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Review

Application of Plant Waxes in Edible Coatings

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Abstract: The aim of the paper is to present edible coatings based on lipids and their application in the food industry. Therefore, this paper discusses the following: different types of plant waxes; the need for plant waxes; the advantages and disadvantages of edible coatings based on plant waxes; edible coatings based on lipids applied in the food industry; application of the most popular Carnauba wax; Candelilla Wax in the composition of edible coatings. Plant waxes are presented with their specific characteristics. Moreover, the cuticle waxes obtained from waste peels of fresh fruits and vegetables are presented; their properties and application in the composition of edible coatings are based on plant waxes. In this regard, an effective and applicable method for the industrial extraction/separation of plant wax from the cuticle and waste peels of fresh fruits and vegetables before their processing (production of wine, high-alcohol beverages, fruit-sugar preserves, vegetable preserves, juices, etc.) is proposed. Properties and possible applications of the isolated cuticle plant waxes are presented.

Keywords: plant waxes; cuticle; edible coatings

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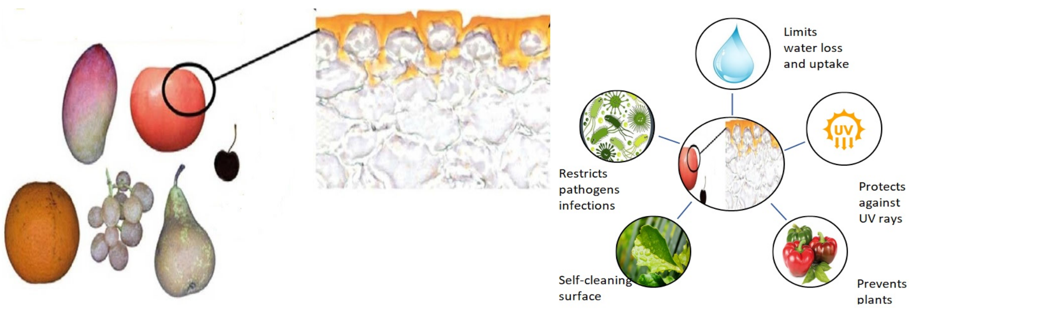
1. Introduction

Natural waxes are of plant or animal origin. They are resistant to moisture, oxidation, and microbiological decomposition. Plant waxes of commercial and industrial importance are obtained from various plant species and are used to produce cosmetic products, ink, varnishes, luster, candles, pastels, etc. Some of them are used in the composition of some edible coatings applied to various foodstuffs. By using them, the properties and quality of food products are preserved during storage.

Fresh fruits and vegetables have a natural shell in the form of skin, covered by a cuticle (a natural shell of higher plants that covers and protects the flowers, leaves, fruits, and vegetables from adverse external influences) (Figure 1) and a shell in the case of nuts [1–4]. These natural barriers regulate the exchange of oxygen, carbon dioxide, and water and reduce the loss of volatile flavor and aroma substances. Nowadays, coating emulsions are used for foods, made up of different components, including wax, shellac, beeswax, morpholine, and candelilla, usually combined with carnauba wax [5–7].



(a) (b)

Figure 1. Plant cuticle (**a**) and its functions (**b**). Source: Fernández-Muñoz et al., 2022; Martin and Rose, 2014 [4,5].

In modern conditions, uncoated foodstuffs produced via food technology are not protected by a natural coating. Therefore, various edible coatings are applied to them, which protect the product from the adverse effects of the environment, thus preserving its properties and quality. Usually, the quality of foods decreases as a result of the loss of water and aromatic substances and as a result of the influence of oxygen on the individual components of the composition of the product. Therefore, attention should be paid to the properties of the used edible coatings for food products, regarding their permeability to oxygen, water vapor, and aromatic substances [8].

According to the EU Directive [9,10] and USA regulations [11], edible coatings are classified as food products, food components, food additives, and substances in direct contact with food or food packaging material. They are part of the foods and, therefore, should meet the requirements for the components contained in them. The components in the content of coatings must be non-toxic, and all processes related to their preparation and application to foods must comply with hygienic requirements [12,13].

Other very important requirements for edible coatings are to be safe and cover/meet the requirements of the legislation of a certain country and international recommendations, including those of the Food and Drug Administration (FDA), Codex Alimentarius Commission [14], and the European Union [15].

The US Food and Drug Administration (FDA) provides that all components that should be included in the composition of edible coatings must be safe, or the used food additives should be in a specifically defined amount.

In Europe, the components that can be included in the composition of edible coatings are considered food additives and are included in the list of additives for general use (ED 1995). In each of the cases, the use of the individual components of the composition of edible coatings is allowed, but only when the principle "in reasonable quantities" is observed. This directive has been supplemented with the introduction of specific criteria for the purity of food additives [16]. Edible films may contain components with a functional purpose, which should be written on the label of the product. In Europe, food additives must be reflected on the label, referred to the relevant category (antioxidants, preservatives, colors, etc.) with their full name or with their E-number.

Each country has its own requirements regarding the permitted additives (ED, 1995, USDA—U. S. Food and Drug Administration, 2006). According to the US requirements, organic acids—acetic, lactic, citric, malic, propionic, tartaric, and their salts—are accepted as safe and applicable for general use [17]. On the other hand, most of the essential oils used in the food, pharmaceutical, and cosmetic industries are also classified as safe and approved for use as food additives [18].

Another very important point in the regulatory framework is the presence of allergens. Most of the edible coatings contain components that can cause allergic reactions. Some of them are fresh milk, soy, fish, peanuts, oilseeds, and cereals, and some edible coatings contain milk protein (whey protein and casein), wheat protein (gluten), soy protein, and proteins from peanuts and tree nuts. Therefore, the allergens in the composition of edible coatings must be accurately and clearly presented on the label of the product on which the coating is applied [19].

The purpose of this study is to present plant waxes, lipid-based edible coatings applied in the food industry, modern trends of industrial separation of plant waxes from the cuticle of waste peels obtained from fresh fruits and vegetables before their processing, and their use in the composition of edible coatings. To achieve the research objective, scientific works and regulations were studied and subjected to systematic analysis.

2. Plant Waxes—Types

Waxes are esters of high molecular weight monohydroxy alcohols and high molecular weight carboxylic acids. They are chemically different from fats and oils, from hydrocarbon or paraffin waxes, and from synthetic waxes such as carbowax [20]. Natural waxes are used in the food and cosmetic industries and have many other industrial applications [21].

Plant waxes are waterproofing components found on the outer surface of plants. They are the main barrier against environmental stress. Some of them have gained GRAS (Generally Regarded as Safe) status approved by FDA, which allows their use in foods. Plant waxes such as candelilla wax, carnauba wax, rice bran wax, sunflower wax, etc. (Table 1) with commercial and industrial importance are derived from different plants and used for the production of cosmetics, ink, varnish, polish, candles, crayons, etc. They are also used to obtain edible coatings for various food commodities. It was found that they maintain the properties and the quality of foods during their term of storage [22].

Table 1. Plant Waxes.

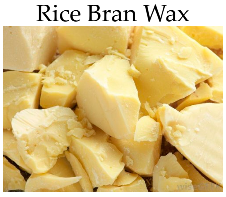
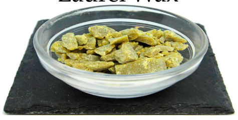
Name	Plant Source of Wax	Application
Carnauba Wax 	Palm tree	Coatings, cosmetics, automobiles, furniture wax, etc.
Candelilla Wax 	Bush	Cosmetics and coatings
Japan Wax 	Tree	Candles and varnishes
Ouricury Wax	Palm tree	Inks, varnishes
Rice Bran Wax 	Rice husks	Coatings, chewing gums, candles, textiles, lubricants, cosmetics, etc.
Sunflower Wax 	Seed and Seed Hulls	Cosmetics (lipsticks, mascaras, lip balms), emulsions, etc.
Laurel Wax 	Fruit of the Myrica Pubescens (laurel) shrub	Scented candles Natural cosmetics and personal care products (lip balms, lipstick, lotion bars, hair pomade, ointments, salves, mascaras, creams, and lotions)

Table 1. *Cont.*

Name	Plant Source of Wax	Application
Cane Wax 	Cane (dry wastes after its treatment for sugar manufacturing)	Main substitute for Carnauba wax
Cuticle Wax	Cuticular wax (obtained from the peel wastes of fresh fruit and vegetables)	Coatings, packaging, etc.
	Berry wax (obtained from the peel wastes of berry fruits)	Food packaging, cosmetic industries, and coatings

Source: own research.

The main source of Carnauba wax (CW), sometimes called the “Queen of Waxes”, is the Brazilian palm tree (Coernicia cerifera Martius), also known as carnauba wax palm. The wax is found on the surface of the palm leaves. One of the unique characteristics of carnauba wax is that it contains long-chain alcohols and esters: unesterified alcohols (12%), x-hydroxy esters (14%), and esters of hydroxylated cinnamic acid (30%). Carnauba wax is one the hardest plant waxes, with melting temperatures ranging from 82.5 to 83 °C. Therefore, it is often used as a hardener to elevate the melting temperature of wax mixtures. Carnauba wax is the most commercially important plant wax. It has extensive applications in foods, confectionery coatings, cosmetics, automobiles, furniture wax, etc. [21], and CW-based emulsions, edible coatings, oleogels, etc. [23]. Food-related use of carnauba wax is outlined in the FDA regulation 21 CFR 184.1978 [22].

Candelilla wax, or The “Great Wax Rush” (Figure 2), is mainly obtained from the leaves of the plant E. antisyphilitica Zuccarini native to northern Mexican and southwest Texas [24]. Unpurified candelilla wax contains approximately 42% hydrocarbons, 39% wax, resin, and sitosteroyl esters, 8% free wax and resin acids, 6% lactones, and 5% free wax and resin alcohol. Candelilla wax is an FDA-approved food additive used for glazing in certain foods. Microemulsions of candelilla wax are used as coatings with good gloss for fruits [25].

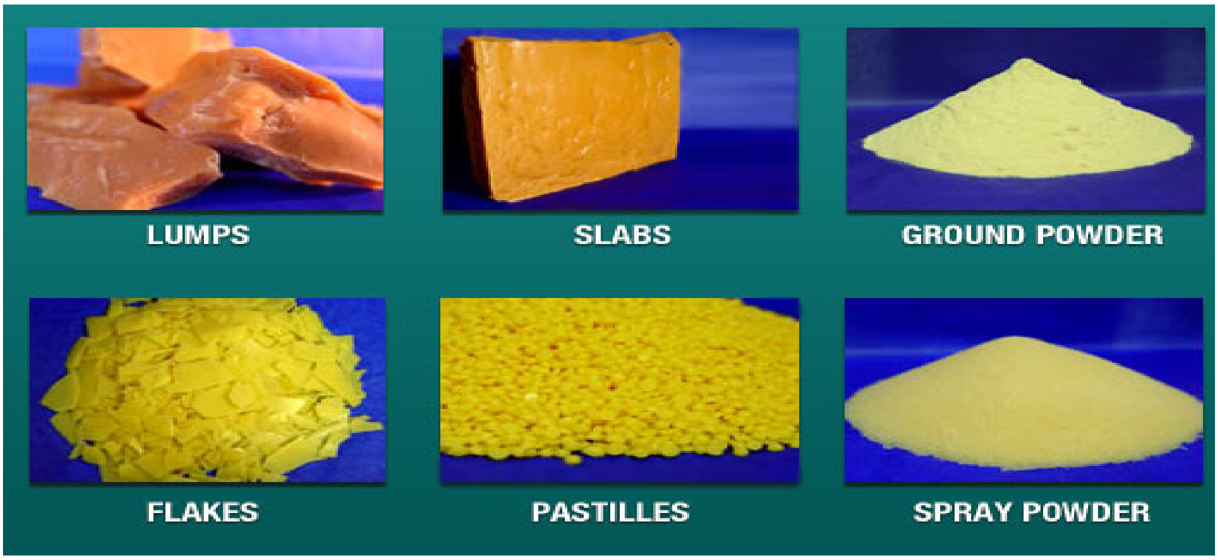


Figure 2. Different Candelilla wax products, which differ in their presentation and refining grade. Source: Candelilla Institute, http://www.candelilla.org/?page_id=2, accessed on 1 March 2023.

Japan Wax (木蝋 Mokurō), known as sumac wax, sumach wax, vegetable wax, China green tallow, and Japan tallow, is a pale-yellow, waxy, water-insoluble solid with a gummy feel obtained from the berries and stems of the Rhus succedanea tree. It is not a true wax and contains 5% of fatty acid, resulting in more viscosity than other waxes. It thickens formulas, as well as gives a nice, malleable texture to the blend. It has been used by sumo wrestlers and geishas for centuries to shape and maintain their hairstyle. It is frequently used nowadays in haircare products. Japan wax is used in the composition of candles, furniture polishes, floor waxes, wax matches, soaps, food packaging, pharmaceuticals, cosmetics, pastels, crayons, buffing compounds, metal lubricants, adhesives, thermoplastic resins, and as a substitute for beeswax. Because it undergoes rancidification, it is not often used in foods [26].

Ouricury wax is a brown-colored wax obtained from the leaves of a Brazilian feather palm (*Syagrus coronata*) by scraping the leaf surface. Harvesting ouricury wax is more difficult than carnauba wax, as ouricury wax does not flake off the surface of the leaves. The physical properties of ouricury wax resemble carnauba wax, so it can be used as a substitute where light color is not required, e.g., in carbon paper inks, molding lubricants, and polishes [22,27].

Rice bran wax is another high-melting vegetable wax found in rice husks (*O. sativa*). It is obtained as a by-product from the de-waxing of rice bran oil [22]. The rice bran wax is a reddish brown, dark composite separated from rice bran oil and has good nutritional properties. It is separated from rice bran, which has several health-benefiting components. Rice bran wax (RBW) has been approved by the FDA as a safe food additive (21 CFR, 172.890). It has extensive applications due to its relatively low cost and abundance in Asia. It can be used as an efficient edible coating substance due to its excellent film-forming properties. The RBW has been effectively used in several food applications, such as forming oleogels, structured lipids, and edible coating of food products [28]. Food applications include fruit and vegetable coatings, confectionery, and chewing gums; other applications include candles, textiles, lubricants, cosmetics, etc. [29].

Sunflower wax is found in the seed and seed hulls of sunflower (*H. annuus*). It is obtained through the winterization of sunflower oil. Like rice bran wax, it is a hard wax. Sunflower wax has not been approved for GRAS status by the FDA. Therefore, its applications are primarily in cosmetics, such as lipsticks, mascaras, lip balms, emulsions, etc. It functions as a consistency modifier and regulates the hardness, texture, and mold release of cosmetic formulations. It can also be used as a replacement for candelilla wax, carnauba wax, and rice bran wax [21].

The cuticle is synthesized in the epidermal cells of various plants, such as leaves, fruits, stems, and flowers, as a barrier between the plant surface and the environment. The cuticle is a hydrophobic layer composed of two lipophilic components, cuticular wax, and cutin. One of the most important functions of the cuticle is due to its hydrophobic component: the waxes [30]. Cuticular wax (obtained from the leaf/peel wastes of fresh fruit and vegetables, etc.) is a continuous layer outside or within the cuticle of plants. The presence of waxes on the leaf/fruit surface affects the degree of colorization, and the effect varies according to the plant species [31]. Berry wax is isolated from the cuticle of different varieties of berry fruits. It is obtained from the peel berry wastes from the berry juice industry and is a potential source of natural waxes. Waxes find application in food packaging, cosmetic industries, coatings, etc. [32].

Only the plant waxes approved by the FDA are used in the composition of wax coatings applied in the food industry. There is a high interest and a lot of research presenting wax coating with incorporated bioactive compounds.

3. Necessity, Advantages, and Disadvantages of Edible Coatings Based on Plant Waxes

Coatings based on plant waxes used in food technology are subtle, invisible to the naked eye, and safe for consumers. Applied to food products, they slow down the loss of moisture, gases (oxygen and carbon dioxide), and volatile components of the composition, and they improve the appearance and mechanical properties of the product.

Coatings based on plant waxes are also considered as a layer of edible materials used and located between the components of the product, providing a barrier to overall exchange. In other words, edible coatings represent an integrated part of the food product that does not change its sensory properties [33,34].

Edible coatings are consumed together with the product on which they are applied. Therefore, the components included in their composition, such as antimicrobials, antioxidants, and food additives, should not affect the properties of food.

The addition of some anti-browning components in edible coatings can cause an unpleasant nuance in the aroma, especially when their concentration is high [35]. There are limited studies that present the sensor characteristics of fresh-cut fruits with applied coatings in the composition, in which food additives are included. The taste of these components is considered an extremely important point, as most of the components have a naturally bitter, astringent, or another aftertaste that will change consumer preferences. It was found that the presence of vitamin E reduces the surface gloss of coated strawberries, and this affects the appearance of the product and consumer preferences [36].

The need to use edible coatings based on plant waxes in food technology is directly related to the fact that they have some advantages over synthetic ones (Table 2). A major advantage of edible over synthetic coatings is that they can be consumed together with the food on which they are applied. Their use contributes to reducing environmental pollution. The coatings are prepared entirely from plant waxes, so their degradation is faster than polymer materials. The coatings can emphasize the organoleptic properties of the product on which they are applied since they contain various components (flavoring substances, coloring agents, and sweeteners). Coatings can be used for individual packaging of small quantities of a certain product, especially for goods that are not individually packaged, such as pears, nuts, strawberries, etc. It is possible to apply them inside heterogeneous products between individual layers. Thus, they protect the product from becoming wet and prevent the passage of moisture into it (pizza, pie, candies, etc.). Coatings can also be considered a source of antimicrobial, antioxidant, and anti-browning (cut, filleted fruit) components. They are most often applied to the surface of the product, thus preventing the penetration of unwanted components through the surface to the interior of the product. It is also possible to use edible coatings with multilayer packaging materials together with non-edible ones. In this case, the edible coating is applied as an inner layer directly on the product. There is negligible waste and environmental pollution in the production of edible coatings, and their permeability and mechanical properties are better than those of synthetic films [37–41].

The disadvantages of coatings are connected with their composition and properties, with the thickness of the layer applied on the surface of foods, the cost of the components included in the composition of coatings and the absence of requirements for the composition and application of edible coatings [42–44].

Thick coatings prohibit oxygen exchange and cause off-flavor development. Sometimes due to the surface of foods and chosen method of applying the edible coatings a thick layer of the coating can form, which reduces the properties and efficiency of the edible coatings. Some coatings are hygroscopic in nature, which helps to increase the growth of certain microorganisms, which do not allow coatings to fulfill their main purpose. For this reason, it is necessary to choose the right components (including antimicrobial agents if necessary) in the composition of edible coatings. The high cost of the components included in the composition of edible coatings increases the cost and reduces their economic efficiency. In most cases, edible coatings are more expensive than synthetic packaging, and this is one of the reasons connected with their application in the food industry. Another obstacle is the lack of sufficient information on the use of machinery and equipment for the production of edible coatings with different compositions. Finally, there are no separate requirements for the composition and use of edible coatings [43,45].

Table 2. Advantages and disadvantages of edible coatings.

Advantages	Disadvantages
Safe, not containing toxic, allergic substances; well digestible.	Thick coating can prohibit oxygen exchange and causes off-flavor development.
Improve food appearance and retention of acids, color, flavor, and sugar.	Causes anaerobic respiration of fresh fruits and vegetables due to the normal ripening during storage.
Maintain the quality of foods during storage as follows: - Slow down the loss of moisture and gases (oxygen and carbon dioxide) in foods; - Slow down the loss of volatile components from foods; - Improve the appearance and mechanical properties of food.	Some edible coatings are hygroscopic in nature, which helps to increase microbial growth.
Reduce weight loss of foods.	High cost of the components and reduced economic efficiency.
Reduce the use of plastic packaging and waste.	Difficulties in applying some edible coatings on the surface of foods.
Consumed together with foods.	No separate regulatory requirements for the use of edible coatings.

Source: own research.

4. Edible Coatings Based on Lipids Applied in the Food Industry

The increased demands of consumers nowadays raise the question of active packaging—a type of packaging that changes the conditions around the product itself, in order to preserve its quality and freshness, improve its sensory properties, and thus also guarantee food safety and storage duration.

Through the use of packaging for food products, the aim is to preserve their quality and safety from the moment of their production until their use by consumers. A very important function of packaging is the protection of goods from physical, chemical, or biological damage. The most widely distributed and used packaging material that fully meets these criteria is polyethylene and similar materials, which have been used in the food industry for more than 50 years. These materials are not only harmless, cheap, and applicable, but also suitable for packaging various goods and have good flexibility.

Nowadays, the main part of the materials used as raw materials for packaging are by-products of the processing of petroleum products and are practically non-degradable. This is the main reason why food packaging, like all other disposable packaging used to store foods for a short period of time, creates a serious global problem.

The world production of packaging materials is more than 180 million tons per year, and it is increasing every year [46]. A major limitation of using plastic packaging materials is the fact that their degradation period is long. Another point is the direct dependence of the production of polyethylene packaging on the extraction of petroleum products, and the reserves on a global scale are significantly decreasing with each subsequent year, along with increasing oil prices [47].

The properties of lipid edible coatings have been extensively investigated in recent years. By means of lipid films, unwanted loss of water vapor from foodstuffs is regulated, the quality is improved, and their shelf life is extended. By replacing synthetic packaging materials with edible lipid coatings, waste is reduced, and the recyclability of synthetic packaging materials is increased.

Various lipid components, such as animal fats and vegetable oils, are used in the production of edible coatings. Edible lipids are neutral lipids, waxes, and resins, which usually provide a coating material for fresh products, provide an effective moisture barrier property, and improve surface appearance. Resin coating is fairly effective for water loss [48]. Resins are a group of substances secreted by special plant cells in response to injury or infection in many trees and shrubs [49]. Lipid coatings have excellent moisture-protecting properties, and as a coating component, they add shine to confectionery and sugar products. Waxes are used in the composition of coatings in order to reduce respiration and moisture loss [50].

Kester and his colleagues offer an edible coating in a composition in which lipids and cellulose are combined. The edible coating is rated as a good barrier and protects the commodity from water vapor loss [51]. Cellulose-based coatings with included wax provide the best balance between the loss of aromatic substances and the prevention of natural storage losses of the goods due to water loss. These coatings are applied to fresh fruit immediately after harvest in order to preserve (reduce) the loss of aroma substances [52].

The structure of the matrix of some edible coatings includes wheat gluten and lipids, which are the main components that retain the loss of water vapor. It has been established that the combination of wheat gluten protein with diacetyl tartrate ester of monoglycerides reduces the penetration of water vapor, increases the strength of the coating, and ensures its transparency [53].

Lipid–cellulose edible coatings are designed to retain the moisture in two-component food products stored in a frozen state. It is applied between the two components of the bread and tomato sauce product. It was found that the coating successfully arrests moisture migration from the tomato sauce to the bread during storage [54].

It was established that the inclusion of plasticizers in the composition of lipid edible coatings prevents the appearance of pores and cracks after their application. For example, the addition of sunflower oil to starch-based coatings reduces the water vapor permeability of it [55].

Edible wax coatings are widely used in the food industry in order to extend the shelf-life of foods by regulating gas exchange and moisture migration. Waxes (carnauba wax, paraffin wax, etc.) are commercially used as a protective coating for fresh fruits and vegetables. They reduce moisture loss and surface abrasion during fruit handling. Generally, wax coatings are resistant to moisture loss as compared to lipid and non-lipid coating. Wax coating is effective on citrus, apple, mature green tomato, cucumber, and other vegetables, such as asparagus, beans, carrots, eggplant, okra, sweet potatoes, turnips, etc., where a shiny surface is desired. Beneficial properties of lipid-based coatings include good compatibility with other coating agents and high water vapor and gas barrier properties as compared to polysaccharide and protein-based coatings [56]. The lipid-based coating gives a greasy surface and undesirable organoleptic properties such as a waxy taste and lipid rancidity [57,58].

Carnauba wax is considered safe for human consumption by several certified organizations. European Union has authorized carnauba wax (E 903) as a food additive (coating agent). In 2012, the Panel of Additives and Nutrient Sources (ANS) on the safety of carnauba wax for human consumption jointly assessed by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), and Scientific Committee on Food (SCF), and they determined 7 mg/kg body weight/day [6]. Its hydrophobic nature and meltability make it an attractive alternative to petroleum-based synthetic wax for coatings of fruits and vegetables, and in recent years, it has been explored as an additive in biopolymer-based composite packaging films. Incorporation in coatings improves their hydrophobicity, barrier against light, etc. [59,60]. Carnauba wax emulsion coating showed good commercial attributes such as glossiness, early drying nature, and reduced physiological weight loss. Its extended shelf life and enhanced antioxidant activity of packaged eggplants during storage up to 12 days [61]. Some examples connected with the application of Carnauba wax in the composition of edible coating are presented in Table 3.

Table 3. Application of Carnauba wax (CW) in composition of edible coatings.

Commodities	Coatings/Emulsions	Advantages	Source
Fresh tomatoes	Carnauba wax nanoemulsion.	Improve the gloss of tomatoes.	Miranda et al. [62].
Strawberries	Bio-nanocomposite coatings developed using arrowroot starch (AA), cellulose nanocrystals (CNC), carnauba wax nanoemulsion (CWN), and Cymbopogon martinii and Mentha spicata essential oils (CEO and MEO, respectively).	Preserve the post-harvest quality of fresh strawberries.	Gonçalves de Oliveira Filho et al. [63]
Eggplant	Poly ethylene glycol and Sodium alginate in CW emulsion.	Improve shelf life of eggplant during storage in both unpackaged and packaged.	Singh et al. [61]
Fresh-cut apples	Edible coatings/films formulated with cassava starch, glycerol, carnauba wax, and stearic acid.	Improve barrier properties of coatings applied in fresh-cut apples (respiration rate and water vapor resistance).	Chiumarelli et al. [64]
Indian jujube (*Zizyphus mauritiana Lamk.*) fruit	Carnauba wax (CW) and CW containing glycerol monolaurate (CW-GML) coating.	Shelf-life extension and quality maintenance of jujube fruit stored at 20 °C.	Chen et al. [65]
'Valencia' orange fruit	Carnauba wax-nanoclay emulsion.	Retarding respiration rates and weight loss, preserving sensory and nutritional quality of fruits.	Motamedi et al. [66]
Sweet potato (*Ipomoea batatas* (L.) *Lam.*) roots	Carnauba wax-based nanoemulsion without or with glycerol monolaurate.	Preserve food quality and extend shelf life of sweet potato roots.	Huqing et al. [67]
Fresh and minimally processed apples	Edible coatings made up of starch, carrageenan, soy proteins, corn zein, whey proteins, and waxes.	Improve functional properties of apples besides sensory and nutritional attributes.	Aayush et al. [68]
Fuji' apples	Carnauba-shellac wax-based nanoemulsion containing lemongrass oil.	Improve the quality of 'Fuji' apples during storage.	Wan-Shin et al. [69]

An aqueous emulsion containing 15% *candelilla waxes* is used for coating lemons. It has been established that lemons with a wax coating have fewer natural losses during storage. Changes in pH, acidity, and vitamin C content during the storage of fruits coated with candelilla wax were similar to those coated with commercial wax [70]. Some examples showing the application of Candelilla wax in composition of edible coatings are presented in Table 4.

Table 4. Application of Candelilla wax in composition of edible coatings.

Commodities	Coatings/Emulsions	Advantages	Source
Lemons	An aqueous emulsion containing 15% candelilla waxes.	Reduce natural losses during storage.	Paredes-Lopez et al. [70].
Strawberry	Edible films of candelilla wax alone or in combination with a *Bacillus subtilis.*	Prolong the shelf life of strawberries.	Oregel-Zamudio et al. [71].
Golden delicious apples	Edible coating formulated with candelilla wax and fermented extract of tarbush.	Improve the quality and shelf life of apples in marketing conditions.	De León-Zapata et al. [72].
Persian limes	Composite edible coatings were formulated with candelilla wax alone, and candelilla wax blended with beeswax, white mineral oil, and oleic acid (2:1 ratios).	Improve water vapor permeability, provide the lowest physiological weight loss, best dark shade green color retention, and unaltered physicochemical parameters.	Bosquez-Molina et al. [73].

Table 4. *Cont.*

Commodities	Coatings/Emulsions	Advantages	Source
Avocados	Addition of ellagic acid (at three different concentrations) into a candelilla wax matrix.	Improve the quality and shelf life of avocados.	Saucedo-Pompa et al. [74].
Apples at the industrial level	Phyto molecules of tarbush incorporated into the candelilla wax-based nanocoating.	Increase the shelf life of apples in marketing conditions and refrigeration at the industrial level.	De León-Zapata et al. [75].
Pears	Coating composed of carboxymethylcellulose (CMC), candelilla wax, and potassium sorbate (KS).	Prevent fungal infections in pears stored.	Kowalczyk et al. [76].

Paraffin wax or mineral oils have been found to be used and applied as an edible surface coating on turnips, cucumbers, sweet potatoes, eggplant, and on most citrus fruits [77].

Edible coatings based on lipids are mainly used to reduce natural losses during storage and to provide good protection of goods from the active action of oxygen from the air. Lipid applications include coatings for poultry, poultry products, shrimp, meat patties or patties, minced meat products, etc. Waxes and plant oils are added to protein- and polysaccharide-based edible coatings. They give flexibility and elasticity, improve coating properties and prevent products from sticking to each other during culinary processing.

Lipid-based edible coatings are prepared from waxes and oils. The benefits of food products coated with lipid-based coatings have been proven. Lipids not only provide hydrophobicity, cohesiveness, and flexibility but also act as an excellent barrier for the release and penetration of moisture into the respective commodity. This is due to the structure of the lipids. They prevent the passage of water vapor and preserve the quality of goods during their storage.

Edible coatings based on lipids and especially those based on plant waxes have the potential to meet consumer requirements. Their application guarantees harmlessness and preservation of the properties and quality of the product. Edible coatings partially replace some of the traditional synthetic packaging materials. Applied to food products, they protect them from unwanted processes, guarantee their quality, and extend the shelf life of the product. Lipid-based edible coatings are biodegradable, non-harmful, edible, and non-polluting to the environment.

4.1. Modern Trends, Possibility of Industrial Separation of Plant Waxes from the Cuticle of Waste Peels of Fresh Fruits and Vegetables, and Their Use in the Composition of Edible Coatings

Modern trends described and applied in food technology focused on the use of recovered, recycled, natural materials in the composition of edible coatings. In this way, the properties of foods are preserved and improved, and the efficiency of their use affects the cost price and the price of the respective goods. A major advantage of edible coatings based on plant waxes over traditional synthetic films is that they are consumed together with the food on which they are applied. Their use reduces and limits the use of natural oil reserves, which decrease every year, and contributes to preserving the ecological balance and the environment from pollution.

In this regard, the possibility of industrial extraction (separation) of plant waxes from the cuticle (peel wastes of fresh fruits and vegetables), peeled, and separated before their processing into different products (vegetable juices, fruit juices, vegetable concentrates, fruit-sugar products, wines, etc.) is proposed. The separated plant waxes should be used to obtain edible pectin-based or wax-based coatings. Lipid-based edible coatings are mainly used to extend the shelf life of foodstuffs and to preserve their quality during storage.

4.1.1. Method for Industrial Separation of Plant Waxes from the Cuticle (Waste Peels of Fresh Fruits and Vegetables)

The method should find application in the food industry and, more precisely, in the stage before using fresh fruits and vegetables for processing them into different products (vegetable juices, fruit juices, wines, vegetable concentrates, fruit and sugar products, etc.).

The present method solves the problem of full utilization and separation of plant waxes from the cuticle of fresh fruits and vegetables, which are currently not the object of attention and are not used by fresh fruits and vegetable processors. The advantage of the proposed method is the possibility of separating the plant waxes from the cuticle and using them in the composition of edible coatings based on plant waxes and emulsion coatings based on pectin or wax.

The method of industrial separation of plant waxes from the cuticle of fresh fruits and vegetables involves the following stages (Figure 3): Cleaning and sorting of the fresh fruits and vegetables. The next stage of the proposed method is to separate the peels (using suitable machines) from the surface of fresh fruits and vegetables. Plant waxes should be extracted from the separated peels with chloroform heated to 40–50 °C for 1–3 min. For this purpose, it is necessary to place the separated peels in a container and cover them with an organic solvent (chloroform). The obtained warm solution (extract containing plant waxes) should be filtrated, followed by its concentration (separation of the organic solvent from the filtrate). The obtained plant waxes finally are dried and stored in dark conditions, at a temperature of 1–3 °C.

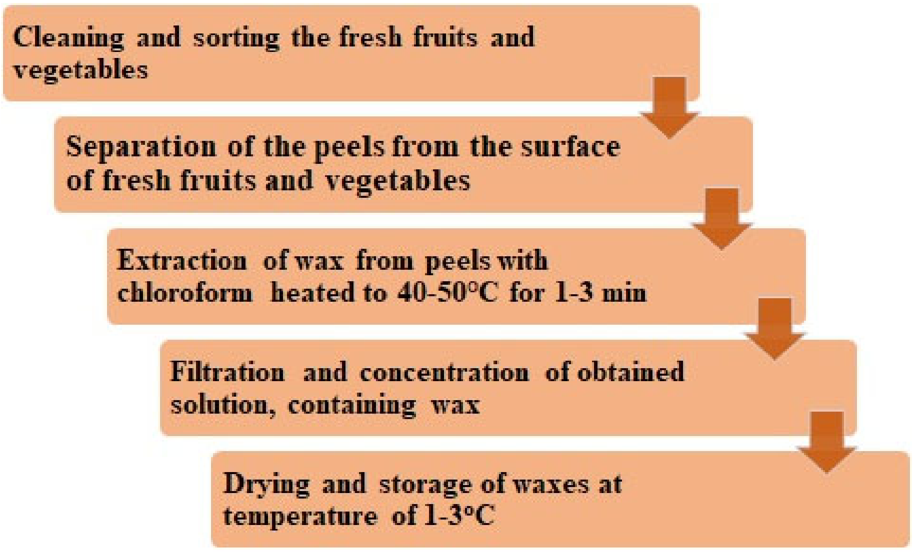


Figure 3. Stages of the industrial extraction of plant waxes from the waste peels (cuticle) of fresh fruits and vegetables.

In most plants, waxes are not present in large quantities, so they are extracted from them using organic solvents. Hexane is the most suitable solvent for the extraction of waxes, chloroform or methylene chloride may be used for the extraction of hard, high-melting waxes and for waxes containing triterpene acids [78]. According to Nawrath [79], chloroform dissolves mainly the hard wax, small amounts of the soft wax, and triterpene compounds, and cutin is insoluble in this solvent.

The proposed method makes it possible to separate the plant waxes included in the composition of the plant cuticle, as well as the surface plant waxes from the waste products (the separated peels of fresh fruits and vegetables before their processing). The amounts of plant wax obtained by the described method are suitable for use in the composition of edible coatings based on plant waxes. The extracted plant wax has a low cost, and this will also affect the price of the food products to which the edible coating will then be applied.

The obtained edible coatings based on plant waxes will reduce and limit the use of natural oil deposits and the production of slow-degrading packaging based on petroleum products. The production of such packages is currently a serious global problem, as it pollutes the environment with disposable packages thrown away by consumers every day.

The proposed method and the possibility of industrial separation of plant waxes from the peels of fresh fruits and vegetables limit the need to import expensive carnauba and candelilla waxes. The method is effective, easy to implement, and combines the economic interests of producers and the possibility of applying plant waxes to obtain edible coatings, widely used in modern conditions in the food industry to preserve the quality and shelf life of food.

4.1.2. Properties of the Isolated Plant Waxes

Studies that have been conducted determined the content of plant waxes in the cuticle of different varieties of plums and determined the influence of the amount and composition of waxes on the shelf life of plum fruits [80]. The isolated waxes were examined using a differential scanning calorimeter (DSC), infrared spectroscopy (IR spectroscopy), and X-ray structural analysis. From the conducted research, it was found that the isolated plant waxes are suitable and can be used as the main component in the composition of edible coatings, with the exception of the soft wax isolated from the cuticle of red sedge—*Prunus cerasifera* (characteristics: the melting point is 36.91 °C., i.e., it is 3.09 °C lower than the required temperature of 40 °C) [81].

Next, the rheological and optical characteristics of an aqueous solution of pectin containing plant wax and beeswax were investigated. It was established from the conducted research of plant waxes isolated from the cuticle (with the exception of a soft wax isolated from the cuticle of the blue plum variety Stanley—*Prunus domestica*) that they possess the necessary properties and can be used to obtain edible coatings. On the basis of the carried-out research, it has been proven that plant waxes isolated from the cuticle are suitable and can be used in the composition of edible pectin-based or wax-based coatings intended to extend the shelf life of food to preserve their properties and quality [82].

Modern trends applied in food technology aim to use recovered, recycled, natural plant-based waxes in the composition of edible coatings. That reduces and limits the use of natural oil deposits (petroleum products are the raw material for obtaining single-use packages that pollute the environment and degrade slowly), which decrease every day and year. This contributes to preserving the ecological balance by using more plant-based waxes for a sustainable greener economy.

5. Conclusions

As a result of the research, the following conclusions can be outlined, and directions for the application of plant waxes in the composition of edible coatings used in the food industry can be summarized.

Edible coatings are considered to be biopolymers of great variety, with properties desired by consumers, obtained from polysaccharides, lipids, and proteins, alone or in combination with other components. The advantages of edible coatings are associated with the main ingredients included in their composition, such as antimicrobial agents, aroma substances, antioxidants, coloring substances, vitamins, probiotics, etc. The disadvantages of coatings are connected with their composition and properties, the thickness of the layer of some coatings applied on the surface of foods, the cost of the components included in them, and the absence of requirements for the composition, safety, and application of edible coatings.

The necessity to use edible coatings based on plant waxes in food technology is related to their advantages over synthetic films and the possibility of preserving the properties and quality of foods on which they are applied for a longer period during their storage. Edible coatings based on lipids are widely used in food technology. Applied over food products, they protect them from unwanted processes, guarantee their quality and safety, and extend the shelf life of products. Edible lipid-based coatings are biodegradable, harmless, can be consumed with the products, and do not pollute the environment. The food industry needs edible coatings that will find application in a greater variety of foods that will extend their shelf life and preserve their quality.

Waxes isolated from plants are Carnauba Wax, Candelilla Wax, Japan Wax, Ouricury Wax, Rice Bran Wax, and Sunflower Wax. Only three of them (carnauba, candelilla, and rice bran wax), approved by the FDA, are used in the composition of edible coatings. Plant waxes isolated from the cuticle of fresh fruits and vegetables have the necessary properties and should find application in the composition of edible coatings based on plant waxes.

In this regard, an effective and applicable method for industrial separation of plant wax from peels of fresh fruits and vegetables before their processing (production of wine, high-alcohol beverages, fruit-sugar preserves, vegetable preserves, juices, etc.) is proposed. It was found that the separated waxes possess the necessary properties and should be recommended and find application for obtaining edible coatings on a pectin or wax basis. The method combines the economic interests of producers and the possibility of applying plant waxes in order to obtain edible coatings used in modern conditions in food technology to preserve the quality and shelf life of food.

In conclusion, it should be noted that consumers' demands provoke the deepening of scientific research towards new alternatives of packages not based on petroleum products, offering new ones that are recycled and have nutritional value, and one of them is ingredients (plant waxes) obtained from agricultural products. Plant waxes, isolated from the cuticle of fresh fruits and vegetables are an example of suitable, sustainable constituents obtained from agricultural products that should be used in the composition of edible coatings.

Future challenges and perspectives in the area of edible coatings on the basis of plant waxes can be presented in the following directions:

- The application of edible coatings in the food industry should be considered and presented to consumers as an innovation that supports the creation of an ecological and waste-free production by using natural plant wax; a possible way for improving the cleanliness of the environment;
- The edible coatings on the base of plant waxes should become a reality, moving from scientific research to industrial application for a greater variety of foods and having continuous growth in the future.

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References

1. Bai, J.; Plotto, A.; Baldwin, E. *Edible Coatings and Films to Improve Food Quality*; Hagenmaier, R., Bai, J., Eds.; CRC Press: Boca Raton, FL, USA, 2011; pp. 185–242.
2. Maringgal, B.; Hashim, N.; Syafinaz, I.; Amin Tawakkal, M.; Tengku Muda Mohamed, M. Recent advance in edible coating and its effect on fresh/fresh-cut fruits quality. *Trends Food Sci. Technol.* **2020**, *96*, 253–267. [CrossRef]
3. Nor, S.; Ding, P. Trends and advances in edible biopolymer coating for tropical fruit: A review. *Food Res. Int.* **2020**, *134*, 109208. [CrossRef] [PubMed]
4. Fernández-Muñoz, R.; Heredia, A.; Domínguez, E. The role of cuticle in fruit shelf-life. *Curr. Opin. Biotechnol.* **2022**, *78*, 102802. [CrossRef] [PubMed]
5. Martin, L.; Rose, J. There's more than one way to skin a fruit: Formation and functions of fruit cuticles. *J. Exp. Bot.* **2014**, *65*, 4639–4651. [CrossRef]
6. Andréa Silva de Freitas, C.; Henrique Machado de Sousa, P.; Josino Soares, D.; Ytalo Gomes da Silva, J.; Rathinaraj Benjamin, S.; Izabel Florindo Guedes, M. Carnauba wax uses in food—A review. *Food Chem.* **2019**, *291*, 38–48. [CrossRef]

7. Puttalingamma, V. Edible coatings of carnauba wax—A novel method for preservation and extending longevity of fruits and vegetables—A review. *Int. J. Food Saf.* **2014**, *16*, 1–5.
8. Pashova, S. *Application of Vegetable Waxes in Food Technology*; IK SAFO: Lovech, Bulgaria, 2011; pp. 147–148.
9. ED European Parliament and Council Directive No98/72/EC 1998. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31998L0072 (accessed on 25 September 2022).
10. ED European Parliament and Council Directive No95/2/EC 1995. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A31995L0002 (accessed on 25 September 2022).
11. FDA. Food Additives Permitted for Direct Addition to Food for Human Consumption 21 CFR 172, Subpart C. Coatings, Films and Related Substances. 2006. Available online: https://www.law.cornell.edu/cfr/text/21/part-172 (accessed on 10 December 2022).
12. Guilbert, S.; Gontard, N. Edible and biodegradable food packaging. In *Foods and Packaging Materials—Chemical Interactions*; Ackermann, P., Jagerstad, M., Ohlsson, T., Eds.; The Royal Society of Chemistry: London, UK, 1995; pp. 159–168.
13. Nussinovitch, A. *Water Soluble Polymer Applications in Foods*; Blackwell Science: Oxford, UK, 2003.
14. General Standard for Food Additives CODEX STAN 192-1995. 1995. Revision 1997, 1999, 2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2018. Available online: http://www.fao.org/gsfaonline/docs/CXS_192e.pdf (accessed on 12 January 2023).
15. EFSA. Annual Report 2012. Committed to Ensuring that Europe's Food Is Safe. 2012. Available online: https://www.efsa.europa.eu/sites/default/files/corporate_publications/files/ar12en.pdf (accessed on 15 February 2023).
16. ED European Parliament and Council Directive No 2008/84/EC 2008. Available online: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:253:0001:0175:EN:PDF (accessed on 30 October 2022).
17. Doores, S. Organic acids. In *Antimicrobials in Food*; Davidson, P.M., Branen, A., Eds.; Marcel Dekker Inc.: New York, NY, USA, 1993; pp. 95–136.
18. Kabara, J. Phenols and Chelators. In *Food Preservatives*; Russell, N.J., Gould, G., Eds.; Blackie: London, UK, 1991; pp. 200–214.
19. Franssen, L.; Krochta, J. Edible Coatings Containing Natural Antimicrobials for Processed Foods. In *Natural Antimicrobials for Minimal Processing of Foods*; Roller, S., Ed.; CRC Press: Boca Raton, FL, USA, 2003; pp. 250–262.
20. Bodmier, R.; Hermann, J. Encyclopedia of Pharmaceutical Technology. In *Waxes*; Swarbrick, J., Boylan, J.C., Eds.; Marcel Deckker Inc.: New York, NY, USA, 1997; Volume 16, pp. 335–361.
21. Tinto, W.; Elufioye, T.; Roach, J. *Waxes*; Pharmacognosy; Badal, S., Delgoda, R., Eds.; Academic Press: Cambridge, MA, USA, 2017; Chapter 22; pp. 443–455. [CrossRef]
22. Lan, Y. Waxes. In *Encyclopedia of Food Chemistry*; Melton, L., Shahidi, F., Varelis, P., Eds.; Academic Press: Cambridge, MA, USA, 2019; pp. 312–316. [CrossRef]
23. Néstor, E.; Ledesma, A.; Bautista-Hernández, I.; Rojas, R.; Aguilar-Zárate, P.; del Pilar Medina-Herrera, N.; Castro-López, C.; Cristian Guadalupe Martínez-Ávila, G. Candelilla wax: Prospective suitable applications within the food field. *LWT Food Sci. Technol.* **2022**, *159*, 113170. [CrossRef]
24. Arato, M.; Speelman, S.; Van Huylenbroeck, G. The contribution of non-timber forest products towards sustainable rural development: The case of Candelilla wax from the Chihuahuan Desert in Mexico. *Nat. Resour. Forum* **2014**, *38*, 141–153. [CrossRef]
25. Hagenmaier, R.; Baker, R. Edible Coatings from Candelilla Wax Microemulsions. *J. Food Sci.* **1996**, *61*, 562–565. [CrossRef]
26. Krendlinger, E.; Wolfmeier, W. *Natural and Synthetic Waxes: Origin, Production, Technology and Applications*; Wiley-VCH: Hoboken, NJ, USA, 2022. [CrossRef]
27. Pashova, S. Plant Waxes—Nature, Types and Application; Forum Ware International. In *Excellence in Business, Commodity Science and Tourism*; Special Issue; Bucharest Academy of Economic Studies: Bucharest, Romania; International Society of Commodity Science and Technology (IGWT): Wien, Austria, 2011; Volume 1, pp. 166–170.
28. Modupalli, N.; Natarajan, V. Fractionation and extraction of functional compounds from rice bran wax. *Pharma Innov. J.* **2022**, *11*, 1682–1686.
29. Sabale, V.; Sabale, P.; Lakhotiya, C. Comparative evaluation of rice bran wax as an ointment base with standard base. *Indian J. Pharm. Sci.* **2009**, *71*, 77. [CrossRef] [PubMed]
30. Bhanot, V.; Fadanavis, S.; Panwar, J. Revisiting the architecture, biosynthesis and functional aspects of the plant cuticle: There is more scope. *Environ. Exp. Bot.* **2021**, *183*, 104364. [CrossRef]
31. George, N. Chapter five—How Pathogens Attack Plants. In *Plant Pathology*, 5th ed.; Agrios, G.N., Ed.; Academic Press: Cambridge, MA, USA, 2005; pp. 175–205. [CrossRef]
32. Trivedi, P.; Karppinen, K.; Klavins, L.; Kviesis, J.; Sundqvist, P.; Nguyen, N.; Heinonen, E.; Klavins, M.; Jaakola, L.; Väänänen, J.; et al. Compositional and Morphological Analyses of Wax in Northern Wild Berry Species. *Food Chem.* **2019**, *295*, 441–448. [CrossRef]
33. Baldwin, E. Edible coatings for fresh fruits and vegetables: Past, present and future. In *Edible Coatings and Films to Improve Food Quality*; Krochta, J.M., Baldwin, E., Nisperos-Carriedo, M., Eds.; Technic: Basel, Switzerland, 1994; pp. 25–64.
34. Park, J.; Testin, R.; Vergano, P.; Park, H.; Weller, C. Application of Laminated Edible Films to Potato Chip Packaging. *J. Food Sci.* **2006**, *61*, 766–768, 777. [CrossRef]
35. Rojas-Grau, M.; Sobrino-Lopez, A.; Tapia, M.; Martin-Bellosso, O. Browning Inhibition in Fresh-cut 'Fuji' Apple Slices by Natural Antibrowning Agents. *J. Food Sci.* **2006**, *71*, S59–S65. [CrossRef]

36. Han, C.; Lederer, C.; McDaniel, M.; Zhao, Y. Sensory Evaluation of Fresh Strawberry (*Fragarai ananassa*) Coated with Chitosan-based Edible Coatings. *J. Food Sci.* **2005**, *70*, S172–S178. [CrossRef]
37. Guilbert, S.; Biquet, B. Edible films and coating. In *Food Packaging Tech.*; Bureau Multon, J.L., Ed.; VCH Publisher: New York, NY, USA, 1996.
38. Nesperos-Carriedo, M.; Baldwin, E.; Shaw, P. Development of an Edible Coatings for Extending Postharvest Life of Selected Fruits and Vegetables. *Proc. Annu. Meet. Fla. State Hortic. Soc.* **1992**, *104*, 122–125.
39. Park, H. Development of advanced edible coating of fruits. *Trends Food Sci. Technol.* **1999**, *10*, 250–260. [CrossRef]
40. El-Ghaouth, J.; Ponnampalam, R.; Boulet, M. Chitosan coating effect on stability of fresh Strawberries. *J. Food Sci.* **1991**, *57*, 1618–1620. [CrossRef]
41. Park, J.; Testin, R.; Rank, H.; Vergano, P.; Wlter, C. Fatty acid concentration effect on textile strength, elongation and water vapor permeability of laminated edible films. *J. Food Sci.* **1994**, *59*, 916–919. [CrossRef]
42. Okcu, Z.; Yavuz, Y.; Kerse, S. Edible Film and Coating Applications in Fruits and Vegetables. *Alınteri J. Agric. Sci.* **2018**, *33*, 221–226. [CrossRef]
43. Raghav, P.; Agarwal, N.; Saini, M. Edible coating of fruits and vegetables: A review. *Int. J. Sci. Res. Mod. Educ.* **2016**, *I*, 188–204.
44. Radev, R. Edible Films and Coatings for Food Products—Advantages and Disadvantages. Union of Scientists: Varna, Bulgaria, 2021; Volume 10, pp. 43–51.
45. Radev, R. Positive and Negative Aspects of Edible Films and Coatings for Food. In Proceedings of the Modern Commodity Expertise: Theoretical Developments: Practical Experience, Problems and Prospects, International Scientific and Practical Conference, Lviv, Ukraine, 27–28 May 2021; Volume 7, pp. 31–34.
46. Tice, P. Packaging Materials. 4. Polyethylene for Food Packaging Applications. International Life Sciences Institute Report. 2003. Available online: http://orig.ilsi.org/file/PM4_Polyethylene.pdf (accessed on 12 November 2022).
47. Weber, C.; Haugaard, V.; Festersen, R.; Bertelsen, G. Production and Application of Bio based Packaging Materials for the Food Industry. *Food Addit. Contam.* **2002**, *19*, 172–177. [CrossRef] [PubMed]
48. Morillon, V.; Debeaufort, F.; Blond, G.; Capelle, M.; Voilley, A. Factors affecting the moisture permeability of lipid based edible films: A review. *Crit. Rev. Food Sci. Nutr.* **2002**, *42*, 67–89. [CrossRef] [PubMed]
49. Debeaufort, F.; Quezada, G.; Voilley, A. Edible films and coating: Tomorrow's packaging: A review. *Crit. Rev. Food Sci. Nutr.* **1998**, *38*, 299–313. [CrossRef]
50. Avena-Bustillos, R.; Krochta, J.; Saltveit, M.; Rojas-Villegas, R.; Sauceda-Pbrez, J. Optimization of Edible Coating Formulations on Zucchini to Produce Water Loss. *J. Food Eng.* **1994**, *21*, 197–214. [CrossRef]
51. Kester, J.; Fennema, O. An Edible Film of Lipids and Cellulose Ethers: Barrier Properties to Moisture Vapor Transmission and Structural Evaluation. *J. Food Sci.* **1989**, *54*, 1383–1389. [CrossRef]
52. Nisperos-Carriedo, M.; Shaw, P.; Baldwin, E. Changes in Volatile Flavor Components of Pineapple Orange Juice as Influenced by the Application of Lipid and Composite Films. *J. Agric. Food Chem.* **1990**, *38*, 1382–1387. [CrossRef]
53. Gontard, N.; Duchez, C.; Cuq, J.; Guilbert, S. Edible Composite Films of Wheat Gluten and Lipids: Water Vapor Permeability and Other Physical Properties. *Int. J. Food Sci. Technol.* **1994**, *29*, 39–50. [CrossRef]
54. Kester, J.; Fennema, O. An Edible Film of Lipids and Cellulose Ethers: Performance in a Model Frozen-Food System. *J. Food Sci.* **1989**, *54*, 1390–1392. [CrossRef]
55. Garcia, M.; Martino, M.; Zaritzky, N. Lipid Addition to Improve Barrier Properties of Edible Starch-based Films and Coatings. *J. Food Sci.* **2000**, *65*, 941–944. [CrossRef]
56. Greener, I.; Fennema, O. Lipid-based edible films and coatings. *Lipid Technol.* **1992**, *4*, 34–38.
57. Robertson, G. *Food Packaging, Principle and Practices*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2009.
58. Vaishali, H.; Samsher, V.; Chaudhary, S.; Mithun, K. Importance of edible coating on fruits and vegetables: A review. *J. Pharmacogn. Phytochem.* **2019**, *8*, 4104–4110.
59. Devi, L.; Kalita, S.; Mukherjee, A.; Kumar, S. Carnauba wax-based composite films and coatings: Recent advancement in prolonging postharvest shelf-life of fruits and vegetables. *Trends Food Sci. Technol.* **2022**, *129*, 296–305. [CrossRef]
60. Saji, V. Wax-based artificial superhydrophobic surfaces and coatings. *Colloids Surf. A Physicochem. Eng. Asp.* **2020**, *602*, 125–132. [CrossRef]
61. Singh, S.; Khemariya, P.; Rai, A.; Rai, A.C.; Koley, T.; Singh, B. Carnauba wax-based edible coating enhances shelf-life and retain quality of eggplant (*Solanum melongena*) fruits. *LWT Food Sci. Technol.* **2016**, *74*, 420–426. [CrossRef]
62. Miranda, M.; Mori, M.; Ribeiro, M.; Spricigo, P.; Pilon, L.; Mitsuyuki, M.; Correa, D.; Ferreira, M. Carnauba wax Nano emulsion applied as an edible coating on fresh tomato for postharvest quality evaluation. *Heliyon* **2022**, *8*, e09803. [CrossRef]
63. De Oliveira Filho, J.; Albiero, B.; Calisto, Í.; Bertolo, M.; Oldoni, F.; Egea, M.; Junior, S.; de Azeredo, H.; Ferreira, M. Bio-nanocomposite edible coatings based on arrowroot starch/cellulose nanocrystals/carnauba wax nano emulsion containing essential oils to preserve quality and improve shelf life of strawberry. *Int. J. Biol. Macromol.* **2022**, *219*, 812–823. [CrossRef]
64. Chiumarelli, M.; Hubinger, M. Stability, solubility, mechanical and barrier properties of cassava starch—Carnauba wax edible coatings to preserve fresh-cut apples. *Food Hydrocoll.* **2012**, *28*, 59–67. [CrossRef]
65. Huiyun, C.; Zhengxuan, S.; Huqing, Y. Effect of carnauba wax-based coating containing glycerol monolaurate on the quality maintenance and shelf-life of Indian jujube (*Zizyphus mauritiana Lamk.*) fruit during storage. *Sci. Hortic.* **2019**, *244*, 157–164. [CrossRef]

66. Motamedi, E.; Nasiri, J.; Malidarreh, T.; Kalantari, S.; Naghavi, M.; Safari, M. Performance of carnauba wax-nanoclay emulsion coatings on postharvest quality of 'Valencia' orange fruit. *Sci. Hortic.* **2018**, *240*, 170–178. [CrossRef]
67. Huqing, Y.; Xia, L.; Guoquan, L. Effect of Carnauba Wax–Based Coating Containing Glycerol Monolaurate on Decay and Quality of Sweet Potato Roots during Storage. *J. Food Prot.* **2018**, *81*, 1643–1650. [CrossRef]
68. Aayush, K.; McClements, D.; Sharma, S.; Sharma, R.; Singh, G.; Sharma, K.; Oberoi, K. Innovations in the development and application of edible coatings for fresh and minimally processed Apple. *Food Control* **2022**, *141*, 109188. [CrossRef]
69. Wan-Shin, J.; Hye-Yeon, S.; Nak-Bum, S.; Ji-Hyun, L.; Sea, M.; Kyung, S. Quality and microbial safety of 'Fuji' apples coated with carnauba-shellac wax containing lemongrass oil. *LWT Food Sci. Technol.* **2014**, *55*, 490–497. [CrossRef]
70. Paredes-Lopez, O.; Camargo-Rubio, E.; Gallardo-Navarro, Y. Use of Coatings of Candelilla Wax for the Preservation of Limes. *J. Sci. Food Agric.* **1991**, *25*, 1207–1210. [CrossRef]
71. Oregel-Zamudio, E.; Angoa-Pérez, V.; Oyoque-Salcedo, G.; Noé Aguilar-González, C.; Mena-Violante, H. Effect of candelilla wax edible coatings combined with biocontrol bacteria on strawberry quality during the shelf-life. *Sci. Hortic.* **2017**, *214*, 273–279. [CrossRef]
72. De León-Zapata, M.; Sáenz-Galindo, A.; Rojas-Molina, R.; Rodríguez-Herrera, R.; Jasso-Cantú, D.; Aguilar, C. Edible candelilla wax coating with fermented extract of tarbush improves the shelf life and quality of apples. *Food Packag. Shelf Life* **2015**, *3*, 70–75. [CrossRef]
73. Bosquez-Molina, E.; Guerrero-Legarreta, I.; Vernon-Carter, E. Moisture barrier properties and morphology of mesquite gum–candelilla wax based edible emulsion coatings. *Food Res. Int.* **2003**, *36*, 885–893. [CrossRef]
74. Saucedo-Pompa, S.; Rojas-Molina, R.; Aguilera-Carbó, A.; Saenz-Galindo, A.; de La Garza, H.; Jasso-Cantú, D.; Aguilar, C. Edible film based on candelilla wax to improve the shelf life and quality of avocado. *Food Res. Int.* **2009**, *42*, 511–515. [CrossRef]
75. De León-Zapata, M.; Ventura-Sobrevilla, J.; Salinas-Jasso, T.; Flores-Gallegos, A.; Rodríguez-Herrera, R.; Pastrana-Castro, L.; Rua-Rodríguez, M.; Aguilar, C. Changes of the shelf life of candelilla wax/tarbush bioactive based-nanocoated apples at industrial level conditions. *Sci. Hortic.* **2018**, *231*, 43–48. [CrossRef]
76. Kowalczyk, D.; Kordowska-Wiater, M.; Zięba, E.; Baraniak, B. Effect of carboxymethylcellulose/candelilla wax coating containing potassium sorbate on microbiological and physicochemical attributes of pears. *Sci. Hortic.* **2017**, *218*, 326–333. [CrossRef]
77. Lawrence, J.; Iyengar, J. Determination of Paraffin Wax and Mineral Oil on Fresh Fruits and Vegetables by High Temperature Gas Chromatography. *J. Food Saf.* **1983**, *5*, 119–129. [CrossRef]
78. Jouret, C.; Puech, J. Composition de La Cire Cuticulaire de la Prune D'ente. *Ann. Agric. Sci.* **1972**, *21*, 25–33.
79. Nawrath, C. *The Biopolymers Cutin and Suberin*; Arabidopsis Book; American Society of Plant Biologists: Rockville, MD, USA, 2002; Volume 1, p. e0021. [CrossRef]
80. Pashova, S. Research on the Cuticle and Shelf Life of Plum Fruits. Ph.D. Thesis, Varna, Bulgaria, 2007; p. 219.
81. Nikolova, K.; Panchev, I.; Kovacheva, D.; Pashova, S. Thermophysical and Optical Characteristics of Bee and Plant Waxes. *J. Optoelectron. Adv. Mater.* **2009**, *11*, 1210–1213.
82. Panchev, I.; Nikolova, K.; Pashova, S. Physical Characteristics of Wax-containing Pectin Aqueous Solutions. *J. Optoelectron. Adv. Mater.* **2009**, *11*, 1214–1217.