



The Use of Essential Oils in Active Food Packaging: A Review of Recent Studies

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ARTICLE INFO	ABSTRACT
<p><i>Review Article</i></p> <p>Received : 29/04/2019 Accepted : 13/09/2019</p> <p>Keywords: Essential oils Food processing Packaging Films Coatings</p>	<p>Public concern on the excessive use of synthetic food additives has raised a great interest to use natural products due to their potential in food and pharmacological industries. Nowadays, chemical food additives are questioned due to their contribution to the health risks and environmental impacts. Among natural additives, essential oils (EOs) are extracted from aromatic compounds and responsible for their biological activities namely antimicrobial and antioxidant capacity. Incorporation of bio-active compounds particularly EOs directly in food or edible/biodegradable food packaging seems to enhance the shelf life and quality characteristics of processed food and protect the consumers against oxidative and bacterial deterioration effects. However, inclusion of EOs in films/coatings for food packaging may put some effects on various properties (optic, tensile and etc.), which can affect the consumer acceptability. Their addition in food can cause some allergic and hypersensitivity reactions to the individuals who use them often. This paper aims to review the latest findings on the use of EOs incorporated with edible/biodegradable films and coatings to enhance the shelf life and quality of the food. Further investigations about essential oils are expected to clarify their exact action and build up their standard use in food industry.</p>

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Introduction

Since urbanization, modernization and industrialization started to put demands for longer shelf life of foodstuffs, the use of chemical food additives has been the best choice. Nowadays, consumers demand food with less synthetic additives with the expectations that food must be free from pathogens, their toxins and other deteriorating factors. The main challenge to food industry is to satisfy the customer demands with the minimum changes in food quality. This industry was compelled to devise new technologies to satisfy customer's expectations. Consequently, active food packaging has emerged.

Several herbs, spices, plants and fruits have volatile antimicrobial and antioxidant compounds. These substances can be used in food packaging. Active food packaging may be an alternative to traditional preservative techniques. It protects the food from external risks like humidity, light and temperature, odours, pathogens, shocks, dust and compressive forces (Ribeiro-Santos et al., 2017). The essential oils (EOs) have become the focus of research not only for being a natural food additive but also due to their beneficial effects on human health. They exhibit antimicrobial and antioxidant properties, which

make them interesting food additives in food industry (Ribeiro-Santos et al., 2017).

The EOs have raised the extraordinary intrigue for being a characteristic natural compound and they have exhibited beneficial effects on food and human health as well. As of now, they are being considered for their diverse biological properties, for example, antioxidant, antimicrobial, anti-inflammatory, analgesic and immunomodulatory agents (Brahmi et al., 2016; Periasamy et al., 2016). Both EOs and their major constituents are being added specifically into food or fused with food packaging in order to increase food storage and shelf life. Antimicrobial and antioxidant activities of EOs and their components minimize the microbial pathogen density and decrease the occurrence of lipid oxidation (Ribeiro-Santos et al., 2017; Ruiz-Navajas et al., 2013). In this way, they can go about as an option in contrast to synthetic additives. A large variety of EOs are approved by the Food and Drug Administration (FDA) which are safe to use directly in food or in food packaging (Food and Drug Administration, 2016).

This review clarifies the current advancements in the utilization of EOs in food industry to possibly benefit food preservation and human health. It also highlights the present status, ongoing advances, and future patterns in regards to utilization of EOs for food processing and packaging.

Definition and Chemistry of EOs

The EOs are secondary metabolites which are volatile and aromatic in nature present in edible, herbal and medicinal plants. They can be extracted easily by using conventional methods (steam distillation, hydro distillation, and solvent extraction) and innovative techniques such as supercritical fluid extraction, microwave-assisted extraction, and ultrasound-assisted extraction (Pateiro et al., 2018). Different parts of the plant are producing different types and composition of EOs. For example, EOs extracted from seeds and immature leaves of the same plant possess different compositions (Delaquis et al., 2002).

Principally, the most commonly occurring EOs are a combination of two chemical groups: Terpenoids and phenylpropanoids. Within terpenoids, major compounds of EOs belong to the monoterpenoids (C₁₀), sesquiterpenes (C₁₅) and occasionally diterpenes (C₂₀) may also exist. Phenylpropanoids are less abundant of EOs as compared to terpenoid compounds containing side chain of 3rd carbon with an aromatic ring of C₆. The different types of low molecular weight aliphatic hydrocarbons, acids, alcohols, aldehydes, acyclic esters or lactones, and exceptionally N- and S- containing compounds and coumarins are also present (Calsamiglia et al., 2007).

Antimicrobial and antioxidant properties of EOs

Plant and plant extracts have traditionally played a vital job in wellbeing and health of human being and animals. Due to essence, flavour, antimicrobial and preservative properties, plant secondary metabolites have been used by mankind since early history (Benchaar et al., 2008). EOs perform antimicrobial, antioxidant and flavouring functions when applied to food. The most important purpose of addition of EOs is to minimize or eradicate the pathogenic microbes and/or decrease the phenomenon of lipid oxidation. For the preservation of food, EOs are required in high concentrations. EOs and their major components are hydrophobic in nature, which can penetrate lipidic layer of bacteria resulting in disturbance of cell osmotic pressure by interrupting membrane integrity. The EOs are more potent against gram-positive organisms than gram-negative bacteria in the light of the fact that hydrophobic components cannot penetrate into the cell membrane of gram-negative bacteria. However, small molecules of EOs can infiltrate the membrane of gram-negative bacteria and interrupt the cell functions by passing through diffusion with the help of membrane proteins and/or lipopolysaccharides (Benchaar et al., 2008). Cherrat et al., (2014) studied the *Laurus nobilis* and *Myrtus communis* EOs for their antimicrobial activity against foodborne pathogens. They observed that *Staphylococcus aureus* was the least resistant bacteria against both EOs, while *Listeria monocytogenes* and *Escherichia coli* proved

most resistant strains. EOs possess antimicrobial activity due to terpenoids and phenolic compounds. Thyme and oregano EOs inhibited the growth of pathogenic strains like *S. enteritidis*, *S. choleraesuis*, *S. typhimurium* and *E. coli* (Peñalver et al., 2005) which is attributed to the phenolic components such as thymol and carvacrol. Likewise, combination of EOs obtained from 97 plants was examined against *Penicillium corylophilum* to check the synergistic antifungal effects. A combination of cinnamon bark, citronella, and May chang EOs showed the synergistic activity and inhibited the growth of *P. corylophilum* on minced beef (Ji et al., 2019). Similarly, combination of oregano and rosemary EOs were proved more effective against *E. coli* O157:H7, *S. choleraesuis*, *L. monocytogenes*, and *S. aureus* compared to individual EOs doses (Alvarez et al., 2019). Pendleton et al., (2012) found that valencia oil has the ability to reduce the growth of *E. coli* O157:H7 at refrigeration temperatures isolated from beef.

Synthetic antioxidants are primitively used with the expectations to limit the lipid peroxidation by diminishing the formation of free radicals or scavenging chain-carrying peroxy radicals (Pisoschi and Pop, 2015). From last few decades, interest in using antioxidant agents from natural sources has been heightened to increase the shelf life of food due to customer preferences and possible toxic effects of synthetic additives. The resulting compounds produced from oxidation process affect the texture, water holding capacity, nutritional and quality characteristics of the foodstuffs. As antioxidant agents, EOs have various modes of actions. They perform their role by neutralizing the free radicals, making chelate transitional metals and quenching the singlet and triplet oxygen by the decomposition of peroxides (Tongnuanchan and Benjakul, 2014).

Packaging

EOs can be included directly in food or incorporated in packaging material (Espitia et al., 2012; Wen et al., 2016). The lack of reproducibility of EO's activity is one of the major obstacle (Negi, 2012). EOs may possess both qualitative and quantitative variations due to a great diversity of bioactive compounds resulting in variable biological effectiveness. Strong aroma is another hindrance in using EOs in food, which may limit their application. However, undesirable aroma of EOs can be controlled via selecting EO carefully according to the kind of food used. The effect of EOs is relying on their chemical composition and the quantity used. In addition to direct contact, EOs can exhibit its function by means of active food packaging. It can be possible with the assistance of independent system (sachets and wrappers containing EOs) or EOs incorporated in packaging material (edible films and coatings) (Espitia et al., 2012; Wen et al., 2016). There are many polymers are being used for food packaging (Wen et al., 2016). These polymers can be incorporated with synthetic or natural additives, which are responsible for showing their function. (Li et al., 2014; Sanches-Silva et al., 2014). Incorporated substances in food packaging release in a controlled way and increase/maintain the sensorial properties, quality characteristics and microbiological integrity of food (European Commission, 2009).

Table 1 Examples of films/coating incorporated with essential oils or their components.

Film/coating composition	AR	Food	Observations	References
Oregano				
Polypropylene, polyethylene and terephthalate	AB	Ripened sheep Cheese model	Inhibited the <i>E. coli</i> O157:H7	(Otero et al., 2014)
Whey protein	AN	Processed meat (sausages)	RLO, reduced microbial load, extend shelf life by 15-20 days.	(Catarino et al., 2017)
Pullulan	AB	Meat and poultry products	Inhibited <i>S. aureus</i> and <i>S. typhimurium</i> . No effects against <i>L. monocytogenes</i> and <i>E. coli</i> O157:H7.	(Morsy et al., 2014)
N, O-carboxymethyl chitosan	AB	Chicken breast fillets	Inhibited <i>L. monocytogenes</i> . Extend the shelf life.	(Khanjari et al., 2013)
Nano emulsion-based edible coatings (2.0% (w/w) sodium alginate, 0.5% (w/w) mandarin fiber, 2.5% (w/w) Tween 80)	AN	Low-fat cut cheese	Inhibited <i>S. aureus</i> , psychrophilic bacteria, molds and yeasts	(Artiga- Artigas et al., 2017)
Alginate	AO	Beef	RLO	(Vital et al., 2016)
Rosemary				
Pullulan	AB	Meat and poultry products	Inhibited <i>S. aureus</i> , <i>L. monocytogenes</i> , <i>E. coli</i> O157:H7, and <i>S. typhimurium</i> when stored at 4 °C for up to 3 week	(Morsy et al., 2014)
Alginate	AO	Beef	RLO	(Vital et al., 2016)
Chitosan	AB	Fresh chicken meat	Reduced <i>B. cereus</i> and <i>S. enterica</i> number. Increased shelf life	Souza et al., 2019
Oregano and rosemary				
Pectin coatings	AF	Broccoli florets	Antimicrobial protection to fresh-cut broccoli without negatively affecting its sensorial acceptability	Alvarez et al., 2019
Clove				
Linear low-density polyethylene (LLDPE)	AB	Chicken meat	Inhibited <i>S. Typhimurium</i> and <i>L. monocytogenes</i> when stored in refrigerator for 21 days.	(Mulla et al., 2017)
Agar	AB	Fish (Flounder fillets)	Inhibited <i>S. aureus</i> , <i>Y. enterocolitica</i> , <i>A. hydrophila</i> , <i>D. hansenii</i> , and <i>L. innocua</i> at 5°C for 15 days.	(da Rocha et al., 2018)
Carboxymethyl cellulose, polyvinyl alcohol	AB	Chicken meat	Inhibited the <i>S. aureus</i> and <i>B. cereus</i> growth. Extend the shelf life by 12 days.	(Muppalla et al., 2014)
Clove leaf				
Foxtail Millet Starch	AN	Queso blanco cheese	<i>L. monocytogenes</i> , RLO	(Yang et al., 2018)
Zataria multiflora oil				
Zein	AN	Minced beef	Inhibited the <i>L. monocytogenes</i> and <i>E.coli</i> during 3 days of storage at 4°C, RLO	(Moradi et al., 2016)
Ginger oil				
Nano emulsion based coating	AB	Chicken breast fillets	Reduced the total aerobic psychrophilic bacteria, enhanced the consumer acceptability.	(Noori et al., 2018)
Thyme				
Chitosan	AF	Meat	Reduced the yeast population but had no effects on aerobic mesophilic bacteria.	(Quesada et al., 2016)
Cinnamon				
Compression moulded LLDPE film with Ag-Cu	AB	Chicken meat	Reduced the growth of <i>L. monocytogenes</i> , <i>S. Typhimurium</i> and <i>C. jejuni</i>	(Ahmed et al., 2018)
Cinnamaldehyde				
Gliadin	AF	Bread and cheese spread foodstuffs	Reduced the growth of <i>P. expansum</i> and <i>A. niger</i>	(Balaguer et al., 2013)
Anethum graveolens oil				
Plantago major seed mucilage	ABF	Beef	Reduced the total viable count, psychrotrophic bacteria, <i>E. coli</i> , <i>S. aureus</i> , and fungi. Extend the shelf life by 3 days.	(Behbahani et al., 2017)
Tumeric EO				
Chitosan	AF	Marinated Chicken	Inhibited the growth of <i>A. flavus</i> .	Li et al., 2019a
Thyme, oregano, tea tree and peppermint oil				
Chitosan	AF	Rice	Inhibited the growth of <i>A niger</i> , <i>A flavus</i> , <i>A parasiticus</i> , and <i>P. chrysogenum</i> . No effect on the organoleptic properties.	Hossain et al., 2019
Cinnamon				
carboxymethyl cellulose polyvinyl alcohol based films	AOF	Bread	Showed complete inhibition of <i>P. digitatum</i> . Exhibited a good UV inhibitory effect. Increased the shelf life.	Fasihi et al., 2019
Bergamot EO				
polylactic acid	PH	Mangoes	Maintain the quality of fresh mango and extend its postharvest life to 15 days.	Chi et al., 2019
Citrus EO				
Chitosan	AN	Pacific mackerel	Increased the shelf life. Improved the sensorial properties.	(Li et al., 2019b)

AR: Active role, AB: Antibacterial, AN: Antibacterial & antioxidant, AF: Antifungal, AO: Antioxidant, ABF: Antibacterial & antifungal, AOF: Antioxidant & Antifungal, PH: Physicochemical, RLO: reduced lipid oxidation, LAB: lactic acid bacteria

Films and coating are two types of strategies in active food packaging technology. Films are thin and delicate foils and applied on the processed food or among the layers. It can be used as packaging, covers and/or layer partition material. Coatings are the type of films whose base applies directly on the surface of the product and it forms coating after drying (Krochta, 2002). Some examples of packaging incorporated with EOs or their active components are arranged in Table 1. The films and coatings are applied to food with the intention to enhance the shelf life, nutritional and organoleptic features of food. Generally, films are prepared by a casting method. In this method, the solvent evaporates from film-forming solution (without providing heat) resulting in the formation of the structured and compact film (Shojaee-Aliabadi et al., 2013).

An important element of food packaging is the assessment of the mechanical, optical and barrier characteristics of the film. Mechanical properties of active packaging incorporated with EOs depend upon several features like the composition of EO, the amount added, and the material used for packaging (Abdollahi et al., 2012; Shojaee-Aliabadi et al., 2013). Abdollahi et al., (2019) reported that incorporation of summer savoury EO with Carboxymethyl cellulose-agar biocomposite film inhibited the *S. aureus*, *B. cereus* and *L. monocytogenes* and *E. coli* growth as well as modified the properties of the film such as increased the microstructural heterogeneity, water vapour permeability and improved the mechanical flexibility and surface hydrophobicity of the film.

EOs do not show the same effects on food as they showed in-vitro. They become less effective when they applied on food in the same conditions (Fisher & Phillips, 2006). This is due to different variables that are the attributes of foods such as fat, protein, water content, pH, additives, salt and external determinants such as storage temperature and the atmospheric composition (Otero et al., 2014). Da Silva et al., (2019) reported that edible coatings based on apple pectin and cellulose nanocrystals incorporated with lemongrass EO improved the quality and shelf life of strawberries. In another study, Lee et al., (2019) observed that hydroxypropyl methylcellulose film combined with oregano EO was effective at 5.0% (v/v) inhibiting the growth of *S. typhimurium*. Antioxidant properties of film with EO were higher than control showing that it could potentially be used as active packaging with antibacterial and antioxidant properties.

Migration action of EOs from package to food

In active packaging, biologically active compounds migrate from packaging to the food through diffusion (Tian et al., 2013). Mechanism of migration can be influenced by various factors. The high fat content in food can affect the migration process of active compounds (Huang et al., 2013). Likewise, high temperature and hydration level of film influence the diffusion rate of biologically active compounds from film to the food (Oussalah et al., 2004; Zinoviadou et al., 2009; Kuorwel et al., 2013). The mechanism of action may also be influenced due to film thickness and chemical solubility between migrant and simulant (Huang et al., 2013). Kuorwel et al., (2013) checked the effects of high temperature on migration rate

of antimicrobials components of EOs from starch-based film to the food. They documented that high temperature increased the migration process.

Limitations of EOs

EOs have been registered as flavouring agents by EU commission. The EU generated a list of approved flavourings which is periodically updated (European Union, 2008). The EU regulations ban the addition of some natural unsavoury additives and provide the list of maximum inclusion level of certain substances. Despite of registering as safe food additives, EOs are causing some undesirable effects such as allergic reactions and toxicity (Bleasel et al., 2002; Trattner et al., 2008). Some EOs may cause allergy and dermatitis in some individuals when they use them frequently. Kejlová et al., (2010) reported that three (orange, lemon, and *Litsea cubeba*) out of eight EOs evoked phytotoxic reaction. Information Network of Departments of Dermatology (IVDK) declared the data between 2000 and 2008. A total of 637 cases of hypersensitivity were recorded due to ylang-ylang oil, lemon-grass oil, jasmine oil, sandalwood oil, and clove oil (Uter et al., 2010). More than 80 EOs have caused skin contact allergy. Out of them nine EOs (laurel, turpentine, orange, tea tree, citronella, ylang-ylang, sandalwood, clove, and costus root) showed severe hypersensitivity reactions. They also described that occupational contact dermatitis may occur in professionals performing massages (De Groot et al., 2016). In addition, ingestion of these compounds at higher doses can cause serious issues of oral toxicity.

Conclusion

Several foodstuffs exhibited a long shelf life when EOs were applied as food preservatives like vegetables, meat, and fish. Active food packaging incorporated with EOs has widely been used to protect and preserve the foodstuffs. The biological active compounds migrate from packaging to food by diffusion and can be affected by numerous variables *i.e.* composition of EOs, polymers, type of food, storage time and temperature. Incorporation of EOs in active food packaging instead of using directly in food can be viewed as a promising field of study. Despite registering as safe food additives, the EOs are causing some undesirable effects such as toxicity and hypersensitivity reactions. Moreover, ingestion of these compounds at higher doses can cause serious health problems. It is a fundamental and challenging task to discover the balance between the optimum dose of EOs and the possible toxicity.

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