the trunk and branches of wild/mountain almond tree *(Prunus scoparia* Spach). This gum is a transparent, semi cloudy, odorless exudate and can be found in different shapes such as large granules, sugar crystals and powder with diverse colours varying from white to brownish red. It easily dissolves in water and has no odor. Khorram et al. (2017) studied a wide variety of coating formulations such as 1% Persian gum (PG), 5% gum Arabic (GA), 1% carboxymethyl cellulose (CMC), 0.5% beeswax (BW), 1% carnauba wax (CA) (w/v) to retain the fruit glossiness along with other postharvest quality attributes of Kinnow mandarins (*Citrus reticulata*). One of the reasons for fruit coating is increasing gloss to enhance the external appearance of them and 1% PG was the most effective treatment for increasing the glossiness of Kinnow mandarins.

Guar gum

Guar gum is a galactomannan rich flour, water soluble polysaccharide obtained from the leguminous Indian cluster bean *Cyamopsis tetragonoloba* (L.) Taub. The backbone of this hydrocolloid is a linear chain of D-mannopyranose units connected to each other by β-1,4-bonds linked to galactose residues by 1,6- bonds forming short side-branches. It is one of the most important thickeners and a versatile material used in the food industry. This galactomannan has similar properties as carrageenan, alginate, xanthan gum, and gum Arabic but guar gum has the advantage of being cheaper than the others. Saberi et al. (2018) studied edible composite coatings based on pea (*Pisum sativum*) starch and guar gum (PSGG), PSGG blended with lipid mixture containing the shellac wax (PSGG-Sh), and bilayer approach (PSGG as an internal layer and shellac as an external layer), on postharvest quality of ‘Valencia’ oranges stored at 5 °C for four weeks and at 20 °C for 7 days. The incorporation of lipid compounds into the PSGG coatings (PSGG-Sh) reduced fruit respiration rate, ethylene production, weight and firmness loss, peel pitting, and decay rate. Oranges coated with PSGG-Sh and a single layer PSGG coatings resulted in higher scores for overall flavor and freshness after four weeks at 5 °C followed by one week at 20 °C than uncoated fruit, as assessed by a sensory panel. However, although the bilayer coating reduced weight loss and respiration rate with improved firmness retention to a greater extent than the single layer PSGG coating, the bilayer coating resulted in higher levels of ethanol causing increased perception of off-flavors.

Ruelas-Chacon et al. (2017) studied the potential of guar gum edible coating on extension of shelf life and maintaining quality of tomato cv. Roma. Tomatoes harvested at light red stage of ripening were coated with 1.5% guar gum and stored for 20-days at 22 ± 2 °C, 40% RH. The treatment significantly enhanced fruit firmness while recording reduced weight loss, delayed changes on soluble-solids-content, retarded loss of total acidity, and decreased respiration rate compared to uncoated control.

Locust bean gum (LBG)

Locust bean gum is a polysaccharide belonging to the group of galactomannans, extracted from the seeds of carob tree (*Ceratonia siliqua*) and native to the Mediterranean region. Among a variety of biopolymers, LBG has been identified as an efficient protective coating component for FFVs preservation because of its selective permeability to O_2, excellent film forming properties, and its ability to act as an effective delivery matrix of different natural antimicrobial agents. Aloui et al. (2021) produced coatings based on three concentrations of LBG (1, 0.8 and 0.6%) by incorporating different concentrations of cutin monomers (0.2 and 0.4%) and/or cuticular wax (0.2 and 0.4%) extracted from tomato pomace. Their efficacy was evaluated in extending the shelf life of tomatoes (*Solanum lycopersicum*, cv. Cerasiforme) stored at 4 °C, 85–90% RH for 28 days. Coatings incorporating cutin monomers-based fraction were the most efficient in controlling weight loss, retaining firmness of coated tomatoes and reducing the growth of *Botrytis cinerea* by more than 55%.

Arabinoxylans

Arabinoxylans (AX) are important cereal non-starch polysaccharides constitute of a linear backbone of ß-(1-4)-linked D-xylopyrxylopyranosyl units to which α-L arabinofuranosyl substituents attached through O-2 and/or O-3. González-Estrada et al. (2017) studied incorporation of antagonistic yeasts *Debaryomyces hansenii* into AX based edible coating and evaluated its efficacy in preventing infection by *Penicillium italicum* that cause blue mold in Persian lime (*Citrus latifolia* Tanaka). Results revealed AX as a matrix compatible with *D. hansenii* maintained more than 97% viability of initial inoculum at temperatures (13 and 25 °C) examined. This may be due to polymeric matrix providing nutrients needed to sustain their survival. Preventive application of treatments was more effective than curative applications in controlling blue mold decay. This study demonstrates the potential application of bioactive AX coatings with *D. hansenii* as an alternative postharvest disease management tool. In addition, the applied coating was able to retain color and reduced the rate of weight loss.

Soy protein isolates

Soybean protein isolate (SPI) has excellent film-forming properties to prevent the migration of oxygen, carbon dioxide, and solute into the food matrix. SPI can be served as an ideal edible coating because of its low cost, availability and eco-friendliness. However, its hydrophilic property considerably leads to poor water-barrier performance (Li et al., 2019). Dave et al. (2017) studied the effect of optimized coatings of SPI, hydroxypropyl methylcellulose (HPMC), olive oil and potassium sorbate on quality parameters and shelf-life of pears (*Pyrus communis* L.) cv. Babughosha stored at ambient temperature (28 ± 5 °C , 60 ± 10% RH). The SPI based coatings retained the firmness of fruits, lowered the moisture loss, could also retain the levels of ascorbic acid, chlorophyll and sugars in the treated fruits. Activities of enzymes associated with fruit softening (β -galactosidase, polygalacturonase, pectin methyl esterase) showed delayed peaks. Amongst the treatments examined SPI 5.0%, HPMC 0.40%, olive oil 1%, potassium sorbate 0.22% (T1) and SPI 5.0%, HPMC 0.40%, olive oil 0.98%, potassium sorbate 0.20% (T2) were found to have pronounced effect on retention of nutritional quality in pears. Observations of shelf-life extension established that T2 was successful in extending shelf-life up to 15 days, as compared to 8 days for untreated pear fruits.

Coatings produced from plant leaf extracts

Aloe vera

Aloe vera (*Aloe barbadensis* Miller) is a succulent plant belonging to the family Asphodelaceae. *A. vera* leaves have been used for many centuries for their therapeutic properties, and over 75 active ingredients have been identified in its gel. An enormous number of research articles published in the last decade evident that *A. vera* gel coatings act as a partial barrier to moisture and O_2, reducing the respiration rate, thereby preventing anaerobic conditions and conserving fruit quality. Moreover, its odourless and colourless properties along with eco and consumer friendly properties make it highly researched plant leaf extract during the last decade. Guava fruits (cv. Thai) when treated with *A. vera* gel 25% + Chitosan 1% exhibited 13 days of postharvest life at 22±2 °C and 70-85% RH compared to the uncoated control samples where the postharvest life was 6 days (Supa et al., 2024). Similarly, Hassan et al. (2022) studied 20 and 40% *A. vera* gel alone or in combination with 1% lemongrass essential oil (EO) as an edible coating for strawberries stored at 5 ± 1 °C, 90–95% RH for up to 16 days. Treatment with *A. vera* gel 40% + lemongrass EO 1% led to the lowest weight loss, retained firmness and acidity, but increased the TSS and total anthocyanins compared to uncoated fruits during storage. The antioxidant activity was relatively stable of the fruits coated with *A. vera* gel combined with lemongrass EO up to 8 days under the said storage conditions.

A study was conducted by Khaliq et al. (2019) to find out the effect of *A. vera* gel (at 50 and 100%) alone or enriched with *Fagonia indica* plant extract at 1% on physiological and biochemical responses of sapodilla (*Manilkara zapota* L.) fruit stored at 20 °C for 12 days. Sapodilla fruit treated with *A. vera* 100% and *F. indica* 1% significantly reduced weight loss, decay incidence, TSS, and kept a high level of firmness and TA compared to untreated fruit. Both doses of *A. vera* (50% or 100%) when incorporated with 1% *F. indica* were effective in maintaining higher ascorbic acid, total flavonoids, total phenolics and radical scavenging activity of sapodilla fruit alongside optimal sensory quality attributes. Significant reduction in weight loss (by 30%) and better sensory attributes were shown when jujube (*Ziziphus jujuba* Mill.) fruit were coated by *A. vera* 33% (v/v) after 40 days of storage at 4 ± 1 °C, 80% RH compared to the untreated control (Moradinezhad et al., 2018).

Chrysargyris et al. (2016) examined 0, 5, 10, 15 and 20% *A. vera* gel coating on fruit quality maintenance of tomato up to 14 days at 11 °C, 90% RH. Results showed that 10 and 15% *A. vera* coating reduced the fruit ethylene production. The ripening index (TSS/TA) decreased after 7 days of storage in 10% *A. vera* gel coated fruit, maintaining the overall quality of treated tomatoes. Increased ascorbic acid content was reported in the tomatoes treated with 10% *A. vera* gel. In the tomatoes coated with 20% *A. vera* gel total phenolics and antioxidative status were increased. However, the authors reported that fruit firmness, TA, weight loss, respiration rate and fruit colour properties (L*, a*, b*) did not differ significantly among treatments.

Moringa

Moringa (*Moringa oleifera* Lam., Fam: Moringaceae) is one of the most useful trees in the tropics and subtropics of Asia and Africa. The leaf, bark, sap, root, flower and seed extracts of moringa plants possess antimicrobial and antioxidant activities, contributed by a high concentration of phenolics, vitamins and carotenoids. Vast potential of moringa plant parts to be used as an ingredient in the development of different functional food products is well documented (Ngcobo et al., 2024).

(Tesfay & Magwaza, 2017) studied the efficacy of 2% moringa leaf extract coating along and in combination with two concentrations of chitosan (0.5 and 1%) and two concentrations of CMC (0.5 and 1%) on avocado (*Persea americana*, Mill. cv. Fuerte and Hass) fruit quality attributes during cold storage (5.5 °C, 95±2% RH) for 21 days. Fuerte fruit treated with combination of 2% moringa + 1%CMC showed significantly lower weight loss (1.78±0.08%), electrical conductivity (192.0±3.0 S/m) and respiration rate (167.4±40.8 mg/kg/h) compared to the untreated control with respective values of 4.7±0.7%, 290.0±5.0 S/m and 290.0±62.0 mg/kg/h. The same treatment maintained higher fruit firmness (50.0±4.25 N), lower polyphenol oxidase and lipid peroxidation activities in the cv. Fuerte. Similar results were shown for the cv. Hass too where a combination of 2% moringa leaf extract with 1% of CMC reduced mass loss almost by 50%, while mannoheptulose (a rare seven-carbon sugar which acts as an intracellular glycolytic inhibitor and its concentration is high in unripe avocados), was maintained by 8-folds.

Olive

Olive (*Olea europaea*, Fam: Oleaceae) leaf extract (OLE) is known to possess high antioxidant and antimicrobial activities, and it is reported as effective against several diseases such as coronary disease, diabetes, and some bacterial infections. Zam (2019) studied the addition of OLE (1%) in to chitosan (1%) and alginate (3%) based coatings on the quality of sweet cherries (*Prunus avium* L. Cv. Bigarreau Burlat) stored at 25 ± 5 °C, 65 ± 5% RH. The ripening process and increase in anthocyanins were found to be delayed with coating treatment. Chitosan and alginate coatings when enriched with OLE showed retarded rate of deterioration in ascorbic acid and total phenolic contents at the end of 20 days of storage.

Cashaw

Cashaw (Prosopis juliflora, Fam: Fabaceae) leaves have traditionally been used for curing mouth and throat infections, and many other diseases such as bronchitis, ulcers and skin parasitic infections. In vitro studies conducted by Saleh and Abu-Dieyeh (2022) has shown the effectiveness of *P. juliflora* water-soluble leaves ethanolic (PJ-WS-LE) extracts against pathogenic fungi and bacteria. the efficacy of this treatment has been investigated in-vivo by spraying 8 mg/mL of PJ-WS-LE extract on cucumbers (*Cucumis sativus* cv. Qatari). Samples sprayed with 8 mg/ml of PJ-WS-LE extract increased cucumber shelf life stored at 22 °C by 77%. At week 2, cucumber coated with PJ-WS-LE extract showed less than 10 CFU/g of mold as well as 76.9% and 85.8% reduction of total yeast and aerobic bacterial counts, respectively. PJ-WS-LE extract treated samples maintained the slightest change in TSS and 2,2-DPPH free radical scavenging activity.

Lotus

Lotus (*Nelumbo nucifera* Gaertn) is a widely cultivated aquatic perennial plant, and its leaf powder is traditionally used as herbal tea in China (Fan et al., 2019). Investigations indicated that lotus leaves have strong free radical scavenging and antioxidant activity, and these capacities are related to their flavonoid and phenolic compounds. Furthermore, lotus leaves have been confirmed for the effects of anti-oxidation, antimicrobial over the past years thus widely used as food and drugs. Fan et al. (2019) studied the effect of composite coating of lotus leaf extracts (LLE - 0.25, 0.5, 1.0, 2.0, 4.0 g/l) in combination with film formers sodium alginate, konjae glucomannan and starch (22% amylose content) on quality of fresh goji fruit

(*Lycium barbarum* L.) during storage at ambient temperature. The best coating formulation was 0.25% LLE+1% film former (the blend mass ratio 2:3:3 included sodium alginate, konjae glucomannan and starch) + 1% glycerin + 0.5% $CaCl_2$ which is defined based on the effect of the weight loss and decay ratio on goji berries. Goji fruit coated with LLE incorporated coating had significantly lower weight loss, decay rate and MDA content than the blank control (uncoated) and the positive control (fumigated with 1- methylcyclopropene) after 9 days of storage. Moreover, LLE incorporated coating was found to be effectively maintained ascorbic acid, TA, TSS and superoxide dismutase (SOD), catalase (CAT), peroxidase (POD) activities at higher levels compared to other treatments. LLE incorporated coating could extend the shelf life of goji berries by about 4 days compared to the uncoated samples.

Betel

Among the natural polyphenols, *Piper betel* L. leaf extract (PBE) is rich in phenolic acid derivatives and flavonoids, which exhibit excellent antibacterial and antioxidant performance. PBE has also been found to be efficient in imparting antibacterial and antioxidant functions to chitosan, sago starch, and polyvinyl alcohol. Pham et al. (2023) focused on developing pectin/agarose-based edible coatings (PeA), which was functionalized with PBE (20, 30 and 40%) and its efficacy has been evaluated by applying it on Chiquita bananas stored at 20 °C, 64 %RH. Scanning electron microscope (SEM) analyses showed that PeA enriched with 30% PBE (PeA-PBE- 30) coating effectively sealed and uniformly dispersed on the fruit skin. Besides, PeA-PBE-30 coating significantly reduced the respiration rate of fresh bananas during the 8 days of storage period. Protective efficacy of PeA-PBE-30 coating was exhibited by having reduced rate of weight loss, retention of TSS, TA and juice pH of treated bananas compared to uncoated fruits and other treatments.

Lipid based coatings

Carnauba wax

Carnauba wax is derived from leaves of palm trees (*Copernica prunifera* Mill.) which are native to the tropical rainforest of Brazil. It is a GRAS compound and its use as a promising ingredient in plant-based edible coatings are discussed below. Carvalho do Lago et al. (2023) reported physicochemical quality and antioxidant capacity of Valencia Late and Natal IAC sweet oranges coated with carnauba wax/wood resin (also known as rosins that are residues left after distillation of the volatile fraction of pine oil and turpentine from the crude resin of the pine trees) stored in a cold chamber at 5 ± 1 °C, 60–70% RH for 60 days. Carnauba wax/wood resin coating treatment efficiently delayed fruit color development and prevented weight loss for both sweet oranges cultivars up to 60 days. Moreover, the physicochemical (firmness, TSS, TA and ripening index) and sensory quality of wax-coated fruits were preserved during cold storage. It has been observed that uncoated fruits showed a decrease in juice content compared to the fruit treated of both cultivars.

Indian jujube (*Ziziphus mauritiana* Lamk. cv. Cuimi) were immersed in canauba wax (CW) coating, CW containing glycerol monolaurate (CW-GML) coating, or distilled water (uncoated control) respectively for 60 s at 20 °C (Chen et al., 2019). Compared to the control, both CW and CW-GML coatings reduced jujube weight loss, respiration rate, and ethylene production, maintained lower activities of cell wall degrading enzymes namely polygalacturonase, pectin methylesterase and cellulase resulting in delayed flesh softening. The two coatings also delayed the change of skin color and retained higher contents of chlorophyll and ascorbic acid. The CW-GML coating significantly inhibited the decay of jujube fruit and retained better sensory quality. After 12 days of storage at 20 °C, 60–70%

RH, the decay index was lowest in CW-GML-coated jujube followed by CW-coated jujube while the highest was shown by the control fruit.

Nazoori et al. (2023) studied carnauba wax (0.5, 1, 1.5%) and CMC (0.5, 1, 1.5%) on postharvest quality, decay, physiological disorders, and antioxidant properties of pomegranate cv. Shirin Shahvar. The fruits were dipped for 5 min in the respective treatments and stored at 4 ± 0.5 °C, RH 85 ± 5% for 150 days. The carnauba wax treatment was effective in preserving the anthocyanin, flavonoid, and firmness of fruit while minimizing peroxidase and polyphenol oxidase activities.

Candelilla wax

Candelilla wax (CW) is derived from *Euphorbia antisyphilitica* Zucc., which is grown in the arid regions of northern Mexico and southern United States. Oregel-Zamudio et al. (2017) developed an edible film made of CW added with biocontrol bacteria to prolong the shelf life of strawberry. CW-based coatings were applied on fresh strawberries, inoculated with *Bacillus subtilis* HFC103, to evaluate their antifungal efficacy against *Rhizopus stolonifer*. Strawberries were immersed in the respective emulsion (without coating and non-inoculated), film (CW-based edible coating), bacteria (inoculated with *B. subtilis* HFC103) and film + bacteria (CW-based edible coating + *B. subtilis* HFC103) at 25 °C for one second and were allowed to dry at 25 °C for 15 min. The results showed that the combination of CW-based edible coating + biocontrol bacteria (*B. subtilis*) as a promising alternative for the reduction of postharvest decay caused by *Rhizopus stolonifer.*

Lacquer wax

Lacquer wax is an important fatty resource obtained from the mesocarp and seed of the berries of *Toxicodendron vernicifluum* which belongs to family Anacardiaceae. It contains hexadecanedioic acid, eicosanoic acid and dodecanedioic acid which contribute to its elasticity. Therefore, unlike general wax such as palm wax, insect wax and beeswax, lacquer wax is more elastic and softer in performance making a wide range of applications in different fields of the food, pharmaceutical and medical industries. Lacquer wax has also been applied in the field of high-end cosmetics due to its good moisture retention ability. In China, it has been used as edible vegetable oil for thousands of years. Hu et al. (2019) explored the effectiveness of lacquer wax coating (immersed in 1, 2, and 3% for 30 s) solutions in retarding the postharvest senescence of kiwifruit (*Actinidia deliciosa*) cv. Xuxiang. After the treatments fruits were stored at ambient temperature (22–26 °C, 45–60 % RH) and compared its effect with chitosan coatings. Results indicated that, apart from the effectiveness against the decrease of weight loss, coated kiwifruit exhibited slower ripening than uncoated samples, as indicated by inhibited loss of firmness, organic acids, and antioxidant activity, as well as decreased respiratory rate, and a delayed increase in the level of ethylene, MDA, and sugar. In addition, 2% lacquer wax exerted the same effect as 3% chitosan did in delaying kiwifruit senescence. These results suggest that lacquer wax coating is an effective alternative for prolonging the postharvest life of kiwifruit.

Rice bran wax

Rice bran wax (RBW) is a secondary by-product separated from the rice bran oil during the process of refining. It has good applicability in the formation of lipid-based edible coatings, after refining and removal of crude resinous matter. Being a hydrophobic substance, it avoids moisture loss from the product during storage and protects the commodity from microbial infestation. The RBW-based coating could prevent moisture loss from FFVs, retard the rate of metabolic activities thus delay the ripening process by modifying the immediate environment of the product. Abhirami et al. (2020) examined the effect of RBW (5, 10, and 15% W/V) on shelf-life extension of tomato cv. Marutham CO3. Tomatoes of uniform colour (30-60% pink) and medium size were dipped 2-3 min in the respective coating solutions and stored at 32.7–34.4 °C and RH of 57.5- 88.3%. The results showed that 10% RBW emulsion effectively suppressed the rate of water loss, reduced the rate of deviation of TSS and fruit firmness from the initial values while reducing the rate of change of lycopene content compared to the uncoated fruit. RBW coating hindered the gas exchange recording a reduced rate of respiration compared to the uncoated tomatoes. Overall, the 10% RBW coated tomatoes had a shelf life of 27 days, compared to 18 days of the control samples.

Plant extracts, particularly essential oils offer great functionalities in biopolymer-based composites, for improving barrier properties as well as bioactivities such as antioxidation and antimicrobial properties. The following content describes the essential oils derived from wide range of plant materials and their efficacy in maintaining postharvest life of FFVs leading to loss reduction.

Olive oil

Dovale-Rosabal et al. (2015) evaluated the influence of chitosan-olive oil coatings (1% Ch+2% olive oil, 1% Ch+ 4% olive oil, 2% Ch+ 2% olive oil, 2% Ch+ 4% olive oil) on the quality of tomatoes cv. Charleston harvested at breaker stage. Coatings from chitosan-olive oil emulsion delayed the ripening and maintained the firmness of tomato cv. Charleston with respect to uncoated fruit, contributing to extend their shelf life during storage at ambient conditions (27±1 °C and 80% RH). However, the coating did not act as an effective barrier against weight loss as evidenced by higher weight losses of tomatoes coated with chitosan at 2% (w/v) with 2 and 4% (v/v) of olive oil.

Castro-Cegrí et al. (2023) studied dextrin (a natural polysaccharide obtained from potato starch) based edible coating enriched with oleuropein (major phenolic component in olive leaf extract) and olive oil on postharvest quality of Zucchini (*C. pepo* L. morphotype Zucchini). Freshly harvested fruits were dipped in dextrin (D), 1% (w/v) dextrin plus 0.3% (w/v) oleuropein (DO) and 1% (w/v) dextrin plus 0.2% (v/v) extra-virgin olive oil (DOO) for 5 min and then stored at 4 °C and 85–90% for 14 days. The application of dextrin coatings improved the storability of zucchini fruit at low temperature, maintaining fruit quality, increasing antioxidant defense, and diminishing oxidative stress. The addition of oleuropein and olive oil to the dextrin coating showed higher induction of antioxidant enzymes, and a greater accumulation of ascorbate and total phenolics.

Cinnamon essential oil

Cinnamon essential oil (CEO) is a yellow to reddish brown clear liquid with the unique pungent aroma of cinnamon. CEO has been proven to be an excellent antioxidant with broad-spectrum antimicrobial effect, with its main component being cinnamaldehyde. Use of CEO has been limited due to its instability and poor water solubility and prevalence of strong odours upon its application on FFVs.

CEO at concentrations of 1 and 2% and gum Arabic (GA) at concentrations of 5 and 10%, and the combination of GA and CEO for quality improvement of guava stored in cold storage (10 ± 1 °C, 90–95% RH) for 28 days were studied by Etemadipoor et al. (2019). The results showed that GA treatment enriched with CEO preserved color, firmness, chlorophylls, carotenoids and showed a slower rate of deviation of juice pH and soluble solids content. GA enriched with CEO maintained the qualitative characteristics of guava fruit by reducing the ripening rate. Ascorbic acid content decreased with a lower rate due to intensified antioxidant properties when enriched with CEO, which is rich in phenolic compounds such as transcinnamaldehyde. They observed that 10% GA enriched with 1% CEO showed more water vapor barrier suppressing weight loss more than other treatments and maintained the quality and storability of guava fruit.

Spearmint essential oil

Spearmint (*Mentha spicata*, Fam: Lamiaceae) EO are widely used in the food, cosmetic, confectionary, chewing gum, toothpaste, and pharmaceutical industries. It has been reported to be an effective antibacterial and antioxidant agent that inhibits the growth of spoilage microorganisms contributing to extending the shelf life of different foods. Shahbazi (2018) examined the effects of antimicrobial active packaging based on 1% CMC and 1% chitosan coatings containing two different concentrations of *M. spicata* EO (MSO 0.1 and 0.2%) on physicochemical (weight loss, titratable acidity and pH); microbial (total viable count, psychrotrophic bacteria, yeasts and molds); sensory (appearance, color, texture and overall acceptability) properties; and respiration rate of strawberries during storage under refrigerated condition (4 ± 1 °C). The treatment of fruits with chitosan + MSO 0.2% and CMC + MSO 0.2% resulted in the best microbial, physicochemical and organoleptic properties after 12 days storage. The final population of *Listeria monocytogenes* in treated samples was decreased by 3.92–3.69 compared to control groups.

Pomegranate seed oil

Pomegranate seed oil (PSO) contains high levels of antioxidant activity and has been shown to have an antimicrobial effect on gram-negative and gram-positive bacteria. Melikoğlu et al. (2022) studied the effect of CMC enriched with different concentrations (0.1, 1, 2, and 3%) of PSO on postharvest quality attributes of strawberry cv. Emiralem. The fruits were dipped in respective coating solutions for 1 min and stored in the refrigerator (5 ± 1°C, 50 ± 5% RH) for 16 days. The addition of PSO contributed significantly to the improvement of moisture barrier properties of CMC films. The 3% PSO-enriched CMC coating showed higher efficacy in preserving weight loss, color, pH, and total phenolic content of strawberry cv. Emiralem during the storage period.

Tea seed oil

Tea seed oil (TSO) is a natural oil extracted from seeds of tea tree (*Camellia sinensis*, Family: Theaceae). Research evidenced that it contains 19.88% oil which is composed of unsaturated fatty acids, (70% oleic acid, 10% linoleic acid), and high levels of antioxidants such as phenolics along with many vitamins and minerals. It is used for many purposes such as cooking, antioxidant agents, medicine or biodiesel. Tran et al. (2021) studied different concentrations of TSO (0.05, 0.25, and 0.5% w/v) in combination with 1% chitosan (CH) on postharvest quality of pears cv. Kosui dipped for 1 min and stored at 25 °C,85 ± 5% RH for 21 days. CH incorporated with TSO showed a downward trend in respiration rate and showed significant differences in some biochemical properties such as TSS, pH, and color. Adding TSO enhanced the antifungal ability both in vitro and invivo during the storage of pears inoculated with a spore suspension of *Botrytis cinerea*.

Citrus fruit peel oil (Citral)

Citral is a main component of citrus fruit peel oil. It is a mixture of neral and geranial which are monoterpene aldehydes. Citral has been applied to food, cosmetics, and beverages as a natural ingredient for its passionate lemon aroma and flavor. EOs, which present citral have been demonstrated to show antimicrobial, antifungal, and antiparasitic characteristics, accomplishing citral a natural preservative and potential candidate in edible coatings.

Guerreiro et al. (2015) studied the different concentrations of alginate-based edible coatings enriched with citral (Cit) and eugenol (Eug) on fruit of the strawberry tree (*Arbutus unedo* L.) for enhancing the postharvest quality, safety and shelf-life extension. Arbutus berries were dipped in different concentrations of alginate (1%), Cit (0.15 and 0.3%) and Eug (0.1 and 0.2%) alone or combined solutions for 2 min. Results showed that combined treatment of alginate 1% + Cit 0.15% + Eug 0.10% preserved sensory and nutritional attributes and reduced microbial spoilage of arbutus berries compared to the other treatments and the control samples stored at 0.5 ^oC.

Plant byproduct incorporated edible coatings

Pomegranate peel extracts

Pomegranate peel is considered an important source of phenolic compounds namely gallic acid, ellagic acid, punicalagin A, punicalagin B and other tannins. In the domain of plant-derived compounds with antimicrobial potential, pomegranate peel extract (PPE) has been extensively investigated for its free radical scavenging effect and strong antioxidant capacity caused by the high concentration of biologically active components. Kumar et al. (2021) studied the effect of chitosan–pullulan (50:50) composite edible coating enriched with PPE on postharvest physicochemical characteristics of Safeda mango at ambient (23 °C, RH-45%) and cold (4 °C, RH-95%) storage conditions for up to 18 days. The chitosan–pullulan composite edible coating enriched with 5% PPE recorded significant retention of postharvest characteristics such as color, TSS and TA along with reduced physiological loss in weight compared to the control. Incorporating PPE in edible coating formulation enhanced the phenolic, flavonoid contents and antioxidant activity of coated mango and extended the postharvest life by 9 days compared to the control.

Use of edible coatings namely chitosan (CH) and locust bean gum (LBG) incorporated with chemically characterized water PPE (WPPE) or methanol PPE (MPPE) to control the growth of *Penicillium digitatum (green mold)* of orange has been reported by Kharchoufi et al. (2018). The results proved that the addition of 0.361 g dry WPPE/mL, both to CH and LBG coatings, significantly reduced disease incidence by 49 and 28% respectively, with respect to the controls.

Apple peel polyphenols

Riaz et al. (2021) investigated the efficacy of chitosan (CH)-based apple peel polyphenols (APP) composite coatings to enhance the storage quality of strawberries (*Fragaria ananassa* cv Hongyan). Strawberries were coated with CH alone (0.0% APP), CH-APP1 (0.25% APP), CH-APP2 (0.50%), CH-APP3 (0.75%), CH-APP4 (1.0%). After dipping the strawberries in respective coating solutions for 30 s they were stored at 20°C, 35–40% RH. The results showed that CH-APP composite coatings inhibited the deterioration in total flavonoids and total anthocyanin while delayed fruit senescence. The weight loss and decay percentage were reduced to 10.91% and 19%, respectively, in the CH-APP4 treatment group. The highest value of TSS (6.8%) was observed in the CH-APP3 treatment group on the 6th day of storage. Coatings with CH-APP4 exhibited the maximum TA content (0.78 g/100 g) as compared to the CH only (0.68 g/100 g). The total phenol content was highest (1.3 mg/g) in the CH-APP2 treatment group at the end of storage.

Grape seed extracts

Grape seed is a byproduct of the juice or wine industry, and its extract has shown promising antioxidant and antimicrobial activities. It contains high amounts of polyphenols, quinones, flavonoids, catechin, epicatechin, gallic acid, proanthocyanidins, and alkaloids, which have increased its antimicrobial properties against both gram-negative and gram-positive bacteria by membrane-disruptive effects. Emamifar et al. (2019) studied the effect of salep gum (*Orchis mascula*, obtained from dried and milled tuberous wild orchids) solution (SS) and grape seed extract (GSE) based edible coating on shelf life of strawberry cv. Parous harvested at maturity stage of 80% red colour. Fruits were dipped in coating solutions of 1.5% SS incorporated with three concentrations of GSE (0.5%, 1.5% and 3%) for 5 min. After that fruits were stored at 1 °C, 95% RH and evaluated for treatment efficacy at 4-day intervals up to 20 days. SS along with GSE showed synergistic effects on the quality of strawberries. The best coating formulation for retarding the microbial growth of fresh strawberries during cold storage were 1.5% SS + 3% GSE that kept the microbial load of fresh strawberries below the limit of microbial shelf life (5 log CFU/g) up to 20 days. It is also reported the lowest weight loss and TSS, and the highest firmness, TA and ascorbic acid content compared to uncoated fruit up to 20 days of cold storage. Furthermore, as the concentration of GSE in the coating formulation increased (0.5 to 3% as examined in the study), anthocyanin, total phenolic contents, antioxidant activity and SOD activity increased while POD activity decreased compared to uncoated strawberries. Moreover, the sensory evaluation showed that 1.5% SS + 3% GSE increased shelf life of fresh strawberries up to 20 days without any negative effects on their sensory attributes.

Edible coating formulae with grape juice (GJ) and cross-linked maize starch (CLMS) enriched with three different doses of GSE (0.5, 1 and 1.5%) were examined for the postharvest quality attributes of strawberries during storage at 4 °C for 12 days (Yıldırım-Yalçın et al., 2022). With increased amount of GSE in the coating formulation, it caused a significant decrease in microbial counts and retarded the rate of firmness loss of treated strawberries. Formula containing GJ (16.15:83.85 of GJ: water volume ratio) and 1.5% GSE had the lowest ($p \leq 0.05$) total mesophilic aerobic bacteria counts and yeast/mold counts respectively. GSE enriched coatings significantly suppressed the rate of deviation of initial color, preserved ascorbic acid, total anthocyanin, total phenolic content, and antioxidant capacity of strawberries during storage. However, they have reported that high amounts of GSE coating decreased the sensory attributes of strawberries.

REGULATORY ASPECTS OF EDIBLE COATINGS

Edible films are regarded as intrinsic components of the food they contain hence, every single component that is utilized for making edible films must follow food safety and quality laws and regulations. According to European Union Regulation No. 1935/2004, all food-contact ingredients and commodities must fulfil the four fundamental standards: (a) they must be made in accordance with excellent manufacturing practices; (b) they must not alter the food's color, odor, taste, or texture; (c) the material must not have an adverse effect on the composition of food, and (d) it must not endanger to human health (Armghan Khalid et al., 2022).

Each country has its own requirements regarding the permitted additives (ED, 1995, USDA—U. S. Food and Drug Administration, 2006). According to the US requirements, organic acids—acetic, lactic, citric, malic, propionic, tartaric, and their salts—are accepted as safe and applicable for general use. On the other hand, most of the essential oils used in the food, pharmaceutical, and cosmetic industries are also classified as safe and approved for use as food additives. In Sri Lanka, it's mandatory to comply with the Food Act No.26 of 1980 and should be adhered to the amendments made recently such as Food (Additives - General) Regulations 2019 and Food (Preservatives) Regulation, 2019.

CONCLUSION

The scanning of literature published during the last decade in the domain of PBECs showed that a wide range of compounds have been researched commencing from starches, proteins, lipids, gums & waxes, plant leaf extracts, essential oils, byproducts of plant processing industries. Use of PBECs in preserving quality and shelf life of harvested FFVs showed positive impact on retardation of rates of respiration, ethylene emission, physiological weight loss, colour degradation of which controlling the said properties are imperative in extending the shelf life of fresh produce. Further, due to high occurrence of antioxidant properties, PBECs have contributed to increased antioxidant defense system by upregulating enzymes (SOD, CAT, POD) involved in ROS scavenging mechanism resulting in reduced electrolyte leakage and MDA content and alleviated chilling injury. Plant based active ingredients suppressed the cell wall degrading enzymes such as PME, PGU and cellulase maintaining cellular membrane integrity. The influence on aforesaid properties resulted in maintaining fruit firmness for an extended period along with internal biochemical quality attributes and sensorial properties. Moreover, by reducing the rate of degradation of phenolic, flavonoids and ascorbic acid contents of treated FFVs PBECs have shown promising results in suppressing the growth of decay causing organisms of which one of the major causes of postharvest losses.

The key innovative areas in the field include (i) development of composite coatings to enrich functional properties to the FFVs for the benefit of consumers (ii) overcoming limitations such as altering flavor of the food items when coated, (iii) minimize susceptibility to degradation of their properties upon exposure to light, oxygen and high temperature, (iv) increase effectiveness with sustained release of active substances and (v) effective stabilization of the developed emulsion excluding hazardous emulsification agents which have been achieved by means of formulating them as hydrocolloid bio-composites. Moreover, preparation of edible coating formulations in powdered form instead of liquid form by freeze or spray drying techniques have been investigated which aid in preserving their properties for an extended period while providing a convenient way of use, ease of storage and transportation due to the weight and volume reduction.

FUTURE TRENDS

The key problem which requires future study is extending the storage life of FFVs without compromising their sensory and nutritional properties. Several researches including innovative and cost-effective food packaging for fresh produce are still at the early phase of study and at inquiry phase prior to large-scale industrial implementation. The formation of innovative edible coating materials is predicted to come from a detailed examination of biochemistry and its relationships with antimicrobial, physicochemical, and possible toxicity, as well as risk assessment. Primarily, more advancement is needed in terms of coating materials, particularly in terms of nutritional value, mineral migration and efficiency, ratio of cost-effectiveness, and current technological protocols to ensure and enhance storage life and preserve the quality of coated FFVs.

Conflict of interest
The authors have no conflict of interest in reporting.

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