The Pharma Innovation Journal 2023; 12(6): 3992-4002

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(6): 3992-4002

www.thepharmajournal.com
Received: 17-04-2023
Accepted: 21-05-2023

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Edible coatings for improving the storability of fresh fruits and vegetables: A review

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Abstract
Fruits and vegetables are highly perishable commodities because of their high metabolic rates, loss of moisture, and susceptibility to diseases. As a result, the transportation and handling of horticultural goods result in considerable losses every year. Several pre-harvest, as well as post-harvest techniques, are available to reduce these losses. Among them, using edible coatings is an essential means to improve the shelf life of commodities. Edible coatings offer fresh produce, an additional layer of protection and have the same effect as modified atmospheric storage in terms of altering the internal gas composition. The management of internal gas composition is absolutely necessary for the effectiveness of edible coatings for fresh produce. The development of coatings with certain characteristics like enhanced performance due to the addition of specific texture enhancers, antimicrobials and nutraceuticals represents a paradigm change. By adding active chemicals to the polymer matrix of active edible coatings, which can be digested along with the food and improve safety, nutritional value, and sensory qualities, the keeping quality of the produce can be extended in a novel way. The smart edible packaging, on the other hand, uses immobilised antimicrobial nanoparticles that are put to the food surface to manage the release of active chemicals that prolong the storability. This review covers the properties of edible coatings and their mechanism of action, recent advances in the development of these coatings with the objective of maximising quality and storability of produce pointing towards a prospective view and future applications.

Keywords: Edible coatings, sensory qualities, metabolic, storability, nutraceuticals, anti-microbials

Introduction

Nutrients needed to maintain bodily health can be found in abundance in fruits and vegetables. However, they are highly perishable commodity as they contain 80 - 90% of water by weight coupled with high metabolic activity, susceptibility to pathogens and water loss. These variables impact its commercialisation resulting in significant financial loss. Every year major losses in terms of quantity and quality of fruits and vegetables are attributed to the post-harvest activities like handling, transportation, and storage (Gutiérrez *et al*., 2016) [39]. The horticultural produce is perishable in nature and are prone to softening, shrinkage, colour changes during handling and storage. The storability and shelf life of this fresh produce can be extended by controlling the respiration of these living tissues. However, a certain level of respiration activity is required to prevent the tissues from decaying and senescing (Brecht *et al*., 2004) [18]. To lessen these losses, numerous pre- and post-harvest treatments are available. The application of edible coatings is one of the most important ways to improve the product's storability. Edible coatings have gained prominence among the various methods for extending the shelf life of fresh fruits and vegetables because they are simple to use and may be made to have any desired functional property.

The edible coatings offer a more environmentally conscious, greener approach for reducing losses after harvest. To reduce the alterations brought on by biochemical reactions, edible materials with acceptable moisture and gas barrier characteristics are applied as a thin coating on the product's surface. These coatings can be applied by dipping, spraying, or brushing on the commodity (Guilbert *et al*., 1996; Krochta and Mulder-Johnston, 1997; McHugh and Senesi, 2000) [36, 52, 64] thereby creating a modified micro-environment. The coatings provide a modified environment that acts as a barrier to oxygen, moisture, and the movement of solutes and adheres to the surface of fruits and vegetables (Gutiérrez and Álvarez, 2017; Tapia-Blácido *et al*., 2018) [40, 99].

What are edible coatings?

An edible coating is created when a thin layer of an edible substance is applied to the surface of unprocessed or minimally processed fruits and vegetables to create a barrier of protection (Guilbert, 1986) [35]. They are added as a replacement to the naturally occurring protective waxy coatings in order to create a barrier for oxygen, moisture, and movement of solute (Smith *et al*., 1987; Nisperos-Carriedo *et al*., 1992b; Baldwin, 1994; Guilbert *et al*., 1996; Lerdthanangkul and Krochta, 1996; Avena-Bustillos *et al*., 1997; McHugh and Senesi, 2000) [92, 74, 11, 36, 9, 64]. An ideal edible coating is one that can increase the shelf life of fresh produce without resulting in anaerobiosis and that minimises decay without lowering the quality of the produce. Since the edible films and coatings will be consumed, the material used for their preparation should be generally regarded as safe (GRAS) (Park *et al*., 1994; Krochta and Mulder-Johnston, 1997) [78, 52] certified by the FDA and must comply with the rules that are relevant to the concerned commodity (Guilbert *et al*., 1996) [36]. Formerly, edible coatings were majorly utilised to prevent loss of water. However, a wider spectrum of permeability qualities in edible coatings has recently been developed, expanding the possibility for fresh produce use (Avena-Bustillos *et al*., 1994; Park *et al*., 1994) [8, 78].

Historical view of edible coatings

Since ancient times, edible coatings have been widely used to prolong the shelf life of products, enhance food appearance, and prevent loss of moisture. The first edible coating used on fruits was wax by dipping method which was quite popular since the beginning of the 12th century (Krochta and Mulder-Johnston, 1997) [52]. During the 12th and 13th centuries, the Chinese wax-coated oranges and lemons (Hardenburg, 1967) [47]. Although they were unaware that the primary purpose of edible coatings was to slow down the respiratory exchange of gases, they discovered that fruits with wax coatings were able to be stored for a longer period than fruits without wax coatings. In Asia, during the 15th century, a protein-based edible coating known as "Yuba" was ordinarily employed to enhance the visual appeal and preservation of particular food items (Gennadios *et al*., 1993) [34].

During the nineteenth century, sucrose was used as an edible protective coating to prevent dried nuts from oxidising and becoming rancid during storage. Later, hot-melted paraffin waxes became available commercially in the 1930s as edible coatings for fruits like apples and pears (Park, 1999) [77]. In 1982, a new edible coating was reported to be effective in preserving fruits and vegetables and was tasteless, odourless and non-phytotoxic in nature. This coating material is a blend of SFAE i.e., sucrose fatty acid esters, mono- and di-glycerides and sodium carboxymethyl cellulose. SFAE was first created as an emulsifier. However, it has been scientifically proven that a coating of SFAE will delay the fruit ripening process. Since the 1980s, SFAE formulations have been sold commercially as fruit and vegetable coatings under the trade names "Semperfresh" and "TAL Pro-long" (Banks, 1984; Smith and Stow, 1984; Chu, 1986; Santerre *et al*., 1989; Lau and Meheriuk, 1994; Park *et al*., 1996, Dhall, 2013) [15, 91, 21, 87, 54, 79, 26]. Zein proteins were used to coat the surface of fruits and vegetables such as tomatoes to retain the fruit firmness during storage and delay change in colour and weight loss (Park *et al*., 1994) [78]. The most significant usage of edible coatings to date is the application of an emulsion of oil and waxes in water to fruits and vegetables to prevent moisture loss, enhance their colour and gloss, and delay the softening and onset of mealiness (Debeaufort *et al*., 1998) [24].

Properties of edible coatings

Edible coating characteristics are mostly influenced by molecular structure rather than molecule size and chemical composition. Not all materials can be employed for coating purposes. There are certain specifications for edible films and coatings such as (Arvanitoyannis and Gorris, 1999) [6]:

- It should not affect the quality and flavour of fruits and vegetables and not impart any undesirable or offensive aroma.
- The coating must be water-resistant in order to stay in place after application and completely covers the product.
- It should not reduce oxygen levels or produce too much carbon dioxide. To prevent a switch from aerobic to anaerobic respiration, the region around a commodity must have a minimum of 1-3% oxygen.
- It should convey volatile taste compounds, maintain structural integrity, improve mechanical handling properties, and be aesthetically pleasing. It should also contain active elements like vitamins and antioxidants.
- It ought to lessen the permeability of water vapour.
- It should be non-sticky and easily emulsifiable. It should also be non-tacky and able to perform efficiently after drying.
- Coating should be able to be dissolved in all kinds of solvents like water, alcohol or mixture of various solvents.
- It should be cost-effective and have low viscosity.
- The coating material ought to be transparent to opaque, but not like glass, and capable of withstanding light pressure.
- Above 40 °C, it should melt without decomposing.

Fruits and vegetables that are to be coated

It is significant to notice that not all fruits and vegetables have edible coatings on them. It can be used on both whole and freshly cut fruits and vegetables. Freshly cut commodities are extremely perishable, mostly because their skin, which is the natural protective layer, is removed and because of the physical strain which is imposed on them while cutting, peeling, shredding, slicing, coring, trimming, etc. (Dhall, 2013) [26].

Following is the list of whole and fresh-cut fruits and vegetables that are coated

	Fruits	Vegetables
Whole	Orange, lime, lemon, kinnow, grapefruit, apple, peach, passion fruit, avocado	Tomato, bell pepper, cucumber, melons
Freshly-cut	Fresh-cut apple, fresh-cut peach, fresh-cut pear	Fresh-cut potato, fresh-cut tomato slices, minimally processed onion, minimally processed carrot, fresh-cut cabbage, fresh-cut lettuce, fresh-cut cantaloupe and muskmelon

Composition of edible coatings

Edible coatings are recognised to enhance food quality because they act as selective barriers to uptake of oxygen, moisture transfer, and the loss of volatile tastes and aromas. Analysing the water vapour properties of edible coatings has enabled researchers to learn a great deal about their moisture barrier qualities because water plays a crucial role in food deteriorating processes. However, the key factor affecting the barrier qualities of edible coatings is the source material from which it is mainly derived. Majority of the edible coatings are made from naturally occurring polymers with the potential to form films, such as proteins, lipids, and polysaccharides (Álvarez *et al*., 2017) [3].

Film-forming substances are used to produce edible coatings. It includes polysaccharides such as starch, cellulose, chitin, chitosan (Cs), pectins, alginates etc., proteins namely whey protein, casein, collagen, keratin, gelatin, soy protein, corn-zein, wheat gluten, peanut protein, cottonseed protein etc., and lipids such as wax and oil-based coatings, fatty acid resins and emulsions, monoglycerides etc. (Gennadios *et al*., 1994; Gutiérrez and Alvarez, 2017c; Gutiérrez, 2018b; Merino *et al*., 2019) [33, 41, 38, 67]. While manufacturing edible coatings, the film materials are dispersed and dissolved in solvents like water, alcohol or a mixture of both, or a mixture of various other solvents. In this technique, plasticizers, antimicrobials, vitamins, minerals, colours, or flavours may be added. For a particular polymer, the pH may be changed and/or the solutions heated to aid in dispersion. After casting and drying the film solution at a suitable temperature and humidity levels, freestanding films are produced. There are numerous ways to apply the film solutions on food, including dipping, brushing, spraying, and panning, followed by drying (Donhowe and Fennema, 1993; Park *et al*., 1994; Guilbert *et al*., 1996; Li and Barth, 1998; Arvanitoyannis and Gorris, 1999) [28, 78, 36, 57, 6]. However, polysaccharides, proteins and lipids cannot offer the desired protection singly and hence, are used in combinations for greater results (McHugh *et al*., 1994; Guilbert *et al*., 1996) [65, 36].

Action of edible coatings

Even after being harvested, fruits and vegetables continue to respire, consuming all the oxygen present which is not replaced as quickly due to edible covering. This causes carbon dioxide to build up inside the produce because it cannot easily exit via coating. The fruit and vegetable ultimately switch to partial anaerobic respiration, which uses less oxygen about 1-3% (Park *et al*., 1994; Guilbert *et al*., 1996; McHugh and Senesi, 2000) [78, 36, 64]. An edible coating is created when a thin film of an edible substance is applied to the surface of unprocessed or minimally processed fruits and vegetables thereby acting as a partial barrier of protection (Guilbert, 1986) [35] to gases, moisture and others consequently preserving the quality (Baldwin, 1994) [11].

The quality and nutritional value of the produce is preserved during storage when the internal O2 composition is reduced leading to decreased respiration responsible for senescence, but special care must be taken to prevent an extremely low internal O_2 concentration as it can lead to anaerobic respiration, which can result in the formation of ethanol and the development of off flavours (Kays and Paull, 2004) [50]. Edible coverings that act as barriers to the volatile compounds that give fruits and vegetables their natural aromas (Chalier *et al*., 2006, Quezada-Gallo *et al*., 2000, Baldwin *et al*., 1999) [19, 83, 12] or as transporters of tastes and flavor-precursors can help retain their flavour. A very low internal O_2 content, however, may result in a reduction in the formation of the molecules that give fruits and vegetables their distinctive flavours, so it is important to take precautions to stay away from such circumstances (Fellman *et al*., 2003) [30]. When moisture loss from the commodity is prevented or reduced, the changes in enzymatic metabolism are automatically reduced which further contribute to an accelerated senescence (Kays and Paull, 2004) [50], however, the minimally-processed produce possess a high water activity on its surface making it difficult to develop such coatings that can effectively hinder water loss as the property of coating to act as water vapour barrier is inversely proportional to the water activity of commodity (Hagenmaier and Shaw, 1992) [44]. Enzymatic browning is a serious problem in minimally-processed commodities that significantly shorten the shelf-life of the produce during storage. Edible coatings can act as antioxidants carriers thereby serving as an alternative to reduce enzymatic browning. Coating formulation can be amended with addition of antimicrobials and texture enhancers with the objective of preserving the quality and freshness of produce during storage (Vojdani and Torres, 1990) [103].

Nanomaterials in Edible Coatings

Nanotechnology has become a crucial technique in recent years for extending the shelf life of food items. When compared to particles of a larger size, the utilisation of nanoscale particles offers distinct and superior properties. Due of the enhanced properties they impart, nanotechnology has an array of applications in films and coatings related to products (Nile *et al*., 2020) [73]. It is now possible to investigate functional modifications in coating materials, such as nanoemulsions, nanostructured lipid transporters, polymeric nanoparticles, nanotubes, nanofibers, nanocrystals, and others, owing to advancements in the development of nanosystems combined with food-grade ingredients (Zambrano-Zaragoza *et al*., 2018) [106]. Incorporating nanosystems into hydrocolloid-based matrices (proteins or carbohydrates) results in nanocomposites, which are mixtures of multiple substances, at least one of which is on the nanoscale, to enhance coating qualities (Zambrano-Zaragoza *et al*., 2018, Liu *et al*., 2017) [106, 58].

The moisture barrier, refractive and microstructural mechanical characteristics, as well as the antibacterial and antioxidant properties, are the key modifications brought on by the usage of nanosystems in nanocomposite coatings. By permitting their slow and regulated release during storage of produce, occasionally under different storage conditions, nanoparticles in coatings strengthen these processes when antimicrobial or antioxidant compounds are included in the coating while improving the absorption and utilisation of such compounds over time (Zambrano-Zaragoza *et al*., 2018, McClements, 2020) [106, 63]. The maintenance of food quality and the reduction of the growth of the bacteria, filamentous fungus, and yeasts that cause food to deteriorate and shorten its shelf life are both dependent on improvements in these qualities (Kumar *et al*., 2020) [53]. Another benefit of incorporating active agents into nanosystems is that less of these compounds are required to achieve good activity, which means that using these substances in modest amounts will not have an adverse impact on the sensory qualities of food (Hasan *et al*., 2020) [48].

Application of edible coating on fresh fruits and vegetables

Fresh fruits and vegetables, such as apples, citrus fruits, and cucumbers, can be coated with edible substances to preserve their quality and increase shelf life (Baldwin *et al*., 1996; Li and Barth, 1998) [14, 57]. The functional qualities of the coatings are being improved through research and development, depending on which aspects of the fruit are needed to be maintained or strengthened. These can be accomplished by creating various edible coatings, evaluating their gas permeation properties, assessing both the flesh and the skin diffusion properties, determining the internal gas compositions of coated fruits coated, and assessing the effects of coatings on quality changes. Edible coverings have been created using a range of edible ingredients, such as lipids, polysaccharides, and proteins, either alone or in combination (Ukai *et al*., 1976; Kester and Fennema, 1986) [100, 51]. The usage of edible coatings and the rates at which they are applied are governed by the laws of the nation where the coating is applied or the country to which the fruits and vegetables are being exported. For most products, appropriately developed edible coatings can be used to address issues with consistent quality, market safety, nutritional content, and affordable manufacturing costs. The following is a list of possible applications for edible coatings:

Edible coatings as colourant, flavour and texturizer agent

To enhance the quality of the produce, edible coatings can deliver and retain desired concentrations of beneficial substances. Flavours, colourants, seasonings, vitamins, and other useful plant-derived substances can all be added to edible coatings (Montero-Calderon *et al*., 2008; Han *et al*., 2004; Lee *et al*., 2003) [70, 46, 55].

Shows the produce coating used concentration and effect

Produce	Coating used	Concentration	Effect
Pineapple	Alginate	Calcium chloride 2% w/v	Retention of internal liquids
Raspberry	Cs	Calcium gluconate 5% w/v	Retention of textural quality
Apples	Whey protein concentrate	Calcium chloride 1% (w/v)	Retains firmness

Edible coatings as nutraceutical carriers

Additionally, edible coatings may contain a variety of active substances that could be employed to improve the nutritive and functional characteristics of produce (Gutiérrez and Álvarez, 2016; Gutiérrez, 2017) [39, 40]. Few researchers have, however, documented the incorporation of nutritious or nutraceutical components into food coatings, although interest is rising in this field (Han *et al*., 2004; Tapia *et al*., 2007; Tapia *et al*., 2008) [46, 98, 97].

Shows the produce coating used concentration and effect

Produce	Coating used	Concentration	Effect
Apple	Alginate and gellan	*Bifidobacterium lactis* @ 2.0 (w/v)	Fruit quality maintained up to 10 days during storage
Papaya	Alginate	Ascorbic acid @ 1.0 (w/v)	Retention of ascorbic acid
Strawberry	Cs coatings	Cs containing 0.2% dl-α-tocopheryl acetate	Delayed colour change, pH and titratable acidity during cold storage

Edible coatings as probiotic organisms' carrier

Probiotics are living microorganisms that, at a specific concentration, can help improve the well-being of the host (Sanders, 2008) [86]. Probiotics aid in the growth of advantageous microorganisms, decrease of potentially hazardous bacteria, and reinforce the body's defence mechanisms. Such active packaging solutions assist in providing consumers with unique, health-beneficial items (Sharma *et al*., 2006; Aloui *et al*., 2015; Shigematsu *et al*., 2018) [89, 2, 90].

Shows the produce coating used Probiotics incorporated and effect

Produce	Coating used	Probiotics incorporated	Effect
Slices of carrot	Sodium alginate	*Lactobacillus acidophilus*	Control growth of *Bacillus cereus* and *Staphylococci*.
Orange	Sodium alginate & locust bean gum	*W. anomalua*	Control green mould (*P. digitatum*)
Tomato	Cs	*C. utilis*	Prevent the growth of *A. alternata* and *G. candidum*

Edible coatings as antimicrobial agents' carrier

Edible coatings contain active ingredients such antimicrobials to keep food surfaces effectively coated with such ingredients, preventing the growth of spoilage/pathogenic microorganisms. The following antimicrobial groups may be included in edible coatings: fatty acid esters like glyceryl monolaurate, organic acids like acetic, lactic, propionic, benzoic, and sorbic, polypeptides like peroxidase, lactoferrin, lysozyme, and nisin, and plant essential oils like cinnamon, oregano, and lemongrass, as well as nitrites and sulphites. Employing these antimicrobials can offer safe produce (Nair, 2018a; Aloui, 2014; Alvarez, 2013) [72, 1, 4].

Shows the produce coating used Antimicrobial compound Concentration and effect

Produce	Coating used	Antimicrobial compound	Concentration	Effect
Capsicum	Cs and alginate	Pomegranate peel extract (PPE)	Cs (1% w/v) and alginate (2% w/v) in combination with 1% w/v PPE	Controls *Colletotrichum gloeosporioides* during low temperature storage for 20 days
Dates	Cs and locust bean gum	Citrus essential oils	Cs–2% (v/v) mixed with 2% citrus essential oil	Inhibition of Aspergillus flavus during storage of 12 days.
Broccoli	Cs	Essential oils and bioactive compounds	Cs solutions (2 g/100 mL) mixed with 1 mL essential oils and bioactive compounds	Control of *E. coli* and *L. monocytogenes*

Edible coatings as antioxidants carrier

Antioxidants are free radical acceptors that prevent, delay or terminate the spread of autooxidation. This help prevent fruits and vegetables from turning brown due to enzyme activity and oxidative rancidity. Natural antioxidants can enhance performance of edible coatings and suitability for use in food products by being included into them. To increase their bioactive capabilities, a variety of pure chemicals, including α-tocopherol and ascorbic acid, as well as natural antioxidants such plant extracts and essential oils have been added to edible coatings. Additionally, antioxidants inhibit vitamin C depletion and browning processes, particularly in freshly-cut fruits and vegetables, preserving colour and extending the product's shelf life and acceptability (Nair *et al*., 2018b; Das *et al*., 2013; Chiumarelli *et al*., 2011) [71, 22, 20].

Shows the Produce Coating used Anti-oxidant additive and its effect

Produce	Coating used	Anti-oxidant additive	Effect
Guava	Cs and alginate	Pomegranate peel extract	Improvement in shelf life and quality
Tomato	Rice starch	Green tea extract and coconut oil	Improvement in total phenols and ascorbic acid content and control of ripening
Fresh-cut mango	Cassava starch	Citric acid	Delay in quality deterioration, respiration rate retarded and better colour development

Methods of edible coating application

The efficiency and success rate of edible coatings in preserving fruits and vegetables is majorly influenced by the method of its application which will in turn be determined by the nature of the commodity to be coated, the surface characteristics, the rheological features of the solution, and the primary objective of the coating (Suhag *et al*., 2020) [94]. For coatings to serve the purpose for which they were designed, they must adhere to the product surface (Raghav *et al*., 2016; Senturk Parreidt *et al*., 2018) [84, 88]. The interface interaction that takes place between the coating and the product surface is measured using wettability. While evaluating the effectiveness of the coating solution on surface of the product, this factor should be taken into consideration (Nor and Ding, 2020) [75].

The most popular techniques for coating fresh produce with edible materials are

- Dipping
- Spraying
- Hand coating

Some other techniques that are rarely used on laboratory or commercial scales are (Suhag *et al*., 2020) [94]

- Fluidized bed
- Foaming

Dipping

Due to its ease, independence from equipment, and homogeneity of film application, immersion is one of the most popular methods for coating fruits on a laboratory scale. This technique involves immersing the entire surface of produce at a steady rate in the film-forming solution, ensuring that the entire surface is completely moist (Valdés *et al*., 2017) [101]. Following application, extra solution is drained to remove the surplus of solution from the fruit surface (Tahir *et al*., 2019) [96]. After the produce has been dried, the excess liquid and solvent evaporated, leaving the film in contact with the food surface. Following draining the solution, drying can happen at ambient temperature or with the aid of a heated air tunnel. This method enables the use of coating solutions with a wide variety of viscosities (Senturk-Parreidt *et al*., 2018) [88]. The potential for cross-contamination between fruits during the process of immersion due to build-up of residues and microbiological organisms (Suhag *et al*., 2020) [94] is a drawback of this method. It is necessary to thoroughly clean and sanitise the produce that are going to be coated in order to prevent this issue, and to change the coating solution periodically (Andrade *et al*., 2012) [5]. Typically, fruits and vegetables are submerged in the coating solution for 5 to 30 seconds (Raghav *et al*., 2016) [84].

Spraying

The spraying method, which is most common in packaging houses, offers a uniform and attractive covering. Additionally, it prevents the coating solution from becoming contaminated (Dhanapal *et al*., 2012) [27]. By creating drops, this procedure increases the fluid's surface area and disperses it across the produce (Suhag *et al*., 2020) [94]. The fruit or vegetable is placed under manually or mechanically operated dispersing nozzles while being sprayed, either on a tray or rotating rollers at a synchronised pace. Until the desired coating thickness is reached, this process is repeated. This method has the disadvantage that viscous liquids cannot be sprayed because they clog the machinery (Atieno *et al*., 2019) [7].

Hand Coating

Another alternative to apply the filmogenic solution to the fruit surface is with the use of gloved hands. When coating fruits, an even layer of coating solution can be applied with hands while wearing rubber gloves. On a lab scale, it is appropriate to prevent contamination of solution and reduce wastage of such solution during screenings. However, a drawback is the uneven thickness of film that develops on the fruit surface (Miranda *et al*., 2020; Sun *et al*., 2015) [69, 95].

Potential active ingredients to be carried by edible coatings

The ability of edible coatings to incorporate active substances into the matrix and improve its functionality and effectiveness is one of its special features. As a result, adding antioxidants, antimicrobials, or other functional compounds can substantially increase the produce quality, shelf life, safety, and stability.

Antimicrobial Agents

Another potential solution to improve the safety of produce is the application of edible coatings as antimicrobial compounds carriers. During post-harvest handling, the epidermis' chemical as well as physical barrier, which hinders the growth of germs on the surface of produce, is destroyed (Martın-Belloso *et al*., 2006) [61]. The most practical method for extending the microbial longevity of produce is to immerse them in aqueous solutions containing antimicrobials.

Applying antimicrobial compounds/agents directly to surface, however, may have limited effects due to the active ingredients' fast neutralisation or diffusion into the product, limiting the effectiveness of antimicrobial compounds (Min and Krochta, 2005) [68]. Accordingly, antimicrobial edible coatings might offer improved inhibiting properties against spoilage and harmful bacteria by preserving efficient concentrations of the active components on the product surface (Gennadios and Kurth, 1997) [32].

There are several types of antimicrobial compound that can be added into the edible coatings. These include organic acids (acetic acid, lactic acid, benzoic acid), fatty acid esters, polypeptides (peroxidase, lysozyme), essential oils extracted from plants such as lemon grass, cinnamon etc. and nitrites and sulphates (Franssen and Krochta, 2003) [31].

Texture enhancers

Pectic enzymes induce an extensive degradation in firmness of fruit tissues during storage. Treatments with salts of calcium are the most typical method of preventing the softening of fresh fruit. Fruits and vegetables that have pectic polymers in them combine with calcium ions to create a connected network that boosts mechanical strength, delaying senescence and regulating physiological diseases (Poovaiah, 1986) [82]. To reduce produce softening phenomena, texture enhancers can be included into the coating formulation.

Nutraceuticals

To improve the nutritional content of some fruits and vegetables that are deficient in micronutrients, researchers have tried to add vitamins, minerals and fatty acids to edible coating compositions. Since it is crucial to understand the effects on the fundamental functionality of coatings, especially on their protective and mechanical characteristics, the amount of nutrients applied to the coatings needs to be thoroughly examined.

Mei and Zhao, 2003 [66] examined the viability of using milk protein-based edible films to deliver high levels of calcium (5 or 10% w/v) and vitamin E (0.1 or 0.2% w/v) concentration. In contrast, Park and Zhao (2004) [81] showed that increasing the content of mineral (5-20% w/v zinc lactate or vitamin E) in the film matrix increased the water barrier function of the chitosan-based films.

Current Status and Recent Advances

Currently, edible coatings are utilised in various culinary applications to enhance handling, increase shelf life, and alter taste and appearance. It can be viewed as an innovative approach for delivering antimicrobials to surfaces of food with high moisture content, preserving the flavour characteristics of foods with strong aromas, and delaying oxidation in meals with moderate and low levels of moisture. Even after the package has been opened, edible coatings can preserve the food quality. The food sector uses edible coatings in several ways. This involves prolonging the longevity of foods that are sensitive to oxygen, minimising the packing of entire and already cut fruits and vegetables, and extending the storage life of frozen items by minimising respiration, moisture loss and colour change. These techniques also include avoiding oxidation and preventing moisture, colour or aroma migration (Marín *et al*., 2016) [60]. The dynamic packaging systems market is predicted to have a promising future due to its integration with packaging materials.

Advantages of edible coatings

Edible coating offers the following advantages: (Nisperos-Carriedo *et al*., 1992b; Park *et al*., 1994; Sothornvit and Krochta, 2000) [74, 78, 93]

- Enhances appearance of fruit surface by adding more shine.
- Prevents fruit from weight loss and keeps it firm, preserving its fresh appearance.
- Slows down the generation of ethylene and respiration rate, postponing senescence.
- Protects produce from storage disorders and injuries caused by freezing.
- It acts as a hindrance to free gas exchange.
- Offers a vehicle for chemical post-harvest treatments.
- Consists of nutritional components such vitamins, antioxidants, pigments, and ions that prevent browning reactions.
- Limits the use of artificial packaging materials.
- The use of edible coatings and films helps reduce taxes imposed on the shipment of packaging materials in some nations.

The ability to stabilise the food and hence increase shelf life is typically one of the possible advantages of coatings for minimally processed fruits and vegetables (Baldwin *et al*., 1995) [13]. Coatings have the ability to lessen loss of moisture (Risse and Miller, 1983; Avena-Bustillos *et al*., 1994; Baldwin *et al*., 1995; Avena-Bustillos *et al*., 1997) [85, 10, 13, 9] and firmness, offer moisture and oxygen barrier characteristics (Avena-Bustillos *et al*., 1994, Li and Barth, 1998) [10, 57], slows down the respiration rates (Banks, 1984) [15], obstruct solute movement (Li and Barth, 1998) [57], slows down chlorophyll loss (Banks, 1984) 15], production of ethylene (Banks, 1984; Baldwin *et al*., 1995) [15, 13], hinders metabolism and oxidation rates, carry chemicals that could reduce discoloration and microbial growth (Baldwin *et al*., 1995) [13], and enhance the appearance (Davis and Hofmann, 1973) [23]. The use of edible coatings would make it much easier to achieve relative humidity levels close to 100% (Watada *et al*., 1996) [104]. The main advantages of edible coatings are that they can be consumed with food, offer nutrients, that they can improve sensory qualities, and that they can include antimicrobial agents for improving quality (Guilbert *et al*., 1996) [36].

Challenges to the use of edible coatings

Choosing the right coating is a difficult task. The appropriate choice of an edible coating will rely on the commodity's rate of respiration and transpiration as well as the ambient factors in the storage. The effect of edible coatings on coated fruits' quality might vary substantially. Since each fruit differs in terms of characteristics such as gas diffusion, skin resistance and respiration rate, coatings produced for one species of fruit may not be suitable for another (Park *et al*., 1999) [80]. In this context, the method of application and coating thickness will additionally have a significant impact on the percentage of pores obstructed by the coating and, consequently, on all parameters connected to transport phenomena (Banks, 1993) [16]. It has been found that individual fruit coating tends to give results with greater individual variance than what is seen in non-coated fruits and vegetables, which is another issue to consider (Hagenmaier, 2005) [45].

The capacity of edible coatings to maintain a low internal O_2 to slow ripening but not too low to cause anaerobic respiration is crucial to the success of employing edible coatings on the preservation of the quality of fruits and vegetables. Additionally, it depends on their capacity to block water vapour while not being too oily or thick to turn off customers. Edible coatings must stick to the produce's surface, which is fundamentally hydrophilic in the case of less processed fruits and vegetables. It is expected that edible coatings will have no taste and a great appearance.

More research is needed to determine how edible coatings affect the quality of whole and minimally processed fruits and vegetables during storage, particularly how the modified storage environment caused by the coating affects produce metabolism and results in quality changes, special flavour loss, and nutritional losses. Additionally, consumer acceptance and the price of the coated product must be studied. Even if a coating has good mechanical and barrier capabilities, it will not be commercially viable if it has a strange appearance, an unpleasant taste, or is expensive.

Edible coatings contain active ingredients such antioxidants, antimicrobials, flavourings and nutraceuticals. Because the incorporation of food-grade chemicals may dramatically modify them, research is being done to maintain the mechanical properties. Producing coatings with improved functional, mechanical, and barrier properties is essential. The cost is one of the main obstacles, limiting its application in high-end gadgets. In addition to price, other factors that restrict the commercial use of edible coatings include a scarcity of materials with the required functions, the expense of installing coating machinery, the stringent nature of the rules and regulations, and the complex nature of the manufacturing process. Despite these limitations, the food sector keeps looking for edible coatings that might be used in various foods in order to increase the value of its goods, extend the shelf life, and reduce packaging. The development of innovative edible coatings that release active chemicals using nanotechnological methods like multi-layered systems and nano encapsulation is another recent breakthrough.

Regulations regarding the application of edible coatings

Because edible coatings constitute a crucial component of produce edible parts, they must abide by all laws pertaining to food additives. Every component, in addition to valuable additives, should be made of food-grade and non-toxic materials to preserve the quality and safety of the product. All processing plants must also closely adhere to current Good Manufacturing Practices (GMP) and be suitable for the preparation of food. Food and Drug Administration (FDA)-approved substances must be used within the specified limitations and be generally recognised as safe (GRAS) in order to be utilised in edible coatings. According to the European Directive (1998), pectins, shellac, beeswax, carnauba wax, candelilla wax polysorbates, lecithin, fatty acids, and fatty acid salts are among the components that can be used to create edible coatings. On the contrary, the FDA lists additional chemicals such as polydextrose, morpholine, sorbitan monostearate, SFAEs, castor oil and cocoa butter that are used as parts of protective coatings put to fresh produce (Vargas *et al*., 2008) [102].

Future trends

A novel type of edible coatings is being developed with the objective of incorporating active substances and/or controlling their release utilising nanotechnological techniques such multi-layered systems and nanoencapsulation. By using nanoscale additives, vitamins and minerals, and nanosized delivery methods for bioactive chemicals, nanotechnologies are currently being employed to improve the nutritional qualities of food (Bouwmeester *et al*., 2007) [17]. Active substances may be protected against moisture, heat, and other harsh conditions by being micro- and nano-encapsulated in edible coatings, which may assist control their release under particular circumstances (Lopez-Rubio *et al*., 2006) [59]. This will increase their degree of stability and viability and protect them from these environments. (Jimenez *et al*., 2004) [49].

Although substances from other sources may additionally be employed, alginate is the substance that is most frequently used for encapsulating. The best useful compounds to be encapsulated include enzymes, prebiotics, probiotics and marine oils (omega-3 fatty acids). On the contrary, using layer-bilayer (LbL) multi-layered nanolaminate systems, where the charged surfaces are covered with interfacial films made of several nanolayers, offers interesting potential (Decher, 2003; Weiss *et al*., 2006) [25, 105].

The process of producing structures with multiple layers involves immersing the substrate repeatedly in multiple coating solutions that include species with opposing charges (Guzey and McClements, 2005) [62]. Foods are either dipped in a series of fluids containing compounds that will ultimately be adsorbed by their outermost layer or sprayed with substances to create a nano laminated coating (McClements *et al*., 2005) [62]. These nanolaminate coatings might be made solely of components that are safe for consumption (proteins, lipids and polysaccharides), and they might also contain a variety of functional additives such flavourings, colours, antimicrobials, enzymes, and anti-browning agents. (Weiss *et al*., 2006) [105].

Conclusion

By delaying dehydration, preventing respiration, enhancing texture quality, aiding in the retention of volatile flavour compounds, and lowering microbiological contamination, coatings can prevent perishable fresh products from deteriorating. Edible coverings with distinct functions will undoubtedly become more significant in the future along with the increasing demand from consumers for fresh and least processed produce. Many protein- and polysaccharide-based coatings, particularly those with built-in antibacterial or antifungal properties, are gaining popularity as alternatives to conventional lipid coatings. At low to moderate humidity levels, these coatings typically function well as oxygen barriers but poorly as moisture barriers. Continued work is required to create stable emulsion coatings with the correct moisture-barrier characteristics to be able to achieve the primary objective of decreasing the loss of moisture from commodities with edible coatings. In the meantime, research on the sensory quality and acceptance by customers of coated items, as well as studies to improve its adhesion and persistence on the outer layer of fruits and vegetables, are required.

Future research should focus heavily on creating new technologies to enhance the delivery capabilities of edible coatings. Currently, most of the research on food applications are being carried out on a lab scale. To use more accurate data, however, to commercialise edible coated fresh produce, more study on a commercial basis is required. Additionally, while creating new edible coating applications, more research is required to comprehend the interactions between active substances and coating components. The addition of active substances (antioxidants, antimicrobials and nutrients) to edible coatings can have a significant impact on their mechanical, sensory, and even functional qualities.

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