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Essential Oils and Biodegradable Packaging Materials: Application on Food Preservations

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Abstract

Essential oils are concentrated hydrophobic oily liquid substances extracted from different plant organs. The most common source of essential oils are clove, lavender, cinnamon, lemon grass, coriander, rosewood, cumin, ginger, oregano etc. Essential oils are a good source of several bioactive compounds and serve as antimicrobial and antioxidant compounds. In addition, essential oils have been used as natural additives for the shelf-life extension of food products, due to the risk in using synthetic preservatives. Furthermore, essential oils can be incorporated into packaging materials to prevent unavoidable microbial spoilage, and to extend shelf-life of the product. The extraction method of essential oil is most important because inappropriate extraction may damage the chemical properties. Essential oil can be extracted by several methods such as distillation, steam distillation, expression, and solvent extraction. This review article covers up the essential oil including sources, chemical composition, extraction process, antimicrobial activity of EOs, and their applications, particularly with the emphasis on preservation and the shelf-life extension of food products.

Keywords: Essential oils; Antimicrobial activity of EO; Bioactive packaging materials; Food preservation

1. Introduction

Essential oils (EOs), also called volatile odoriferous oil, are concentrated hydrophobic aromatic oily liquids extracted from different parts of the plants, such as leaves, peels, barks, flowers, buds, seeds, and so on. EOs can be extracted by several different methods such as steam distillation, expression, and so on. Among all methods, steam distillation method has been commonly used, especially for commercial scale production [1, 2].

Traditional plastics are derived from petroleum, which causes serious environmental distress. So, several biopolymers have been exploited to develop biodegradable films and coatings for eco-friendly food packaging, represent an interesting alternative to regular plastic materials [3, 4]. Polysaccharides, proteins and lipids are the most common materials for the formulation of edible or biodegradable films and coatings and the combination of these allows for producing blends of improved characteristics [5].

There has been a rising interest in using natural food additives with antimicrobial and antioxidant properties that do not have any negative effects on the human health, instead of using chemical additives in food industry, [6]. EOs have been known to posses antimicrobial and antioxidant properties [7], thereby serving as natural additives in food industry. Besides, most of them are acknowledged as Generally Recognized as Safe (GRAS) [8]. EOs have been widely used as food flavors [9]. But, their use as food preservatives is often limited because of their strong flavor. In order to avoid this problem, EOs can be used in active food packaging that is an innovative way to inhibit microbial growth and spoilage of foods, and maintaining the food quality, freshness, safety. About 50% of agricultural products are destroyed because of the proper packaging [10]. EOs are incorporated into packaging materials to prevent surface growth of microorganisms in foods. This technique is an alternative technology to non-thermal process which does not prevent growth of heat-resistant microorganisms and their spores. As antimicrobial packaging films are used for surface preservation, antimicrobial containers and utensils are used for liquid foods [11]. Bioactive packaging has application in packaging of food, pharmaceutical, and consumer goods products, with a common goal of improving shelf life, safety, or quality of packaged goods.

Modern technologies have been continuously developed to overcome the limitation of conventional methods, and to develop the extraction efficacy. Due to the increasing interest in natural additives, EOs have been used more widely, especially in combination with other preservations under concept of “hurdle technology” [2].

The review discusses about the efficiency of several natural EOs and incorporation into edible films to use them as antimicrobial food packaging material to extend their good quality and shelf-life.

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2. Sources and Chemical Compositions

EOs are composed of lipophilic and highly volatile secondary plant metabolites, reaching a mass below a molecular weight of 300 [12]. The constituents in EOs are terpenes (monoterpenes and sesquerpenes), aromatic compounds (aldehyde, alcohol, phenol, methoxy derivative, and so on), and terpenoids (isoprenoids) [13, 14]. Generally, the major components of EOs are formed by mono- and sesquiterpenes. In some cases, the key derivatives are hydrocarbons (e.g., turpentine, formed by α- and β-pinene) while in others, the major components are oxygenated (e.g., cloves, formed by eugenol). In a reduced number of species, the foremost derivatives are aromatic principles; these include thyme with thymol and carvacrol, peppermint with menthol, and anise with anethol [13, 15, 16].

2.1. Terpenes

Terpenes are the most common class of chemical compounds found in EOs that are usually composed of mono- and sesquiterpenes, which may be hydrocarbons or oxygenated, as described above. Besides, they can also be obtained from aliphatic or alicyclic derivatives and some may have aromatic structures. Examples of EOs from this broad group include turpentine (*Pinus* spp.) with α- and β-pinene, tea tree oil (*Melaleuca alternifolia*) with terpinen-4-ol, coriander (*Coriandrum sativum*) with linalool, peppermint (*M. piperita*) with menthol, geraniol from damask rose (*Rosa damascena*), wormwood (*A. absinthium*) with thujone, lemon (*Citrus limon*) with limonene, caraway (*Carum carvi*) with carvone, eucalyptus (*Eucalyptus globulus*) with cineol, and chenopodium (*Chenopodium ambrosioides*) with ascaridole as examples of monterpenes. Furthermore, examples of sesquiterpenes include German chamomile (*Matricaria recutita*) with bisabolol, sandalwood (*Santalum album*) with santalol, and ginger (*Zingiber officinale*) with zingiberol [12].

2.2. Allyl Phenols

EOs can be derived from allyl or isoallyl phenol of aromatic plants. These compounds are rarer than terpenes, but that only serves to make this kind of compound selective. Some significant examples of EOs with these types of compounds are those from aniseed (*Pimpinella anisum*), star anise (*Illicium verum*), and fennel (*Foeniculum vulgare*), all with *trans*-anethol; cinnamon (*Cinnamomum verum*) with *trans*-cinnamic aldehyde; and clove (*Syzygium aromaticum*) with eugenol [12].

3. Plant, Plant Parts and Essential Compounds

EOs are derived from different parts of the plant such as bark, leaves, flowers, resins, seeds, roots, woods, rhizomes, and so on. The most common sources of EO and their main chemical constituents are shown below:

Essential oil	**Source**	**Essential compounds**
Clove Flower	Buds	Eugenol (72-90%)
Lavender	Flowers	Linalool (26%), Caryophyllene (8%) [17]
Cinnamon	Bark	Linalool (36.0%), Methyl eugenol (12.8%), Limonene (8.3%), α-terpineol (7.8%) and Terpinen-4-ol (6.4%) [18]
Juniper	Berries	Alpha-pinene (29.17%), Beta-pinene (17.84%), Sabinene (13.55%), Limonene (5.52%) and Mircene (0.33%)
Lemon	Peel	Dl-limonene (78.92%), *α*-pinene (5.08%), l-α- terpineol (4.61%), *β*-myrcene (1.75%), *β*-pinene (1.47%) and *β*-Linalool (0.95%) [19]
Rosewood	Wood	Citronellol, Geraniol, Nerol, Linalool, Phenyl ethyl alcohol, Farnesol, Stearoptene, α-pinene, β-pinene, α- terpinene, Limonene, p-cymene, Camphene, β- caryophyllene, Neral, Citronellyl acetate, Geranyl acetate, Neryl acetate, Eugenol [20]
Oregano	Leaves	Carvacrol, Thymol [21]**.** Cumin Seed Cuminaldehyde, Cymene and Terpenoids [22]

4. Extraction of Essential Oils

Extraction method is one of key factors that determine the quality of EO. Inappropriate extraction conditions can damage or alter the chemical property of the EOs [2, 9, 23]. These effects need to be investigated according to the application of EOs [24, 25]. Thus, appropriate extraction method and extraction technique are important considerations in producing an EO with desirable characteristics. Therefore, new extraction techniques of EOs [26-28] are recently proposed as alternatives to the traditional methods [27, 29]. Essential oils can be extracted by several different methods are shown below:

4.1. Conventional Extraction Methods

4.1.1. Steam Distillation

Masango [30] studied that the percentage of EOs extracted by steam distillation is 93% and the remaining 7% can be further extracted by other methods. Basically, water is boiled, and plant sample is exposed to the resulting steam. The heat applied is the major cause of burst and break down of cell structure of plant material. As a consequence, the volatile aromatic compounds or EOs from plant material are released by steam and transported into a tube where the resulted vapor cool down to produce a mixture of distilled water and EO. Later, the EOs are separated from aqueous phase due to the differences in their specific gravity. Steam temperature, pressure and extraction duration are the most important considerations in the steam distillation process. In addition, steam distillation is a time-consuming process that sometimes involves a redistillation of the EO [31, 32]. Besides, one disadvantage of this conventional extraction method is the degradation of some volatile compounds as a result of long extraction times and relatively high temperatures [33]

4.1.2. Hydrodistillation

Hydrodistillation is one of the oldest and standard method of EO extraction technique [34]. In this process, EOs are extracted from the fragile parts of the plants through a solid-liquid extraction between plant material and hot water in a distillation container equipped with a Clevenger apparatus. The plant sample and water mixtures are boiled to get a vapor phase in the condenser section and collect the isolated EO in a receiver flask. This extraction method requires several disadvantages, such as long extraction times, which could promote hydrolysis of some heat sensitive components of the EOs and produce unwanted compounds [27, 29, 34]. Moreover, process parameters such as, process temperature and time, are difficult to control which may result in incomplete or prolonger extraction. So, researchers are looking for alternatives to this tedious extraction technique [27, 35, 36].

4.1.3. Hydrodiffusion

It is a one kind of steam distillation, which is only different in the inlet way of steam into the container of still. This method is suitable for use when the plant material has been dried and is not damaged at boiling temperature [37]. In this process, steam is applied from the top of plant material, while steam is entered from the bottom for steam distillation method. This method can also be operated under low pressure and reduces the steam temperature to below 100°C. Hydrodiffusion method is better than steam distillation due to shorter processing time and a higher oil yield with less steam used [2].

4.1.4. Solvent Extraction

This process is used when plant materials are delicate or cannot be distilled by other techniques. The purpose of solvent extraction is extracting the odoriferous lipophilic materials from the original plant by food grade solvents like methanol, ethanol or hexane [38]. It is important to select proper extraction solvents in this process, and the experts avoid solvents that can interfere with the extraction process or react with the extract. At first, plant samples are washed with the extraction solvent (breaking the material or centrifuging in a rotating drum) and the solvent is filtered and subjected to vacuum distillation to remove solid plant materials. The resulting mixture contains the aromatic and lipid-soluble compounds. After that, a second solvent (usually alcohol) is used to remove non-aromatic fractions. Lastly, another vacuum distillation is operated to eliminate the second solvent and obtain a pure mixture. In this case, the product is called “herbal extract” which has a diverse composition from that of EO [25].

4.1.5. Innovative Extraction Techniques

EOs are thermo-labile. So, high temperatures can alter their structures (hydrolyse, isomerization, oxidation) and inversely affect their antioxidant and antimicrobial properties during traditional extraction methods. Several alternative methods have been developed and proposed recently to solve these issues [32]. Besides, the combination of these innovative extraction techniques could improve the performance of the extraction process and increase the extraction yield [39].

4.2.1. Supercritical Fluid Extraction

This process occupies the supercritical fluids, such as carbon dioxide, as an inert solvent to separate the volatile compounds from medicinal plants. The CO_2 gas reach a supercritical state under low pressure and temperature, becoming a liquid which can diffuse throughout plant material to extract aromatic compounds. The resulting extracts are considered as high quality, clean and pure, have a great similarity to the aroma of the original plant before extraction process [40]. In this extraction process, around 35ºC temperature are used for thermally and sensitive compounds, maintaining the quality of the final product [41]. Though supercritical fluid extraction is expensive, it is very efficient due to its low viscosity and high diffusivity. The use of shorter extraction times (around 25 minutes) and the versatility of this method compared to conventional extraction ones, offers the possibility of selecting the characteristics of the resulting EO by modifying the temperature, pressure and extraction duration. In addition, this method can be considered as an environment-friendly extraction technique for the extraction of bioactive ingredients [42].

4.1.6. Microwave-Assisted Extraction

Microwave-assisted extraction is basically a combination of microwave heating and a conventional extraction method such as solvent extraction and hydrodistillation [32, 43, 44]. To facilitate the principles of “green” extraction methods, a new methodology as solvent-free microwave-assisted extraction was also developed [45]. In this process, the plant material is extracted without any organic solvent or water. This technique is considered as superior to traditional methods because it can reduce the extraction time and energy [46, 47]. Moreover, some EOs obtained by this method is reported to be more valuable owing to its greater content in aromatic compounds [48].

4.1.7. Ultrasound-Assisted Extraction

This technique releases the EOs from aromatic plants mostly through the cavitation phenomenon, which develops the penetration of the solvents in the plant material [49, 50]. Cavitation occupies the formation, expansion, and growth of small liquid-free zones or bubbles which collapse strongly producing mechanical forces as well as local high temperatures and pressure at ambient conditions, therefore allowing the release and dissolution of intracellular materials such as EOs [24, 32]. This process can enhance the quality of the extract by minimizing thermal degradation of the EO components at a reduced temperature. [51].

5. Bioactive Packaging Material

Synthetic polymers, polyethylene or copolymer-based materials, are widely used as packaging materials because of their excellent mechanical properties, low permeability values and low cost. But they have a big problem to be discarded with being very little recycled. Researchers and industries have been gaining more interest to develop alternative biodegradable packaging materials that have mechanical permeability properties and economical fabrication.

Biodegradable packaging is defined as packaging that contains raw materials originating from agricultural and marine sources. There are three such categories of biopolymers: (a) produced by chemical synthesis from bio-derived monomers; (b) produced by microorganisms; (c) extracted directly from natural raw materials, such as cellulose [52].

Biodegradable packaging, made from entirely renewable natural polymers, could contribute to solving environmental pollution and creating new markets for agricultural products. Environmental problems can thus result from using non-renewable raw materials and accumulation of such non-biodegradable packaging. One solution is used of biodegradable materials made from polysaccharides, proteins, lipids, polyesters or a combination of these. Moreover, some additives such as colorants, antioxidants and antimicrobial agents can provide to packaging materials some functional properties that can prevent or delay microbial or chemical spoilage of food products [53].

6. Application of Active Food Packaging

Many researchers focused on the application of active food packaging on a broad range of real food systems to study their antioxidant and antibacterial effect [3].

Otoni, *et al.* [54] developed methylcellulose packaging films with clove bud and oregano EOs and this film applied on sliced bread and extended the self-life for 15days. Erdohan and Turhan [55] developed bioactive packaging films using olive leaf extract that extends the food shelf-life and maintains the quality by extending the lag phase and reducing the growth rate of food borne microorganisms specially *Staphylococcus aureus*. Sánchez-González, *et al.* [56] used bergamot EO into hydroxypropylmethylcellulose (HPMC) or chitosan edible coatings and tested their efficiency on coated grapes. According to Osés, *et al.* [57], a rancidity test was performed by Atarés, *et al.* [58] to estimate the antioxidant capacity of sodium caseinate films with cinnamon or ginger EOs. The same test performed by Atarés, *et al.* [59] used almond oil coated with HPMC films to test the effect of ginger oil addition. A better protection was found in films containing ginger oil, even though this oil caused a major oxygen permeability increase. Moreover, same formulations were applied on roasted almonds as coatings and results showed that almonds stored at intermediate relative humidity were efficiently protected against lipid oxidation because of ginger oil addition. Valencia-Chamorro, *et al.* [60] obtained the antimicrobial activity of organic acid salt against *Penicillium digitatum, P. italicum.* When this oil incorporated into HPMC packaging films, these films protected mandarin and extend the food quality. Jesus, *et al.* [61] investigated the thyme EO in chitosan packaging film. The film showed antimicrobial activity against yeast populations, aerobic mesophilic bacteria, lactic acid bacteria, enterobacteria, and extended the shelf-life of packaged meat with better appearance. Gómez-Estaca, *et al.* [62] used gelatin based films, with or without chitosan, that coated with oregano or rosemary EOs applied on cold-smoked sardine in order to test their effect. Results showed that the stability of the product was improved by coating with gelatin based edible films, and films containing EOs were able to slow lipid oxidation. Coma, *et al.* [63] obtained antimicrobial activity of cellulosic films made with HPMC by the incorporation of nisin into the film-forming solution. The activity was tested against *Listeria innocua* and *Staphylococcus aureus*, and used to protect food and extend their shelf-life. It was proved that the combined effect of carrageenan edible films and lemon EO can enhance the shelf life of trout fillets, as compared to the films without EO. Emiroğlu, *et al.* [64] investigated antimicrobial activity of thyme and oregano EOs coated with soy edible films on fresh ground beef patties and found microbial count reductions over refrigerated storage. Furthermore, the antimicrobial activity of gelatin-chitosan films with oregano EO was proved on the storage of carp muscle [65].

7. Conclusion

Essential oils from various sources can be exploited as the natural additives in foods. More work is needed in this research area to optimize the effectiveness of the bioactive compounds. Innovative technology must be employed for lowering the unique and undesirable smell of EO, which can limit their use in foods, such as encapsulation, and so on. Therefore, EO can be commonly used without any negative effect on sensory property of foods. In addition, EO can be incorporated into polymer aqueous solutions to get cast films. But, casting is not readily applicable in packaging industry, unlike compression molding or extrusion, where high temperature is applied to the material. In this regard, some studies are reported [66, 67] and the challenge is how to maintain the antimicrobial activity of EO in the films during the high temperature of the plastic production processes.

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