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Recent advances in edible coating of food products and its legislations: A review

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ABSTRACT

Food products are highly perishable in nature which undergoes quick quality deterioration. In this note, the kind of packaging decides the active preservation of food qualities. Especially, edible coating plays a significant role in minimizing the post-harvest losses like moisture loss, ripening and physio-chemical losses. The application of edible coating shows promising results in increasing the shelf-life, also preserving its quality. The application of edible coating for foods could be an alternative for harmful non-biodegradable packages. This current review provides the elaborate research knowledge on edible coatings composition, methods of production, regulations, pros and cons.

1. Introduction

The consumption of healthy and natural foods is amplifying the need for fresh food produce in the market throughout the year. As the population increases the requirements in food sector also multiplies drastically. Though there are numerous existing food processing facilities, the requirements could not be matched up in eco-friendly manner. In addition, the fresh produces are mostly perishable by nature, also leads to quality deterioration quickly during storage and transportation [1]. Therefore, it faces major post-harvest losses in various manners before reaching the consumers. A study Galanakis [2]. revealed that about one third of food is wasted worldwide, around 14% waste occurs in various processing levels like harvest, farming and slaughtering. Thus, there is a huge demand in the food industry for finding alternative and innovative ways to enhance the shelf life of fresh foods including fruits and vegetables. The packaging sector takes an integral part in deciding the shelf life of foods. The conventional packaging material is composed of non-biodegradable compounds. These compounds after the usage leave undesirable and unhealthy impacts on the environment. Since the consumers prefer highly safe and stable food products [3], the rise in biodegradable films and coatings turns into a vital segment in the packaging sector. The thickness below 0.025 mm is considered as edible coating whereas the thickness above 0.050 mm is considered as edible films/sheets [4]. These edible coatings and films not only fulfil the packaging needs but also minimize the post harvest losses of the fresh foods. The edible films can be used as an inner layer directly interacting with the foods in multi-layered packages with non-edible films. They can be effectively used in pizza, pie and candies to preserve their inner moisture and solute movement [5]. Apart from this, edible coatings can be used to preserve fresh and minimally processed fruits and vegetables [6,7], cheese [8] and meat products [9].

In 1992, the application of wax on the fruit surface termed to be the first official edible coating in practice [4]. Edible coating, a thin layer of solution applied over the surface of food to prevent it from quick deterioration. It also acts as a primary packaging in food packaging as they tend to maintain the textural and sensorial properties [1]. Different kinds of biopolymers like lipids, proteins, polysaccharides and composite substances are used in the making of edible coating. Thus, the coating material remains to be of a complete edible substance. The essential oils extracted from plant exhibits advantageous properties like antimicrobial and antioxidant action. There are growing research in the inclusion of essential oils in edible coating for functional foods [10].

The quality and safety of meat and dairy products majorly rely on the kind of packaging [11,12]. Meat and dairy products are consumed worldwide in large amount. Since they are enriched with full of proteins, vitamins, fatty acids and energy rich compounds. The inclusion of these foods in human diet is enough in fulfilling the protein, fatty acids and other micronutrients requirement [13]. The deterioration of meat starts to take place once the cattle is slaughtered. The complex chemical reactions in meat results in the discolouration, off-flavours and many

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undesirable chemical and structural changes. The myoglobin is the heme protein which imparts colour to the meat. This myoglobin gets oxidised and forms the oxymyoglobin (MbO_2), further it gets converted into metmyoglobin (MetMb) in meat resulting in the brown colour of meat. The important parameter in consumer acceptance is itself getting affected in meat after slaughtering [14]. Similarly, the lipid oxidation occurs in the meat, forming primary and secondary products like alcohols, aldehydes, ketones. These secondary products are key responsible factors in meat deterioration. The meat browning and lipid oxidation are major processes in meat spoilage, which are presented in the Fig. 1. Lipid oxidant happens in three distinct ways namely lipid autoxidation, photo-oxidation and enzymatic oxidation [15]. The inclusion of antioxidant rich additives in edible coatings of meat could easily scavenge the free radicals thereby reducing the meat deterioration process [10].

Whereas, in fruits and vegetables processing sector, the important quality deterioration processes are respiration and transpiration [16]. In transpiration, the slow reduction in the food quality is traced namely undesired texture, colour and appearance through water loss. Similarly, if respiration takes place there will be major weight loss as a result of reduction in carbon dioxide content. Thus, these edible coatings act as a barrier against moisture loss and gas (oxygen and carbon dioxide) exchanges, thereby increasing the shelf-life of food [6]. The impacts of using edible coatings on fruits and vegetables are presented in the Fig. 2. The oxygen concentration below 10% is required for controlling the respiration rate of fruits and vegetables. Cheese, an example for highly

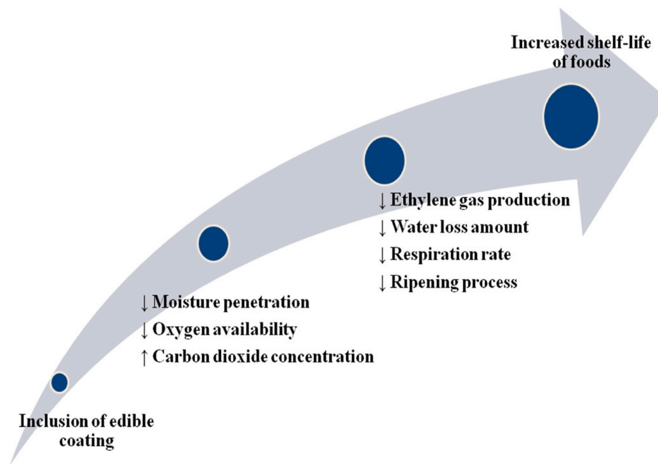

Fig. 2. Impact of edible coatings on fruits and vegetables.

perishable food in dairy products possess higher percentage of moisture, serving a suitable environment for the growth of yeast, mold and bacteria [12]. On the basis of packaging, cheese is classified into hard, soft, semi hard and semi soft cheese with moisture percentage of <25, >40, 25–36 and 36–40, respectively. Edible coatings on cheese shows better

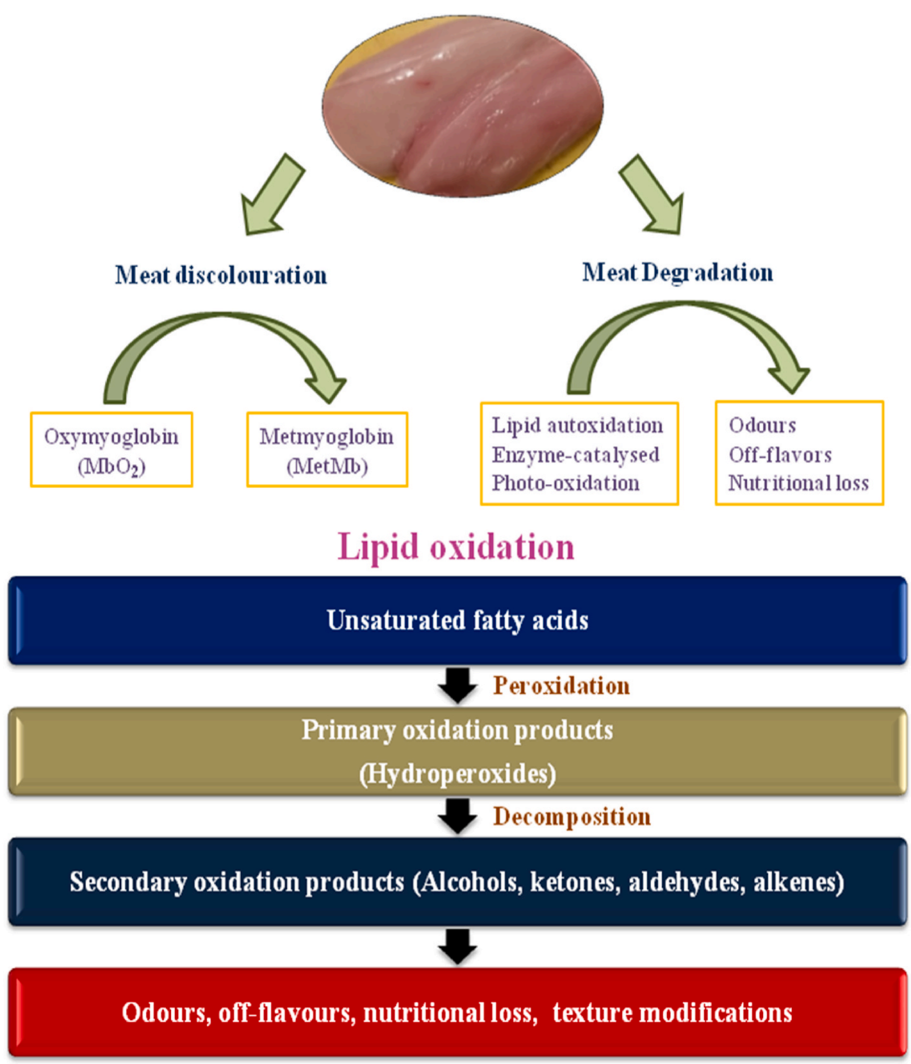

Fig. 1. Chemical changes in meat deterioration.

oxygen barrier properties, reduced water loss and water vapour permeability [17].

The Covid-19 pandemic mainly affected the food packaging sector since the need for fresh and nutritious food has increased among people drastically. The packaging should ensure high food safety and security with innovative ideas using distinct bioactive compounds [18]. Diverse functional bioactive compounds can also be incorporated in the coating solution involving antioxidants, minerals, flavours, vitamins, colorants, antimicrobials and nutraceuticals [19]. The bioactive compounds like vitamin A, D, E, and C aids in boosting innate immune system against common cold. Even the phenolic acids and flavonoids inhibits the replication of coronavirus thereby provides anti-inflammatory, antioxidant and antimicrobial activities. Meanwhile the COVID-19 virus entry is disturbed by the action of bioactive lipids namely phytosterols, carotenoids and fatty acids. The virus replication is inhibited by the action of secondary metabolites like quinoline alkaloids, isoquinoline alkaloids and β-carboline. Flavonoids and polyphenols like riboflavin, tercatain, genistein and hesperidin proven as strong inhibitors against corona virus protease enzyme. Thus, the consumption of herbal medicines and natural foods containing these bioactive ingredients could eventually boost the immune system [20].

In order to achieve microbial inactivation while preparing the edible coating, various non-thermal technologies have been used. It includes pulsed light, ultra violet light, gamma radiations, hydrostatic pressure and ozone [21]. The wide analytical tools implemented in food packaging are block chain technology, artificial intelligence, sensor techniques and block chain technology. These technologies have led to the development of active, biodegradable and intelligent packaging. Pulsed light technique, non-thermal disinfection for the making of an eco-friendly food packaging system [18]. From edible coating till active intelligent packing the research works in this field have increased tremendously with intense and more innovative range of applications. Nowadays, applications of nanotechnology in developing edible coatings have been the major focus of research.

The food industry faced major problems all over the world during the corona virus pandemic time. The problems like reduction in the supply of bioactive ingredients rich foods, maintaining food safety, security and the sustainability. This virus affected the people by particularly disturbing the immune system. In such case, the foods rich in bioactive ingredients helped in managing the collapsed immune level. For instance, the virus infectious rate gets lowered while consuming the fruits (sweet potato, spinach, carrots) rich with vitamin A (carotene, retinol and retinoic acid). FDA insisted more hygiene food package practise right from the preparation till the delivery stage in order to stop the spread of deadly COVID-19 virus. The supply of food during the uncertain condition is of primary importance which is monitored by Food and Agriculture Organization (FAO) [2].

Since the fruits and meat remains to be as living cells even after their harvest, the control over respiration and oxidation rate respectively could improve the shelf life. Therefore, the edible coating should possess certain characteristics for maintaining the quality standards of food produce. Some of the characteristics of edible coatings are listed below,

- Low gaseous permeability is the important property of edible coating in order to slow down the respiration and transpiration processes, thereby reducing the ripening and senescence [9].
- The coating mainly controls/prevents the migration of oxygen, carbon dioxide, solute compounds and moisture from outside environment into the foods [22].
- Inertness of coating substances is required to assure it as non reactive one with the food items which gets packed in.
- The coating must be highly transparent in nature without any dark coloration since the coated food has to be clearly visible.
- The edible coatings also retain the fresh juiciness of meat products (poultry, beef, pork) when packed [23].
- The coating material should not produce any off flavour, smell or dark coloration over the food. Thereby the sensory properties should be retained as such without any modifications.
- Some minimum scale of permeability barrier against water vapour to prevent desiccation of fruits and vegetables. Since, fruits and vegetables loose freshness upon the loss of water.
- Edible coatings should be digestible if consumed along with the packed foods, thus the coating substances should be non-toxic in nature [9].
- The melting point of coating solution should be above 40 °C; the solution must be non-sticky, low viscous, economical and possess quick drying nature [24].
- Study on the three regions (the environment, the coating layer and the food substance) is prominent in developing an edible coating to any fruits/vegetables.
- The appearance of coating and light barrier properties plays a vital role in obtaining the attention of consumers.
- In order to achieve uniform spreading and contraction of coating solution, it is important to maintain the proper ratio of adhesion and cohesion molecules [25].

In this descriptive review, the application of edible coatings in fruits, vegetables, meat and milk products were brought under one frame. This review is important in enriching wider knowledge about the post harvest deteriorations and solutions to overcome those in the food processing sector. Especially the rules and regulations followed for edible coating production and implementation is discussed. Using these cumulative knowledge on edible coatings as foundation, numerous novel research techniques can be developed with the existing facilities.

2. Coating

The thin layer of formulation applied over the food commodities in the urge of extending the product shelf-life is termed as an edible coating. The coating solution can be prepared by dissolving the specific coating materials/compounds in any organic or inorganic solvents. These materials could be of mainly polysaccharides, lipids, proteins or any kinds of composites [24]. The different types of edible coating materials were given in Fig. 3. To enhance the physiochemical properties of the coating, a required amount of plasticiser or additives/active ingredient is added. The active ingredients employed in the solution preparation stage are antimicrobial agents, vitamins, antioxidants, essential oils, plasticisers. The solution is completely homogenised and then coated either by dipping, spraying, foaming, fluidized bed, brushing or panning techniques. A detailed description on the coating composition, nature and properties are as follows,

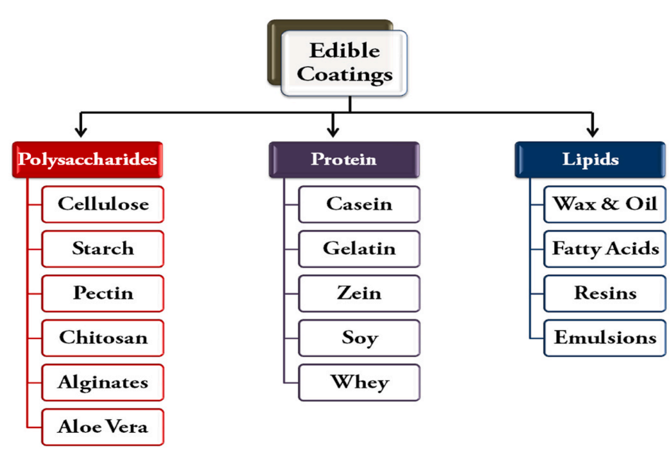

Fig. 3. Various types of edible coating materials.

2.1. Polysaccharides

Polysaccharides are more commonly available biopolymers used in the edible coatings and edible films [5]. The major polysaccharides used for the edible coating of fruits and vegetables include starch, chitosan, carrageenan, cellulose, alginates, pectin, etc [26]. The polysaccharides-based edible coating can inhibit foods' oxygen and moisture migration thereby improving the foods' mechanical properties [27]. Since polysaccharides are hydrophilic in nature, they have a poor water vapour barrier that limits their commercial application in edible coatings [5]. To overcome this drawback, the polysaccharides are used in combination with other polysaccharides or proteins and fats [27]. Panahirad et al. [19] discussed about the use of carboxymethyl cellulose and pectin in edible coating of various fruits and vegetables. The pectin based coatings in raspberry, apple, plum, persimmon and peach have greater results in reducing the microbial growth and spoilage. Application of gum arabica along with extract of moringa leaf enhanced the storage period of guava by reducing the decay and rhizopus infection during cold storage [28]. Vital et al. [10] worked on the application of alginate based coatings incorporated with essential oils extracted from oregano and rosemary. The meat subjected with this oregano essential oil coating showed reduced lipid oxidation than that of the uncoated one. Pork patty showed improved free radical scavenging activity and reduced lipid oxidation process when coated with pectin based edible coating [29]. Merits of using edible coating on meat are given in the Fig. 4. Coatings made using gum arabic acts as a strong antifungal layer for fruits like tomatoes and strawberries [30]. Similarly, coatings made using gum arabic and almond gum proved to slow down the ripening of sweet cherries, thereby increasing the storage period.

2.1.1. Chitosan

Chitin is an abundantly available natural polysaccharide present in insects, algae, fungi, crustaceans, vertebrates, and yeasts [5,31]. A derivative of chitin comprising of 1,4-linked 2-amino- deoxy-β-D-glucan, is termed as Chitosan which is a cationic linear polysaccharide [27]. Chitosan is non-toxic and biodegradable in nature and acts compactable with numerous substances like minerals, antimicrobial agents, and vitamins of foods [6,32]. Chitosan coatings are partially permeable coatings that act as an excellent oxygen barrier and help in retarding the transpiration and ripening of fruits and vegetables [5]. Chitosan possesses hypolipidemic and hypoglycemic antioxidant activity, which prevents the microbial spoilage of coated food [26]. Suseno et al. [33] reported that the application of chitosan edible coating to Cavendish banana extended the shelf life of banana by reducing the decay and retarding the ripening process. Application of chitosan-based nano--emulsions coating to fruits and vegetables acts as a suitable method for retaining the freshness and quality. It helps in satisfying the consumer expectations of chemical-free products [34]. Divya et al. [35] incorporated chitosan nanoparticles in edible coating for the preservation of vegetables (tomato, chilly and brinjal). These chitosan nanoparticles resulted in significant antioxidant and antifungal activity against selected microorganisms.

2.1.2. Cellulose

Cellulose, a highly crystalline linear polymer comprising of D-glucose units joined through β-1,4-glycosidic bonds. Cellulose possesses some intramolecular hydrogen bonds, which makes it insoluble in water [36]. The cellulose-based edible coatings are more commonly used for the edible coating of fruits and vegetables as they act as a barrier to moisture migration and gases like O_2 and CO_2 [27]. Generally, four different cellulose derivatives were used in edible coatings and edible films, namely carboxymethyl cellulose, hydroxypropyl methylcellulose, hydroxypropyl cellulose, and methylcellulose [26]. One per cent concentration of carboxymethyl cellulose coatings of plum fruits reduced the enzyme activity and improved the flavonoids and phenolic content of the fruit [37]. Ali et al. [38] reported that the application of

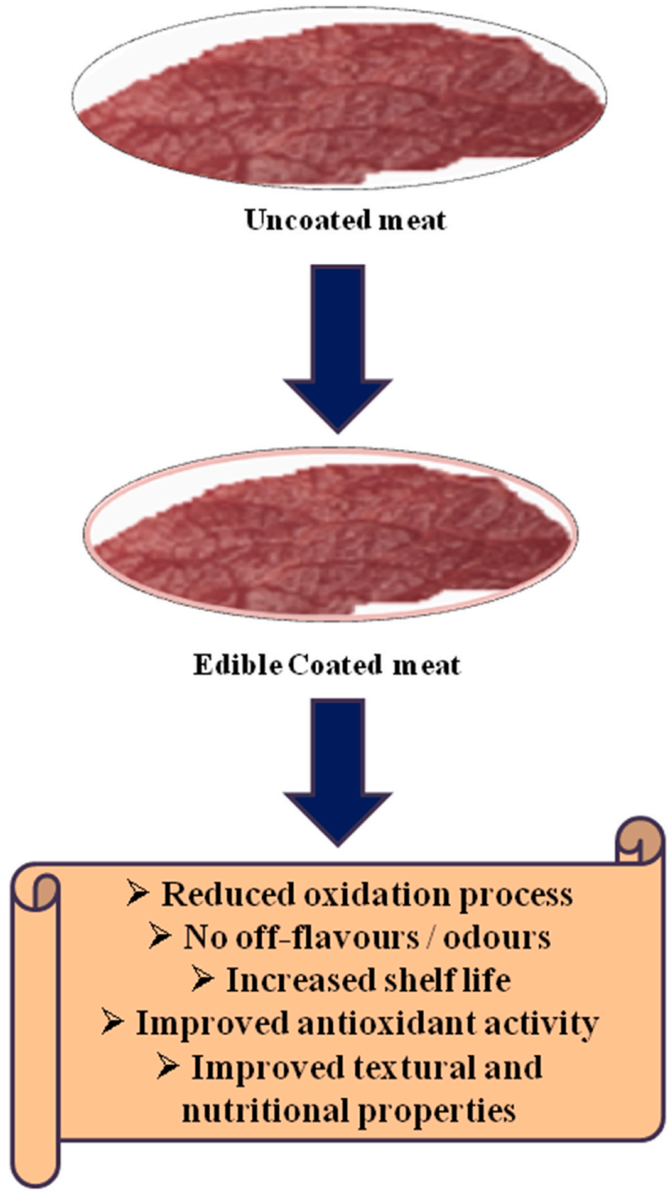

Fig. 4. Merits of edible coating on meat.

carboxymethyl cellulose coating on kinnow mandarins had better sensory properties compared to uncoated fruits. The edible coating of pakchoi using novel carboxymethyl cellulose cross-linked with paraffin wax considerably reduced the peroxidation of lipids and enhanced the ROS scavenging activity [39]. The application of carboxymethyl cellulose edible coating to mangoes reduced the weight loss and delayed the softening of mangoes, which eventually enhanced their shelf life [40]. The edible coating of strawberries using hydroxyethyl cellulose of asparagus waste controlled the colour change during storage and had higher antifungal activity against *Penicillium italicum*. The coating even preserved the phenolic and flavonoid contents of the strawberry and extended the shelf life to 8 days at 25 °C and 80% Relative Humidity (R.H) [41]. The carboxymethyl cellulose coating of guava fruit cv. 'Allahabad Safeda' maintained the firmness and quality of the fruits and extended the shelf life up to 12 days under ambient conditions [42].

2.1.3. Starch

Starch acts as an important polysaccharide used in the edible coating due to its natural availability, low cost, and filmogenic capacity. Starch based coatings are colourless, non-toxic, tasteless, and odourless, making them more suitable for edible coating [36]. The potato, corn, sweet potato, and tapioca starch are the major starches used for the edible coating of fruits and vegetables due to their higher cultivation and production [43]. Starch based edible coatings of fruits and vegetables provide excellent gas barrier properties to reduce senescence, which aids in increasing the shelf life. This kind of coating possesses a strong gas permeability ratio as a result the respiratory exchange ratio can be controlled [44]. Starch based coating marks good record in maintaining the qualities of meat. The application of starch based edible coatings on meat and meat products helps in reducing the browning reactions, dehydration and oxidation [23].

The beef coated with plant based starch had maintained the colour and pH of meat with increased antimicrobial property [29]. Rice starch and cassava starch coating of minimally processed pummelo had less weight loss and low water vapour transmission rate with great extension in the product's shelf life [45]. Applying starch based edible coatings of fruits and vegetables with antimicrobial agents can enhance the sensory and functional properties of coated materials. These antimicrobial coatings are advantageous compared to synthetic packaging in controlling the microbial activity [46]. The respiration rate of the minimally processed strawberry was considerably reduced using a cassava starch edible coating. The coatings increased the water vapour resistance of the strawberry and enhanced its sensorial acceptance [47]. Lemongrass essential oil incorporated cassava starch edible coating of papaya MJ9 inhibited the microbial growth and weight loss of papaya fruits [48]. The edible coatings of tomatoes using mango kernel starch delayed fruit ripening and reduced tomato decay [49]. Rice starch sucrose esters blend edible coating of cavendish banana delayed the degradation of chlorophyll and ethylene synthesis which sequentially extended the shelf life up to 12 days at 20 $\pm$ 2 °C [50].

2.1.4. Aloe vera

Aloe vera gel consists of a high amount of polysaccharides along with sugars, minerals, proteins, vitamins, and a low amount of fats [51]. It has numerous applications in the medicinal industry in promoting the immune system of humans as it possesses antiviral, wound healing, anti-diabetic, and anti-tumor properties [52]. Aloe vera is odourless and edible in nature with antimicrobial activity, making it more commonly used to coat fruits and vegetables [53]. Aloe vera coatings of fresh fruits and vegetables can be a better substitute for chemical-based processing methods and synthetic edible coatings used in post-harvest processing of fruits and vegetables [53]. The rosehip oil combined with aloe vera edible coating of plums and prunes delayed the ripening process by inhibiting the ethylene synthesis [54]. Chrysargyris et al. [55] reported that the application of 10% and 15% aloe vera coating to tomatoes prevented the ethylene production and preserved the quality characteristics of tomatoes. Aloe vera coating of tomatoes retarded the softening process and delayed the ripening of tomatoes [56]. Aloe vera gel edible coating of table grapes reduced the weight and moisture loss due to the low respiration rate. It also inhibited the browning reactions during storage [57]. The edible coating of aloe vera gel along with sage essential oil led to a reduction in the decaying of tomatoes stored at 11 °C and 90% R.H [58]. Application of Aloe vera gel along with neem extract and citric acid to tomatoes showed ripening on the 36th day of storage and preserved the quality of fruits [59].

2.2. Protein

Generally, the different globular proteins like whey, gluten, soy, and zein are used in edible coating and possess excellent oxygen barrier properties [5]. Protein coatings are hydrophilic in nature which can be easily affected by a change in temperature and relative humidity of the storage environment [24]. Storage studies conducted for edible coating of guava using flaxseed proteins indicated that the browning of the fruits is controlled. The coating extended the decaying of fruits and enhanced the shelf life of guava fruits compared to control fruits by 6 days [60]. Similarly, the application of whey protein edible coating to freshly sliced potato and apple delays the occurrence of browning reaction [61]. Edible coating of fresh melons using tilapia protein isolates was found to be efficient in maintaining the colour and firmness. The coating also prevented the growth of yeasts, mold, and psychotropic microorganisms till 12 days of storage [62].

2.3. Lipids

Lipids are small hydrophobic molecules, more commonly used in edible coatings to prevent moisture migration and water vapour transmission. Generally, lipids are used along with other materials like proteins and polysaccharides in combination for edible coating due to their low mechanical strength [63]. Lipid-based edible coating provides excellent moisture barrier property and improvises the appearance of foods due to its glossy and shining nature [64]. The materials used in lipid-based edible coating include natural waxes, petroleum-based waxes and oils, mineral oils, fatty acids, and resins [65]. Yaman and Bayoindirli [66] reported that the edible coating of cherries using commercial Semperfresh™ coating solutions, which are made up of sucrose esters of fatty acids, increased the firmness and effectively reduced the weight loss during storage. Edible coating of tomatoes using candelilla wax along with *Flourensia cernua* inhibited fungal growth and had consumer acceptance [67]. Waxes and shellac are the lipids used extensively for the edible coatings as it is used to improve the appearance of the fruits due to their shinning and glossiness [65].

Lipids are even mixed with other ingredients (extracted from natural sources) and coated on varied kinds of food stuffs. Few majorly used ingredients for lipid based coatings are lipids, oils (essential oils, petroleum based oils, vegetable and mineral oils), fatty acids, resins and waxes (natural and synthetic waxes) [4]. All the above mentioned substances are naturally hydrophobic in nature. Pérez-Gago and Rhim [68] discussed various composite films, developed using different combinations of lipid with polysaccharide and protein. Some commonly used lipid materials are corn oil, mineral oil, lauric acid, oleic acid, palm oil, beeswax, carnauba wax, shellac, candelilla wax, wood rosin, polyethylene wax coumarone indin resin and paraffin wax [19].

2.4. Composite

Nowadays, composite or multiple layered edible coatings of food products are focused to eradicate the barriers of individual compounds and obtaining positive effects from individual compounds [69]. The application of composite edible coatings to fresh produce is generally based on the addition of lipids and hydrocolloids, which improvise the moisture retention and mechanical strength of the coating [70]. The different combinations that could be used for composite edible coating are carbohydrate and protein, proteins and lipids, carbohydrate and lipids [69]. In these combinations, the mechanical properties of the coating are greatly dependent on the carbohydrate or proteins used [6]. The shellac-tannic acid edible coating prolonged the storage of mangoes at room temperature and maintained the firmness and weight loss. The antifungal activity of the coatings was improved due to the addition of tannic acid, which led to increased shelf life [71]. The edible coating of tomatoes using whey protein – xanthan gum combination incorporated with clove oil improved the retention of total sugar, phenolics, and reducing sugar content. The coating inhibited the microbial growth and reduced the respiration rate, which increased the shelf life of tomatoes up to 15 days at 20 °C [72]. Multilayered antimicrobial edible coating of pineapples preserved the texture and quality attributes of fruits during storage, effectually reduced the microbial contamination [73]. Thakur et al. [74] reported that the composite coating of plum fruits using rice starch and carrageenan blended with sucrose fatty acid esters preserved the phytochemical properties during storage.

Similarly, Jiao et al. [75] reported that the edible coating of peach fruits using chitosan grafted with chlorogenic acid inhibited the decay index, respiration rate and maintained the ascorbic acid content of the fruits for 8 days at 20 °C. The multiple layer coating of native/cross-linked sesame protein, guar gum, calcium chloride, and mango puree increased the shelf life of fresh-cut mangoes at 5 °C for 15 days. The coating preserved the colour, total sugars and delayed the degradation of carotenoid contents in fresh-cut mangoes upon storage [76]. Zhang et al. [77] reported that composite edible coating of soybean protein isolate – chitosan prevented the degradation of pectin in apricots, which led to the firmness of the coated fruits. The hydroxypropyl methylcellulose and beewax coating of red guavas formed a modified atmospheric condition around the surface of the fruits, which retarded the ripening of guava. They maintained the firmness and green colour of fruits during storage [78]. Arnon et al. [79] concluded that bi-layer coating of citrus fruits like mandarin, navel orange, and star ruby grapefruit using carboxymethyl cellulose in combination with chitosan improved the glossiness and retained the flavour of the fruits. The antimicrobial activity against *Staphylococcus aureus* has been achieved in beef muscle slices immersed in alginate solution having nisin-palmitoyl [23]. The effect of edible composite coatings on cheese made by combining chitosan with other polysaccharides like starch, cellulose, gelatin and alginate [8]. This kind of coating provides protection against ultra violet rays and temperature. Higher retention of sensory properties can be seen in the ultra filtration cheese which is coated with composite having probiotics and sodium alginate [80].

3. Legislations

3.1. Regulations

The material used in edible coating makes direct contact with the food so that it supposed to gain safety approval before using it for commercial purpose. Thus, the edible material has to be Generally Recognised as Safe (GRAS) by the American Food and Drug Administration (FDA) federal agency prior to use [4]. In addition, the use of approved natural plant extracts and essential oils shows some allergic reactions with few toxic effects depending on the dosage. Therefore, proper measure has to be implemented to periodically check the toxicity, allergic nature of extracts and essential oils used in edible coating production. Green-packaging initiatives like US Environmental Protection Agency supported the research to develop pectin-based edible coatings which could improvise the shelf-life and quality of packed foods [36].

The materials used in edible coatings formation must be of food grade and non-toxic with proper hygiene processing practice. Edible coating production has to follow Goods Manufacturing Practice (GMP). Generally, edible coatings are categorised as food additives, food ingredients or substances and food packaging materials as per the US FDA regulations and European Directive in the year 2006 and 1998 respectively [24]. A list of acceptable additives in each country varies with respect to the regulations. In Europe Directive regulations shellac, pectin, lecithin, fatty acids, polysorbates, arabic gums, karaya gums and beeswax, are included as food ingredients [81]. Whereas castor oil, cocoa butter, polydextrose and sucrose fatty acids are used as food additives in edible coating formulations under FDA, United States.

For clear understanding about the nature of chemicals present in the food industries, the FDA and EFSA (European Food Safety Authority) grouped chemicals under three different categories [4]. The incorporation of nanoparticles, antimicrobial, anti-browning, antioxidant and antifungal like agents in coating formulation is termed as food coating materials (FCM). The final product of packaging like coating or films is known as food contact articles (FCA), whereas the substances employed in making are known as food contact substances (FCS). While producing packaging materials the food producers must adhere to the norms implemented by both the country of origin and destination, as per the Codex Alimentarius. The packaging requirements and the GMP of such FCM has to abide to the norms set by the newly framed regulations no. 1935/2004 and no. 2023/2006 respectively [13].

The edible coating materials for fresh foods must be made using acceptable materials which adhere to the regulations as they are part of the edible portion of food using good manufacturing and good hygienic practices [31,82]. The edible coating materials, which are considered as GRAS or a food additive approved by Food and Drug Administration (FDA), can be used as a coating material for fresh fruits and vegetables [36]. The primary ingredients used for edible coatings are generally made using the listed food additives in European countries. The regulations and rules governing the food additives and approved edible coating biopolymers vary based on country and care must be taken while developing any new edible coating materials [31]. A biopolymer which is not listed as GRAS cannot be used for edible coatings as it can lead to some toxicity and allergenicity upon consumption by humans [36]. The wax coating of fresh fruits and vegetables using carnauba or bee wax is permitted in India by the Prevention of Food Adulteration Act (PFA), which regulates proper labelling and declaration of material used for edible coating [24]. The application of synthetic resins and chemically modified resins for the edible coating of fruits and vegetables are monitored based on the standards given by USFDA and European legislation. Shellac, a GRAS substance is the more commonly used resin for edible coating; it is also used as a food additive.

4. Coating methods with applications

4.1. Dipping

Dipping is the most widely used method in edible coating for fruits and vegetables. The primary advantage of dipping is to attain complete and uniform coating of food products. The food compound to be coated is completely immersed in the coating solution for a certain period of time [3]. The stages in the dipping method is as follows,

- Immersion of food sample which has to be coated.
- Contact with coating mixture for the deposition of thin layer of edible coating.
- Evaporation/Drying of coating and removal of excess coating mixture by heating.

The time of exposure/contact depends on the parameters (density, surface tension, viscosity) of the coating solution, which usually lasts between 5 s and 3 min [83]. Then, the coated sample is left undisturbed for drying of the coated layer. Through this method a uniform layer of coating is attained over the fruits/vegetables sample. The contact time is crucial since the long time exposure leads to adsorption of more moisture. Meanwhile, the less period of contact leaves the food unevenly coated. In order to achieve coating on layers of hydrophobic nature, the layer-by-layer multifaceted/multilayered edible coating method can be carried out [83]. Usually higher viscous coating solutions are coated by dipping method only. The additives of interest like antimicrobial or antioxidant agents are mixed in the coating solution at appropriate ratios prior to the coating process. Sometimes, the coating is applied in the form of foam which results in uniform layer on the food's surface upon rolling [3].

Khodaei et al. [84] studied the effect of edible coating on shelf-life of strawberries using four different compounds namely low methoxy pectin, carboxymethyl cellulose (CMC), persian and tragacanth gum. Upon coating of strawberries by dipping method, CMC showed better results in controlling the weight and decay loss. Whereas in Del-Valle et al. [85] work, the cactus mucilage was used as coating for extending the shelf-life of strawberries. The application of prickly pear cactus mucilage retained the colour and firmness of strawberries to major extent. The researches on various kinds of coating formulations using the dipping technique are tabulated in the Table 1. Chen et al. [16] dealt with the use of protein-based coatings and films for fruits/vegetables packaging. In which, the coatings made using plant (soy protein, zein,

Table 1
Examples of edible coating of foods by dipping technique.

Coating agents	Additives	Food Products	Method of coating	Advantages	References
Chitosan	Lemon essential oil	Strawberry	Dipping	Enhancement of fermentative process	[89]
Cactus pear	Glycerol/Tween 20	Kiwifruit	Dipping	Maintained fruit firmness, ascorbic acid and pectin	[90]
Soy protein/Wheat gluten	Thyme essential oil	Strawberry	Dipping	Lowered post harvest losses	[82]
Shellac	Aloe vera	Tomato	Dipping	Slowed down senescence	[91]
Aloe vera	Tween 20	Nectarine	Dipping	Retards ripening	[92]
Shellac	Sodium alginate	Green chillies	Dipping	Shelf-life extension	[93]
Aloe vera	Garlic oil, Sodium alginate	Tomato	Dipping	Extension of shelf-life	[94]
Pectin	Green tea leaf extract	Pork patty	Dipping	Decrease in lipid oxidation rate	[95]
Chitosan	Aloe vera	Tomato	Dipping	Shelf-life extension & delayed ripening	[96]
Aloe vera	–	Tomato	Dipping	Reduced lycopene, β-carotene and ethylene production	[50]
Basil mucilage	Cumin essential oil	Tomato	Dipping	Decreased weight loss & increased shelf-life	[97]
Aloe vera	Rose hip oil	Plums	Dipping	Improved post harvest attributes	[49]
Cactus mucilage	Glycerol	Strawberry	Dipping	Increase in shelf-life	[81]

gluten) and animal proteins (gelatin, whey, casein) shows remarkable gas barrier properties. Atress et al. [86] investigated the effectiveness of wheat gluten and soy protein along with calcium chloride or thymol as a carrier for achieving better linkage between the food surface and the edible coating. The coating formulations were adjusted to make four different treatments to find the suitable one for increasing the shelf-life of strawberries. The coating prepared using thymol in wheat gluten or soy protein claimed to be the most promising one in maintaining the quality attributes of strawberry. Geraldine et al. [87] observed reduced respiration rate and moisture loss in garlic coated with agar-agar based coating containing chitosan and citric acid. The composite edible coatings (1% carboxymethyl cellulose and 1% chitosan; 1% hydroxypropylmethyl cellulose and 1% chitosan) prepared by Gol et al. [32] showed excellent inhibition action on enzymes involved in strawberry cell wall degradation. As a result, the ripening and senescence processes in strawberries are reduced to notable extent. Therefore, the coated food is preserved for longer time without quality deterioration. The various quality attributes of mango like colour, weight loss, firmness and ripening in research carried out by Moalemiyan et al. [88] The edible coating made up of pectin and beeswax incorporated with monoglyceride and a plasticiser (sorbitol) was used.

4.2. Spraying

In this technique, the coating solution is sprayed over the food sample with the help of an atomizer. As the solution is sprayed at higher pressure, fine droplets are created over the food sample with the size ranging from micrometre to nanometre. The efficiency of spray coating is dependent on the rheological properties of the fluid like surface temperature, viscosity and temperature [83]. Therefore, coating mixture with proper fluid rheology is prepared and made to pass through the nozzle of atomizer. After spraying, the coated sample has to be allowed for some drying to take place. In this stage, the drying method, time and temperature decides the coating efficiency [3]. In addition, the design and kind of nozzle also plays a significant role in spraying. In industries, three different spraying procedures have been accomplished namely air spray atomization, air-assisted airless atomization and pressure atomization. In air spray atomization, the solution is dispersed at slower speed along with the air at higher velocity which induces atomization. Whereas, in air-assisted airless atomization technique, the atomization is carried out using compressed air after the ejection of coating solution from the nozzle. The coating of solution with the assist of pressure alone is termed as pressure or air-less atomization [98].

The nozzle used in spraying is categorised into different types based on their operations. The most commonly used nozzles are pneumatic and hydraulic atomizing nozzles (Solid stream, hollow cone, flat spray, full cone). Andrade et al. [98] discussed about the mechanisms on spray formation by the forces involved in atomization process. The viscous, inertial, surface tension and aerodynamic forces were the major contributors for the fine droplets formation. They are of two kinds namely disruptive and cohesive [99]. The disruptive forces (aerodynamic & inertial) involves in breakdown of large size droplets into smaller one. Whereas, the cohesive forces (aerodynamic & surface tension) involves in the initial formation of droplets over the surface of material.

Spraying techniques provides uniform thin layer of coating solution in mozzarella cheese [100]. The edible coated cheese is given in the Fig. 5. The coating solution made out of starch from pea and guar gum was sprayed over the oranges for analysing the postharvest quality losses. From this Saberi et al. [101] found there was a reduced level of ethylene production in fruits coated with pea starch and guar gum. As well as, the loss of weight and firmness also declined to notable level when compared with the uncoated fruit samples. This results due to the effect of incorporated lipid molecules (shellac and oleic acid) in the coating mixture [101]. Ribeiro et al. [102] reported that, the carrageenan films loaded with calcium chloride reduced the rate of microbial growth on strawberries upon edible coating application by spraying method. It also improved the firmness of the fruit in terms of external firmness recorded at day 2 and day 5, meanwhile the internal firmness did not show any significant difference.

4.3. Fluidized bed processing method

The first fluidized bed was found during the 1950s and coined as Wurster process. It is a modified version of fluidized bed drier, which is widely used in food industries for drying. Fluidized bed processing requires large amount of coating solution when compared with other

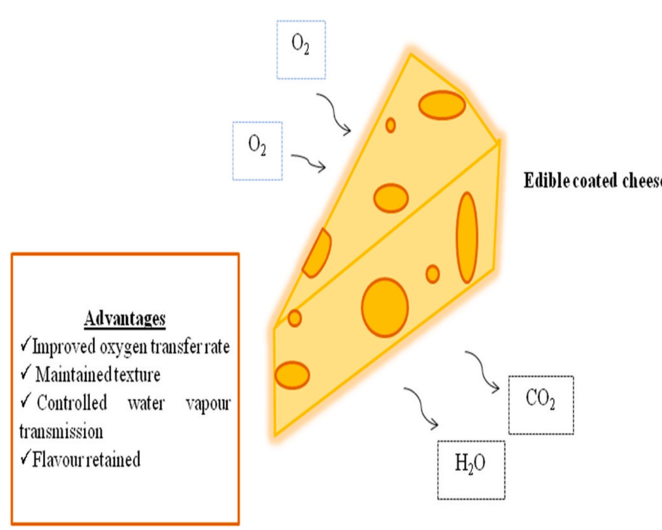

Fig. 5. Edible coated cheese.

methods of coating. Among the three methods of fluidized bed (top, rotary and bottom spray) process, the top spray type remains to be the most efficient method [103]. In top spray fluidized bed, the coating is sprayed on the food stuffs through the nozzle (binary/pneumatic) at a low pressure. Also, Solís-Morales et al. [103] investigated the performance of fluidized bed coating method by comparing with the conventional tumbling process. It was found that fluidized bed coating recorded reduced amount of weight loss of ready to eat food with more resistant to attrition and increased crispness. This technique faces solution loss while coating the food, since major amount of coating gets adhered to the side walls of the coating unit [89]. At times, premature evaporation happens which could lead to uneven coating on the food surface. The advantage of using fluidized bed is no cluster formation and lesser processing time.

4.4. Panning method

A large pan like rotating container is utilised for the edible coating process named as panning method. In this method, the food to be coated is placed inside the pan, on which the coating solution is sprinkled or sputtered. A spray gun is fitted inside the coating chamber for the release of coating solution over the food products [7]. During the cycle of coating, the pan is continuously rotated at particular speed for overall distribution of the coating material [83]. Once the coating is done, the product is moved into the drying cycle, where the hot air is made to pass through it to achieve complete drying. The foods with round or oval shapes can be coated effectively by this technique. As mentioned by L. Kumar et al. [7], the amount of coating solution applied decides the thickness of the coating.

5. Factors affecting coating process

The post-harvest quality loss defines the challenges encountered during the production and application of edible coatings on fruits and vegetables. There are few factors which constrains the usage of edible coating on food products. These factors are listed below,

5.1. Improper storage condition

Maintaining the suitable storage condition for coated food products is more crucial and tedious one. The coating material modifies the internal atmosphere by which the exchange of gases is controlled; therefore the ripening of coated food products is delayed [6].

5.2. Limited gas barrier property

The production of ethylene gas is only responsible for the ripening of fruit, thus the ethylene production is directly related to the ripening and senescence [90]. The action of strong barrier towards gaseous exchange is more predominant in edible coatings.

5.3. Low adhesion

The proper adhesion of coating material on the surface of food is an important parameter in making a successful edible coating. The post-harvest losses could be maintained in control, upon the proper coating of food material. The hydrophilic coatings have poor adherence to the hydrophobic surface of entire fruits as the two surfaces have distinct chemical compositions in nature. In such cases, surfactants are added to improve the adhesion and wettability of the edible coatings [6]. Also, the improper/uneven adhesion of coating mixture over the fruit to some extent looks unappealing in consumer views.

5.4. Inadequate moisture barrier property

If the moisture retention is low then the food firmness will be lost due the accumulation of more amount of water. The percentage of water present in the packed food is important to maintain the freshness and textural properties. The coatings based on mineral oils had lesser moisture loss when compared with the uncoated food [91].

5.5. Undesired sensory effects

A careful selection of film-forming agents, additives and plasticisers is must in order to prevent off-flavours or undesirable sensory changes in the coated food [6]. The coating solution itself might be the reason for off-flavours in some cases. Therefore, utmost care has to be taken in framing the coating composition.

6. Advantages and disadvantages of edible coating

Few advantages of edible coating described by Dhall et al. [24] are listed below,

- Edible coating provides glossy appearance to the coated food products.
- Decreases the respiration rate and emission of ethylene gas, thereby declining the senescence phase of fruits/vegetables.
- Eliminates the use of non-biodegradable and hazardous packaging.
- Prevents the loss of volatile compounds present in food products.
- Maintains fruit firmness and reduces the weight loss to some extent.
- Aids in the shelf-life extension of fruits and vegetables.
- Free from toxic and reactive chemicals which leads to harmful effects on humans.
- Moisture loss can be minimized by the application of coating, which acts as a barrier.
- Incorporation of some active ingredients provides antimicrobial protection to the coated food products.
- Few physical damages can also be controlled.
  However, edible coatings also hold few disadvantages which are as follows,
- Loss of food quality due to few modifications in the coating with respect to gaseous exchanges upon packaging.
- Increased coating thickness leaves undesirable changes in the coated food product by altering its flavour, weight loss and texture.
- Some sensory related alterations are noted while imparting antimicrobial compounds.
- The raw materials used for coating preparation results in allergic reaction when consumed.
- Few kinds of coating methods incur huge cost, which eventually leads to hike in the price of commodities.

7. Future trends

Nowadays, consumer awareness of safe and chemical-free foods has changed the market dynamics, which has led to the emergence of edible coating as a better alternative solution in the current scenario. Generally, permissible and GRAS-grade materials are used for edible coatings of different commodities. However, the coatings' adequate moisture, oxygen barriers and other properties significantly affect their commercial usage. Therefore, determining the perfect combination of different polymers for the specific agricultural produce effectively enhances its shelf life. Even though the concept of edible coatings has evolved over a long period, the possibilities for commercialization in the market remain challenging. Further, research in the edible coating field is warranted to determine precisely the changes occurring due to the active compounds added in the edible coatings in the sensorial and organoleptic properties of the food products.

8. Conclusion

This review article discussed the kinds of materials used in edible coatings as well as the techniques and regulations followed in the application. The edible coatings incorporated with essential oils, antimicrobials and other active ingredients have more potential applications in protecting the foods from spoilage. The utilization of various polysaccharides, proteins and lipids from waste biomass aids in valorising the waste. With these innovative and novel kinds of edible coatings, the storage life of highly perishable foods can be increased to greater extent. Still intense research is required to know about the safety and reactivity of incorporated active ingredients in the coatings. Above all, the application of edible coatings in food products (fruits, vegetables, meat, and milk products) is an important and promising research field in the food sector.

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Declaration of competing interest

The authors declare no potential conflict of interest.

Data availability

Data will be made available on request.

References

[1] A.C. Miteluț, E.E. Popa, M.C. Drăghici, P.A. Popescu, V.I. Popa, O.C. Bujor, V. A. Ion, M.E. Popa, Latest developments in edible coatings on minimally processed fruits and vegetables: a review, Foods 10 (2021) 1–18, https://doi.org/10.3390/foods10112821.
[2] C.M. Galanakis, The food systems in the era of the coronavirus (COVID-19), Foods 9 (2020) 523.
[3] J. Ju, Y. Xie, Y. Guo, Y. Cheng, H. Qian, W. Yao, Application of edible coating with essential oil in food preservation, Crit. Rev. Food Sci. Nutr. 59 (2019) 2467–2480, https://doi.org/10.1080/10408398.2018.1456402.
[4] S. Paidari, N. Zamindar, R. Tahergorabi, M. Kargar, S. Ezzati, N. shirani, S. H. Musavi, Edible coating and films as promising packaging: a mini review, J. Food Meas. Char. 15 (2021) 4205–4214, https://doi.org/10.1007/s11694-021-00979-7.
[5] B. Hassan, S.A.S. Chatha, A.I. Hussain, K.M. Zia, N. Akhtar, Recent advances on polysaccharides, lipids and protein based edible films and coatings: a review, Int. J. Biol. Macromol. 109 (2018) 1095–1107, https://doi.org/10.1016/j.ijbiomac.2017.11.097.
[6] D. Lin, Y. Zhao, Innovations in the development and application of edible coatings for fresh and minimally processed fruits and vegetables, Compr. Rev. Food Sci. Food Saf. 6 (2007) 60–75, https://doi.org/10.1111/j.1541-4337.2007.00018.x.
[7] L. Kumar, D. Ramakanth, K. Akhila, K.K. Gaikwad, Edible films and coatings for food packaging applications: a review, Environ. Chem. Lett. 20 (2022) 875–900, https://doi.org/10.1007/s10311-021-01339-z.
[8] M.W. Iqbal, T. Riaz, I. Yasmin, A.A. Leghari, S. Amin, M. Bilal, X. Qi, Chitosan-based materials as edible coating of cheese: a review, Starch/Staerke 73 (2021), https://doi.org/10.1002/star.202100088.
[9] P. Umaraw, A.K. Verma, Comprehensive Review on Application of Edible Film on Meat and Meat Products: an Eco-Friendly Approach, 2017, https://doi.org/10.1080/10408398.2014.986563.
[10] A.C.P. Vital, A. Guerrero, J.D.O. Monteschio, M.V. Valero, C.B. Carvalho, B.A. De Abreu Filho, G.S. Madrona, I.N. Do Prado, Effect of edible and active coating (with rosemary and oregano essential oils) on beef characteristics and consumer acceptability, PLoS One 11 (2016) 1–15, https://doi.org/10.1371/journal.pone.0160535.
[11] M. Hashemi, M. Hashemi, S. Daneshamooz, M. Raeisi, B. Jannat, S. Taheri, S.M. A. Noori, An overview on antioxidants activity of polysaccharide edible films and coatings contains essential oils and herb extracts in meat and meat products, Adv. Anim. Vet. Sci. 8 (2020) 198–207, https://doi.org/10.17582/journal.aavs/2020/8.2.198.207.
[12] S. Jafarzadeh, A. Salehabadi, A. Mohammadi Nafchi, N. Oladzadabbasabadi, S. M. Jafari, Cheese packaging by edible coatings and biodegradable nanocomposites; improvement in shelf life, physicochemical and sensory properties, Trends Food Sci. Technol. 116 (2021) 218–231, https://doi.org/10.1016/j.tifs.2021.07.021.
[13] P. Umaraw, P.E.S. Munekata, A.K. Verma, F.J. Barba, V.P. Singh, P. Kumar, J. M. Lorenzo, Edible films/coating with tailored properties for active packaging of meat, fish and derived products, Trends Food Sci. Technol. 98 (2020) 10–24, https://doi.org/10.1016/j.tifs.2020.01.032.
[14] A.B. Amaral, M.V. Da Solva, S.C.D.S. Lannes, Lipid oxidation in meat: mechanisms and protective factors - a review, Food Sci. Technol. 38 (2018) 1–15, https://doi.org/10.1590/fst.32518.
[15] R. Domínguez, M. Pateiro, M. Gagaoua, F.J. Barba, W. Zhang, J.M. Lorenzo, A comprehensive review on lipid oxidation in meat and meat products, Antioxidants 8 (2019) 1–31, https://doi.org/10.3390/antiox8100429.
[16] H. Chen, J. Wang, Y. Cheng, C. Wang, H. Liu, H. Bian, Y. Pan, J. Sun, W. Han, Application of protein-based films and coatings for food packaging: a review, Polymers 11 (2019) 1–32, https://doi.org/10.3390/polym11122039.
[17] S. Beikzadeh, A. Khezerlou, S.M. Jafari, Z. Pilevar, A.M. Mortazavian, Seed mucilages as the functional ingredients for biodegradable films and edible coatings in the food industry, Adv. Colloid Interface Sci. 280 (2020), 102164, https://doi.org/10.1016/j.cis.2020.102164.
[18] C.M. Galanakis, M. Rizou, T.M.S. Aldawoud, I. Ucak, N.J. Rowan, Innovations and technology disruptions in the food sector within the COVID-19 pandemic and post-lockdown era, Trends Food Sci. Technol. 110 (2021) 193–200, https://doi.org/10.1016/j.tifs.2021.02.002.
[19] S. Panahirad, M. Dadpour, S.H. Peighambardoust, M. Soltanzadeh, B. Gullón, K. Alirezalu, J.M. Lorenzo, Applications of carboxymethyl cellulose- and pectin-based active edible coatings in preservation of fruits and vegetables: a review, Trends Food Sci. Technol. 110 (2021) 663–673, https://doi.org/10.1016/j.tifs.2021.02.025.
[20] C.M. Galanakis, T.M.S. Aldawoud, M. Rizou, N.J. Rowan, S.A. Ibrahim, Food ingredients and active compounds against the coronavirus disease (COVID-19) pandemic: a comprehensive review, Foods 9 (2020) 1701, https://doi.org/10.3390/foods9111701.
[21] A. Pirozzi, G. Pataro, F. Donsì, G. Ferrari, Edible coating and pulsed light to increase the shelf life of food products, Food Eng. Rev. 13 (2021) 544–569, https://doi.org/10.1007/s12393-020-09245-w.
[22] M. Lacroix, K.D. Vu, Edible Coating and Film Materials: Proteins, Elsevier Ltd, 2013, https://doi.org/10.1016/B978-0-12-394601-0.00011-4.
[23] Y.B. Bhagath, K. Manjula, Influence of composite edible coating systems on preservation of fresh meat cuts and products: a brief review on their trends and applications, Int. Food Res. J. 26 (2019) 377–392.
[24] R.K. Dhall, Advances in edible coatings for fresh fruits and vegetables: a review, Crit. Rev. Food Sci. Nutr. 53 (2013) 435–450, https://doi.org/10.1080/10408398.2010.541568.
[25] H.M.C. de Azeredo, Edible coatings, in: Adv. Fruit Process, Technol., 2012, pp. 387–414, https://doi.org/10.1201/b12088.
[26] N. Kumar, Neeraj, Polysaccharide-based component and their relevance in edible film/coating: a review, Nutr. Food Sci. 49 (2019) 793–823, https://doi.org/10.1108/NFS-10-2018-0294.
[27] Y. Zhang, C. Rempel, D. Mclaren, Edible Coating and Film Materials: Carbohydrates, Elsevier Ltd, 2014, https://doi.org/10.1016/B978-0-12-394601-0.00012-6.
[28] S.F. El-Gioushy, M.F.M. Abdelkader, M.H. Mahmoud, H.M. Abou El Ghit, M. Fikry, A.M.E. Bahloul, A.R. Morsy, L.A. A, A.M.R.A. Abdelaziz, H.A. S. Alhaithloul, D.M. Hikal, M.A. Abdein, K.H.A. Hassan, M.S. Gawish, The effects of a gum Arabic-based edible coating on guava fruit characteristics during storage, Coatings 12 (2022) 90, https://doi.org/10.3390/coatings12010090.
[29] D.H. Song, V.B. Hoa, H.W. Kim, S.M. Khang, S.H. Cho, J.S. Ham, K.H. Seol, Edible films on meat and meat products, Coatings 11 (2021), https://doi.org/10.3390/coatings11111344.
[30] S. Galus, E.A.A. Kibar, M. Gniewosz, K. Kraśniewska, Novel materials in the preparation of edible films and coatings-A review, Coatings 10 (2020) 1–14, https://doi.org/10.3390/coatings10070674.
[31] K. Aayush, D. Julian, S. Sharma, R. Sharma, G. Pal, K. Sharma, K. Oberoi, Innovations in the development and application of edible coatings for fresh and minimally processed Apple, Food Control 141 (2022), 109188, https://doi.org/10.1016/j.foodcont.2022.109188.
[32] N.B. Gol, P.R. Patel, T.V.R. Rao, Improvement of quality and shelf-life of strawberries with edible coatings enriched with chitosan, Postharvest Biol. Technol. 85 (2013) 185–195, https://doi.org/10.1016/j.postharvbio.2013.06.008.
[33] N. Suseno, E. Savitri, L. Sapei, K.S. Padmawijaya, Improving shelf-life of cavendish banana using chitosan edible coating, Procedia Chem. 9 (2014) 113–120, https://doi.org/10.1016/j.proche.2014.05.014.
[34] S. Chaudhary, S. Kumar, V. Kumar, R. Sharma, Chitosan nanoemulsions as advanced edible coatings for fruits and vegetables: composition, fabrication and developments in last decade, Int. J. Biol. Macromol. 152 (2020) 154–170, https://doi.org/10.1016/j.ijbiomac.2020.02.276.
[35] K. Divya, V. Smitha, M.S. Jisha, Antifungal, antioxidant and cytotoxic activities of chitosan nanoparticles and its use as an edible coating on vegetables, Int. J. Biol. Macromol. 114 (2018) 572–577, https://doi.org/10.1016/j.ijbiomac.2018.03.130.
[36] A. Kocira, K. Kozłowicz, K. Panasiewicz, M. Staniak, E. Szpunar-Krok, P. Hortyńska, Polysaccharides as edible films and coatings: characteristics and influence on fruit and vegetable quality—a review, Agronomy 11 (2021) 1–38, https://doi.org/10.3390/agronomy11050813.
[37] S. Panahirad, R. Naghshiband-Hassani, S. Bergin, R. Katam, N. Mahna, Improvement of postharvest quality of plum (Prunus domestica L.) using polysaccharide-based edible coatings, Plants 9 (2020) 1–16, https://doi.org/10.3390/plants9091148.
[38] S. Ali, M.A. Anjum, S. Ejaz, S. Hussain, S. Ercisli, M.S. Saleem, H. Sardar, Carboxymethyl cellulose coating delays chilling injury development and

maintains eating quality of 'Kinnow'Mandarin fruits during low temperature storage, Int. J. Biol. Macromol. 168 (2021) 77–85.
[39] K. Yu, L. Zhou, J. Xu, F. Jiang, Z. Zhong, L. Zou, W. Liu, Carboxymethyl cellulose-based water barrier coating regulated postharvest quality and ROS metabolism of pakchoi (Brassica chinensis L.), Postharvest Biol. Technol. 185 (2022), 111804.
[40] S. Ali, M.A. Anjum, A.S. Khan, A. Nawaz, S. Ejaz, G. Khaliq, S. Iqbal, S. Ullah, R.N. U. Rehman, M.M. Ali, Carboxymethyl cellulose coating delays ripening of harvested mango fruits by regulating softening enzymes activities, Food Chem. 380 (2022), 131804.
[41] C. Liu, T. Jin, W. Liu, W. Hao, L. Yan, L. Zheng, Effects of hydroxyethyl cellulose and sodium alginate edible coating containing asparagus waste extract on postharvest quality of strawberry fruit, Lwt 148 (2021), 111770, https://doi.org/10.1016/j.lwt.2021.111770.
[42] S. Kumar, A.K. Baswal, A. Ramezanian, K.S. Gill, A.A. Mirza, Impact of carboxymethyl cellulose based edible coating on storage life and quality of guava fruit cv. 'Allahabad Safeda' under ambient storage conditions, J. Food Meas. Char. 15 (2021) 4805–4812, https://doi.org/10.1007/s11694-021-01057-8.
[43] M. Sapper, A. Chiralt, Starch-based coatings for preservation of fruits and vegetables, Coatings 8 (2018), https://doi.org/10.3390/coatings8050152.
[44] F. Versino, O.V. Lopez, M.A. Garcia, N.E. Zaritzky, Starch-based films and food coatings: an overview, Starch/Staerke 68 (2016) 1026–1037, https://doi.org/10.1002/star.201600095.
[45] O. Kerdchoechuen, N. Laohakunjit, P. Tussavil, N. Kaisangsri, F.B. Matta, Effect of starch-based edible coatings on quality of minimally processed pummelo (citrus maxima merr.), Int. J. Fruit Sci. 11 (2011) 410–423, https://doi.org/10.1080/15538362.2011.630588.
[46] W. Oyom, Z. Zhang, Y. Bi, R. Tahergorabi, Application of starch-based coatings incorporated with antimicrobial agents for preservation of fruits and vegetables: a review, Prog. Org. Coating 166 (2022), 106800.
[47] L.C. Garcia, L.M. Pereira, C.I.G. de Luca Sarantópoulos, M.D. Hubinger, Selection of an edible starch coating for minimally processed strawberry, Food Bioprocess Technol. 3 (2010) 834–842, https://doi.org/10.1007/s11947-009-0313-9.
[48] S.N. Kane, A. Mishra, A.K. Dutta, Effect of cassava starch-based edible coating incorporated with lemongrass essential oil on the quality of papaya MJ9, in: Interantional Conf. Adv. Mater. Better Futur., 2017, https://doi.org/10.1088/1742-6596/755/1/011001.
[49] A. Nawab, F. Alam, A. Hasnain, Mango kernel starch as a novel edible coating for enhancing shelf- life of tomato (Solanum lycopersicum) fruit, Int. J. Biol. Macromol. 103 (2017) 581–586, https://doi.org/10.1016/j.ijbiomac.2017.05.057.
[50] R. Thakur, P. Pristijono, M. Bowyer, S.P. Singh, C.J. Scarlett, C.E. Stathopoulos, Q.V. Vuong, A starch edible surface coating delays banana fruit ripening, Lwt 100 (2019) 341–347, https://doi.org/10.1016/j.lwt.2018.10.055.
[51] L. Mohammadi, A. Ramezanian, F. Tanaka, F. Tanaka, Impact of Aloe vera gel coating enriched with basil (Ocimum basilicum L.) essential oil on postharvest quality of strawberry fruit, J. Food Meas. Char. 15 (2021) 353–362, https://doi.org/10.1007/s11694-020-00634-7.
[52] I. Nicolau-Lapeña, P. Colàs-Medà, I. Alegre, I. Aguiló-Aguayo, P. Muranyi, I. Viñas, Aloe vera gel: an update on its use as a functional edible coating to preserve fruits and vegetables, Prog. Org. Coating 151 (2021), https://doi.org/10.1016/j.porgcoat.2020.106007.
[53] J. Misir, F.H. Brishti, M.M. Hoque, *Aloe vera* gel as a novel edible coating for fresh fruits: a review, Adv. J. Food Sci. Technol. 2 (2014) 93–97, https://doi.org/10.12691/ajfst-2-3-3.
[54] D. Martinez-Romero, D. Paladines, M. Valverde, F. Guillén, P.J. Zapata, D. Valero, Rosehip oil added to Aloe vera gel as postharvest coating of 'Songría' plums and 'President' prunes, Acta Hortic. 1194 (2018) 321–325, https://doi.org/10.17660/ActaHortic.2018.1194.46.
[55] A. Chrysargyris, A. Nikou, N. Tzortzakis, Effectiveness of Aloe vera gel coating for maintaining tomato fruit quality, N. Z. J. Crop Hortic. Sci. 44 (2016) 203–217, https://doi.org/10.1080/01140671.2016.1181661.
[56] K.A. Athmaselvi, P. Sumitha, B. Revathy, Development of Aloe vera based edible coating for tomato, Int. Agrophys. 27 (2013) 369–375, https://doi.org/10.2478/intag-2013-0006.
[57] J.M. Valverde, D. Valero, D. Martínez-Romero, F. Guillén, S. Castillo, M. Serrano, Novel edible coating based on Aloe vera gel to maintain table grape quality and safety, J. Agric. Food Chem. 53 (2005) 7807–7813, https://doi.org/10.1021/jf050962v.
[58] N. Tzortzakis, P. Xylia, A. Chrysargyris, Sage Essential Oil Improves the Effectiveness of Aloe Vera Gel on Postharvest Quality of Tomato Fruit, 9, Agronomy, 2019, https://doi.org/10.3390/agronomy9100635.
[59] J.A. Kumar, K. Simple, B. Tripti, Studies to enhance the shelf life of tomato using aloe vera and neem based herbal coating, J. Postharvest Technol. 6 (2018) 21–28.
[60] M. Sharma, C.S. Saini, Efficacy of flaxseed protein-based edible coatings on the quality of whole guava (Psidium guajava) during storage, Food Sci. Appl. Biotechnol. 2022 (2022) 2022.
[61] M. Guo, Whey Protein Production, Chemistry, Functionality, and Applications, John Wiley & Sons, 2019.
[62] R.C. Chevalier, S. Pizato, J.A.F. de Lara, W.R. Cortez-Vega, Obtaining protein isolate of tilapia (Oreochromis niloticus) and its application as coating in fresh-cut melons, J. Food Saf. 38 (2018) 1–10, https://doi.org/10.1111/jfs.12496.
[63] B. Yousuf, Y. Sun, S. Wu, Lipid and lipid-containing composite edible coatings and films, Food Rev. Int. (2021) 1–24, https://doi.org/10.1080/87559129.2021.1876084, 00.
[64] B. Yousuf, O.S. Qadri, Preservation of Fresh-Cut Fruits and Vegetables by Edible Coatings, Elsevier Inc., 2019, https://doi.org/10.1016/B978-0-12-816184-5.00011-2.
[65] J.W. Rhim, T.H. Shellhammer, Lipid-based edible films and coatings, in: Innov. Food Packag., Elsevier Ltd, 2005, pp. 362–383, https://doi.org/10.1016/B978-0-12-816897-4.00027-8.
[66] Ö. Yaman, L. Bayoindirli, Effects of an edible coating and cold storage on shelf-life and quality of cherries, LWT–Food Sci. Technol. 35 (2002) 146–150, https://doi.org/10.1006/fstl.2001.0827.
[67] J. Ruiz-Martínez, J.A. Aguirre-Joya, R. Rojas, A. Vicente, M.A. Aguilar-González, R. Rodríguez-Herrera, O.B. Alvarez-Perez, C. Torres-León, C.N. Aguilar, Candelilla wax edible coating with flourensia cernua bioactives to prolong the quality of tomato fruits, Foods 9 (2020) 1–12, https://doi.org/10.3390/foods9091303.
[68] M.B. Pérez-Gago, J.W. Rhim, Edible coating and film materials: lipid bilayers and lipid emulsions, in: Innov. Food Packag, second ed., 2013, pp. 325–350, https://doi.org/10.1016/B978-0-12-394601-0.00013-8.
[69] A. Bizymis, C. Tzia, Edible films and coatings: properties for the selection of the components , evolution through composites and nanomaterials , and safety issues, Crit. Rev. Food Sci. Nutr. (2021) 1–16, https://doi.org/10.1080/10408398.2021.1934652, 0.
[70] A. Yadav, N. Kumar, A. Upadhyay, S. Sethi, A. Singh, Edible coating as postharvest management strategy for shelf-life extension of fresh tomato (Solanum lycopersicum L.): an overview, J. Food Sci. (2022), https://doi.org/10.1111/1750-3841.16145.
[71] J. Ma, Z. Zhou, K. Li, K. Li, L. Liu, W. Zhang, J. Xu, Novel edible coating based on shellac and tannic acid for prolonging postharvest shelf life and improving overall quality of mango, Food Chem. 354 (2021), 129510, https://doi.org/10.1016/j.foodchem.2021.129510.
[72] A. Kumar, C.S. Saini, Edible composite bi-layer coating based on whey protein isolate, xanthan gum and clove oil for prolonging shelf life of tomatoes, Meas. Food. 2 (2021), 100005, https://doi.org/10.1016/j.meafoo.2021.100005.
[73] N. Mantilla, M.E. Castell-Perez, C. Gomes, R.G. Moreira, Multilayered antimicrobial edible coating and its effect on quality and shelf-life of fresh-cut pineapple (Ananas comosus), LWT–Food Sci. Technol. 51 (2013) 37–43, https://doi.org/10.1016/j.lwt.2012.10.010.
[74] R. Thakur, P. Pristijono, J.B. Golding, C.E. Stathopoulos, C.J. Scarlett, M. Bowyer, S.P. Singh, Q.V. Vuong, Development and application of rice starch based edible coating to improve the postharvest storage potential and quality of plum fruit (Prunus salicina), Sci. Hortic. (Amsterdam) 237 (2018) 59–66, https://doi.org/10.1016/j.scienta.2018.04.005.
[75] W. Jiao, C. Shu, X. Li, J. Cao, X. Fan, W. Jiang, Preparation of a chitosan-chlorogenic acid conjugate and its application as edible coating in postharvest preservation of peach fruit, Postharvest Biol. Technol. 154 (2019) 129–136, https://doi.org/10.1016/j.postharvbio.2019.05.003.
[76] L. Sharma, C.S. Saini, H.K. Sharma, K.S. Sandhu, Biocomposite edible coatings based on cross linked-sesame protein and mango puree for the shelf life stability of fresh-cut mango fruit, J. Food Process. Eng. 42 (2019) 1–9, https://doi.org/10.1111/jfpe.12938.
[77] L. Zhang, F. Chen, S. Lai, H. Wang, H. Yang, Impact of soybean protein isolate-chitosan edible coating on the softening of apricot fruit during storage, Lwt 96 (2018) 604–611, https://doi.org/10.1016/j.lwt.2018.06.011.
[78] A.S. Formiga, J.S. Pinsetta, E.M. Pereira, I.N.F. Cordeiro, B.H. Mattiuz, Use of edible coatings based on hydroxypropyl methylcellulose and beeswax in the conservation of red guava 'Pedro Sato, Food Chem. 290 (2019) 144–151, https://doi.org/10.1016/j.foodchem.2019.03.142.
[79] H. Arnon, Y. Zaitsev, R. Porat, E. Poverenov, Effects of carboxymethyl cellulose and chitosan bilayer edible coating on postharvest quality of citrus fruit, Postharvest Biol. Technol. 87 (2014) 21–26.
[80] H.S. El-Sayed, S.M. El-Sayed, A.M.M. Mabrouk, G.A. Nawwar, A.M. Youssef, Development of eco-friendly probiotic edible coatings based on chitosan, alginate and carboxymethyl cellulose for improving the shelf life of UF soft cheese, J. Polym. Environ. 29 (2021) 1941–1953, https://doi.org/10.1007/s10924-020-02003-3.
[81] M. Vargas, C. Pastor, A. Chiralt, D.J. McClements, C. González-Martínez, Recent advances in edible coatings for fresh and minimally processed fruits, Crit. Rev. Food Sci. Nutr. 48 (2008) 496–511, https://doi.org/10.1080/10408390701537344.
[82] S.L. Nayak, S. Sethi, R.R. Sharma, U. Prajapati, Polymers for agri-food applications, in: Polym. Agri-Food Appl., 2019, pp. 417–432, https://doi.org/10.1007/978-3-030-19416-1.
[83] R. Suhag, N. Kumar, A.T. Petkoska, A. Upadhyay, Film formation and deposition methods of edible coating on food products: a review, Food Res. Int. 136 (2020), 109582, https://doi.org/10.1016/j.foodres.2020.109582.
[84] D. Khodaei, Z. Hamidi-Esfahani, E. Rahmati, Effect of edible coatings on the shelf-life of fresh strawberries: a comparative study using TOPSIS-Shannon entropy method, NFS J 23 (2021) 17–23, https://doi.org/10.1016/j.nfs.2021.02.003.
[85] V. Del-Valle, P. Hernández-Muñoz, A. Guarda, M.J. Galotto, Development of a cactus-mucilage edible coating (Opuntia ficus indica) and its application to extend strawberry (Fragaria ananassa) shelf-life, Food Chem. 91 (2005) 751–756, https://doi.org/10.1016/j.foodchem.2004.07.002.
[86] A. Atress, M.M. El-Mogy, H.E. Aboul-Anean, B.W. Alsanius, Improving strawberry fruit storability by edible coating as a carrier of thymol or calcium chloride, J. Hortic. Sci. Ornam. Plants 2 (2010) 88–97.
[87] R.M. Geraldine, N. de F.F. Soares, D.A. Botrel, L. de Almeida Gonçalves, Characterization and effect of edible coatings on minimally processed garlic

quality, Carbohydr. Polym. 72 (2008) 403–409, https://doi.org/10.1016/j.carbpol.2007.09.012.
[88] M. Moalemiyan, H.S. Ramaswamy, N. Maftoonazad, Pectin-based edible coating for shelf-life extension of Ataulfo mango, J. Food Process. Eng. 35 (2012) 572–600, https://doi.org/10.1111/j.1745-4530.2010.00609.x.
[89] J. Zank, M. Kind, E. Schlunder, Kind Zank, Schlünder - 2001 - Particle Growth and Droplet Deposition in Fluidised Bed Granulation, pdf, 2001, pp. 76–81.
[90] S. Jafarzadeh, A. Mohammadi Nafchi, A. Salehabadi, N. Oladzad-abbasabadi, S. M. Jafari, Application of bio-nanocomposite films and edible coatings for extending the shelf life of fresh fruits and vegetables, Adv. Colloid Interface Sci. 291 (2021), 102405, https://doi.org/10.1016/j.cis.2021.102405.
[91] E. Ayranci, S. Tunc, The effect of edible coatings on water and vitamin C loss of apricots (Armeniaca vulgaris Lam.) and green peppers (Capsicum annuum L.), Food Chem. 87 (2004) 339–342, https://doi.org/10.1016/j.foodchem.2003.12.003.
[92] M.J. Ahmed, Z. Singh, A.S. Khan, Postharvest Aloe vera gel-coating modulates fruit ripening and quality of "Arctic Snow" nectarine kept in ambient and cold storage, Int. J. Food Sci. Technol. 44 (2009) 1024–1033, https://doi.org/10.1111/j.1365-2621.2008.01873.x.
[93] K. Chitravathi, O.P. Chauhan, P.S. Raju, Postharvest shelf-life extension of green chillies (Capsicum annuum L.) using shellac-based edible surface coatings, Postharvest Biol. Technol. 92 (2014) 146–148, https://doi.org/10.1016/j.postharvbio.2014.01.021.
[94] M.S. Abdel Aziz, H.E. Salama, Developing multifunctional edible coatings based on alginate for active food packaging, Int. J. Biol. Macromol. 190 (2021) 837–844, https://doi.org/10.1016/j.ijbiomac.2021.09.031.
[95] H.J. Kang, C. Jo, J.H. Kwon, J.H. Kim, H.J. Chung, M.W. Byun, Effect of a pectin-based edible coating containing green tea powder on the quality of irradiated pork patty, Food Control 18 (2007) 430–435, https://doi.org/10.1016/j.foodcont.2005.11.010.
[96] D. Khatri, J. Panigrahi, A. Prajapati, H. Bariya, Attributes of Aloe vera gel and chitosan treatments on the quality and biochemical traits of post-harvest tomatoes, Sci. Hortic. (Amsterdam) 259 (2020) 108837, https://doi.org/10.1016/j.scienta.2019.108837.
[97] H.S. Tabarestani, N. Sedaghat, E.S. Pooya, Shelf life improvement and postharvest quality of cherry tomato (Solanum lycopersicum L.) fruit using basil mucilage edible coating and cumin essential oil, Intl. J. Agron. Plant. Prod. 4 (9) (2013) 2346–2353.
[98] R.D. Andrade, O. Skurtys, F.A. Osorio, Atomizing spray systems for application of edible coatings, Compr. Rev. Food Sci. Food Saf. 11 (2012) 323–337, https://doi.org/10.1111/j.1541-4337.2012.00186.x.
[99] M.A. Rahman, T. Heidrick, B.A. Fleck, Correlations between the two-phase gas/liquid spray atomization and the Stokes/aerodynamic weber numbers, J. Phys. Conf. Ser. 147 (2009), https://doi.org/10.1088/1742-6596/147/1/012057.
[100] Y. Zhong, G. Cavender, Y. Zhao, Investigation of different coating application methods on the performance of edible coatings on Mozzarella cheese, LWT–Food Sci. Technol. 56 (2014) 1–8, https://doi.org/10.1016/j.lwt.2013.11.006.
[101] B. Saberi, J.B. Golding, J.R. Marques, P. Pristijono, S. Chockchaisawasdee, C. J. Scarlett, C.E. Stathopoulos, Application of biocomposite edible coatings based on pea starch and guar gum on quality, storability and shelf life of 'Valencia' oranges, Postharvest Biol. Technol. 137 (2018) 9–20, https://doi.org/10.1016/j.postharvbio.2017.11.003.
[102] C. Ribeiro, A.A. Vicente, J.A. Teixeira, C. Miranda, Optimization of edible coating composition to retard strawberry fruit senescence, Postharvest Biol. Technol. 44 (2007) 63–70, https://doi.org/10.1016/j.postharvbio.2006.11.015.
[103] D. Solís-Morales, C.M. Sáenz-Hernández, E. Ortega-Rivas, Attrition reduction and quality improvement of coated puffed wheat by fluidised bed technology, J. Food Eng. 93 (2009) 236–241, https://doi.org/10.1016/j.jfoodeng.2009.01.020.