Edible Coatings Enriched with Essential Oils and their Compounds for Fresh and Fresh-cut Fruit

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Abstract: Fresh fruit and vegetables consumption has increased in the past few years due to the enhanced awareness of consumers for healthy food. However, these products are highly perishable, and losses can be of great significance if postharvest correct management is not provided. Fresh-cut products are of increasing importance, since they are presented to the consumer in a state that allows for direct and immediate consumption. However, those products are even more perishable since cutting can induce a series of senescence associated responses to wounding, and are more susceptible to microbial spoilage. Edible coatings, which intend to reduce ripening processes and protect the fruit from water loss and spoilage may be a good way to enhance the shelf life of these products. More recently, the inclusion of additives into these edible coatings to increase their effectiveness, such as essential oils and their constituents with antimicrobial and antioxidant activities, has been reported and patented.

Keywords: Edible coating, essential oils, film coating, fresh-cut, fruit, vegetables.

INTRODUCTION

The consumption of fruit and vegetables is widely accepted as health beneficial, and the market for fresh ready to eat produce is increasing markedly due to dramatic changes in the consumer life style [1, 2]. Fresh-cut products are fruit or vegetables presented to the consumer in a state that allows for direct and immediate consumption, without the need for previous preparation or transformation. It is more difficult to maintain the fresh-like quality and nutritional value throughout shelf life of these products compared with entire fruits and vegetables. In fact, wounded tissue responds with a rise in respiration rate and ethylene production, inducing ripening and rapid senescence [3]. Hence, it is of paramount importance to determine the best way to preserve minimally processed fruits, considering that all the previously mentioned factors promote quality loss. Several studies have been conducted regarding the preservation of these products and their respective quality. For better preservation of fresh-cut commodities, investigations are towards the use of preservatives such as anti-browning and/or firming agents [1, 4].

Low storage temperature and modified storage packaging (MAP) are used to extend the shelf life of many whole and fresh-cut fruit and vegetable products, as they reduce the respiration rate, surface damage and browning [5]. More recently, it has been reported that film coating can extend shelf life in fresh-cut produce [6, 7]. Edible coatings have been used widely in whole fruits to reduce water loss and preserve quality [3]. For example, lipid-based edible coatings are excellent for preventing dehydration, and add brightness to the epidermis. Edible coating can also include some additives such as antimicrobials. These can effectively protect fresh-cut fruit against bacterial contamination by retaining preservatives on the surface of the cut fruit where they are needed, avoiding diffusion into the tissue [8].

Recent exploitation of natural products to control decay and extend storage life of perishables has received more and more attention. Essential oils are natural compounds isolated from aromatic plants. Some of these oils are generally recognized as safe (GRAS) for environment and human health. In this way, the interest in the use of such oils for a sustainable agriculture has increased and a lot of research has been done, proving for many cases, that plant essential oils and extracts may play the role as pharmaceuticals and food preservatives [9-11]. Studies on the use of essential oils and their constituents against microbial pathogens present in horticultural commodities have provided a set of results that can lead to effective options in what concerns food safety [11]. Due to the antimicrobial effect of essential oils and their components, their incorporation into edible coatings shows a great potential to increase shelf life and improve quality of fresh and fresh-cut fruits.

To our knowledge, very few patents have been made concerning the use of essential oils and their components incorporated into edible coatings to ensure quality and safety of fresh and fresh-cut horticultural produce extending shelf life. We intend to make a review on what is published about edible coatings, including patents from 2010, used to preserve shelf life of fresh horticultural products.

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EDIBLE COATINGS

An edible coating is a thin layer of edible material formed as a coating on a food product. Edible coatings are applied in liquid form on the food, generally by immersion of the product in a solution containing carbohydrate, protein, lipid or a multi-component mixture. Edible film coating is previously molded as solid sheets, made of edible material and applied as a thin layer on the food product [12].

Edible coatings are generally used for retarding gas transfer, reducing moisture and aroma loss, delaying color changes, and improving the general appearance of fruits, vegetables and minimally processed fruits through storage. The layer of edible coating applied on the surface of fruits, vegetables or their fresh-cut products aim to extend their shelf life [3].

The choice of a proper edible coating for fresh horticultural products is complex because it depends on the specific respiration and transpiration rates of the commodity and the outside environmental conditions [13]. A clear understanding of how an edible coating will work on different produce is not easy, because the response of different commodities will differ significantly with the cultivar and storage conditions. In fact, it has been demonstrated that the respiration rate of apple slices decreased 20% when coated with a film based on whey protein [14], and the rate of ethylene production decreased by about 90% when apple slices were coated with a polysaccharide/lipid bilayer coating [15].

Edible coatings with different composition have been tested and used to prolong storage life of fruit because they can provide an additional protective coating, retarding microbial growth, and can also create a protective barrier to reduce respiration and transpiration rates, retarding senescence. According to their components, edible coatings can be divided into three categories: hydrocolloids, lipids, and composites. Hydrocolloids include proteins and polysaccharides. Lipids include waxes, acylglycerols, and fatty acids. Composites contain both hydrocolloid components and lipids [8, 16, 17].

Carrageenan, maltodextrin, methylcellulose, carboxymethyl cellulose, pectin, alginate and microcrystalline cellulose are some examples of carbohydrates used in hydrocolloid-based edible coatings, as well as whey protein concentrate, whey protein isolate, casein, and soy protein concentrate [3]. Some of the lipids constituting edible coatings include beeswax, acylated monoglycerides, fatty alcohols, and fatty acids, although almost always in combination with a carbohydrate or protein. A minimum amount of plasticizers, such as sorbitol and glycerol, may be added to improve the film's mechanical properties [3, 18]. Beyond these constituents, edible coatings can also have food additives such as antioxidants, colorants, flavoring agents, and antimicrobial compounds [19]. For example, organic acids (acetic, lactic, propionic, malic), metals (silver), bacteriocins (nisin, lacticin), enzymes (lysozyme, lactoperoxidase), peptides and natural antimicrobials (spices, essential oils, propolis) have been also incorporated in edible coatings [18].

In recent reviews, some authors have reported the main components used in edible films and edible coatings structural matrices as well as the functional ingredients added to those matrices for improving the quality and extending the shelf life of horticultural products [3,12, 20]. However the characteristics of vegetables, fruits or minimally processed products wrapped with the edible films or coatings are influenced by the kind of material implemented as structural matrix (composition, molecular weight distribution), the conditions under which films are performed (type of solvent, pH, concentration of components and temperature) and the type and concentration of additives (plasticizers, cross-linking agents, antimicrobials, antioxidants or emulsifiers) [12].

Some patents regarding edible films for extending shelf life of food products were compiled in a recent review of 2009 [21]. From this date, several other patents regarding edible coatings for protecting fruit and vegetables against microorganisms, water loss and to improve their appearance and, consequently, their marketability have been registered [22-25]. Chitosan or selected hydrolysates of chitosan along with acetic acid, water and a nonionic carnauba wax emulsion is an edible coating patented as an alternative to existing and conventional coatings for fruits, vegetables and nuts [22]. Some additives may also be added to this preparation. Other patents refer the utilization of rice starch, pullulan or xanthan gum, gum lac, natural wax, edible plant oleic acid, sucrose, vitamin C, milk protein (casein) and sorbitol in the preparation of edible coatings for preserving color, freshness and brightness of fruit and quality structure of pulp for a longer time [23-25].

Still in the field of fresh preservation and treatment of fruit and vegetables with edible coatings, there is a specific patent directed to the preservation of drupes using an edible compound coating antistaling [26]. Along with chitosan, the coating also contains glyceryl monostearate, Tween 80, sodium ascorbate and sodium chloride for enhancing the connecting strength of antibacterial components as well as for improving the toughness and air permeability of the coating [26].

ESSENTIAL OILS AND THEIR CONSTITUENTS

For inhibiting the spoilage flora and to decrease the risk of pathogens in horticultural products some antimicrobial agents must be used in the formulation of edible films and coatings. GRAS antimicrobial compounds must be used not only to satisfy consumer demands but also for guarantee healthy foods [27]. The utilization of antimicrobials in edible coatings has as advantage to mantain effective concentrations of the active compounds on the food surfaces in contrast to the direct application of the antimicrobials. In the latter, there is a rapid neutralization of the active compound or diffusion from the surface into the food product, decreasing the antimicrobial effect [28, 29].

Several categories of antimicrobials can be incorporated into edible films and coatings: organic acids (acetic, benzoic, lactic, propionic, sorbic), fatty acid esters (glyceryl monolaurate), polypeptides (lysozyme, peroxidase, lactoferrin, nisin), nitrites and sulphites, plant essential oils (cinnamon, oregano, lemongrass), among others [20].

An essential oil is defined internationally as the product obtained by hydrodistillation, steam distillation or dry distillation or by a suitable mechanical process without heating (for citrus fruits) of a plant or some of its parts [30]. Essential oils have a complex composition, containing from a dozen to several hundred components. The great majority of components identified in essential oils include terpenes (oxygenated or not), with monoterpenes and sesquiterpenes prevailing. Furthermore, allyl- and propenylphenols (phenylpropanoids) are also important components of some essential oils [31]. They are aromatic oily liquids, volatile, characterized by a strong odor, rarely colored, and generally with a lower density than that of water [32].

Several biological properties have been attributed to the essential oils (insect repellent, anti-nociceptive, anticancer, anti-inflammatory, antioxidant, anti-viral and antimicrobial) [33-36]. The mechanisms of action of essential oils as antimicrobials are not clearly known; nevertheless it seems that such activity is basically due to their hydrophobicity. The constituents of the essential oils are able to disrupt and penetrate the lipid structure of the bacteria cell membrane, disturbing cell structures and make them more permeable. Other studies have demonstrated that some components are able to act on the cytoplasmic membrane proteins or to inhibit the activity of some enzymes involved in cell metabolic pathways [37-41].

The antimicrobial activity of essential oils cannot only be attributed to those components present in higher concentrations (main components) because several authors have demonstrated that whole oils are more effective antimicrobial agents than a mix of the main constituents [42-44]. In addition, as the chemical composition of the essential oils depends on the geographic origin of the plant, harvesting period, plant part used, among other factors, and this may explain the variability in the degree of susceptibility of microorganisms to the essential oils [18, 44].

ESSENTIAL OILS IN THE CONTROL OF POST-HARVEST DISEASES

A recent review by Antunes and Cavaco [11] has shown the beneficial effect of essential oils and their constituents on the control of postharvest diseases either *in vitro* or *in vivo*, although most studies focus on *in vitro* than on horticultural produce infected with decay diseases.

The essential oil from *Origanum minutiflorum* has shown a strong antimicrobial activity against many ciprofloxacin-resistant *Campylobacter* spp., *in vitro*, suggesting that it may be used as a natural preservative in fresh produce against food-borne diseases [45]. Also, citrus oils have been found to be inhibitory against a range of both Gram-positive and Gram-negative bacteria making this group of oils suitable as antimicrobials for food industry [46]. *Botrytis cinerea* and *Alternaria arborescens*, isolated from tomato, showed complete *in vitro* growth inhibition when exposed to oregano, thyme and lemongrass vapours [47]. Carvone, cuminaldehyde, perillaldehyde, cinnamaldehyde, salicylaldehyde and benzaldehyde Fig. (**1**) strongly reduced the growth of *Penicillium hirsutum in vitro* [48].

The same essential oil and/or respective compounds can be active against a wide spectrum of microorganism species, although the minimum inhibitory concentration (MIC) used can be very changeable, according to the microbial species and/or the commodity [11]. Essential oils of different origins and their constituents can have different MIC for the same pathogen. Essential oil from *Origanum compactum* Benth. and *Thymus glandulosus* Req., consisting mostly of carvacrol and thymol Fig. (**1**) were effective at a concentration of 100 mg/L, in controlling *in vitro* the *Botrytis cinerea*, which is a critical pathogen in postharvest of horticultural products [49]. Essential oils from other species such as *Chenopodium ambrosioides* L., *Eucalyptus citria* Hook, *Eupatorium cannabinum* L., *Lawsonia inermis* L., *Ocimum canum* Sim., *Ocimum Gratissimum* L., *Ocimum Sanctum* L., *Prunus persica* (L.) Batsch, *Zingiber cassumunar* Roxb. and *Zingiber officinale* Rosc. exhibit *in vitro* fungitoxic activity against *B. cinerea* at only 500 mg/L concentrations [50].

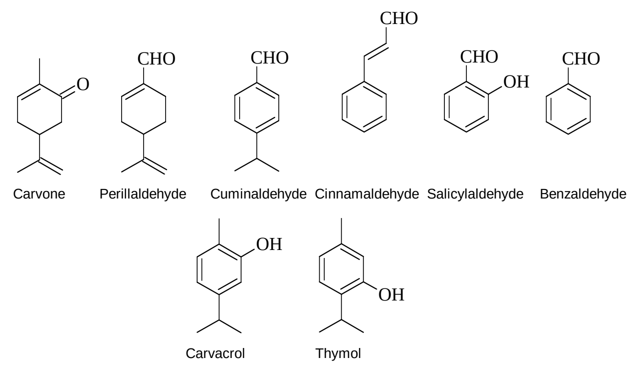

Fig. (1). Some constituents of the essential oils with antimicrobial activity.

The effect of essential oils and their constituents on postharvest diseases of horticultural products has been investigated for pears, citrus, bananas, strawberries, tomato, cherries and grapes [47, 51-55]. Essential oils from *O. sanctum*, *P. persica* and *Z. officinale* showed MIC values of 200, 100 and 100 mg/L, respectively, in the control of *B. cinerea* in grapes during storage and promoted the enhancement of storage life up to 4–6 days [50]. The thyme oil exhibited a higher degree of inhibition of *A. alternata* (62.0% at 500 mg/L) than cassia oil (40–50% at 500 mg/L) in tomato [56]. In tulip bulbs, it was found a 40-fold reduction of the fungal population when dipped in an aqueous solution of 515 mg/L cinnamaldehyde [48]. Also basil oil (*Ocimum basilicum* L.) emulsion of 160 mg/L controlled crown rot and anthracnose, prolonging the storage life in bananas [57]. Eucalyptus (*Eucaliptus globulus* L.) and cinnamon (*Cinnamomum zeylanicum*, Blume) essential oil vapours applied at 50 mg/L concentrations for 8 h at 20°C reduced fruit decay and improved the quality of tomatoes and strawberries during late storage life [55]. Tsao and Zhou [52] found that thymol and carvacrol were effective in controlling brown rot caused by *Monilinia fructicola* in sweet cherries (*Prumus avium* L.).

However, when applied in concentrations effective to reduce microbial growth as *in vitro*, essential oils and their constituents can cause phytotoxicity on the fresh commodities reducing quality and shelf life [11]. Indeed, the use of essential oils and their constituents in food industry is an interesting approach, but their intense aroma and potential toxicity, limit their use in the area of food preservation [58]. So it is of great importance to reduce doses of essential oils or their constituents when the aim is to include them into edible coatings. One approach may be making combinations of diverse essential oils which due to their synergistic effects as antimicrobials may permit to use them at sufficiently low concentrations, reducing the negative sensory impact. Such was already performed by some authors [59, 60]. Lowering the concentration of essential oils without compromising the biological activity can also be obtained by applying them in combination with other antimicrobial compounds that provide a synergistic effect [61]. Such combinations have advantages because they may lead to a better biological activity of the antimicrobial agent or to the reduction of the antimicrobial amount needed for obtaining the activity desired or even to the reduction or prevention of resistance development by the target microorganism. Other way to minimize organoleptic effects of essential oils added to fruits and vegetables is to encapsulate essential oils into nanoemulsions with the advantage to increase the stability of volatile compounds, protecting them from interacting with the food matrix [62].

Some patents regarding the utilization of essential oils on the prevention of fruit decay have been developed. For example, *Cinnamomum cassia* Presl., *Brassica nigra*, *Thymus vulgaris*, *Myristica fragrans*, *Eucalyptus citria* Hook oils or their components were reported for the protection of persimmons against *Alternaria alternata*, strawberries against *Botrytis cinerea*, mandarins against *Penicillium italicum* or *Penicillium digitatum* or peaches against *Rhizopus stolonifer* after application in a volatile form into the atmosphere surrounding the fruits [63]. In this patent, the inventors have taken into account the variability of chemical composition of the essential oils due to diverse factors: differences between varieties and individual plants, the growing and environmental conditions of the plant and the extraction procedures used for obtaining the essential oils. Moreover, the composition of an essential oil from the same origin may vary even from batch to batch produced by the same manufacturer. In this way, the essential oils from various manufacturers, with antimicrobial properties, were chemically characterized by the inventors reporting for each compound an interval of concentrations. In addition, the inventors also determined the profile of release of the oil components into vapor phase. They found that not always the main compound of an essential oil in the liquid phase is also the main one in the vapor phase as well as synergistic effects among the components of the oils.

EDIBLE COATINGS ENRICHED WITH ESSENTIAL OILS

Edible coating made of polysaccharide/lipid bilayer is suitable to increase fresh and fresh-cut fruit storage life [6, 7] and to carry many functional ingredients such as antimicrobial and antioxidant agents [17]. As mentioned above, some essential oils and their constituents have been proved to have role as pharmaceuticals and food preservatives due to their, among others, antioxidant and antimicrobial capacity and most of them have GRAS status [9,11,64].The main objective of incorporating essential oils and their constituents into edible coatings is to use their antioxidant and antimicrobial capacity to improve edible coatings in the preservation of fresh and fresh-cut horticultural commodities and by increasing their shelf life.

Although essential oils can be regarded as alternatives to chemical preservatives, little is known on the incorporation of plant essential oils into edible films and coatings. Only few works on this incorporation into edible coatings applied on vegetables or fresh-cut fruit can be found in international databases. Table **1** compiles the essential oils reportedly used in edible films and coatings.

Only recently, one of the first works concerning the utilization of essential oils into edible coatings was explored by Pranoto *et al.* [65]. These authors reported the antibacterial activity of garlic oil added to alginate-based film against *Staphylococcus aureus* and *B. cereus*, using agar diffusion method. Garlic oil was also assayed by Seydim and Sarikus [66] by incorporation in whey protein isolate films, although it was demonstrated to be much less active than oregano essential oil against *Escherichia coli* O157:H7 (ATCC 35218), *Staphylococcus aureus* (ATCC 43300), *Salmonella enteritidis* (ATCC 13076), *Listeria monocytogenes* (NCTC 2167) and *Lactobacillus plantarum* (DSM 20174).

Rojas-Graü [67] demonstrated the antimicrobial activity of oregano, lemongrass and cinnamon oils against *Escherichia coli* O157:H7 in apple puree film-forming solution and in an edible film made from the apple puree solution. This research has also shown that the addition of the essential oils into film-forming solution decreased the water vapor permeability and increased the oxygen permeability, but did not significantly alter the tensile properties of the films [67, 68].

Some authors have used oregano and lemongrass oils added to apple puree-alginate edible coatings and applied to fresh-cut 'Fuji' apples to evaluate their antimicrobial abilities [69]. Coatings containing lemongrass (1.0 and 1.5% w/w) and oregano oil (0.5% w/w) exhibited the strongest antimicrobial activity against *L. innocua*, however lemongrass had the disadvantage of inducing severe fruit texture softening. Vanillin also assayed in the same experiment was revealed to be the most effective in terms of sensory quality. All antimicrobial edible coatings significantly inhibited the growth of psychrophilic aerobes, yeasts and moulds.

Beyond the reported antibacterial activities, some essential oils in edible coatings are also able to prevent fungal growth. Some authors shown that thyme and Mexican lime essential oils incorporated in mesquite gum-based coating and applied on papaya had fungicidal effect, mainly against *Colletotrichum gloeosporioides* and *Rhizopus stolonifer* [70]. The fight against moulds and total flora was also surveyed by Vu *et al* [71] using essential oils of diverse aromatic plants as well as pure components incorporated in functionalized chitosan-based edible coating and applied on strawberries. They have found that formulations based on modified chitosan containing limonene and Tween®80 performed better than other formulations in strawberries [71]. Other diseases caused by fungus (*Colletotrichum* spp.) include anthracnose which is responsible for considerable losses in tropical fruits. *In vivo* studies revealed that gum arabic combined with cinnamon oil was the best for controlling decay due to the infection by *C. musae* and *C. gloeosporioides* in artificially inoculated bananas and papayas, respectively. The results regarding quality evaluation have also confirmed

Table 1. Examples of Essential Oils and/or their Constituents in Edible Coatings used as Antimicrobials

Essential oil or its major compound in the edible coating or film coating	Type of edible coating or film coating	Microorganism target	Effect observed	Fruit	Reference
Thymol	Pullulan	*Bacillus subtilis* ATCC6633 *Staphylococcus aureus* ATCC25923 *Salmonella enteritidis* ATCC13076 *Escherichia coli* ATCC25922	All were susceptible and the ability was dose-dependent	Apples Mandarines	[77]
Lemongrass and cinnamon oils and combination of both	Gum arabic	*Colletotrichum musae* *C. gloeosporioides*	Cinnamomun oil demonstrated to be the most effective	Banana Papaya	[72]
Bergamot essential oil	Hydroxypropylmethylcellulose Chitosan	Total aerobic mesophilic microorganisms Yeasts and mould	Chitosan with bergamot oil produced the most antimicrobial activity	Grapes cv. Muscatel	[76]
Origanum compactum *Thymus vulgaris* *Mentha piperita* *Cymbopogon citratus* essential oils Limonene	*N*-acylated chitosan	Total flora and total moulds	Modified chitosan with limonene and Tween®80 demonstrated to be the most effective	Strawberries	[71]
Coridothymus capitatus, *Salvia lavandulifolia* essential oils	Whey protein isolate (WPI) and cellulose-based filter paper	*Listeria innocua* (Nº 910 CECT) *Salmonella enteritidis* (Nº 7159 CECT) *Staphylococcus aureus* (Nº 976 CECT)	*Coridothymus capitatus* was a promising antimicrobial against food pathogens in edible WPI based films	-	[75]
Carvacrol	Tomato-based film with high methoxyl pectin 1400	E. coli 0157:H7	Positive effect of carvacrol-containing tomato-based edible films	-	[83]
Mexican limes and thyme essential oil	Mesquite gum-based emulsion films	*C. gloeosporioides* *Rhizopus stolonifer*	Excellent control of the microorganism studied	Papaya	[70]
Cinnamon, clove, lemongrass essential oils, cinnamaldehyde, eugenol, citral	Alginate	*E. coli* 0157:H7	Lemongrass and cinnamon oils, citral and cinnamaldehyde were the most effective	Fresh-cut apples	[74]
Cinnamon, palmarosa and lemongrass oils and their active compounds	Alginate	Mesophilic and psychrophilic microorganisms, yeasts, moulds, *S. enterica* serovar Enteritidis 1.82 (NCTC 9001)	Palmorosa oil was a promising preservation alternative for fresh-cut melon	'Piel de sapo' melons (*Cucumis melo* L.)	[73]
Oregano oil, carvacrol, cinnamon oil, cinnamaldehyde, lemongrass oil, citral	Alginate-apple puree edible film	*E. coli* 0157:H7	Carvacrol>oregano oil > citral> lemongrass > cinnamaldehyde > cinnamon oil	-	[68]

(Table 1) Contd….

Essential oil or its major compound in the edible coating or film coating	Type of edible coating or film coating	Microorganism target	Effect observed	Fruit	Reference
Oregano and lemongrass oils, vanillin	Apple puree-alginate edible coating	Psychrophilic microorganisms, yeasts, moulds, *L. innocua*	Lemongrass oil (1; 1.5%, w/w) and oregano oil (0.5%, w/w) exhibited the strongest activity	Fresh-cut 'Fuji' apples	[69]
O. minutiflorum, Rosmarinus officinalis L., *Allium sativum* L.	Whey protein isolate-based-film preparation	*Lactobacillus plantarum* (DSM 20174) *S. enteritidis* (ATCC 13076) *E.coli* 0157:H7 (ATCC 35218) *L. monocytogenes* (NCTC 2167) *S. aureus* (ATCC 43300)	Oregano oil was the most effective	-	[66]
Oregano, cinnamon and lemongrass oils	Apple puree solution	*E.coli* 0157:H7	Oregano oil > lemongrass oil > cinnamon oil	-	[67]
Garlic oil	Alginate-based edible film	*E.coli, Salmonella typhimurium, Staphylococcus aureus, B. cereus*	*Staphylococcus aureus* and *B. cereus* were sensitive to garlic oil	-	[65]

-: not reported

the efficacy of this combination since ripening was significantly delayed [72].

It is noteworthy to refer that Vu *et al.* [71] decided to use the essential oil of peppermint and limonene in edible coatings applied to strawberries only after the results of odor and taste evaluated by a group of panellists. Only these two samples were acceptable in detriment of that of red thyme.

Cinnamon and lemongrass oils have been regularly studied in diverse types of edible or film coatings. In fresh-cut 'Piel de Sapo' melon (*Cucumis melo* L.) coated with alginate-based edible coating containing cinnamon, lemongrass and palmarosa oils and their main active compounds, was able to avoid the microbiological spoilage and therefore to extend the fruit shelf life for over 21 days. However, some fresh-cut melon characteristics were affected, namely, firmness and color, leading to a reduction of physicochemical shelf life. Nevertheless, and according to published results by Raybaudi-Massilia *et al.* [73], palmarosa oil incorporated at 0.3% into the coating appeared to be a promising preservation alternative for fresh-cut melon, since it had a good acceptability by panellists, maintained the fruit quality parameters and inhibited the native flora growth and reduced *S. enteritidis* population. A similar study performed by the same authors but on fresh-cut 'Fuji' apples revealed that lemongrass and cinnamon essential oils, citral, and cinnamaldehyde were the most effective compounds to prevent microbial development, whereas lemongrass, cinnamon, and clove essential oils were the best for maintaining the physicochemical characteristics of the fresh-cut 'Fuji' apples [74].

Antimicrobial effectiveness of oregano and sage essential oils incorporated into two different matrices (whey protein isolate and cellulose-based filter paper), revealed that oregano oil showed antimicrobial activity against *Listeria innocua*, *Staphylococcus aureus* and *Salmonella enteritidis* in both matrices. In contrast, sage oil did not show any activity in whey protein isolate. In cellulose-based filter paper as supporting matrix both essential oils were active, although much more significant for oregano oil [75]. According to the authors, such may reveal that the interactions between the essential oils and the films may be critical on the diffusivity of the active compounds and therefore on the final antimicrobial activity.

Biodegradable coatings based on hydroxypropylmethylcellulose or chitosan with and without bergamot essential oil were applied to table grapes, cv. Moscatel. The results showed that chitosan containing bergamot had the highest antimicrobial activity as well as the greatest capacity to minimize the respiration rates and a reasonably good control over water loss during storage [76]. Although chitosan with bergamot essential oil had the highest antimicrobial activity, the presence of an essential oil in chitosan may reduce the activity of chitosan, which also present antimicrobial activity mainly against Gram negative bacteria, due to the reduction in the available polymer concentration [18].

Pullulan films are formed from extracellular polysaccharide produced by the fungus *Aureobasisium pullulans*, and when combined with thymol expressed strong inhibitory activity against *Bacillus subtilis* ATCC6633, *Staphylococcus aureus* ATCC25923, *Salmonella enteritidis* ATCC13076, and *Escherichia coli* ATCC25922 [77]. In this work, the authors also reported that the aroma of thymol introduced in the pullulan film was not perceptible after the skin of the mandarins had been peeled or after the film had been removed from the surface of apple.

Fresh-cut apples showed a significant reduction in microbial spoilage when lemongrass, oregano and vanillin essential oil were incorporated in apple puree-alginate edible coating [68]. The incorporation of essential oil from cinnamon, palmarosa and lemongrass into alginate-based EC increased shelf life of fresh-cut melon [74]. Some essential oils or their constituents at higher concentrations can be more effective to reduce microbial spoilage but might reduce the physicochemical quality, mainly pulp softening probably due to the action of the essential oil constituents over the cell tissue of the fruit, which possibly undergo structural changes affecting fruit firmness itself [68, 73]. Lemongrass and cinnamon EO (0.7%), citral (0.5%), and cinnamaldehyde (0.5%) were the most effective compounds for extending microbiological shelf life of 'Fuji' apples, whereas lemongrass, cinnamon, and clove essential oils at 0.3% were the best to maintain the physicochemical characteristics of the product [73].

By using an edible coating made of soy or wheat gluten protein as a carrier of thymol or calcium chloride, the quality and shelf life of strawberries were increased and microbial growth was reduced, being coatings with thymol the most effective [78]. Zapata *et al*. [79] found that alginate edible coating including a mixture of essential oils (thymol, menthol, eugenol, carvacrol) had a better effect in reducing ripening processes in tomato, than only alginate at 1%. This, again, suggests that the use of edible coatings enriched with essential oils or their constituents is promising to maintain fruit quality.

Edible coating stability and flexibility, transparency and gloss depend on several factors. The incorporation of essential oils or their components in edible coatings may decrease the mechanical resistance to rupture due to the structural discontinuities caused by the oil-dispersed phase. Essential oils into edible coatings may decrease its transparency and gloss due to the migration of droplets or aggregates of essential oils to the top of the film during drying, which is responsible for surface irregularities. Color of edible coatings supplemented with essential oils is only affected when relative high concentrations are used [18]. Nevertheless some authors concluded that apple-based films with allspice, cinnamon, or clove bud oils darkened the film color [80]. Water vapour permeability properties were not affected by the addition of the essential oils to the apple-based films, in contrast to the results reported by other authors [81], which reported a significant decrease in permeability through apple films formulated with pectin and cinnamon oil. Such may be explained by the fact that water vapour transfer generally occurs through the hydrophilic portion of the film and depends on the hydrophilic-hydrophobic ratio of the film components [82]. Nevertheless some authors reported an increase of water vapour permeability of tomato films with the addition of carvacrol [83].

Edible coatings presenting essential oils, which can be applied to any food or agricultural product requiring extension of shelf-life, have been also patented, although very few could be found. There is a patent which reports a composition for coating fruits, vegetables and fowl eggs, useful for their protection and extension of their shelf life. Such edible coating comprises an aqueous dispersion containing a hydrophobic component encompassing a natural wax, or vegetable oil; an alkali agent; water; an additive selected from rosemary extract, sage extract, green tea water, eucalyptus oil, lavender oil, citrus peel oil, ethanol, chamomile ethanolic extract, cypress ethanolic extract, prickly pear ethanolic extract, or aloe ethanolic extract; and an emulsifier. The hydrophobic components and the extracts or essential oils are derived from natural biological sources [84].

Nevertheless there are also some edible coatings in which nutraceuticals and immune response enhancer can be added to provide additional properties to the coating. An edible coating comprising sodium alginate and pectin along with calcium ascorbate (cross-linking agent) and several additives: antimicrobials (vanillin or an essential oil), flavoring agent (vanillin), antioxidant (citric acid and ascorbic acid), probiotic (*Lactobacillus acidophilus*, *Lactobacillus casei* and *Bifidobacterium lactis*), an immune response enhancer (yeast glucopolysaccharide), and at least a coloring agent, a protein, an amino acid and a vitamin was patented for covering fruit and vegetables by immersing them in the solution [85].

CURRENT & FUTURE DEVELOPMENTS

Edible coatings have been developed with the objective of applying them on fresh and fresh-cut horticultural products to increase their shelf life by retarding senescence.

The permeability of the edible coating is of significant importance to prevent an anaerobic environment or excessive water loss, these depending on the respiration rate of the produce and storage environment. Additionally recent studies have focused on the incorporation of antioxidant and antimicrobial compounds into these edible coatings.

Essential oils and their compounds which have proved to have antioxidant and antimicrobial activities are promising compounds to be added to edible coatings increasing their benefits.

Research comprising the use of different essential oils and their compounds and concentrations, into different edible coatings and their application in different high perishable fresh and fresh-cut produce to increase their quality and storage life is needed.

There is a high potential for the use and development of different edible coatings enriched with essential oils or their compounds formulations, as healthy and environment friendly enhancers of fresh and fresh-cut horticultural produce longevity and quality. However, in developing a new edible coating, attention may be paid to the fact that it must be cost competitive and the availability of raw material (aromatic plants and/or essential oils) must be provided.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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