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Current extraction methods and potential use of essential oils for quality and safety assurance of foods

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Abstract: Essential oils (EOs) or vegetable oils have become the focus of several studies because of their interesting bioactive properties. Their application has been successfully explored in active packaging, edible coatings, and as natural flavoring to extend the shelf life of various types of food products. In addition, alternative methods of extraction of EOs (ultrasound-assisted extraction, microwave-assisted extraction, pressurized liquid extraction and supercritical fluid extraction) have been shown to be more attractive than traditional methods since they present better efficiency, shorter extraction times and do not use toxic solvents. This review paper provides a concise and critical view of extraction methods of EOs and their application in food products. The researchers involved in the studies approached in this review were motivated mainly by concern about food quality. Here, we recognize and discuss the major advances and technologies recently used to enable shelf life extension of food products.

Key words: Food control, shelf life, food preservatives, essential oils, extraction techniques.

INTRODUCTION

Growing consumer preference for safe, non-toxic foods with increased shelf-life has stimulated research on natural food preservatives (Wu et al. 2019). In recent years, the use of essential oils (EOs) has become a very useful technology due to their wide range of natural biologically active compounds, which are capable of aiding in the preservation of food systems (Freitas & Cattelan 2018, Khorshidian et al. 2018).

The EOs have been studied mainly due to their antioxidant, antimicrobial, insecticidal, antitumor and antidiabetic properties, and have been mainly applied in active packaging, edible coatings, and as natural flavoring (Brahmi et al. 2016, Khorshidian et al. 2018, Periasamy et al. 2016, Yen et al. 2015).

In the food industry, the desire to offer packaging that can protect food against external factors and ensure the safety of the food has stimulated studies about the development of packaging incorporated with EOs. These packaging systems, known as active packaging, interact with the food and gradually release bioactive compounds capable of minimizing or eliminating the presence of pathogenic microorganisms and even inhibiting lipid oxidation (Ribeiro-Santos et al. 2017, Sirocchi et al. 2017).

The incorporation of bioactive compounds aims to benefit food products by extending their shelf life. This has become the focus of several studies, and the application of nanotechnology has assisted in overcoming technical challenges, such as solubility and stability of the bioactive compounds. Nanoemulsion contributes efficiently by promoting the application of EOs in real food systems as a means of natural conservation, thus increasing antimicrobial activity and, consequently, food safety. Nanoemulsion has contributed, for example, to significant advances in the development of edible coatings in food products (Abbas et al. 2015, Donsì & Ferrari 2016, Ma et al. 2016).

Furthermore, several materials used in food packaging may be updated to incorporate EOs. The current trend in food packaging is to use polymeric matrixes obtained from renewable and biodegradable resources, such as lipids, proteins and polysaccharides, thus contributing to environmental sustainability (Ribeiro-Santos et al. 2017, Romani et al. 2017).

Another point related to food preservation is the use of additives. There is a considerable interest in use of EOs, because those substances are considered safe food additives by the Food and Drug Administration. Moreover, due to the increase in consumer demand, there is a tendency to research natural additives, since synthetical ones are associated with negative side effects to human health (Cacho et al. 2016).

In this context, the main objective of the present work is to present a literature review in order to disclose the major advances and future trends regarding EO applications in food products. This review focuses on relevant papers published in the last eight years.

Essential oils

EOs are aromatic substances produced from secondary metabolites of plants belonging to the angiosperm family. They can be used for different purposes in several fields, such as pharmaceutical, cosmetic, agricultural and food sectors. Their complexity may vary from 20 to 60 components (Asbahani et al. 2015) and they are characterized by two or three major components which are considered as such due to their high concentration (20 to 70%) in comparison to other components that define the physicochemical properties of the oil. The components existing in lower concentrations are also important to EO composition, due to the synergistic effect of the combined components (Asbahani et al. 2015, Pavela 2015).

Composition and quality of EOs depend on a plant's characteristics, its stage of development, origin, part of the plant used, and age, time, and condition at which the plant has been harvested. In addition to those factors, EOs are also affected by extraction method, analysis conditions and the type of solvent used, therefore, it is fundamental to choose the most suitable method (Ribeiro-Santos et al. 2017, Asbahani et al. 2015).

Conventional extraction methods

These are classic extraction methods based on the distillation of water by heating, traditionally used to recover EOs from oilseeds and medicinal or aromatic plants. Next, some of the main extraction techniques will be presented.

Steam distillation

Although EOs are produced by different methods, the majority (93%) are produced by steam distillation (Masango 2005). In practice, the process uses water as an extraction agent to vaporize or release volatile compounds from the raw material. The compounds are volatilized by absorbing heat from the steam and are then diffused in the vapor phase. The vapor phase is cooled and condensed before the water is separated from the organic phase based on its immiscibility (Prado et al. 2015).

Steam distillation can be combined with other extraction methods, such as microwave or ultrasound, to increase efficiency. This combination can provide faster extraction kinetics, lower costs, reduce environmental impact, and provide a product similar to that obtained by conventional hydrodistillation (Palma et al. 2013). Variants of steam distillation are hydrodistillation and hydrodiffusion, presented in the following sections.

Hydrodistillation

This method is the simplest and oldest method used for the extraction of EO. Avicenna (980-1037), was the first to develop extraction using the still, extracting the first pure essential oil from the rose (Asbahani et al. 2015). The hydrodistillation (HD) system for extracting EO is equipped with a Clevenger type device. In this process, plant materials immersed in water are heated in a balloon; the water evaporates and flows towards the condenser until the EO is released (Gavahian & Farahnaky 2018). This technique is efficient in isolating a wide variety of EOs. However, it requires large amounts of energy and its high temperatures can cause changes in the compounds, with possible degradation (Pavlić et al. 2015).

Consumer demands, unpredictable energy costs in the future, and environmental constraints drive the development of clean technologies that prevent the use of chemicals and consume less energy (Zermane et al. 2016). The HD process with ohmic heating is a relatively new and innovative technique that has gained increasing interest in the last decade for promoting time and energy savings (Gavahian & Farahnaky 2018).

Moreover, several improved modules have been developed in recent years, such as microwave compressed hydrodistillation, microwave accelerated rod distillation, microwave vacuum hydrodistillation, and microwave-assisted hydrodistillation (Singh et al. 2019).

In current studies, HD has been used to obtain oils of pink pepper (Dannenberg et al. 2017, Dannenberg et al. 2016), rosemary (Sirocchi et al. 2017), orange leaves (Alparslan et al. 2016), ginger (Noori et al. 2018), oregano (Asensio et al. 2015, Hashemi et al. 2017), mint (Smaoui et al. 2016), and citronella (Gavahian et al. 2018).

Hydrodiffusion

This is a particular type of steam distillation, where the flow of vapors occurs from the top of the generator (Asbahani et al. 2015). This method has now been improved with the addition of microwave technology. The technique using microwave hydrodiffusion and gravity (MHG) is a solventless extraction method, based on the drilling of oil glands and subsequent oil drainage by gravity (Singh et al. 2019).

The use of MHG technology improved the extraction rate of rosemary, and only 20 min was sufficient to achieve a yield comparable to that obtained in 3 h by the conventional HD method. Also, a mixture of molecules with different properties (for example, polarity and volatility) can be extracted in a single step, such as essential oils and phenolic compounds (Ferreira et al. 2020).

In the extraction of EO from cumin seeds, the researchers observed that the chemical composition was approximately similar for the MHG and HD methods, with a drastic reduction in the extraction time from 150 min of HD to 16 min (200 W) of MHG (Benmoussa et al. 2018).

Organic solvent extraction

The plant material is macerated in an organic solvent; the extract is concentrated by removing the solvent under reduced pressure. This technique avoids the chemical changes and artifacts produced by cold extraction compared to hydrodistillation (Asbahani et al. 2015).

For solvent extraction, organic solvents such as n-hexane, alcohol, chloroform, water, and acetone are used, which provide efficient lipid recovery. (Pavlić et al. 2015). Hexane is also an excellent solvent for oil because of the high oil solubility, and because the oil can be easily recovered by distillation. The main drawback of the use of hexane is its high toxicity. As a result, other solvents have been used to substitute hexane in oil recovery including some medium polarity alcohols such as isopropanol and ethanol (Palma et al. 2013).

Soxhlet is one of the oldest extraction procedures. It is the standard extraction process (Zygler et al. 2012), since the solvent is recirculated in the sample until the oil is completely removed (Luque de Castro & Priego-Capote 2010).

The Soxhlet procedure has many disadvantages. For example, the average time for extraction is 1 to 72 hours; the solutes extracted by this method are obtained in high volume and diluted form and, therefore, need to be concentrated before analysis. Perhaps the biggest disadvantage of this method is the need for expensive, toxic, and high purity organic solvents (Yousefi et al. 2019).

Several modified Soxhlet systems have been designed to overcome the drawbacks of the classical technique. Most of them focus on speeding up the process in an attempt to reduce the solvent consumption and the thermal degradation of the target compounds (Palma et al. 2013). Some alternatives to increase the speed at which the matrix releases components include applying microwaves or ultrasound (Luque de Castro & Priego-Capote 2012).

Alternative extraction methods

Most of the conventional methods need long-term extraction, in addition to the use of high-quality solvents. Alternative processes present some advantages, such as reduction in extraction time and power consumption, moreover, they increase the oil yield and improve quality (Asbahani et al. 2015).

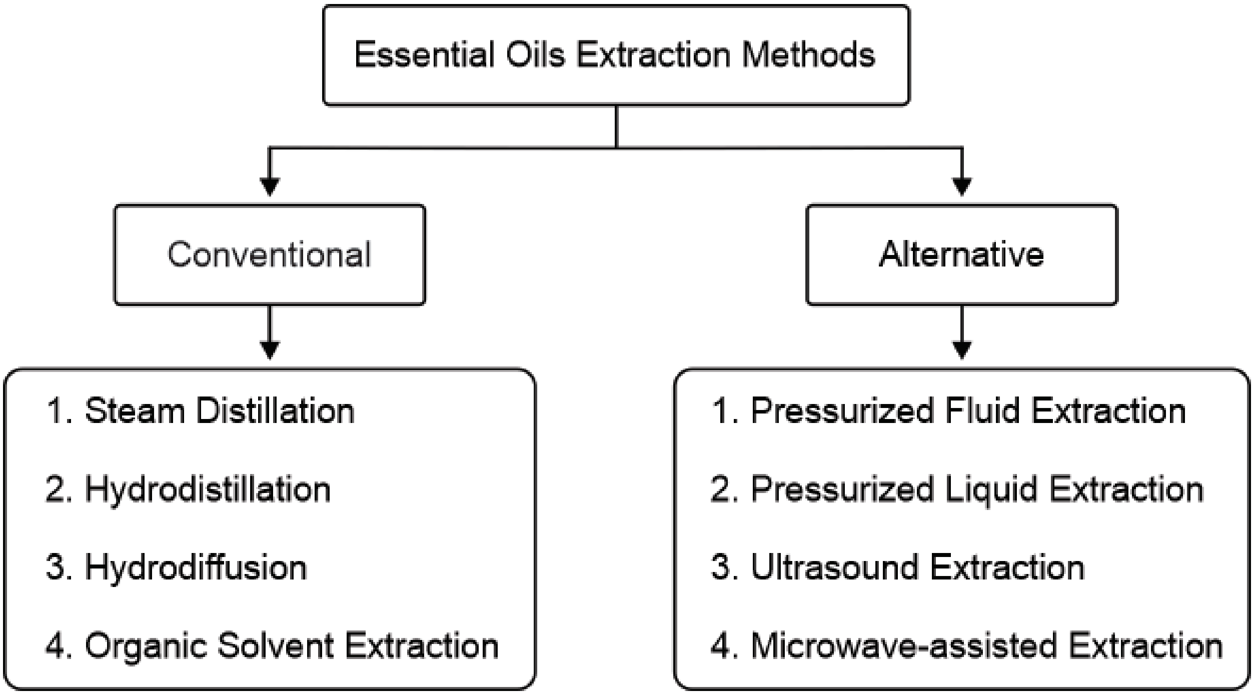

Figure 1. Extraction methods used for obtaining essential oils.

Therefore, several alternative extraction methodologies are reported in literature: ultrasound-assisted extraction (Tekin et al. 2015, Fernandes et al. 2016), microwave-assisted extraction (Franco-Vega et al. 2016, Chen et al. 2017), pressurized liquid extraction (PLE) (Rai et al. 2017), and supercritical fluid extraction (SFE) (Mustafa & Turner 2011, Dawidowicz et al. 2012).

These techniques are considered efficient and economically viable for the extraction of EOs. Green technologies are better options mainly because they are ecologically correct and there are fewer toxic solvents used in the extraction process. In addition, selective extraction, in most cases, occurs through changes in process parameters and can operate at elevated temperatures and pressures, reducing extraction time (Bubalo et al. 2018).

Pressurized fluid extraction

Regarding alternative methods, pressurized fluids under subcritical or supercritical conditions are indicated as a promising technique for the extraction of compounds with high purity (Moncada et al. 2014, Zheng et al. 2017). A supercritical fluid is any substance whose temperature and pressure conditions are above its critical parameters (Sánchez-Camargo et al. 2017). In this state, the substance acquires an intermediate behavior between gases and liquids (Shivonen et al. 1999). Small variations in temperature and pressure cause significant changes in the properties of the supercritical fluid (Panja et al. 2018).

Commonly used in supercritical extraction, carbon dioxide (CO_2) has advantageous properties such as low reactivity, low toxicity, and low cost, and is recognized as safe for use in food products (Cornelio-Santiago et al. 2017, Panja et al. 2018). It is a non-polar solvent and, consequently, has an affinity for other non-polar solvents (Herrero et al. 2006). This disadvantage is usually overcome by the addition of modifiers or co-solvents capable of altering the solvation power of the supercritical fluid, facilitating the solubility and desorption of the analyte. However, to avoid a reduction in selectivity, a maximum of 10% v/v must be added (Pinto et al. 2018).

Meanwhile, the subcritical state occurs when an extraction solvent is used at a temperature between its boiling point and the critical temperature, at a pressure sufficient to maintain the solvent in a liquid state (Lu et al. 2014). It is considered more advantageous than the supercritical state because of the lower pressures used, resulting in shorter extraction times (Miao et al. 2013). Currently, the subcritical pressurized n-propane has been efficient in extracting fatty acids and active compounds such as phytosterols and tocopherols present in oils (Knez Hrnčič et al. 2018, Lopes et al. 2020, Trentini et al. 2017, Zanqui et al. 2020).

An alternative method involves the addition of propane as a solubility modifier. Propane's solvent power is superior to CO_2, requiring lower solvent/feed ratios and lower operating pressures. Also, propane can be easily removed from the oil after extraction by simple solvent depressurization (Palla et al. 2014) and can offer convenient selectivity and safety properties (Hegel et al. 2013), since one of the main disadvantages of extraction with pressurized propane is its flammability.

Pressurized liquid extraction

Pressurized liquid extraction (PLE) is another alternative technique which shows satisfactory results in relation to oil recovery and extraction time, when compared to conventional methods. In this technique, there is no need for filtration steps, since compounds are dissolved in the solvent and may remain inside the extractor. The PLE process consists of placing the sample into the extractor and extracting its compounds using a solvent, with temperatures going up to 200°C and pressures ranging from 4 to 20MPa. The solvent is pumped into the extractor containing the sample and remains there for a period that may vary depending on the type of solvent and matrix used. Then, the extracted material is transferred to a sample container and undergoes specific analyses (Nieto et al. 2010, Dawidowicz et al. 2012).

This method has been successfully used in the extraction of green coffee oil (Xu et al. 2019), pomegranate bark oil (Santos et al. 2019), crambe seed oil (Mello et al. 2019) and cypress oil (Dawidowicz et al. 2012).

Despite being an efficient technique, PLE is not able to separate compounds from similar phenolic classes, and the extracts produced contain a wide mixture of components. Solid adsorbents (solid-phase extraction - SPE) can be used to separate specific classes and phenolic compounds. In this context, the PLE method has been improved through online SPE padding for simultaneous extraction and fractionation (Silva et al. 2020).

Ultrasound extraction

In the ultrasound extraction technique, the ultrasound apparatus promotes a higher rate of solvent penetration in the sample, caused by cavitation bubbles formed during the application of sonic waves. In general, the use of ultrasound causes vibrations in the matrix, thus enhancing the contact surface between the matrix and the solvent and resulting in a higher solvent recovery in a short period of time. Additionally, the technique requires low temperatures, which facilitates the recovery of volatile compounds in EOs (Tekin et al. 2015, Samaram et al. 2014).

Current studies have used this method in pomegranate bark (Sharayei et al. 2019), moringa seed (Zhong et al. 2018), ginger (Fernandes et al. 2016), papaya seed (Samaram et al. 2014), garlic (Tekin et al. 2015) and grape marc (Goula et al. 2016).

A combined method of ultrasound-assisted and microwave-assisted extractions was adopted for the extraction of polyphenols in distilled water (Yu et al. 2017). Another combined method included ultrasound, followed by supercritical CO_2 to extract polyphenols from grape marc (Porto et al. 2015).

Microwave-assisted extraction

Among alternative methods, we also highlight microwave-assisted extraction. This is an emerging technique which improves material recovery, and reduces the time and energy needed in the process. It uses microwave radiation as a heating source in the extraction process. Microwaves, through dipole rotation and ionic conduction, cause instantaneous heating inside the sample, thus leading to faster extractions (Franco-Vega et al. 2016). Hibiscus chalice (Cassol et al. 2019), lemon peel (Rodsamran & Sothornvit 2019), grape marc (Garrido et al. 2019) and orange peel (Franco-Vega et al. 2016) are examples of raw material used in the microwave assisted extraction.

Emerging improvements in microwave-assisted extraction include combining it with other technologies to maximize the yield of target food components. The integration of alternative and environmentally friendly solvents (ionic liquids, deep eutectic solvents, multiphase solvents and nonionic surfactants at cloud point temperature) promotes overall extraction efficiency (Ekezie et al. 2017).

Lately, enormous attention has been given to extraction of food constituents using the synergistic application of microwaves to ultrasound irradiation techniques (Yu et al. 2017), negative pressure cavitation (Yao et al. 2015), sub or supercritical extraction (Matusiewicz &

Ślachciński 2014), enzymatic extraction (Rashed et al. 2017) and hydrodiffusion (Singh et al. 2019).

Applications of essential oils in food

When applied to food, EOs can act as flavoring, antioxidant and antimicrobial agents, with special importance given to the last two functions. EOs can be added directly to food or incorporated into material used for packaging (Ribeiro-Santos et al. 2017, Falleh et al. 2020). Table I presents some important uses of EOs in the food industry, such as their use in active packaging, edible coatings and food additives.

Additives

The inclusion of EOs in food as conserving agents is an alternative to the use of synthetic additives. Antigo et al. (2017) produced milk caramel spread (*dulce de leche*) with an addition of clove and cinnamon EOs. Lipid oxidation, microbiological, physical, chemical and sensorial attributes of the product were analyzed. There were no alterations related to composition, texture, color and sensory attributes. Microbiological analyses indicated the EOs used are active antimicrobial components and including them in *dulce de leche* provided general sensory acceptance similar to the traditional product. The sample with cinnamon EO showed less lipid oxidation during storage.

EOs have been used to reduce the addition of nitrites in meat products. In this context, a study evaluated the effect of adding coriander EO in concentrations of 0.075–0.150 µL/ g on the characteristics of cooked pork sausages, produced with different concentrations of sodium nitrite (0.50 and 100 mg/ kg). The combination of 60 mg/ kg of nitrite with 0.12 µL/ g of EO resulted in a better microbial and oxidative stability and satisfactory values of red color, therefore, it is possible to use the coriander EO to reduce the amount of sodium nitrite added to cooked pork sausages, while retaining high quality and shelf life (Šojić et al. 2019).

The *Melaleuca alternifolia* EO, also known as tea tree EO, is widely used due to its broad-spectrum antimicrobial activity and powerful anti-inflammatory properties. Thus, the objective of one study was to evaluate the antimicrobial potential of this EO (1.5%) in the inhibition of *Listeria monocytogenes* in ground beef. The samples were inoculated with four different suspensions of *L. monocytogenes* (1.5 × 10^8, 4.6 × 10^4, 9.2 × 10^3, and 1.2 × 10^2 CFU/ mL) and stored at 4 °C for 14 days. Except for the sample inoculated with the suspension at 1.5 × 10^8 CFU/ mL, the tests showed that tea tree EO had antimicrobial activity (Silva et al. 2019a).

Shange et al. (2019) evaluated the effect of adding oregano EO (1%) on the shelf life of wildebeest *biceps femoris* muscles, stored anaerobically at 2.6 ºC for 9 days. Lipid oxidation was stabilized at <9 mgMDA/ kg for the sample with EO, while the same was not observed for the control. Samples with EO also showed lower total viable counts (TVC), coliform counts, and lactic acid bacteria (LAB) counts. The count limit for TVC and LAB for this product was reached 3 days later than in the control group. In addition, bacterial growth rates for TVC and LAB were >1.4-fold slower for the samples with EO. *Hyptis suaveolens* EO has also been studied due to its antibacterial, antioxidant and antifungal action. Based on this, Mihin et al. (2019) evaluated the addition of this EO and its effect on the shelf life of beef. During *in vitro* tests, the EO showed inhibitory activity against 11 microbial strains and was able to preserve the quality of the meat for 7 days.

Another alternative to extend the shelf life of meat is the use of EOs in marinades, as in the study by Haute et al. (2016) which consisted of immersing meat (pork fillet, pork bacon, chicken

Table I. Examples of essential oils application in food.

Application	Food	Essential oil	Property	Reference
Additive	Milk caramel spread (*dulce de leche*)	Clove and Cinnamon	Antimicrobial Antioxidant	Antigo et al. 2017
	Cooked pork sausages	Coriander	Antimicrobial Antioxidant	Šojić et al. 2019
	Ground beef	Tea tree	Antimicrobial	Silva et al. 2019
	Wildebeest biceps femoris muscles	Oregano	Antimicrobial	Shange et al. 2019
	Ground beef	*Hyptis suaveolens*	Antimicrobial Antioxidant	Mihin et al. 2019
	Meat	Cinnamon, Oregano, and Thyme	Antimicrobial	Haute et al. 2016
	Pork meat	Cinnamon	Antimicrobial	Haute et al. 2017
	Minas frescal cheese	Oregano and Rosemary	Antimicrobial	Diniz-Silva et al. 2020
	Pressed ewes' cheese	Thyme, Lemongrass and Basil	Antimicrobial	Licon et al. 2020
	Fruit juice	Japanese Mint and Pepper Mint	Antimicrobial	Guedes et al. 2016
	Pomegranate	Eucalyptus, Galbanum, Thymus, and Clove	Antimicrobial Antioxidant	Jahani et al. 2020
	Rice	Nutmeg	Antimicrobial	Das et al. 2020
	Seeds	Lemongrass	Antimicrobial Antioxidant	Deepika et al. 2020
	Bread	Oregano and Thyme	Antimicrobial	Rosa et al. 2020
	Fish burger	Lemon	Antioxidant	Hasani et al. 2020
	Beef patties	Cinnamon	Antimicrobial	Ghaderi-Ghahfarokhi et al. 2017
Active packaging	Cheese	Pink Pepper	Antimicrobial	Dannenberg et al. 2017
	Peach	Ginger and Angelica	Antioxidant	Jiang et al. 2020
	Corn	Oregano and Cinnamom	Antimicrobial	Mateo et al. 2017
	Cherry tomato	Oregano	Antimicrobial	Kwon et al. 2017
	Bread	Lemongrass	Antimicrobial	Oliveira et al. 2020
	Chicken fillets	*Polylophium involucratum*	Antimicrobial	Javaherzadeh et al. 2020
	Shrimp	Clove	Antimicrobial	Ejaz et al. 2017
	Otolithes ruber fish	*Zataria multiflora* and pepper mint	Antimicrobial Antioxidant	Heydari-Majd et al. 2019
	Beef	Chrysanthemum	Antimicrobial Antioxidant	Lin et al. 2019
	Fresh poultry meat	Rosemary	Antimicrobial Antioxidant	Souza et al. 2019

Table I. Continuation.

Edible coatings	Cheese	*Pimpinella saxifraga*	Antimicrobial Antioxidant	Ksouda et al. 2019
	Beef slices	Cumin	Antimicrobial	Behbahani et al. 2020
	Pistachio	Thyme	Antimicrobial Antioxidant	Hashemi et al. 2020
	Mango	Cinnamon	Antioxidant	Yin et al. 2019
	Table grape	Thymus	Antimicrobial	Pina-Barrera et al. 2019
	Guava	Cinnamon and Lemon	Antioxidant	Murmu and Mishra 2018
	Case gooseberry	Rue	Antimicrobial Antioxidant	González-Locarno et al. 2020
	Strawberry	Lemongrass	Antioxidant	Silva et al. 2019
	Rainbow trout fillets	*Ferulago angulata*	Antimicrobial Antioxidant	Shokri et al. 2020
	Chicken breast	Ginger	Antimicrobial Antioxidant	Noori et al. 2018
	Cheese	Oregano	Antimicrobial	Artiga-Artigas et al. 2017

fillet, chicken skin and salmon) in a solution marinated with cinnamon, oregano, and thyme EOs. It was observed that yeast growth was inhibited by immersion in 1% cinnamon EO in all matrixes. Haute et al. (2017) used a marinade with 1% cinnamon EO in pork and salmon and subsequently packed them with modified atmosphere (MAP) or vacuum. Cinnamon EO extended shelf life of pork packed in MAP and vacuum against microbial growth but did not have the same effect on salmon.

Diniz-Silva et al. (2020) evaluated the incorporation of oregano and rosemary EOs in the processing of Minas Frescal cheese stored under refrigeration temperature (7 ºC). In the first 15 days, a significant reduction in *Escherichia coli* counts was observed in the analyzed samples. The addition of EOs to cheese also had a positive impact on sensory analysis. Another cheese study evaluated the addition of different EOs in the production of pressed ewes' cheese. The thyme EO was the most effective in completely inhibiting the growth of *Penicillium verrucosum* and in reducing the *Clostridium tyrobutyricum* count, without affecting the natural flora present in the cheese (Licon et al. 2020).

Traditionally, safety and stability of fruit juices were reached through thermal processing and use of chemical preservatives. Guedes et al. (2016) highlighted the use of EOs as an alternative for the reduction of pathogenic microorganisms in fruit juices. In this study, Japanese mint and peppermint EOs were evaluated. Such EOs induced reductions in counts of *Escherichia coli*, *Listeria monocytogenes* and *Salmonella enteritidis* in cashew, guava, mango, and pineapple juices. Incorporation of these EOs in fruit juices promoted a reduction in pathogenic bacteria without altering their physical-chemical properties; however, it significantly affected the flavour.

In order to reduce the application of synthetic antifungals in pomegranate fruits, Jahani et al. (2020) evaluated the addition of different concentrations of eucalyptus, galbanum, thymus, and clove EOs and their inhibitory effects against *Aspergillus niger*. All analyses were performed on the first and tenth days of storage. In *in vitro* analyses, the growth of *A. niger* was completely inhibited on the first and tenth days by the application of clove EO in the concentrations of 200, 400, 600 and 800 µL/ L. Thyme EO was effective in the concentration of 800 µL/ L on the tenth day. The fruits treated with thyme EO at a concentration of 800 µL/ L showed the least weight loss and the highest firmness in comparison with fruits treated with other EOs. In addition, the highest anthocyanin content was obtained with eucalyptus EO at 800 µL/ L.

The nanoencapsulation of EOs for use in food as a preservative is a recent and promising research field. EOs stored under ambient conditions have some disadvantages, such as insolubility in water, easy oxidation, instability, volatilization and degradation of bioactive compounds in a short period of time. These factors can reduce their effectiveness when used for practical applications. To overcome these drawbacks and keep the original characteristics of EOs, nanoencapsulation is an efficient method (Das et al. 2020). Emulsification, spray drying, ionic gelation and coacervation are the most adopted nanoencapsulation techniques (Chaudhari et al. 2019).

A large number of nanoencapsulation carrier matrixes (nanoencapsulates) can be used to encapsulate EO and their bioactive compounds, such as starch, chitosan, zein, cyclodextrin and cellulose. These encapsulants must be biodegradable and safe for human health. Depending on the method adopted, the nanoencapsulated EOs can take different forms, such as nanoemulsions, nanoparticles, nanotubes, nanogel, nanosponge, nanofibers and nanoliposomes. Among them, nanoemulsion, nanoparticle and nanogel are the most frequently used systems in the food sector (Chaudhari et al. 2019).

A study using nanoencapsulation technology evaluated the antifungal activity of nutmeg EO applied to the chitosan nano-matrix in order to control post-harvest losses of rice grains. The EO was tested against 15 food-borne fungi. In comparison with free EO, nanoencapsulated EO showed greater efficacy against the evaluated fungi, and at lower doses, was able to inhibit the aflatoxin B1 biosynthesis by *Aspergillus flavus* strain LHP R14. In situ efficacy of nanoencapsulated and unencapsulated EO on stored rice seeds showed effective protection against lipid peroxidation, fungal infestation and aflatoxin B1 contamination (Das et al. 2020).

Deepika et al. (2020) tested the potential of lemongrass EO encapsulated into chitosan nanoparticles against *Aspergillus flavus* and 15 other fungi, in order to control the deterioration of stored food. After nanoencapsulation, the EO showed better effectiveness in inhibiting the growth of fungi and production of aflatoxin B1 by *A. flavus*. Furthermore, the nanoencapsulated lemongrass EO exhibited remarkable antioxidant activity and did not have adverse effects on seed germination.

In the research developed by Rosa et al. (2020), oregano and thyme EOs were encapsulated using zein nanocapsules. Nanoencapsulated EOs have been shown to be more effective against gram-positive bacteria compared to gram-negative bacteria. In addition, nano-encapsulated EOs were also effective in preserving bread, protecting against the proliferation of molds and yeasts.

Lemon EO is an antimicrobial and antioxidant compound, used mainly as a food additive. Thus, a study aimed to evaluate the antioxidant effect of lemon EO, (0.5 and 1%) nanoencapsulated in chitosan/modified starch, in fish burgers stored for 18 days. The nanoencapsulated EO in the concentration chitosan: modified starch (1.5: 8.5%) improved the quality characteristics of the fish burgers. This improvement was due to the reduction in the values of peroxides (PV), thiobarbituric acid value (TBA) and total volatile nitrogen base (TVB-N) (Hasani et al. 2020).

Ghaderi-Ghahfarokhi et al. (2017) evaluated the addition of cinnamon EO incorporated into chitosan nanoparticles in beef patties. Both free and nanoencapsulated cinnamon EO were effective in reducing the microbial population of samples compared to the control (without addition of EO) over an 8-day storage period at 4°C. At the end of the storage period, the best formulations in thiobarbituric acid reactive substances (TBARS) test were the samples with 0.05% of ascorbic acid and 0.1% of encapsulated EO. In addition, it was observed that the color of the samples containing nanoencapsulated EO changed slightly, while for the sample with free EO, there were significant changes in color. In the sensory analysis, the beef patties with free cinnamon EO showed lower consumer acceptability in the color and odor parameters.

Active packaging

Through interaction with products, active packaging increases the shelf life of food, improving or maintaining its properties. Due to the antimicrobial and antioxidant properties of EOs, the development of active packaging for food with EO incorporation has become the focus of many research studies (Ribeiro-Santos et al. 2017).

One of these studies developed and evaluated active films made of cellulose acetate incorporated with pink pepper EO. Active films were evaluated based on their action in sliced mozzarella cheese against *Staphylococcus aureus*, *Listeria monocytogenes*, *Escherichia coli* and *Salmonella Typhimurium*. Concentrations of 2, 4 and 6% of the added EO were active against *L. monocytogenes* and *S. aureus*. The tests showed that affinity between nonpolar EO molecules and the lipid components of cheese allow migration of antimicrobial properties to food (Dannenberg et al. 2017).

Ginger and angelica EOs are known for their antimicrobial and antioxidant properties. Thus, a study aimed to develop films based on polylactic acid (PLA) and EO of ginger and angelica for the preservation of peaches. The film with the addition of angelica EO showed the highest antioxidant activity and had the best effect on the preservation of peach samples. Due to the delay in the oxidation process, the shelf life of this fruit was extended to more than 15 days (Jiang et al. 2020).

Mateo et al. (2017) developed a packaging made of ethylene-vinyl alcohol copolymer incorporated with oregano and cinnamon EOs to control the usual fungi associated with aflatoxin contamination in maize grains. The bioactive film that contained an effective dose of cinnamaldehyde was the most efficient in controlling *Aspergillus flavus* and *Aspergillus parasiticus*. Antimicrobial activity was also tested in cherry tomatoes with active packaging containing microencapsulated oregano EO. Results showed that tomatoes' quality and their physical properties were preserved. The packaging with 2% oregano EO was the most efficient, reducing 91.64% of the microbial load (Kwon et al. 2017).

Oliveira et al. (2020) developed cashew gum and gelatin films, incorporated with ferulic acid and lemongrass EO, for application as bread packaging. The packaging with EO provided six days of storage for bread compared to three days for commercial packaging. The increase in the shelf life of the bread samples suggests antimicrobial action of the lemongrass EO packaging.

EO nanoencapsulation techniques have also been widely used for application in active packaging. A study investigated the effect of applying a ploylactic acid film

(PLA) incorporated with nanochitosan and *Polylophium involucratum* EO in chicken fillets stored for 10 days at refrigerated temperature. In the packaged samples, the total microbial population was reduced by approximately 1–3 log CFU/ g. In addition, the films extended the shelf life of the chicken fillet by more than 10 days, without producing adverse sensorial properties (Javaherzadeh et al. 2020).

Ejaz et al. (2018) used clove oil to develope active films for peeled shrimp. The authors produced a not very flexible film with high mechanical resistance, combining nanocomposites, zinc oxide and clove EO. In this study, films with 50% of clove EO showed the maximum antibacterial activity against *Listeria monocytogenes* and *Salmonella typhimurium*.

Heydari-Majd et al. (2019) produced films based on PLA containing 1.5% zinc oxide nanoparticles and different concentrations of *Zataria multiflora* and peppermint EOs. The films were applied to *Otolithes ruber* fish, stored at 4 ºC for 16 days. Compared to the control sample, the shelf life of the packaged fish fillet samples increased from 8 to 16 days. The lowest values of TBARS and TVB-N were obtained for samples packed with films containing 1.5% *Zataria multiflora* EO.

EO extracted from the chrysanthemum plant is used mainly as an organic pesticide and as an insect repellent. This EO has also exhibited antimicrobial properties. Therefore, Lin et al. (2019) incorporated chrysanthemum EO into chitosan nanofibers for application as packaging in beef. After 7 days of storage, the nanofibers with EO were effective against *Listeria monocytogenes* bacteria, with inhibition rates of 99.91%, 99.97% and 99.95% at temperatures of 4 °C, 12 °C and 25 °C, respectively. Due to the release of antioxidant components present in the EO by nanofibers, the TBARS value in beef was 0.135 MDA/ kg lower compared to the control sample, after 12 days at 4 ºC.

Souza et al. (2019) developed bionanocomposites based on chitosan and montmorillonite, with incorporation of rosemary EO in different concentrations (0.5, 1 and 2%) to use as primary packaging for fresh poultry meat. The meat samples were packaged and stored for 15 days at 5 ºC. In comparison to the control, the samples packaged showed a reduction of 1.2-2.1 log UFC/ g in the total count of microorganisms. EO films were also able to delay the lipid peroxidation and discoloration of the fresh poultry meat.

Edible coatings

The coating technique consists of applying a thin layer of a biodegradable and edible material on the food surface in order to prolong the shelf life of a wide variety of products. Some of the functions of the edible coating are to prevent undesirable chemical reactions, to serve as a barrier against moisture loss and to prevent deterioration by microorganisms. A wide variety of polymeric matrixes can be used, such as chitosan, sodium alginate and gelatin, which can be incorporated into EOs to increase the effectiveness of these coatings (Ju et al. 2019, Pina-Barrera et al. 2019).

One of the edible coating studies investigated the effect of adding a coating based on sodium alginate and EO of *Pimpinella saxifrage*, at a concentration of 1-3%, to cheese samples. The EO enrichment of sodium alginate coating, particularly at 3%, improved the preservation of the analyzed samples. The preservation of pH and color were observed, as well as reduction of weight loss and enhanced oxidative and bacterial stability (Ksouda et al. 2019).

Cumin EO is known for its anti-inflammatory and antimicrobial properties. Thus, one study aimed to develop a coating based on Shahri

Balangu and cumin EO to improve the shelf life of beef slices, stored for 9 days under refrigerated temperature. The counts of psychrotrophic bacteria, coliforms, *Escherichia coli*, *Staphylococcus aureus*, molds and yeasts were significantly reduced. Moreover, there was a reduction in lipid oxidation, and the coated samples showed no adverse effects on the sensory characteristics (Behbahani et al. 2020).

Hashemi et al. (2020) evaluated the effects of coatings made with different concentrations of alginate and thyme EO on the postharvest characteristics of fresh pistachios stored for 39 days at 3 °C and 80% relative humidity. The addition of coatings on the fruits contributed to the maintenance of higher antioxidant activity and phenolic content in comparison with the control. In addition, the coated samples reduced mold and yeast growth. The values of free fatty acids and peroxides were also significantly lower in pistachios with the addition of the coating enriched with thyme EO.

Application of edible coatings incorporated with EO in fruits has become a promising field. Yin et al. (2019) evaluated the addition of a coating on fresh mangoes stored for 14 days, at 25 ºC and 50% relative humidity. The samples were packaged in multilayer coatings made from chitosan, cinnamon EO microcapsules and alginate solutions. Compared to the control, the coated fruits could effectively inhibit the decrease of vitamin C content, slow down weight loss and delay the appearance of respiration peaks. Additionally, the mangoes coated with five layers still maintained their commercial value during the evaluated period, although the same was not observed for the control samples.

In another study, Pina-Barrera et al. (2019) developed a multisystemic coating based on pullulan and polymeric nanocapsules containing thymus EO, in order to increase the shelf life of table grapes. The shelf life study showed that the coated grapes maintained their characteristics of firmness, total acidity, color, and total soluble solids for a longer time compared to the control. Furthermore, the coating inhibited the growth of undesirable microorganisms and reduced oxidative stress induced during the postharvest period. Murmu & Mishra (2018) demonstrated improved antioxidant activity in guava coated with arabic gum, sodium caseinate, cinnamon and lemon EO-based coating.

González-Locarno et al. (2020) evaluated the effect of coatings made from chitosan and rue EO in different concentrations for application on cape gooseberries stored at 18 °C for 12 days. The fruits coated with 0.5% EO suffered lower weight loss compared to the uncoated samples. The application of coatings with 1.0 and 1.5% delayed the growth of aerobic mesophilic bacteria, molds and yeasts. The coating also preserved the antioxidant properties of the fruits after 12 days. Silva et al. (2019b) obtained similar results in his research on edible coatings made of pectin, cellulose nanocrystals, glycerol and lemongrass EO, for application on strawberries under refrigeration temperature, during 8 days of storage. Application of the coatings reduced the weight loss and the anthocyanin content of the fruits.

The use of nanoemulsions offers clear advantages, such as better antimicrobial activity, reduced interactions with other components of the food matrix and greater stability to EO compounds (Prakash 2018). Therefore, Shokri et al. (2020) evaluated the efficiency of nanoemulsions in improving the characteristics of a coating based on chitosan and *Ferulago angulata* EO, and the coating's potential to extend the shelf life of Rainbow trout fillets stored at 4 ºC for 16 days. Nanoemulsions with 3% EO showed the best inhibitory effect on the growth of bacteria in the fish fillet samples. In addition, nanoemulsions improved the effectiveness of the coating in retarding the increase of lipid peroxidation and TVB-N of the analyzed samples.

The work of Noori et al. (2018) reported the use of nanoemulsion with ginger EO in a sodium caseinate edible coating applied to chicken breast refrigerated for 12 days. Coating with 6% of EO ginger nanoemulsion resulted in significant decrease of total aerobic bacteria. Although antioxidant activity was not significant, samples coated with nanoemulsion showed less difference in color and cooking loss, and proved effective in prolonging the shelf life of the product.

Artiga-Artigas et al. (2017) applied nanoemulsion-based coatings containing oregano EO incorporated with mandarin fibers and sodium alginate in low-fat cheese in order to extend its shelf life. The authors observed that the cheese's native microbiota was controlled and growth of Staphylococcus aureus was decreased from 6.0 to 4.6 log CFU/g after 15 days.

Legal aspects of the use of essential oils in food

EOs are classified as flavorings by the European Commission (EC) (EC 2008). Since 2012, the European Union has adopted a list of flavorings approved for use, which is updated frequently. EOs are also classified and registered as flavorings by the United States Food and Drug Administration (FDA) and considered Generally Recognized as Safe (GRAS) (FDA 2020).

The EOs classified as GRAS comprise a series of EOs most commonly used, such as oregano, coriander, ginger, thyme, clove, basil, cinnamon, nutmeg, and menthol, among others. Despite being classified as GRAS, EOs have a recommended intake limit, since some of their components can cause allergies. The Codex Alimentarium, the Council of Europe (CoE), Food Chemical Codex (FCC), Manufacturers Association (FEMA), and the International Organization of Flavor Industries (IOFI) have adopted specific protocols to check the toxicity of EOs and their components, as well as established security restrictions.

Some of the EOs, such as lavender, eucalyptus and laurel, have been linked to allergic reactions. Consequently, each EO added to a food matrix must be validated by its safe intake limit for humans, considering the classification of EOs and their limits already pre-established by health organizations, such as the FDA (Falleh et al. 2020).

Future perspectives

The application of EOs in food matrixes has emerged from an increasing trend to replace synthetic preservatives. EOs used as natural additives offer a clear advantage (Falleh et al. 2020). Several studies have been successful in incorporating EOs in food matrixes, either in their free form or added to materials to produce active packaging and edible coating. Ecological technologies capable of increasing the bioactive potential of EOs have also been studied and used, such as the alternative extraction methods and micro and nanoencapsulation techniques previously described in this literature review.

In addition to EOs that already have pre-established limits for use in food, regulated by food safety organizations, it is expected that in the near future, the standardization of new types of EOs will occur, so that they may be safely applied to foods in doses capable of producing desirable results. Moreover, the synergism between different EOs for food applications presents a field of research with promising future perspectives. Future research combining alternative EO extraction methods with emerging technologies such as nanoencapsulation is also expected.

CONCLUSION

The study of the properties and extraction methods of EOs, as well as their application in food, has proved to be a subject of extreme relevance, since safe and high-quality food products have become a requirement of consumers in recent years. Based on this literature review, it was possible to identify the main advances made and technologies used in the development of active packaging, edible coatings and food additives. In addition, the ability of EOs to control microbiological action and extend shelf life of products, thereby providing safe products, has become clear. Thus, future studies should be conducted to further explore the interactions between EOs and food.

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