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REVIEW

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Edible Coatings: An Innovative Green Technology for Quality Maintenance of Fresh Cut Fruits and Vegetables

Pooja Nikhanj*, Juhi Kumari and Priyanka Jindal
Department of Microbiology, Punjab Agricultural University Ludhiana-141004, Punjab, India
*Correspondence for materials should be addressed to PN (email: poojanikhanj.217@gmail.com)

Abstract
Fresh produce is considered as highly beneficial for human health. Post harvest losses and improper storage cause quality related issues. Factors like dehydration, browning, microbial growth, firmness loss, etc contribute to quality loss of fresh-cut fruit. Hence, there are technologies developed to reduce like modified atmospheric packaging, disinfectant washing, and edible coatings have been used to prevent post-harvest losses for quality loss prevention. The use of edible coatings is an area of focus in food industries. Edible coatings have gained considerable attention due to their ability to extend fruit and vegetables shelf life. These coatings are a novel type of primary packaging made up of polysaccharides, proteins, lipids or mixture of these types. They are known to improve quality and appearance of fresh products by decreasing aroma loss and by maintaining its structural integrity. Active coatings can carry supplementary ingredients like antimicrobials, antioxidants, antibrowning agents, texture enhancers, etc which has promising potential for shelf life extension. Information about various types of coatings will help the food processors to identify the most effective formulations to be used for preservation. It is very important to monitor consumer preferences towards the coated products to increase the acceptability of coated fruits and vegetables. This review summarizes the advantages of edible coatings with their types, applying methods and their effect on physicochemical and microbiological and sensorial properties of fresh cut fruits and vegetables.

Keywords: Edible coatings; Fresh-cut; Microbiological; Postharvest management; Quality improvement

Introduction
Fruit is an integral part of our daily diet and is increasingly in demand. They are considered a good source of vitamins, minerals, flavonoids, antioxidants, fiber and flavor. Fruit consumption has been linked to reduced cardiovascular disease and attrition. India ranks second after China in terms of fruit production, with a production area of 6,648 (thousand hectares) and an output of 98,579 (thousand tons). Today, pre-cut fresh fruits are in high demand among consumers because they are ready-to-eat, fresh and nutritious. The International Fresh-Cut Farmers Association (IFPA) develops nutritious products by cutting, peeling, and trimming fresh fruit into 100% usable products, which are then packaged and marketed for consumers. Prolonging shelf life and conserving freshly sliced produce has remained a significant concern since it became accessible to consumers in the 1940s. The primary factors that greatly impact the quality of recently cut products include the kind of utensils used, the surface and size of the slices, the type of water used to rinse the product, handling and storage conditions such as moisture, packaging, temperature, hygienic conditions. Wilting, shriveling, over-ripeness, chilling injury, and loss of texture are some indications of postharvest decay, which are caused by excessive water loss. Reduced postharvest losses, particularly in impoverished nations, could be a long-term solution for increasing food supply, reducing reliance on natural resources, improving livelihoods, and eliminating hunger (Nikhanj, 2023). Freshly sliced fruit should be preserved to decrease respiration rate, surface damage, browning, and extend shelf

life. The exposed surface creates ideal conditions for microbial colonization due to increased fruit moisture as well as dissolved oxygen on the fruit surface. Various preservation methods include edible coatings, modified atmosphere packaging to maintain the desired gas concentration around the freshly sliced surface, and controlled atmospheres to prevent fruit softening, various chemical treatments, such as calcium soaking. Cold storage can alleviate undesirable changes caused by gamma irradiation, such as increased microbial growth, water drying, and fruit discoloration. The coating is considered one of the safest techniques and is of interest in the food industry (Mantilla et al., 2013).

Minimally processed fruits

Fruits and vegetables are a crucial component of our everyday nourishment and are in high demand. Prominent attributes that enhance the marketability of fresh produce include visual appeal, consistency, flavor, nutritional worth, and microbial safety. The issue of fruit decay after harvest is a significant concern, as it swiftly declines during the processes of handling, transportation, and storage conditions (Dizon et al., 2019).

Factors affecting fruit quality

Major causes of freshly cut fruit deterioration include microbial growth, rapid spoilage rates, and dehydration. Three main factors contribute to the deterioration of freshly cut fruit: physical, biochemical, and microbial as follows:

Physical factors

Because of the exposed surface of the fruit following the trimming process, relatively low humidity causes substantial water loss, dehydration and respiration. Freshly cut fruit becomes wilted and discolored as a result of moisture loss and over ethylene production cause loss of texture over the storage period.

Biochemical factors

During cleavage, the enzyme is released forever. The release of polyphenol oxidase is frequently responsible for browning. During storage, the activity of this enzyme is influenced by the grade of the fruit, temperature, pH, and a range of other factors (Shekhari et al., 2021). It is well known that increased ethylene production softens newly sliced tissue (Musacchi and Serra, 2018). Freshly cut fruit may have a higher total soluble solid content due to a faster rate of polysaccharide breakdown to monosaccharides. Coated samples, on the other hand, have a little increase in total soluble solids values (Li et al., 2017; Diaz et al., 2023; Sariful and Fazlul, 2020) discovered comparable results when applying an edible coating on freshly cut kiwifruit.

Microbial factors

Bacteria most commonly found on freshly cut surfaces include *Salmonella sp., Listeria monocytogenes, Campylobacter sp., Cryptospiridium sp.,* and. *Pseudomonas graminis* isolated from the entire apple surface was effective in reducing *E. coli O157* H7 (Tiwari and Singh, 2017; Chein et al., 2019) Chitosan also has a bactericidal action against gray mold and blue mold on tomatoes (Resende et al., 2018).

Approaches for quality improvement of fresh cuts

Disinfection treatments, modified atmospheric packaging (MAP) to maintain gas concentration surrounding cut surface, controlled atmosphere to delay softening, low-temperature storage, and use of radiations were known to reduce harmful changes in fresh-cut fruits and vegetables such as colour loss, microbial growth, and dehydration (Liu and Kerry, 2006).

Pre-disinfectant treatment

The application of germicides and sanitizers like chlorine, peroxyacetic acid, hydrogen peroxide, sodium chloride, and ozone has the potential to decrease the amount of microbes on freshly prepared produce by around 1-2 logarithmic units (Panahirad et al., 2021). Germicides like peroxyacetic acid, chlorine, ozone, hydrogen peroxide, and sodium hypochlorite are capable of diminishing the initial quantity of microorganisms found on newly harvested vegetables by 1-2 logarithmic units.

Edible coatings

Edible coating is one of the techniques used after harvesting to enhance the shelf life and quality of fruits. These coatings are safe to eat along with the product and do not have any negative effects on the food. Since the coating acts as a barrier, it can effectively simplify the process compared to traditional packaging materials that are not eco-friendly, and may be used as a substitute for synthetic polymer materials. Hydrocolloids (proteins, polysaccharides, alginates, etc.), lipids (fatty acids, acylglycerols, waxes, etc.) and derived compounds are some of the other substances added to different edible coatings for various purposes. Other compounds added to various edible coatings for various purposes are described below:

Anti-browning and discoloration

By preserving colour and a shiny water surface, edible coatings often avoid browning and improve fruit attractiveness. A recently cut apple cv. with Aloe vera coating at 75% concentration demonstrated the lowest tanning values after 6 days of storage at 41°C (Maringgal et al., 2019; Thakur et al., 2018). Non-enzymatic and enzymatic reactions, as well as degradation everything from chlorophyll to pheophytin is included. The lower results could possibly be ascribed to the slower change in colour development during storage of coated fruit. The respiratory rate slowed the synthesis of ethylene. This finding is comparable to one made in another study, which discovered that a rice starch-carrageenan coating coated with sucrose was effective in altering the environment for bananas, resulting in slow changes in the fruit's skin colour (Roy et al., 2020).

Aloe vera

Polysaccharides, carbohydrates, minerals, proteins, vitamins, and a trace of fat are abundant in aloe vera gel. It has been widely used in the medical profession to boost the human immune system due to its antiviral, wound healing, antidiabetic, and anticancer qualities. Aloe vera has no smell. The phenolic components were maintained using an aloe vera gel coating supplemented with ascorbic acid, calcium lactate, and cinnamon essential oil. Consumable aloe vera gel applied to consumable grapes minimizes bulk and moisture loss during storage by lowering respiratory rate and minimizing sunburn effects. In tomatoes maintained at 11°C and 90% relative humidity, an edible covering of aloe vera gel containing sage essential oil prevented deterioration (Priya et al., 2023). Aloe vera gel containing neem extract and citric acid was applied to tomatoes to preserve fruit ripeness and quality after 36 days of storage.

Modified atmospheric packaging

Modified atmospheric packaging is the practice of modifying the composition of the inner environment to improve the shelf life of fresh-cut fruit. The fundamental purpose of modified atmospheric packing is to achieve the best possible balance of oxygen and carbon dioxide gases in the container as quickly as feasible. MAP is currently widely used for minimally processed fresh-cut fruit products.

Edible coatings as most proficient postharvest management technique

The edible coating is defined as a coating that can successfully reduce the rate of decay while extending the shelf life of fresh-cut fruit without causing anaerobiosis. Edible coatings are a thin layer of edible substance applied to the surface in addition to or instead of natural coatings to prevent solute mobility, oxygen, or moisture. It is thought to be a safe and convenient method of increasing the shelf life of fresh-cut fruits (Milani et al., 2020).They are non-toxic to mammalian cells, exhibit antibacterial activity, and help to preserve bioactive molecules (Paidari et al., 2020).

Characteristics of an ideal edible coating

The requirements of an ideal edible coating should be like able to improve appearance, odorless, colorless, and tasteless, not interfere with the oxygen and carbon dioxide levels of the commodity, forecast water resistance ability by remaining intact over the fruit when applied over the commodity, to carry active agents like antimicrobial substances, vitamins, and antioxidants.

Various methods for applying coatings

The various methods of applying an edible coating on fruit **(Fig. 1)** can be Spraying, Dipping, Panning, Solvent casting or Brushing. Out of the following methods, dipping methods are used widely for applying edible coatings on fruits. Use of the extrusion method is the best technique for applying an edible coating for industrial purposes. Other coating methods are equally desirable where considerable amounts of fruits and vegetables are coated. Tropical fruit such as carambolas and pineapples are dipped because thicker applications of the coating are required.

Effect of edible coatings on fresh cut fruits and vegetables

The fruit will continue to consume all available oxygen and release carbon dioxide, but the covering will make replacement impossible. As a result, it will enter partial anaerobic respiration, which uses less oxygen. Because there is less oxygen, ethylene synthesis slows and water loss decreases. As a result, the covered fruit will remain fresh, firm, and nutritious for longer. The internal environment (levels of carbon dioxide and oxygen) will be completely altered based on the type and amount of coating used.

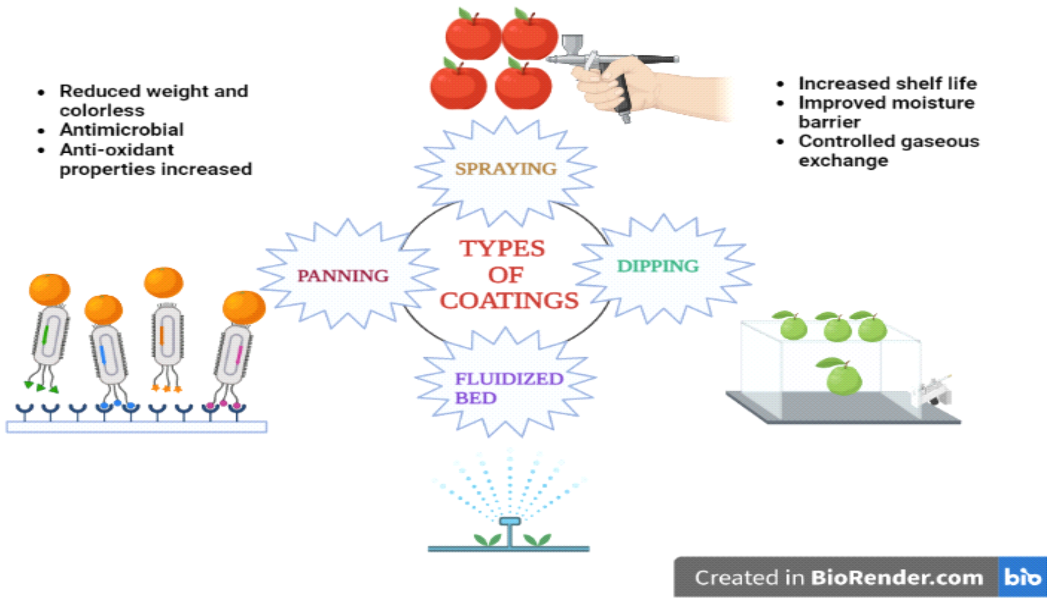

Fig. 1. Different application methods of coatings over fruits and vegetables

Advantages of using edible coatings

Edible coating can be used because these can be safely consumed along with the product. These have the ability to carry active ingredients like vitamins, flavors, antioxidants, antimicrobial agents, etc. These also act as a barrier against the gas exchange. These eliminates the use of polymer packaging and wastage leading to environmental pollution.

Organic acids, fatty acid esters, polypeptides, plant essential oils, nitrates, and sulfites are antimicrobial agents that can be applied to coatings. Nanoparticles mixtures with packaging materials have antibacterial properties that may increase the shelf life of some items (Asl et al., 2020). Organic acids such as acetic acid, benzoic acid, lactic acid, and sorbic acid are protonated acids that are membrane soluble and quickly diffuse into the cytoplasm.The use of essential oils is still restricted because essential oils may have an effect on the organoleptic qualities of the fruit and may interact with its components.

Classification of edible coatings

There are numerous materials on the market that can be used to generate edible coating. Polysaccharides, lipids, protein, and edible coating composites are the main ingredients used in coating formulations (Fig. 2).

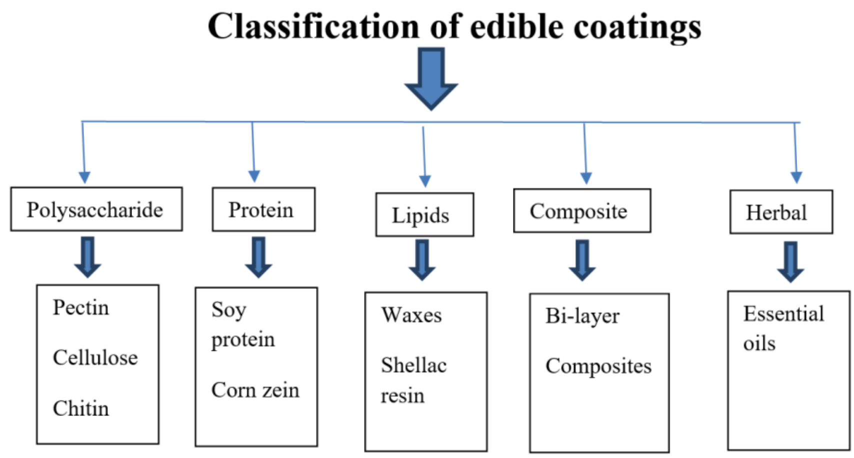

Fig. 2. Classification of edible coatings

Polysaccharide based coatings

Polysaccharides are extended-chain polymeric carbohydrates composed of monosaccharide units joined by glycosidic connections. Coatings derived from polysaccharides can impact the atmospheric conditions surrounding fruits, resulting in reduced respiration rates. The gas barrier properties of polysaccharide-based coatings are widely acknowledged. These coatings possess favorable physical attributes and can enhance the texture, compactness, and adhesiveness of coating formulations.

Cellulose derivatives

Cellulose is a polysaccharide composed of hundreds to thousands of linear chains of beta-linked D-glucose units. Cellulose is the fundamental structural component of plant cell walls. As coatings, cellulose derivatives such as methylcellulose, hydroxypropylmethyl cellulose, and carboxymethyl cellulose are commonly used. Methylcellulose, one of the least hydrophilic cellulose esters, is stable over a wide pH range (2-11). It has excellent barrier properties and is extremely soluble.

Derivatives based on starch

Starch is described as a complex carbohydrate made up of glucose units connected by α-1,4 bonds. The coating made from starch is safe, without odor, color, or taste. It allows some gases, like oxygen and carbon dioxide, to pass through. Plasticizers like water and glycerin are added to make starch into a coating that can be eaten (Garcia et al., 2010). Adding edible cassava starch coating with the plasticizer potassium sorbate improves the resistance to water vapor and slows down the process of respiration in strawberry fruit, leading to better quality during storage. It has been discovered that using a starch-based edible coating can extend the shelf life of mango fruit by as much as 15 days (Hernandez et al., 2020).

Alginate

Alginates are alginic acid salts and derivatives. Alginic acid is made up of D-mannuronic acid and L-guluronic acid and has a high molecular weight. The concentration of D-mannuronic acid and L-glucuronic acid in alginate varies substantially depending on the algae species used (Krasniewska et al., 2014). The ability of alginate coating to enhance the shelf life of freshly cut 'gara' apples without causing anaerobicity.

Chitosan based derivatives

Chitosan is a polysaccharide that is made up of N-acetyl-D-Glucosamine and beta-linked D-Glucosamine. Unlike starch, chitosan possesses good barrier properties without the addition of any plasticizers or antioxidants. Chitosan is known for its ability to generate smooth, glossy coatings with little surface breaking. Chitosan-based coatings enhanced the refrigerator shelf life of fresh cut guava and papaya by up to 12-13 days (Kumari and Nikhanj, 2023). It also inhibits fungal growth and phytopathogens. The results demonstrated that adding a chitosan-based coating (1-2% w/v) to fresh-cut mushrooms, cucumbers, carrots, guava, papaya could extend their shelf life while keeping their quality and, to some extent, limiting degradation (Kumari and Nikhanj, 2022).

Pectin based derivatives

Pectin is a heteropolysaccharide that is found in plant intermediate layers and cell walls. Galacturonic acid, a sugar acid comprised of galactose, is its primary constituent. Pectin is a great edible covering for low-water fruits. Methoxyl Rich Pectin is a type of pectic chemical that is widely utilized to make better coatings (Khan et al., 2019).

Carrageenan based derivatives

Carrageenan is the general term for a group of water-soluble sulfated galactans obtained from the red algae. Carrageenan coatings create a solid three-dimensional network of coatings after the solvent evaporates. Furcellaran is considered to be a variant of κ-carrageenan, but it possesses a distinct type of repetitive polysaccharide structure.Carrageenan-based coatings may have a novel application as carriers for antimicrobial agents. The application of a carrageenan-based coating on freshly sliced grapefruits resulted in reduced shrinkage, undesirable flavors, and leakage after two weeks of storage at 4°C.

Protein-based coating

Protein-based coatings are products obtained from flora and fauna. Plant proteins include dairy protein, casein, zein, gluten, whey protein, soy protein, and others. Animal proteins consist of egg albumin and collagen. Protein-based coverings provide excellent preservation of taste and enhanced physical characteristics, but they do not impede moisture transfer. Due to their hydrophilic nature, proteins are not as effective at preventing the passage of oxygen.

Casein

Casein is a type of phosphoprotein commonly found in mammalian milk. Caseinate is considered the most prevalent form of casein. Casein is utilized as an edible covering for fresh produce to enhance their quality, similar to cellulose and pectin-based coatings. Casein possesses exceptional emulsifying properties, which effectively safeguards the fruit from environmental factors. It was observed that coating kinnow fruit with casein and storing it in high-density polyethylene bags extended its shelf life by 20 days. Recent research indicates that casein protein-based thermoplastics and composites may serve as viable alternatives to biodegradable polymers for biomedical applications.

Whey protein

Whey is a protein derived from the liquid part of milk that is left over after cheese production. It is a combination of alpha-lactalbumin, beta-lactalbumin, and serum albumin. These coverings are recognized as carriers that can release insect pheromones in a controlled manner.Applying them to peanuts has been demonstrated to decrease the development of rancidity and enhance the shine of the surface. Additionally, these coverings have been proven to reduce enzymatic browning in freshly cut apples and potatoes.

Zein

Zein is a protein derived from corn. It is one of the main storage proteins of corn. It is known to possess adhesive and binding characteristics. Coatings made from zein can effectively maintain firmness and prevent loss of weight, thereby increasing the shelf life of fruits. It exhibits exceptional moisture barrier properties when compared to other edible coatings. These findings showed that hydrophobic interactions were important in the production of zein coatings and that disulfide bonding may be responsible for the structural stability of zein protein molecules during coating formation. Because of zein's low oxygen permeability and grease resistance, recyclable coated paper has been developed.

Herbal coatings

It is one of the most recent techniques in the food industry. These coverings are created by utilizing either spices only or by utilizing the combination of other eatable coatings with the spices. Aloe vera gel, rosemary, neem, tulsi, turmeric, lemongrass is widely utilized for this purpose. Spices are known to possess antimicrobial and good gas barrier properties. Oils extracted from spices such as clove oils, mint oil, ginger oil, and other oils are also utilized for formulating coating.They are advantageous for health as they have nutraceutical properties since they are known to carry vitamins, essential minerals, and antioxidants.

Edible Films and Coatings with Functional Additives

The next steps in this field are strongly represented by research focused on improving the effect of edible films based on a polysaccharide matrix by adding functional ingredients. Plasticizers are added to the coating to increase flexibility and prevent blistering, chipping and cracking of the coating. Emulsifiers and surfactants added to improve coating adhesion. Antioxidants to the coating matrix to prevent oxidative spoilage, deterioration and discoloration.

These functional compounds are now recognized as key ingredients in edible films/coatings for extending the shelf life of fruits and vegetables have been started. Two functional compounds (vanillin and trans-cinnamaldehyde) were conjugated to chitosan (polysaccharide matrix) by Schiff base reaction and reductive amination. To test the antibacterial effect, mandarin orange juice was added to a mixture of chitosan, vanillin and trans-cinnamaldehyde.

Characteristics of coated fruits

Generally, sensory, nutritional, and safety aspects are taken into consideration while evaluating the quality of coated fresh-cut fruits (Leena et al., 2020).

Sensory value

The sensory element evaluates factors such as appearance, flavour, colour, and texture. The appearance of the goods has no bearing on the consumer's decision to purchase it. If necessary, anti-browning compounds are included into the edible coating to avoid the browning of fresh-cut fruits.

Nutritional value

Fruits with low nutritional value might be coated with vitamin, fatty acid, and mineral compositions to increase their nutritional worth. The capacity of milk protein-based coatings to carry large amounts of calcium (5% w/v) and vitamin E (0.1% w/v) was reported.Minerals (5% w/v zinc lactate) added to chitosan-based coatings may increase the coating's water barrier function (Mei and Zhao, 2012).

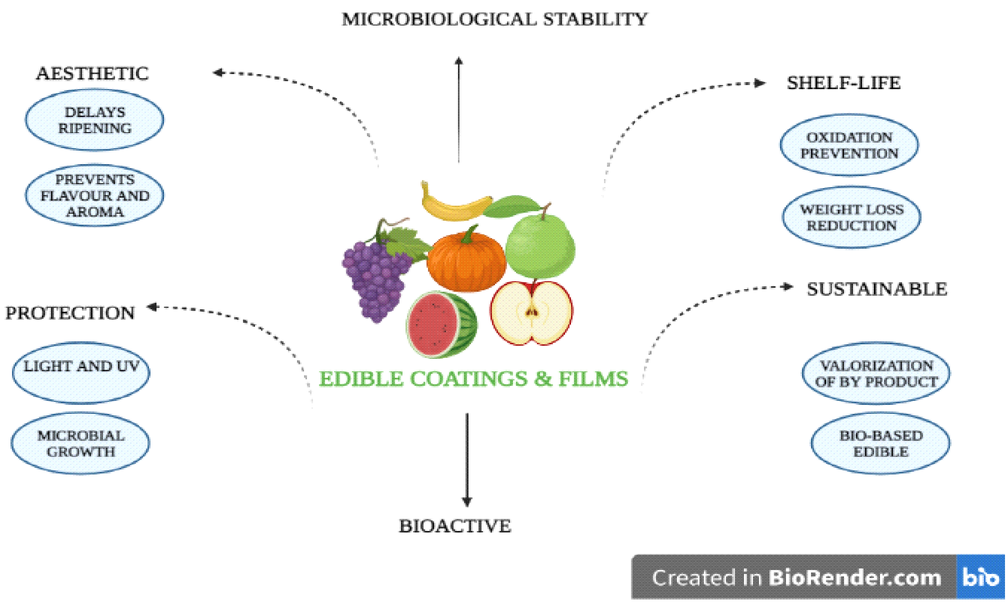

Fig. 3. Effect of edible coatings on physicochemical and microbiological maintenance of fresh cut fruits and vegetables

Conclusion

The idea of applying an edible coating to fresh-cut fruit is an intriguing technique to create packaging material that can extend the shelf life of fresh-cut fruit. Because of differences in the intrinsic properties of the fruits, coatings produced for one fruit may not be suited for the other. Few research has been published on the application of an antimicrobial edible coating to fresh-cut horticultural products, which has the potential to become an emerging concept in horticulture technology that can meet customer demand for safe and natural products.

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PN, JK and PJ conceived the concept, wrote and approved the manuscript.

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