BIOLOGICAL ACTIVITIES, HEALTH BENEFITS, EXTRACTION METHODS, FOOD APPLICATIONS AND BENEFICIAL EFFECTS OF ESSENTIAL OILS

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PREFACE

Today, food technologies are important for food security, safety and sustainability. On the one hand, it aims to produce food without increasing costs by preserving the quality of food in terms of sensory and nutritional aspects to meet expectations of consumers. On the other hand, it aims to achieve zero food-borne waste and improve food safety via the growth control of spoilage microorganisms while simultaneously reducing the use of synthetic preservatives. In this book, effects of essential oils (EOs) as natural preservatives and their components on food production, in addition to the related mechanisms of action, are focused.

EOs derived from aromatic plants are natural components, which constitute an important area of conventional pharmacopoeia; these oils are frequently used as the best alternatives in food preparation because of give flavor to food and drinks or as natural fragrances. The major compounds of EOs exhibit potential antioxidant, antimicrobial and antifungal activities via various mechanisms. In particular, several spices and herbs are known to exhibit antimicrobial activity due to their EO fractions.

This book is a valuable guide for researchers, health professionals, and students as well as the industry. Furthermore, this book can provide information that can benefit those interested in the therapeutic use of EOs for the purpose of practising aromatherapy, as well as for the development of products, with the minimum risk involved.

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CONTENTS

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The author would like to acknowledge to her family, who emphasized the importance of working, being helpful to people and always reminded her that the next step will get better.

INTRODUCTION

The term essential oil (EO) is thought to have originated from the 16th century Swiss medical reformer Paracelsus von Hohenheim, who described it as the effective ingredient of the essential drug Quinta (Guenther and Althausen 1948; Burt 2004). According to the International Organization for Standardization (ISO), EO is defined as 'a product obtained from the outer skin of citrus fruits by distillation using water or steam, or by a mechanical process or obtained from a vegetable natural raw material by dry distillation' (IOS 2013; Feyaerts et al. 2020). Generally, EOs are volatile, aromatic and colourless liquid compounds obtained from whole plants or different parts of plants such as seeds, flowers, shells, stems and peels (Sánchez-González et al. 2011). They have a complex structure that includes odorless, lipophilic, liquid and volatile compounds. They includes chemical compounds such as terpenes, monoterpenes, sesquiterpenes and phenylpropanoids. These compounds effectively have important tasks in their interaction with the environment of the plant, such as attracting pollinators, protecting against their enemies, preventing dehydration, protecting from the damage of UV rays and preventing germination (Oliveira et al. 2006; Hüsnü et al. 2007; Scherer et al. 2009; Silva et al. 2009, 2013; Allam et al. 2020).

Plant EOs exhibit biological activities, such as antibacterial, antifungal, antiviral and antioxidant activities (Ali et al. 2015; Cui et al. 2019). Thus, plant EOs play an effective role in the preservation of food and inhibition of pathogenic microorganisms. For example, terpenes or oxygenated terpenes found in the EO of lemons exhibit antifungal activity against *Candida* spp., such as *C. tropicalis*, *C. glabrata* or *C. albicans* (Ooi et al. 2006). Antimicrobial and antifungal effects of EOs permit their use alone or in combination with chemical preservatives in the preparation of cosmetic products such as creams, gels or ointments (Sticher et al. 2015).

Oil extracts from different vegetable seeds are rich in protein and vitamin content, and a majority of plant seeds, such as sunflower and perilla, contain heterocyclic compounds (e.g. pyrazine), which significantly affect the quality and aroma of products (Cuicui et al. 2018; Bhavaniramya et al. 2019). In addition, the value of plant oils is increasing, especially, in recent years, due to their high content of polyunsaturated fatty acids (PUFAs), which are essential for health. As fats as well as types and amounts of foods affect the individual fat profile, the fatty acid content of fats, in particular, is vital for public health and human nutrition (Cunnane et al. 1993).

Plant families containing EOs are listed below.

Lamiaceae: It is one of the sixth largest plant family comprising about 200 genera and 7000 species growing in China. *Lavandula angustifolia* Mill., *Scutellaria baicalensis* Georgi *Pogostemon cablin* (Blanco) Benth., *Rosmarinus officinalis* Linn., *Mentha haplocalyx* Briq. and *Perilla frutescens* (L.) Britt. is a member of this family. It is used in traditional Chinese treatment to reduce temperatures, to remove bad spirits, to increase blood circulation, to remove stagnation, to create diuresis and to reduce edema (Gaire et al. 2014; Ullah et al. 2014; Luo et al. 2019). It includes volatile compounds, e.g. marjoram, typically collected in glandular trichomes, and an excess of aromatic herbs and shrubs, including lavender, thyme, thyme, mint and sage (Nieto 2017; Mamadalieva et al. 2017; Kachur and Suntres 2020).

Apiaceae (Umbelliferae): It is another of the largest plant families in the world. *Angelica* spp. (angelica), *Apium gravolence* (celery), *Anethum graveolens* (dill), *Anthriscus cerefolium* (chervil), *Cuminum cyminum* (cumin), *Foeniculum vulgare* (fennel) *Coriandrum sativum* (coriander), *Ferula gummosa* (galbanum), *Pimpinella anisum* (anise), and *Carum carvi* (caraway) etc., such as medicinal plants, vegetables and species available in the kitchen, are members of this family (Singh and Jain 2007; Amiri and Joharchi 2016). Most Apiaceae EOs contain active terpenes that are known for their toxic effects against insects, such as anethole, camphor, carvone, cymene, linalool, thymol, a-pinene, and 1-pinene (Ebadollahi 2013a).

Rutaceae: This family of about 150 genera and 1,600 species of trees, shrubs and climbers grows in temperate and tropical regions of the world. *Citrus*, *Zanthoxylum*, *Ruta*, *Ptelea*, *Murraya* and *Fortunella* are the most well-known members of this family (Pollio et al. 2008; Siddique et al. 2012; Supabphol and Tangjitjareonkun 2014). Some components of EOs, such as *Citronella* and bergamot, are produced by distillation from plants belonging to this family (Aziz et al. 2010; Liaqat et al. 2018).

Asteraceae (Achillea): It is a natural herbicide source. There are approximately 20 Asteraceae species collected at the flowering time in terms of quality (anti-weed growth and germination) and yield of EOs (Benvenuti et al. 2017). Uses of the members of the *Asteraceae* genus in traditional medicine date back to the Trojan War and Achilles (Könemann 1999). Approximately 85 species of this family, including *Achillea millefolium* (yarrow), previously collected with phytochemical and ethno-medicinal properties are found in Europe, Asia, and some in North America (Chandler et al. 1982).

Cupressaceae: The wood of this family, which is described as conifer trees, is widely used in the world for different purposes such as toys, furniture, interior material of the flooring, or building material (Matsubara et al. 2020). With 30 genera and especially 142 species of evergreen coniferous trees or shrubs, they show a wide distribution in both hemispheres. There are three genera of 6 species in New Caledonia, all of which are endemic: *Neocallitropsis*, *Callitris,* and *Libocedrus* (Lebouvier et al. 2010).

Myrtaceae: There are at least 133 species in the Myrtle family comprising 3,800 tall tree or woody shrub species. Its diversity centers are Australia, Southeast Asia, and South America, and a few of them also exist in Africa (Ebadollahi, 2013b). The plants in this family are generally known for their oil glands, polystemonous flowers, numerous stamens, internal phloem, inferior to semi-inferior ovaries, and vestured pits in xylene veins (Conti et al. 1997; Wilson et al. 2001; Stefanello et al. 2011).

Pinaceae (Coniferophytina): The majority of commercially important conifers such as cedars, firs, hemlock, larch, pines, and spruce are among this group. Most of this family is found in the Northern Hemisphere, but the majority of its species disperse from the lower polar regions to the tropical regions (Kurose et al. 2007; Tumen et al. 2011). The Pinaceae family includes a total of 12 genera: Cedrus, Pseudolarix, Nothotsuga, Cathaya, Pinus, Keteleeria, Picea, Tsuga, Pseudotsuga, Larix, Hesperopeuce, and Abies. Most of Abies, Picea, and Cedrus in these genera are heteromorphic (Page, 1990; Wolff et al. 2002).

This book provides a general overview of published data on the active ingredients of EOs whose families are given above, explaining their optimal ingredients and effects in food processing. It also provides information on their biological activities, extraction methods, and effects on health to shed light on further research.

2. CHEMICAL STRUCTURES

Essential oils constitute only a small portion of plants, although they represent the most important known characteristics of aromatic herbs. There are chemical differences between essential oils obtained from different plant varieties. The composition and quality of EOs are naturally affected by various factors such as growth stages, variety, geographical origin, harvest time, parts of the plant, and age of the plant. In addition, this situation is also affected by extraction techniques, analysis methods, and solvents (Khajeh et al. 2005; Hussain et al. 2008; Negi 2012; Riahi et al. 2013; Ribeiro-Santos et al. 2017). Essential oils have a complex structure with a few hundred compounds, especially hydrocarbons such as terpenes and sesquiterpene, and oxygenated compounds such as aldehydes, ketones, oxides, acids, ethers, alcohols, lactones, phenols, esters, and acetals. They are effective on the odor and flavor properties of EOs in both groups. Usually, essential oils have terpenes (e.g. carvacrol and thymol) and phenylpropenes (e.g. cinnamaldehyde and eugenol) which are two basic chemical compounds. The chemical structures of the most well-known terpenes are presented in Figure 1 (Blowman et al. 2018).

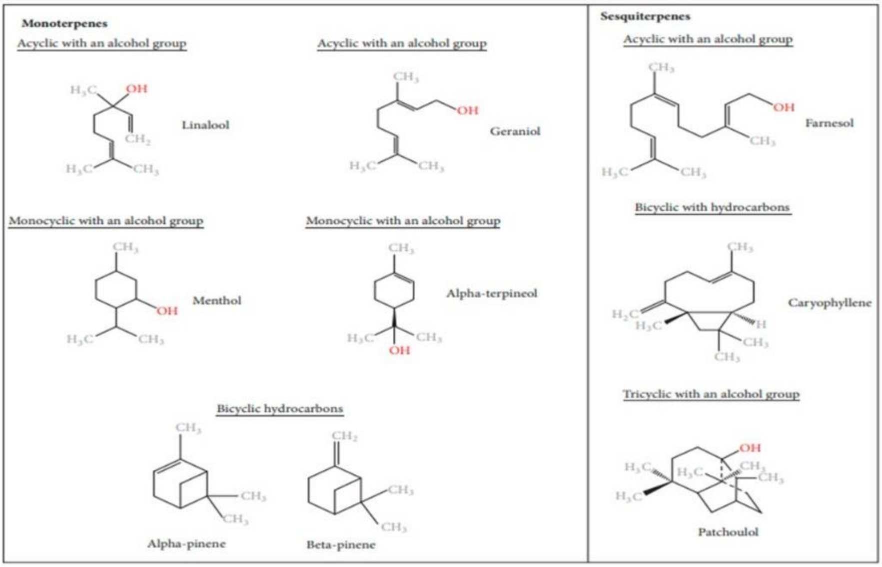


Figure 1. Chemical structures of the most common terpenes

Terpenes are divided into subunits known as isoprene units such as mono ($C_{10}H_6$), sesqui ($C_{15}H_{24}$), and diterpenes ($C_{20}H_{32}$). There are some different sources of terpenes associated with the presence of ring structure, double bond, oxygen, and stereo structure (Lee et al. 2004). Terpenes have some different chemical functions including alcohol (terpineol, linalool, citronellol, geraniol, menthol, carveol, bisabolol, and borneol), aldehyde (citronellal, citral), phenol (carvacrol, thymol), ketone (camphor, carvone), ether (eucalyptol), and hydrocarbon (limonene, phellandrene, cymene, and pinene) (Guimarães et al. 2019). According to their activities, these products provide antimicrobial effects (some of the most effective are oils of thyme, clove, rosemary, and vanillin because of the presence of phenolic compounds), also antioxidant, immune-enhancing, and digestion-enhancing effects in animals (Benchaar et al. 2008; Jayasena and Jo 2013; de Oliveira Monteschio et al. 2017).

Some essential oils also comprise other compounds besides phenylpropenes and terpenes. For instance, garlic oil contains a large amount of sulfurous compounds (vinyl-dithiins, diallyl sulfide, diallyl trisulphide, diallyl disulfide, and adjoenes, etc.,) (Benchaar and Greathead 2011). The chemical structures of some commonly known essential oils are given in Table 1 (Chao et al. 2000; Benchaar et al. 2008).

Table 1. Components and sources of some essential oils

EOs	Plant piece	Raw material	Compounds	%
Angelica	Roots	*Angelica archangelica* L.	α-pinene	24.7
			δ-carene	10.5
			α-phellandrene+ myrcene	10.8
			limonene	12.9
			β-phellandrene	10.4
			p-cymene	7.7
Bergamot	Fruits	*Citrus bergamia* Risso et Poit	β -pinene	7.7
			Limonene + β-phellandrene -	39.4
			Terpinene	8.6
			Linalool	11.1
			Linalyl acetate	28.0
Cinnamon	Inner bark	*Cinnamomum zeylanicum* Blu.	(E)-cinnamaldehyde	77.1
			Eugenol	7.2
Coriander	Seeds	*Coriandrum sativum* L.	p-cymene	6.1
			Linalool	72.0
Dill (Indian)	Seeds	*Anethum sowa* Roxb	Limonene	50.9
			trans-dihydrocarvone	10.4
			Carvone	20.3
			Dillapiole	36.6
Eucalyptus	Leaves	*Eucalyptus citriodora* K. D. Hill	Citronellal	72.8
			Citronellol	14.5
Ginger	Roots	*Zingiber officinale* Rosc.	Camphene	14.1
			Neral	4.9

			Geranial + bornyl acetate	8.1
			β-bisabolene	22.1
			ar-curcumene	14.5
			β-eudesmol	5.4
Juniper	Berries	*Juniperus communis* L.	α-pinene	33.7
			Sabinene	27.6
			Myrcene	5.5
Orange	Peel	*Citrus sinensis* L. Osbeck	Limonene	91.5
Pepper	Fruits	*Piper nigrum* L.	α-pinene	9.0
			β-pinene	10.4
			Sabinene	19.4
			δ-3-carene	5.4
			Limonene	17.5
			β-caryophyllene	14.7
Rosemary	Whole plant	*Rosemarinus officinalis* L.	α -pinene	7.4
			β-pinene	5.0
			1,8-cineole	43.6
			Camphor	12.3
Tea tree	Branches	*Melaleuca alternifolia* L.	α -terpinene	10.4
			1,8-cineole	5.1
			Terpinene-4-ol	40.1
			γ- terpinene	23.0

3. USE OF ESSENTIAL OILS

The term "essential oils" appeared on the basis that "oils" are necessary for life, which has been used by humans since ancient times for cosmetic and medical purposes. Although the widespread use of essential oils was delayed with the discovery of antibiotics in the middle of the 19th century, it has recently been redeveloped. Apart from the 3000 known essential oils, 300 more oils have been identified, which are widely used in various applications in the sectors such as agriculture, pharmaceuticals, food preservatives, cosmetics, perfumes, and cleaning industries (van de Braak and Leijten 1999; Zhai et al. 2018). For example, essential oils such as d-carvone, d-limonene, and geranyl have multiple usage areas in industrial solvents, soaps, perfumes, household cleaning products, creams, as well as, fragrances and foods as flavoring additives. Furthermore, essential oils have other usage areas such as massage with aromatherapy and cleaning of the bathroom (Hajhashemi et al. 2003; Silva and Fernandes Júnior, 2010; Kar et al. 2018).

Most essential oils are plant extracts that do not contain artificial additives and are derived from single bioactive compounds and secondary metabolites of natural aromatic hydrophilic fluids. They have a wide range of biological functions such as antimicrobial, antiallergic, antioxidant, antifungal, and anticancer agents (Seow et al. 2013). Especially essential oils of aromatic and medicinal plants show antibacterial and antifungal effects with their food preservative activities against different pathogens (Basim et al. 2000; Iacobellis et al. 2004; Tripathi and Kumar 2007; Pandey et al. 2014; Sonker et al. 2015; Gormez et al. 2016; Pandey et al. 2017; Figure 2).

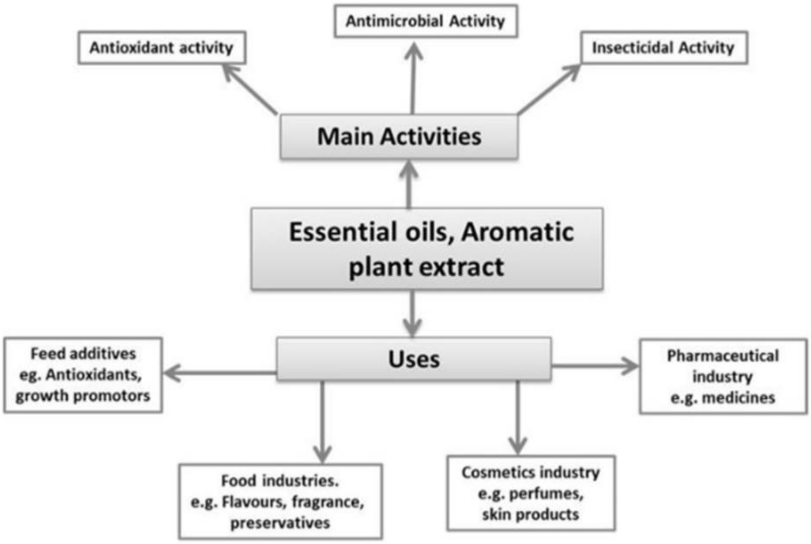


Figure 2. Different activities and uses of essential oils.

According to the FDA (American Food and Drug Administratio 2014), EOs are considered reliable compounds as a potential alternative to synthetic additives (Ju et al. 2018; Atarés and Chiralt 2016; Ruiz-Navajas et al. 2013). Today, consumer awareness and concerns about artificial preservatives have resulted in attentive approaches to various natural antimicrobials such as essential oils. Thus, many essential oils are reliably applied in many fields such as food, pharmaceutical, and cosmetics due to their versatile and biological functions. These volatile compounds, which have such advantages, can deteriorate quickly (oxidation, heat, volatilization, and light) if they are not protected from environmental factors due to their unstable structure. Figure 3 shows the changes in essential oils depending on various environmental parameters (Wadhwa et al. 2017).

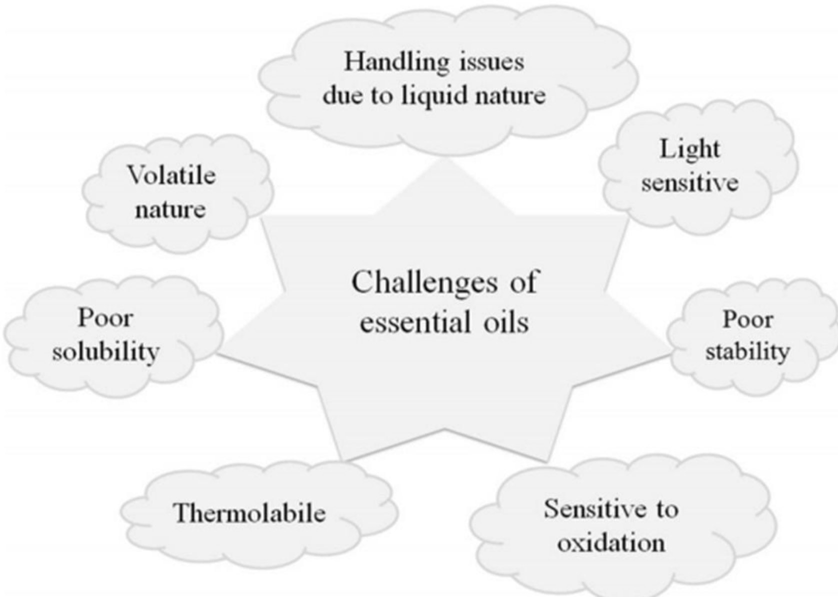


Figure 3. The common challenges of essential oils

Essential oils have a versatile effect (Table 2) due to their dominant components. This situation can also be explained by the antagonistic or synergistic effects of each component (Konopacka-Brud et al. 2010; Taavoni 2013; Michalak 2018).

Table 2. Potential uses of some essential oils in multifaceted areas

Some mechanisms of action	Effect on skin
Tiredness: *Angelica archangelica, Citrus aurantium, Coriandrum sativum, Cymbopogon nardus, Eucalyptus radiata, Juniperus communis, Mentha spicata, Pelargonium graveolens, Pinus*	**Antibacterial:** *Lavandula officinalis, Leptospermum scoparium, Melaleuca alternifolia, Rosmarinus officinalis*

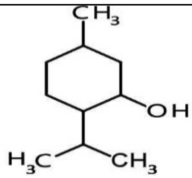
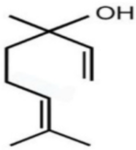
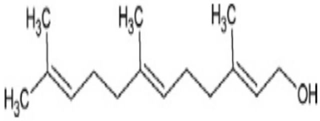
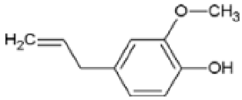
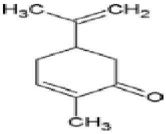
sylvestris, Rosmarinus officinalis, Salvia sclarea, Zingiber officinale	
Insomnia: *Angelica archangelica, Cananga odorata, Citrus aurantium, Cistus ladaniferus, Citrus bergamia, Citrus limon, Citrus reticulata, Citrus sinensis, Cuminum cyminum, Juniperus communis, Lavandula angustifolia, Litsea cubeba, Melissa officinalis, Myrtus communis, Ocimum basilicum, Origanum majorana, Valeriana officinalis*	**Antifungal:** *Angelica archangelica, Artemisia sieberi, Brassica nigra, Cymbopogon nardus, Cuminum cyminum, Melaleuca armillaris, Melaleuca ericifolia, Melaleuca leucadendron, Melaleuca styphelioides, Mentha piperita, Skimmia laureola,*
Fears, agitation, tension: *Angelica archangelica, Cistus ladaniferus, Citrus aurantium, Citrus aurantium, Cymbopogon martinii, Eucalyptus staigeriana, Lavandula angustifolia, Litsea cubeba, Ocimum basilicum, Origanum majorana, Pelargonium graveolens, Pogostemon patchouli, Valeriana officinalis*	**Anti-inflammatory:** *Melaleuca alternifolia, Citrus limon, Lavandula officinalis, Pogostemon patchouli, Rosmarinus officinalis, Santalum album*
In Mental functions: *Mentha piperita, Helichrysum angustifolium, Ocimum basilicum*	**Strengthening vascular walls:** *Citrus amara, Pelargonium graveolens, Rosa damascene, Rosmarinus officinalis*
In memory loss: *Litsea cubeba, Mentha piperita, Rosmarinus officinalis*	**Delaying skin ageing:** *Citrus limon, Citrus amara, Rosa damascena*
Bone and joint pain: *Cinnamonum zeylanicum, Rosmarinus officinalis, Juniperus communis, Lavandula angustifolia, Leptospermum scoparium, Matricaria recutita, Origanum majorana, Pinus mugo, Zingiber officinale,*	**Lymph circulation, disposal of metabolic wastes, anti-cellulite:** *Citrus limon, Citrus paradisi, Cupressus sempervirens, Juniperus communis, Pelargonium graveolens, Rosmarinus officinalis, Santalum album.*

4. BIOLOGICAL ACTIVITIES

Biological activities of EOs such as antibacterial, antiparasitic, antifungal, antioxidant, and pesticide have been proven for a long time (Solórzano-Santos and Miranda-Novales 2012). In addition to some studies have been also carried out to illuminate the effect mechanisms of these bioactive compounds in animals, also there is various research about the use of essential oils to replace antibiotics in animal feed (Li et al. 2012).

Plants produce secondary metabolites of essential oil in order to protect themselves against pests (fungi, insects, etc.). For example, it has been emphasized that thyme essential oil (with its compounds such as carvacrol and thymol) has very powerful biological functions such as antibacterial, anti-inflammatory, and antioxidant effects (Govaris et al. 2010). In addition, the biological activity of clove essential oil (CEO) has been studied and reported to act as an antioxidant, insecticidal, antifungal, and antibacterial agent. Table 3 presents the basic components and biological activities of EOs (Burt 2004).

Table 3. The major components of EOs and their biological activity.

Compound	Chemical formula	Source	Effect
Menthol		Peppermint/mint oils	Antioxidant/antimicrobial/anti-inflammatory
Linalool		Lemon/cinnamon oil	Antimicrobial/antioxidant/insecticide
Farnesol		Rose oil/ citronella oil	Antiseptic/ anti-inflammatory/ antibacterial
Eugenol		Clove oil	Anaesthetic/antiseptic/antibacterial/antifungal
Carvone		Caraway/ spearmint oil	Aromatherapy/alternative medicine

The antimicrobial and antioxidant effects of essential oils are their mechanism of action in food safety (Bhavaniramya et al. 2019). Bioactive compounds of the antimicrobial and antifungal properties of EOs target damaged cell walls and membranes, various cells, and chemical pathways such as proton repulsion. For example, although there is only limited knowledge of the antibacterial and antifungal mechanism of eucalyptus oil, it is associated with synergistic effects between large and small compounds found in oil rather than a single compound. It has been reported that EOs derived from *Eucalyptus odorata* have potent inhibitory and cytotoxic effects against *S. aureus*, *S. pyogenes*, *S. pneumonia,* and *H. influenza* (Tyagi and Malik 2011). Moreover, peppermint oil has an inhibitory effect on the development of staphylococci. At the same time, some studies have found that IC50 concentrations ranging from 0.5 to 8 µg/mL show antifungal activity against both standard and clinical pathogenic strains of *Candida* species and provide a good antifungal effect on azole-sensitive and azole-resistant strains (Cox et al. 2008; Bhavaniramya et al. 2019).

a. Antimicrobial activity

Many spices and herbs have antimicrobial activity due to their volatile fractions. Nychas (1995) reported that essential oils obtained from sage, cloves, thyme, garlic, rosemary, and onion have an antimicrobial effect against bacteria and molds. Which microorganism the essential oils will affect depends on the different active compounds they contain and the nutrients they will be effective on (Moreira et al. 2005). To protect foods with high fat and protein content against bacteria, the activity, and concentration in the aqueous phase is reduced to facilitate their activities at high water and/or salt levels, and essential oils are better absorbed and a protective layer is formed (Smith-Palmer et al. 2001; Carson and Riley, 2003; Perricone et al. 2015). Essential oils can reduce pathogen mobility and effects by altering the normal functioning of bacterial cells (Niu et al. 2006; Brackman et al. 2008; Zhou et al. 2013) that form the basis of communication in different signaling molecules, suppressing the production of exotoxins (Qiu et al. 2010; Li et al. 2011; Soltani et al. 2014; Sutili et al. 2015), reducing biofilm formation (Millezi et al. 2013), inhibiting lipopolysaccharide expression and extracellular protease activity of the cell wall (Iwalokun et al. 2003; Sutili et al. 2018). The cell walls of Gram-positive bacteria allow hydrophobic molecules such as EOs to penetrate to the cell and act into the cytoplasm (Nazzaro et al. 2013). Due to the complexity of the double-layered cell membrane of gram-negative bacteria, they have increased resistance to antibacterial compounds compared to the single-layered membrane of Gram-positive bacteria (Savage 2001). Nevertheless, the second membrane of Gram-negative bacteria is not completely resistant to hydrophobic molecules, and microorganisms can slowly penetrate through pores (Plesiat and Nikaido 1992; Sutili et al. 2018). The antimicrobial activities of EOs are effective against a wide variety of microorganisms, including Gram-positive and Gram-negative bacteria. This effect is due to some terpenoid and phenolic compounds in EOs such as thymol, p-cymene, γ-terpinene and carvacrol (Martínez et al., 2006; Benchaar et al. 2008) as well as some chemical constituents, functional groups, their concentrations and interactions (Dorman and Deans 2000). The antibacterial mechanisms and components of some EOs are presented in Table 4 (Langeveld et al. 2014).

Table 4. The antibacterial mechanisms and components of some EOs

EO/ component	Mode of action
Oregano	Reduction in lipase and coagulase activity, enzyme inhibition (de Barros et al. 2009).
Carvacrol	Membrane disruption, inhibition of ATPase activity, membrane destabilization, leakage of cell ions, fluidization of membrane lipids, reduction of proton motive force (Di Pasqua et al. 2007; Gill and Holley 2006a,b; Ultee et al. 2002).
Thymol	Membrane disruption with potential intracellular targets, citrate metabolic pathway disruption (Di Pasqua et al. 2007, 2010; Trombetta et al. 2005).
r-Cymene	Membrane disruption (Ultee et al. 2002).
Cinnamaldehyde	Membrane disruption by inhibiting ATPase activity (Gill and Holley 2004, Gill and Holley 2006a,b)
Cinnamic acid	Membrane disruption (Hemaiswarya and Doble, 2010; Chen et al. 2011).
Eugenol	Membrane disruption by inhibiting ATPase activity, possible efflux pump blocker, reduction of several virulence factors at sub inhibitory concentrations (Bolla et al. 2011; Di Pasqua et al. 2007; Gill and Holley, 2006a,b; Hemaiswarya and Doble 2009; Qiu et al. 2010).
Melaleuca tea tree	Inhibition of membrane-located metabolic events leading to inhibition of respiration and increased membrane permeability (Cox et al. 2001).
g-terpinene	Membrane disruption (Oyedemi et al. 2009)

Like bacteria, yeasts are effective in food spoilage. These yeasts, which are associated with food spoilage, grow in foods with acidic pH values and high carbohydrates. Food-based yeasts cause the spoilage of plant products such as fruit purees, vegetable/fruit juices and concentrate, soft drinks, brined vegetables, and low acid products (Le-Dinh and

Kyung 2006; Belletti et al. 2007; 2010; Tserennadmid et al. 2011). Food spoilage by molds causes not only economic losses but also harmful effects on health due to the toxicity of secondary metabolites produced such as citrine, aflatoxin, and roquefortine (Ju et al. 2018). In terms of human health, the prevention of mold formation and suppression of mycotoxin formation are necessary both for our health and for the nutritional values of foods not to decrease or disappear. For this, research continues on the antimicrobial properties of numerous essential oils and compounds against different molds (Bakkali et al. 2008; Nieto 2017).

Food poisoning, which is one of the biggest problems in terms of public health, is caused by the consumption of foods infected with pathogen bacteria. Thomas et al. (2013) reported that 4.0 million cases of foodborne illness occur in Canada each year. Food and food products can be contaminated with pathogens during the workflow process such as preparation, processing, production, and distribution (Gaulin et al. 2013). *Salmonella* sp., *Listeria monocytogenes* and *E. coli* are pathogenic microorganisms and are responsible for numerous diseases or deaths (Oussalah et al. 2007). *Pseudomonas aeruginosa* is a food-disrupting microorganism that chilled meat causes the depreciation and discoloration (Gutierrez et al. 2009; Ghabraie et al. 2016). The antimicrobial properties of EO are important because they have a wide range of antimicrobials to protect against bacteria (Dorman and Deans 2000; Burt 2004), yeasts (Conner and Beuchat 1984; Belletti et al.

2010), and molds (Pinto et al. 2006; Kamble and Patil 2008; Viuda-Martos et al. 2008; Tserennadmid et al. 2011).

For example, *Escherichia coli* O157:H7 is inhibited using thyme oil which are contain the two main components such as carvacrol and thymol (Helander et al. 1998; Elgayyar et al. 2001; Benchaar et al. 2008). The Food and Drug Administration according to Federal Regulatory Law has reported that EOs can be used as safe substances and some of their compounds as antibacterial additives (CFR 2015; Ait-Ouazzou et al. 2011; Cox et al. 2001; Deans and Ritchie 1987; Nerio et al. 2010; Muyima et al. 2002; El Asbahani 2015). Eugenol, thyme, coriander, and clove oils are used to control autochthonous flora and pathogens in meat because of cause a significant decrease in the number of living cells (Speranza and Corbo 2010). The antimicrobial activity of EOs in plants increases with the decrease of storage temperature and pH (Smith-Palmer et al. 2001). This situation may also be influenced from diffent parameters. For example, terpineol oil is affected by the fat content of the product. The effect of terpineol oil depends on the fat content, e.g. it caused a microbial decrease of 7 logs CFU mL^{-1} in skimmed milk, 4 CFU mL^{-1} in semi-skimmed milk, and 3 CFU mL^{-1} in whole-fat milk (Fisher and Phillips 2008).

Plant essential oils are also effective against storage product pests and fumigant insecticides. Most toxics of the 22 essential oils were tested against fumigants such as *Acanthoscelides obtectus* (Bruchidae), *Thymus serpilum* (rich in thymol and carvacrol phenols), and Origanum majorama (rich in terpinen-4-ol) in beans (Regnault-Roger et al. 1993).

b. Anti-tumoural and anti-angiogenic effects of essential oils

Angiogenesis is the process of formation of new blood vessels and is an essential feature of endothelial cells in the inner walls of vascular systems (such as veins and arteries) (Kang and Liu 2013). This process provides oxygen and nutrients to cancer cells, so it is considered a prerequisite for the growth of tumor cells. This process provides oxygen and nutrients to cancer cells, so it is considered a prerequisite for the growth of tumor cells.

Angiogenesis processes play leading roles in the progression, invasion, and metastasis of neoplastic cells and are typically considered prognostic markers for tumors (Haghighi et al. 2017). Especially in the last decade (Folkman 2007), some drugs targeting tumor inhibition effect of angiogenesis or tumor vasculature and some antiangiogenic agents such as anti-vascular endothelial growth factor (VEGF-A), bevacizumab antibody, sorafenib, and tyrosine kinase inhibitor sunitinib inhibitors have been used in clinical practice (Weis and Cheresh 2011; Yue et al. 2015). With the development of cancer research, the benefits of natural products and compounds that offer a broad spectrum of angiogenic inhibitors have been proven (Ichikawa et al. 2007; Kıyan et al. 2014). For example, it has been reported that different angiogenic activators, including vascular endothelial growth factor (VEGF) members, inhibit neovascularization under the influence of certain cytokines and other growth factors by playing an important role in the development of metastasis and tumor progression.

Essential oils produce pro-oxidant effects due to their abilities to interfere with mitochondrial functions and are thus recognized as true antitumor agents in recent years (Folkman 1985; Certo et al. 2017). Most free radical-generating agents are used in antitumor treatments. At this point, essential oils perform radical production in a more controlled manner without providing any toxic or mutagenic side effects to healthy tissues (Sinico et al. 2005; Lai et al. 2006; Fang et al. 2006). In short, the anticancer activities of essential oils are mainly due to the excessive suppression of detoxification of enzymes, potential membrane changes, and oncogene modifications, since they produce free radicals (Lesgards et al. 2014).

Recently, some EOs have been proposed as non-toxic anti-angiogenic agents. Bostancıoğlu et al. (2012) reported that *Origanum* EOs can inhibit cancer cell viability and angiogenesis. It has also been reported that the carvacrol (Jayakumar et al. 2012) and thymol components of EOs (Jaafari et al. 2012) have a cytotoxic effect on cancer cells. Liang and Lu (2012) reported that they consider the pro-apoptotic activity of carvacrol as the main essential bioactive compound for anti-angiogenic or pro-apoptotic effects (Nieto 2017).

The angiogenic process has been reported to increase in atherosclerosis studies (Slevin et al. 2006; Lindner 2009). In this reaction, there is a correlation of severe plaque rupture with possible complications such as the development of new blood vessels from the vasa vasorum, and intraplaque hemorrhage. Therefore, modulators of the angiogenic process may be important in the progression of atherosclerosis (Doyle and Caplice 2007; Herrmann et al. 2006; Fishbein 2010; Daleprane et al. 2012).

c. Antioxidant activity

Antioxidants are compounds that eliminate oxidative stress that can be created by free radicals or other molecules. It is very important to find compounds with both antioxidant and antimicrobial properties for the preparation of food products (Sanches-Silva et al. 2014). Natural and synthetic antioxidants are used in food preservation. Although synthetic antioxidants such as butylated hydroxyanisole (BHA), propyl gallate (PG), tertiary butyl hydroquinone (TBHQ), and butylated hydroxytoluene (BHT) are often used in food production, they have been suspected to have a negative impact on health (Barlow 1990; Branen 1975; Chan 1987; Namiki 1990; Pokorný 1991). Therefore, there has been increased interest in the use of antioxidants derived from natural additives. Most sources of plant-derived antioxidants have been studied in recent years. Studies have shown that the antioxidant properties of most aromatic plants and spices are effective in delaying the lipid peroxidation process in oils and fatty foods (Kulisic et al. 2004).

The natural antioxidant activities of herbals/spices essential oils are known. Extensive research has also been conducted to analyze the antioxidant potential of different essential oils, such as DPPH (α, α-Diphenyl-β-picrylhydrazyl) and 2.2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid; ABTs), which are often analyzed for their free radical scavengers effects. The antioxidant activity of essential oils depends on the metabolites which contain phenolic groups or conjugated double bonds (Koh et al. 2002). More specifically, the antioxidant effects of EOs are a result of the complex interactions between EO components and oxidizable material to be preserved. There is an antagonistic and synergistic effect between each component of EOs. For example, the biological effect of *Piper hispidinervum* (Piperaceae) is related to the synergy between its essential oil and other main components (Andrés et al. 2017). EOs, which include the high ratio of phenolic sesquiterpenes/monoterpenes, are known for their antioxidative capacities (Mancini et al. 2015).

Essential oils, rich sources of oxygenated monoterpenes such as aldehydes, ketones and esters, are obtained from traditional plants such as *Anethum graveolens*, *A. rutifolia*, *Achillea filipendulina*, *Mentha longifolia*, *Hyssopusseravschanicus*, *Ziziphorac linopodioides*, and *Galagania fragrantissima*. In addition, phenolic terpenoids such as monoterpene hydrocarbons (*A. scoparia* and *A. absinthium*) or thymol/carvacrol (*Mentha longifolia* and *O. tyttanthum*) are important chemical compounds with strong antioxidative effects (Bhavaniramya et al. 2019). Some non-volatile compounds such as caffeic, quercetin, rosmarinic acid, and carnosol are recognized as good free radical scavengers agents. Furthermore, many studies on the antioxidant activities of essential oils obtained from various aromatic plants have stated that thyme essential oil, which is rich in carvacrol and thymol, has an important antioxidant effect on the lard oxidation process (Lagouri et al. 1993; Tsimidou and Boskou 1994; Kulisic et al. 2004). The simplest way to prevent fat oxidation and the destruction which it will cause is the usage of antioxidant compounds (Frankel 1993; Karpińska et al. 2001). Recently, consumers are worried about the use of synthetic additives, including antioxidants, in the preparation of food products. In particular, some synthetic antioxidants, such as BHT and BHA, can be dangerous for living beings (Attmann et al. 1986; Powell et al. 1986; Tomaino et al. 2005). Most studies have reported that many natural compounds in essential oils show antioxidant activity within the cell. In addition to its antioxidant effect, it has been emphasized that essential oils are directly antimutagenic (Clark 2002) and anticarcinogenic due to their radical binding properties (Bakkali et al. 2008).

d. Insectical and acaricidal activity

The diversity of biological activities such as essential oils, antioxidants, antimicrobials, anti-inflammatory and acaricides in industrial applications, they have many uses such as pharmaceuticals and are also used in perfumery and food products (Bertin et al. 2005; Castro et al. 2006; Morais et al. 2006; Ramos et al. 2006; Camilo et al. 2017). Their effects on acarid cells may be due to tyramine and octopamine receptors, which modulate various functions such as the metabolism and behavior of acarids (Blenau et al. 2012). These oils are known to be caused by the effects of some of their compounds, in relation to acaricide activities (Abbas et al. 2018). They act synergistically to create a powerful acaricidal effect. For example, *Tagetes minuta* oil played a role in the control of *Rhipicephalus mikroplus* ticks in cattle. Through the chromatographic analysis of this oil, it has been determined that dihydrotagetone, β-osimen, tageton, and limonene are bioactive compounds that provide affect. This oil is effective against living larvae count, tick and tick egg weight, and tick count (Andreotti et al. 2013).

The insecticidal effects of vegetable essential oils through contact or as fumigant have been well demonstrated over stored product pests. Among the 22 essential oils tested as fumigants, those with the most toxic effects were identified as *Thymus serpilum* (rich in phenols carvacrol and thymol), *Acanthoscelides obtectus* (Bruchidae), and *Origanum majorama* (rich in terpinen-4-ol) (Regnault-Roger et al. 1993; Isman 2000). Essential oils are produced by plants to defend against pests, parasites, environmental stress and diseases. Some essential oils protect plants from interspecies competition and can attract insects during their reproductive process (Jouany and Morgavi 2007).

Essential oils form volatile mono- and sesquiterpenoids, which are associated with basic metabolic, biochemical, physiological, and behavioral functions in insects, and these oils provide the effects on inhalation, swallow activity, antifeedant activity, growth inhibition, adult emergence, fertility, suppression of fertilization, and repellent action (Tripathi et al. 2009). EOs derived from aromatic plants have been used against pests that cause economically significant problems, and some have been developed as potential alternatives to currently used insect control agents (Isman 2006; Nerio et al. 2010; Isman et al. 2011).

The *Eucalyptus* genus of the Myrtaceae family, which is considered to be one of the largest species (approximately 900 species), is important in terms of antibacterial, antifungal, antiseptic, and insecticidal activities (Rossi and Palacios 2015). The olive tree (*Olea europaea*) synthesizes a variety of phenolic compounds from its leaves and drupes to give an unpleasant taste that is used to defend against microbial and fungal infestation and deter leaf-eating insects (Casamenti and Stefani 2017; Angeloni et al. 2017). Again, many studies cover the insecticidal activity of EOs obtained from the Lamiaceae family.

Researchers evaluated the bioactivities of essential oils of some species including *Lavandula hybrida* Reverchon (Papachristos and Stamopoulos 2002a; 2002b; Papachristos et al. 2004; Cosimi et al. 2009; Conti et al. 2010a; 2010b; Bertoli et al. 2012), *Lavandula angustifolia* Miller (Shaaya et al. 1997; Pavela 2005; Pugazhvendan et al. 2012; Laznik et al. 2012), *Lavandula luisieri* (Rozeira) Rivas-Martinez (Julio et al. 2014), *Lavandula stoechas* L. (Ebadollahi, 2011) and *Lavandula gibsoni* Graham (Kulkarni et al. 2013; Germinara et al. 2017) in the genus *Lavandula* against the stored crop pests (Coleopteran, Lepidoptera, Rhynchota and Diptera).

EOs also act as signal providers to protect themselves against pests, attract beneficial insects such as pollinating insects, communicate between plants by emitting chemical signals in the presence of herbivores, and controlling and regulating their environment. EOs have also been proven to defend against a large number of stored grain insects (Fabres et al. 2014) effectively throughout contact and digestion (Bossou et al. 2015; Lee and Lee 2016). As a recommendation on this issue, the author believes that researchers should plan their biological control studies on the selection of acaricides and insecticides, which may be useful for controlling pests.

5. NUTRITIONAL PROPERTIES

Fats have an important role in human nutrition. In addition to providing calorie, they have carrier duties for fat-soluble vitamins (e.g. A, D, E, and K). The most common type of fats are triglycerides, which vary in composition and distribution according to the fatty acids it contains (Mohammadi et al. 2016; Mozafari et al. 2006; Rodríguez et al. 2016; Desai and Jin Park 2005; Ferreira and Nunes 2019). Fatty acids contain fatty acids such as saturated fatty acid (SFA), monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) according to their functions (Tvrzicka et al. 2011). These fatty acids have been reported to have anti-thrombotic and anti-atherogenic properties that affects lipoprotein concentration, membrane fluidity, membrane enzyme function and modulation of other compounds. (Simopoulos 1999; Yang et al. 2018).

Seafood is a source rich in terms of proteins, vitamins, minerals, and omega-3 long chain polyunsaturated fatty acids (n-3 LCPUFA), eikosapentaenoic (20:5(n-3), EPA) and docosahexaenoic (22:6(n-3), DHA) (Calder 2014; Tocher 2015; Sprague et al. 2017). Health authorities recommend that consuming two servings of fish per week, at least one serving of which is fatty (recommended daily intake of 250-1000 mg EPA+DHA) and necessary to protect against cardiovascular and inflammatory diseases (SACN/COT 2004; GOED 2014; Sprague et al. 2017). Arachidonic acid (AA; 20:4 n-6) is used in the production of lipid mediators (e.g. eicosanoids), which are effective in regulating inflammation (among other functions) with their DHA and EPA ingredients (Serhan 2014). Therefore, supplementing with oil rich as EPA and DHA can exert an anti-inflammatory effect, making it a possible treatment for arthritis pain (Lane et al. 2014; Gerster 1998; Senftleber et al. 2017). Vegetable oils are rich in linolenic acid (n-6). Therefore, seafood and its EPA and DHA-rich oils are very important in our diet. Furthermore, as a dietary supplement, dried fruit and leaf extracts should be taken at the daily dose of 500-2000 mg range, while at the doses of 2000-5000 mg range within oil (Sea Buckthorn, available online, accessed on 11 October 2017; Olas 2018).

6. EFFECTS ON HEALTH

Cardiovascular diseases caused approximately 10% of deaths worldwide at the beginning of the 20th century. In the 21st century, however, it accounts for 25% of deaths in developed countries and almost half of the deaths in developing countries (Lim et al. 2012; Sokoła-Wysoczańska et al. 2018). Vegetable oils are generally considered healthy due to the unsaturated fatty acids (monounsaturated and polyunsaturated fatty acids) associated with a low risk of coronary heart disease. High consumption of saturated fatty acids causes an increase in cholesterol levels and CVD disorders (Bendsen et al. 2011). Hence, to prevent CVD, which is such a risky disease, the rate of saturated fat taken with diet should be limited (Page et al. 1957; Blacket et al. 1965). Fish oil has high amounts of omega-3 long-chain polyunsaturated fatty acids such as eicosapentaenoic acid, docosahexaenoic acid, and small quantities of docosapentaenoic acid (22:5n-3). Also, fatty fish are considered a good source for the protection of our health because they contain a lot of omega-3 long-chain polyunsaturated fatty acids (n-3 LC-PUFA). The European Food Safety Authority (EFSA) has confirmed the suggestions about the intake of DHA and EPA, for instance, they are associated with normal blood triacylglycerol levels, normal vision and brain function, blood pressure, and cardiac function (EFSA Panel on Dietetic Products 2010). Adequate intake of EPA+DHA as at 250 mg/day has been established for adults. Similarly, infants >6 months and <100 mg DHA for children under 24 months have been accept an adequate intake (Van Dael 2021).

In recent years, various studies have emphasized the importance of pumpkin seed oil against many diseases in addition to diseases such as hypertension, diabetes, and cancer (Bardaa et al. 2016; Medjakovic et al. 2016; Wang et al. 2017a). It also shows anti-inflammatory antioxidant and antibacterial properties. Sesame plays an important role in human nutrition, industrial, pharmaceutical, medicinal, and agricultural areas. The oil obtained from raw or roasted of sesame seeds is used especially in the preparation of many bakery products (Yadav et al. 2010; Gutierrez 2016; Montesano et al. 2018). Sesame seed oil, an important oil, is rich in polyunsaturated fatty acids used in the production of margarine and found in edible oils. Sesamin, as a major lignan in sesame seeds which have beneficial effects on serum lipid levels and liver function and impart pronounced antioxidant activity to sesame seed oil. Especially lignans are the most effective compounds in the stability of sesame seed oil against oxidation (Crews et al. 2006; Gharby and Harhar 2017). Palm oil raises plasma cholesterol only when excessive amounts of dietary cholesterol are present in the diet. It stimulates the removal of harmful LDL cholesterol or the synthesis of protective HDL cholesterol. Palm oil is rich in vitamin E, which reduces serum cholesterol concentrations and has powerful anti-oxidant effects (Sutapa and Analava 2009).

It has been stated that the consumption of olive oil with a high content of oleic acid increases insulin production in vivo and in vitro systems (Guasch-Ferré et al. 2015). For this reason, it is stated that a diet rich in olive oil can have a beneficial effect on type 2 diabetes mellitus (Vassiliou et al. 2009). Besides, it is emphasized that a phenolic compound named oleuropein in olive fruit and leaves has an antihyperglycemic effect in diabetic rabbits and rats (Jemai et al. 2009; Al-Azzawie and Alhamdani 2006). The biologically active compounds of olive oil can explain this pharmacological effect (Beidokhti and Jäger 2017). It is known that the Mediterranean diet and olive oil-based nutrition plan have a positive effect against multiple cerebral disorders by providing a general protective effect on the brain (Visioli et al. 2018, Figure 4).

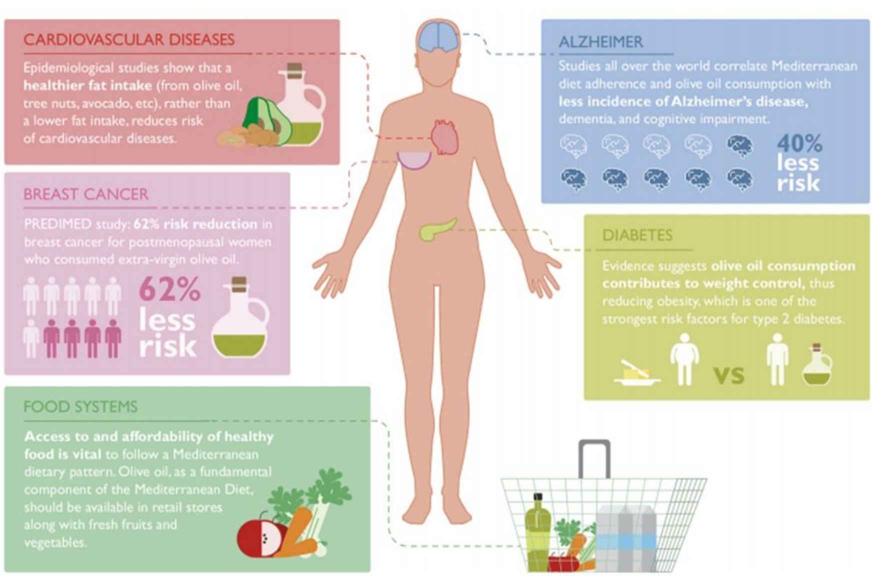


Figure 4. The importance of olive oil for health

Phenolic acids and other phenolic compounds are important secondary metabolites found in a variety foods (Heleno et al. 2015). The type, amount and properties of phenolic compounds vary according to the type of food and oils that contains. These compounds are found in all vegetable oils and impart significant oxidative stability for PUFAs (Siger et al. 2008; Yang et al. 2018). In addition, it is a known fact that phenolic compounds play a role in the prevention of some diseases such as cancer and hyperplasia (Alu'Datt et al. 2017).

7. USE OF AROMATHERAPY

Aromatherapy, also known as "essential oil therapy" is expressed as the art or science of using aromatic essences obtained from plants using natural methods to improve and calm the body and mental health (Sage 2016). Essential oils/essential EOs are complex mixtures of volatile compounds that are secondary metabolites of aromatic plants and are therefore characterized by strong odor. They are responsible for the odor properties of aromatic herbs, as they identify with their strong fragrance (Bakkali et al. 2008).

The chemical structures of these compounds of aromatic plants contain derivatives such as carbon, oxygen, hydrogen, and in some cases sulphur and nitrogen. Carbon and hydrogen atoms, functional groups tend to be relatively inactive atomic essential oil located in the network (Moghaddam and Mehdizadeh 2017). Essential oils are a mixture of saturated and unsaturated alcohol, ethers, ketones, hydrocarbons, esters, oxides phenols terpenes, and aldehydes that can produce characteristic odors (Schiller and Schiller 1994; Wildwood 1996). They are colorless and very fragrant liquid molecules in a high refractive index (Ali et al. 2015). Generally, these oils are mixtures of most organic compounds with therapeutic effects, reflecting the relative amounts of each compound they contain (Stevensen 1998).

Essential oils are colorless compounds with a pleasant fragrance that can be felt via the nose and mouth (Ali et al. 2015). These fluids provide a positive aromatherapeutic effect starting in the mouth and nose. Applying these oils to the skin using either water (poultices, baths, and compresses) or oil carriers (massage) has topical effects, and they must remain on the skin for a long time to enter the bloodstream. Since the inhalation of oil vapors is in such practise air aromatherapy is often included in direct aromatherapy (Warszawski 2011). Many organic compounds with different therapeutic effects are present in essential oils (Table 5, Stevensen 1998; Winkelman 2018).

Table 5. Therapeutic actions and organic compounds in essential oils

Organic compounds	**Therapeutic actions**
Acids	Anti-infectious and immunostimulants
Aromatic aldehydes	Anti-infectious and immunostimulants
C10 alcohols	Anti-infectious and immunostimulants
C15 and C20 alcohols	Estrogen-like activity
Aldehydes	Anti-infectious, calming and litholytic

Coumarins	Balancing and calming
Esters	Antispasmodic and calming
Lactones	Balancing and calming
Ketones,	Cicatrizing (wound healing), mucolytic litholytic and calming
Oxides	Antispasmodic and expectorant
Phenols	Anti-infectious and immunostimulants
Phenyl methyl esters	Anti-infectious and antispasmodic
C10 terpenes	Anti-infectious and cortisone-like activity
C15 terpenes	Antihistamines and antiallergic

In addition to this, the contribution of aromatherapy to the treatment of some diseases has also been proven. The therapeutic, cosmetic and aromatic uses of essential oils have been valued for centuries (Ali et al. 2015). However, since the U.S. Food and Drug Administration has not yet regulated, essential oils cannot be used to treat, cure, reduce or prevent diseases (Manion and Widder 2017). Aromatic essential oils such as lavender (*Lavandula angustifolia*), bergamot (*Citrus aurantium*), lemon (*Citrus limon*), rose (*Rosa damascena*), sandalwood (*Santalum album*), orange (*Citrus sinensis*), Roman chamomile (*Anthemis nobilis*), clary sage (*Salvia sclarea*) and rose geranium (*Pelargonium* spp.) (Lemon 2004; Setzer 2019) were used for the treatment of depression and anxiety (Edge 2003; Watt and Janca 2008). These oils, which have very strong concentrates, are effective on pressure points and rejuvenation. There are various application methods, such as inhalation in small amounts or use on the skin surface. Inhalation or external application of these oils for the treatment of mental and physical balance is the basis of aromatherapy. It has also been reported that these oils are effective in reducing stress and relieving the tiredness on the day (Siddique 2017).

8. BENEFICIAL EFFECTS OF SOME ESSENTIAL OILS

Generally, camelli oil (*Camellia oleifera* Abel.) is one of the edible oils in Asia and is known as tea seed oil. In recent years, *C. sinensis* seeds have been used as edible oil sources. They contain about 30% oil with 22.7-29.4% linoleic acid and 46.3-56.3% oleic acid. It is grown all over the world (over 60 countries) in an area of approximately 4.4 million ha and thus is a potential source for oil production. There are also two other major oil groups known as *C. chekiangoleosa* Hu and *C. oleifera* Abel that have been cultivated in southern China for thousands of years. The seeds of *C. chekiangoleosa* and *C. oleifera* have 40-60% oil content (Wang et al. 2017b). In addition, the oil's bioactive compounds such as catechin and sesamine are effective against reactive oxygen groups (ROS) by increasing the glutathione (GSH) content. People can also reduce cardiac oxidative stress, inflammation and avoiding CVD risk by adding camellia oil in their diet (Lee and Yen 2006; Lee, Shih, Hsu and Yen 2007).

Virgin coconut oil (VCO) is obtained from fresh and ripe coconut milk (*Cocos nucifera* L.), a tropical palm species belonging to the Arecaceae (palm) family (Marina et al. 2009). VCO is mostly consumed in many areas such as baby food, cooking, baking, confectionery and cosmetics. It is an oil used in cosmetics for beautification, moisturizing of the skin, and growth of feathers and hair. It is also used in the preparation of food supplements with beneficial additives on health, as it contains medium-chain fatty acids (MCFA). Thanks to MCFAs, such as lauric, palmitic, myristic, stearic, capric, oleic and linoleic acids, they are also easily digestible (DebMandal and Mandal, 2011). It is also stated that lauric acid, especially in VCO, has a potential effect to prevent obesity (Assunção et al. 2009; Nevin and Rajamohan, 2004; St-Onge and Jones, 2002). Besides, these MCFAs have some special functional and nutritional properties such as antiviral, antiprotozoal, antibacterial, anti-inflammatory, antiplaque, healing, and anti-obesity effects (German and Dillard 2004; Krishna et al. 2010; Ghani et al. 2018). It has been found that with its antioxidant potential, it reduces total lipids, LDL in serum and lipid peroxidation in tissues (Nevin and Rajamohan 2008). Some studies have reported that altering the cis unsaturated configuration of coconut oil changes blood lipid profiles and decreases CVS risk factors (Eyres et al. 2016). In animal experiments, their antioxidant effects showed positive improvements on oxidative stress, providing protective benefits and regulating the bioavailability of nitric oxide (Munshi et al. 2014; Ganesan et al. 2018).

Corn oil has a high nutritional value as it is the best source of polyunsaturated fatty acids such as linoleic acid (18:2) (St-Onge and Travers 2016; Maszewska et al. 2018a). Composition of corn oil covers linoleic (60.60%), palmitoleic (11.67%), oleic (25.16%), stearic (1.85%), linolenic (0.48%) and arachidic acids (0.24%) (Marchetti 2012). It consists of saturated and unsaturated fatty acids. It is also rich in carotenoids and tocopherols (Dauqan et al. 2011). Corn oil intake can replace SMAs with PUFAs, and these combinations have a powerful effect on lowering blood cholesterol levels. PUFAs contained in corn oil greatly reduce the atherogenic LDL-C. In addition, PUFA normally increases the ratio of LDL-C to HDL-C, thus reducing the risk of CVD (Maki et al. 2017; Ganesan et al. 2018). The by-product of corn used in starch and ethanol production is corn oil.

Another potential source of edible oil is rice bran (RBO). The demand for rice bran oil, which is not very popular, is increasing every day due to its health benefits. It contains 15-20% oil depending on the milling process, variety, agricultural and climatic conditions (Lima et al. 2002). Rice bran oil, the raw material of an ancient Asian cuisine, has excellent hypocolemic and anti-inflammatory properties (Ausman et al. 2005). Besides, rice bran oil has high levels of health-promoting compounds, which attracts the attention of consumers. Rice bran oil is one of the most valuable and healthy oils because it contains many nutritional components including vitamin B complex, c-oryzanol, vitamin K and E (a-tocopherol and a-tocotrienol) and protein. C-oryzanol is an important component of rice bran oil and has biological and physiological effects such as anti-oxidation, lowering serum cholesterol, weak tumor inflammation, and anti-carcinogenic effects (Nagasaka et al. 2011; Nagasaki et al. 2008; Yasui et al. 2004; Khoei and Chekin 2016). Linoleic (28-42%), oleic (40-50%) and palmitic (16-21%) acids are the dominant fatty acids in rice bran oil (Khatoon and Gopalakrishna 2004; Chotimarkorn and Silalai 2008; Maszewska et al. 2018a).

Peony (*Paeonia suffruticosa* Andr.) is one of the native tree species of China that grows widely in many countries. Peony, whose flowers are of decorative value, is widely used in traditional Chinese medicine and is also used as a functional food in the food industry due to its various bioactive components (Ning et al. 2015; Zhang et al. 2019). Peony seed oil has potent anti-α-glucosidase activity, low blood sugar, and hepatic lipid accumulation in vitro in STZ-induced diabetic mice. With these effects, although it is a new research subject in China, its market share is rapidly expanding (Su et al. 2015; Cui et al. 2017). Many studies have emphasized that *P. suffruticosa* different solvent extracts of bud and essential oils have antimicrobial activity against food-based pathogen bacteria (Han and Bhat 2014; Wang et al. 2004; Qu et al. 2017).

Peanut oil contains oleic, palmitic and linoleic fatty acids. However, it also includes small amounts of eicosanoic, stearic, behenic, arachidic and lignoceric acids (Carrín and Carelli 2010). Due to their high content of unsaturated fatty acids, they are sensitive to oxidation and cause unwanted changes in taste and color (de Camargo et al. 2016; Maszewska et al. 2018a). When fat profiles are examined, they have 80% short chain unsaturated fatty acids and 20% SFA. In peanut oil, FFAs are found in a percentage of 0.02%-0.6% (Akhtar et al. 2014).

Peanut oil contains a resveratrol bioactive compound that inhibits lipopolysaccharide (LPS)-induced nitric oxide (NO) production and thus demonstrates effective anti-inflammatory and chemopreventive activities in experimental animals (Kang et al. 2010). It is known that diet consumption with a large amount of this oil has a protective effect against breast cancer and CVD diseases (Comba et al. 2010; Ganesan et al. 2018). Asia provides approximately 64% of peanut production in the world. Considering the very low SFA content of this oil, its stability, and its high smoke point, it can be proposed that is more suitable for consumption by frying (Comba et al. 2010). Some in vitro and in vivo studies have shown us that peanut oil provides a beneficial effect in type II diabetes and inactivates the effects of inflammatory cytokines observed in obesity and non-insulin-dependent (type II) diabetes mellitus (Vassiliou et al. 2009).

Fish oil is considered as a nutritional product because it meets most of the nutritional elements we need for our health (Merkle et al. 2017). Fish oils are the main source of polyunsaturated fatty acids (PUFAs) such as eicosapentaenoic acid and docosahexaenoic acid, which have desirable health effects (Morais et al. 2012; Pawełczyk et al. 2015; Song et al. 2018). Fish oil supplementation lowers blood triglyceride levels in patients with hypertriglyceridemia by reducing the production of triglycerides from nonesters of fatty acids as a number of cardiovascular biomarkers (Shearer et al. 2012).

Palm oil (PO) is rich in antioxidants such as tocopherols and tocotrienols, which have protective effects against oxidative stress in biological systems (Marangino et al. 2017). The fatty acid composition of palm oil is extremely important in terms of both biochemistry and human metabolism. It is the second most abundant vegetable oil in the world (Ochang et al. 2007). The production of vegetable oils such as palm oil is aimed to exceed 30% by 2020, especially with the desire of developing countries to supply (Ng et al. 2006). Palm oil accounts for approximately 28.3% and 23.4% of the global production of vegetable and all commercial oils and fats, respectively. It can be an alternative to fish oil. The oil composition obtained from palm seeds contains saturated fatty acids and palmitic acid, which constitutes approximately 35% of total fatty acids. It contains a small amount of capric, caprylic and lauric fatty acids. It also includes oleic acid 39% of monounsaturated fatty acids and more than 10% of omega-6 polyunsaturated linoleic acids (Sambanthamurthi et al. 2000). Crude palm oil, which is red in color, is also rich in alpha and beta carotenoids (Bonnie and Choo 2000).

Sacha inchi (*Plukenetia volubilis* L.) belongs to the Euphorbiaceae family and is known as sacha nuts, Inca nuts, mountain nuts or Inca peanuts (Follegatti-Romero et al. 2009; Guillén et al. 2003). Sacha inchi oil is a vegetable oil such as olive, wheat germ, rice bran, avocado and argan oils. It has many beneficial physicochemical and sensory properties (taste and aroma). Our metabolism cannot synthesize linoleic acid and alpha linolenic acid, which are essential fatty acids beneficial for our health (Gutiérrez et al. 2011; Maurer et al. 2012; de Souza et al. 2013; Zanqui et al. 2016). Alpha linolenic acid (ALA) can be turned into eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids and thus used as an alternative to fish oil (Valenzuela et al. 2014; Calder and Yaqoob 2009). The advantage of this oil is that it does not have a fishy taste (Wang et al. 2018). In sacha inchi oil, the main components of the triacylglycerol fraction (50%) are dilinoleoyl-linolenoylglycerol (LLLn), dilinolenoyl linoleoylglycerol (LnLLn), trilinolene (LnLnLn), and c-tocopherol with the highest amount of tocopherols and d-tocopherol (Ramos-Escudero et al. 2019).

Olive oil is a valuable nutrient containing both high levels of monounsaturated fatty acids and small components with biological properties (Covas et al. 2006). It consists mainly of fatty acids. Due to the high content of fatty acids in the olive oil profile, it has also provided beneficial effects on our health for years (Chiou and Kalogeropoulos 2017; Wani et al. 2018). Polyphenolic compounds, which are particularly abundant in plants, have multiple biological effects, including antimicrobial activity. Olives also contain many physiologically active polyphenols compounds (Altiok et al. 2008; Fleming et al. 1973; Korukoglu et al. 2004; Tuck and Hayball 2002; Markin et al. 2003; Soler-Rivas et al. 2000; Ayana and Turhan 2009). Most studies have emphasized that olive oil and its phenolic compounds have anti-inflammatory and antioxidant mechanisms (Visioli 2012; Martin-Pelaez et al. 2013; Parkinson and Cicerale 2016;

Martinez-Huelamo et al. 2017; Guasch-Ferre et al. 2017; Crespo et al. 2018).

Tea tree oil is obtained from the leaves of *Melaleuca alternifolia*, which belongs to the Myrtaceae family, by distillation method. This herb is native to Australia and its oil is generally recognized as Australian tea tree oil. It gives a feeling of coldness with its sharp camphor smell and compounds such as menthol (SCCP, 2008; Larson and Jacob, 2012; Hammer, 2015; Yadav et al. 2017). Tea tree oil contains most common chemical compounds such as α-Pinene, α-phellandrene, myrcene, β-pinene, sabinene, p-cymene, terpinen-4-ol, 1,8-cineole, linalool, α-terpinene, limonene and α-terpineol (de Groot and Schmidt, 2016). This oil has antifungal, antiviral and antiseptic properties and is mostly used in medicine and cosmetic fields (Bassett et al. 1990; Nenoff et al. 1996; Satchell et al. 2002; Dryden et al. 2004; Larson and Jacob 2012). Tea tree oil has clinical applications, especially in the inactivation of methicillin-resistant *Staphylococcus aureus* (MRSA) carriers or as a hand disinfectant to prevent cross contamination with Gram-positive, Gram-negative pathogenic organisms (May 2000; Mumu and Hossain 2018).

Flaxseed (*Linum usitatissimum* L.) has been used in both industrial and natural health products since ancient times (Jangale et al. 2016). Flaxseed oil is obtained from an important this seed grown all over the world. It contains 50-55% of the total fat, omega-3-fatty acid, also known as α-linolenic acid. It is one of the most preferred oilseeds due to its high ALA content in the preparation of functional foods (Bloedon and Szapary 2004). However, it also contains vitamins, minerals, selenium and cyclodipeptides such as linoleic acid, phenolic compounds, phytic acid, lignans (phytoestrogens), cyclic peptides, alkaloids, polysaccharides and cyanogenic glycosides (Matsumoto et al. 2002). It also slows the progression of diabetic nephropathy associated with inflammation, glycation, and oxidative stress in the liver and kidney. For this reason, it is known that flaxseed oil provides therapeutic effect on type II diabetes by regulating the lipid profiles that are effective (Devarshi et al. 2013; Ganesan et al. 2018). Flaxseed has limited use in the food industry because it does not mix well in water and is sensitive to oxidation. However, it is used in the preparation of feeds in order to protect the reproductive performance and health of animals (Turner et al. 2014).

Citrus essential oils, which are widely used in cosmetics, food and pharmaceutical applications, are obtained mostly from the fruit peel (flavedo) as well as the flowers and leaves (Tranchida et al. 2012; Palazzolo et al. 2013; Md Othman et al. 2016). In addition, since citrus essential oils are considered safe in various foods and beverages, they have a very common use as a natural food additive (Tisserand and Young 2014). However, citrus EOs have biological activity including antimicrobial and antioxidant effects and are used as natural preservatives (Mitropoulou et al. 2017; Dosoky and Setzer 2018). It contains volatile and semi-volatile compounds that meet 85-99% of the total oil fractions (Dugo and Mondello 2010; Tranchida et al. 2012; Sarrou et al. 2013) over 200 compounds (González-Mas et al. 2019).

Soybean oil, derived from a vegetable product, is available all over the world. It is generally composed of triglycet linked by a glycerol with each fatty acid containing 14-22 carbons with 0-3 double bonds (Khot et al. 2001). When we examine the fatty acids profile of soybean oil, it consists of saturated fatty acids such as myristic, lauric, palmitic, stearic and unsaturated fatty acids such as oleic, linoleic and linolenic (Gupta et al. 2014). The oxidative degradation of soybean oil causes bitterness and loss of taste in food products, while in biodiesel derived from soybeans, it causes the accumulation of viscous compounds that block the oil filters (Canakci et al. 1999; Clemente and Cahoon 2009). Soybean oil is widely used in processed products, margarines, salad dressings and snacks. Most food businesses prefer to use soybean oil for its flavor (Roccisano and Henneberg 2011).

Sunflower seed oil is a non-volatile oil obtained by grinding sunflower seeds (*Helianthus annuus*). It constitutes 30% of the edible oils consumed in the world. Its seeds have high PUFA (linoleic acid), MUFA (oleic acid) content, low trans-fat, and SFA content (Arshad and Amjad 2012). Animal studies have shown that linoleic and oleic acids act as cardioprotective agents, reduce the incidence of reperfusion-induced ventricular fibrillation and myocardial ischemia, reduce the occurrence of life-threatening arrhythmias (Knittel et al. 2016; Mahmmoud and Christensen 2011; Ganesan et al. 2018). Sunflower oil is used in the preparation of edible and confectionery products. Commercial cooking oil (high linoleic), margarine and industrial oil (paint etc.) are produced from the same sunflower seed varieties. In addition, this oil with a high content of oleic acid is used for gasoline, cosmetic and other purposes. Edible oils from plant sources are important for food and other industries areas (e.g. cosmetics, pharmaceutical, lubricants) (Alibe and Inuwa 2012).

Cloves (*Eugenia caryophyllata* Thunb.) are widely grown in Madagascar, Indonesia, Sri Lanka and southern China (Bureau of Drug Administration of China 1989). It is one of the medicinal plants widely used in alternative medicine in some countries due to its pharmacological effects. Clove oil is used as a general antiseptic, antispasmodic and analgesic agent in dental treatment applications (Marchesea et al. 2017) including rheumatoid arthritis, warts, acne, asthma, scarring, and various allergies. It has strong biological and antimicrobial activity due to its high eugenol content. This phenolic compound changes the cell permeability of cell membrane phospholipids and causes denaturing of proteins (Briozzo 1989; Deans and Ritchie 1987; Wenqiang et al., 2007). Clove oil, which is used orally in Korea, has been used successfully against asthma and various allergic disorders (Kim et al. 1998; Guan et al. 2007).

There are around 350 species of thymus around the world, 16 of which grow in the Alborz and Zagros mountains of Iran (Tavakolpour et al. 2017). Thymol is found in the essential oil of different plants such as *Thymus vulgaris* L. (Laminaceae), *Monarda didyma* L. (Laminaceae), and *Monarda fistulosa* L. (Laminaceae) (Reddy et al. 1998; Johnson et al. 1998; Savickiene et al. 2002; Zarrini et al. 2010). Thymol, commonly used in soft drinks and confectionery, is present in thyme essential oil and essential oils (0.1% to 0.05%) of mandarin and tangerine (Falcone et al. 2005). Thymol has more inhibitory activity against a wide range of pathogenic bacteria including *Listeria monocytogenes*, *Salmonella typhimurium*, *Escherichia coli* and *Staphylococcus aureus*, while carvacrol has more inhibitory activity against pathogenic bacteria such as *L. monocytogenes*, *E. coli*, *S. typhimurium* and *Bacillus cereus* (Gaysinsky et al. 2007; Moraes-Lovison et al. 2017).

Oregano (*Origanum vulgare*) is a perennial herb native to the Mediterranean. At the same time, 43 species of the *Origanum* genus are widely used in spices and traditional medicine (Yin et al. 2012). Thyme is one of the most preferred spices in the world because of it contains high essential oil that can provide the desired flavor in traditional dishes. According to Ietswaart (1980) glandulosum subsp. (Desfontaines), vulgare L. subsp., *O. vulgare* (gracile subsp. (Kock), Virens subsp. (*Hoffmann segg* et Link), hirtum subsp. (Link) and viride subsp. (Boissier) Hayek has 6 subspecies (Verma et al. 2010). Three common subspecies grow in Iran, known as virid, coarse and graceful, which are defined by their differences in morphology. The essential oil obtained from this species is also used as medicine by the public with its antimutagenic, antimicrobial and antioxidative activities (Bakkali et al. 2008; De Martino et al. 2009; Hashemi et al. 2017).

Peppermint essential oil which extracted from the root, flowers and stem of the plant is used to treat various ailments such as headache, irritable bowel syndrome (IBS) and non-ulcer dyspepsia (Kligler and Chaudary 2007). Mentha, known as the monocyclic terpene alcohol found naturally in plants, is the main component of Mentha plants such as *Mentha piperita*, peppermint oil *Mentha arvensis*, and corn oil (Ahijevych and Garrett 2004). Menthol (29%) and menthone (20-30%) constitute the two main components of peppermint essential oil (Meamarbashi and Rajabi 2013). Generally, peppermint oil is preferred to be used in diseases such as indigestion, nausea, fever, vomiting, bloating, liver problems, headache, migraine and arthritis. It stimulates the nervous system to lower body temperature in high fever or hot weather. It is a powerful breath freshener and digestive aid. Mint, which has a strong antispasmodic effect, is used for massage in physical activity injuries (Sustrikova and Salamon 2004).

Cinnamon is a tree belonging to the *Cinnamomum* genus, which consists of about 250 species, from the Lauraceae family. Cinnamon is one of the traditional medicinal herbs commonly found in China, India, and Australia (Jayaprakasha et al. 2003). Having unique properties, cinnamon is often used for medicinal purposes. The essential oil obtained from the bark is rich with trans-cinnamaldehyde, which has an antimicrobial effect against animal and plant pathogens, food poisoning and spoiling bacteria and fungi (Faix et al. 2009; Wong et al. 2014).

Cinnamon oil is a volatile compound produced from *Cinnamomum zeylanicum* leaf, bark and root. It contains three important compounds such as eugenol, trans-cinnamaldehyde and linalool (derived from the bark extract), which make up 82.5% of the total composition. The most active compound of cinnamaldehyde, which has a potential growth inhibitory effect on gram negative, gram positive bacteria and fungi, is their EOs (Ramage et al. 2012; Pereira et al. 2015; Bhavaniramya et al. 2019).

Rapeseed oil is an important source of vegetable oil in the world. It is the third oil after palm and soybean oil with a production of approximately 27.71 million metric tons, according to 2018 official data of the United States Department of Agriculture (Wu et al. 2019). Rapeseed oil contains more linolenic acid (10-13%) than other oils (Kim et al. 2010; Christopoulou et al. 2004). In other oils, the percentage of this valuable acid is low (0-2%) (Ong and Goh 2002; Kim et al. 2010; Bakota et al. 2014; Bakota et al. 2015; Idrus et al. 2017; Maszewska et al. 2018).

In addition, it also contains about 20-26% linoleic acid in its composition (Fasina et al. 2008). The advantages of this oil include having the best ratio of n-6 to n-3 fatty acids that meeting optimal nutritional recommendations (close to two to one) and a small amount of saturated fatty acids (among popular vegetable oils) (Roszkowska et al. 2015; Marciniak-Lukasiak and Zbikowska 2013; Maszewska et al. 2018a). However, the oil is a rich source of natural antioxidants, including polyphenols, tocopherols, and phytosterols (Scarth and McVetty 1999; Maszewska et al. 2018b). Another advantage of rapeseed oil has higher stanol and tocopherol content than olive, soybean and other vegetable oils (Nydahl et al. 1995; Heggen et al. 2010; Ghobadi et al. 2019).

Patchouli essential oil (PEO) is extracted from *Pogostemon cablin* (Blanco) Benth. (Lamiaceae) by steam distillation or hydrodistillation of dried leaves. This oil, which has a unique woody scent, is used in cosmetics as an indispensable component of most women's and men's perfumes (Anonis 2007). It is mainly shared that “perfumery is one of the most important ingredients” (Haarmann and Reimer 1985; van Beek and Joulain 2018). PEOs have antimicrobial activity and hydrophobic nature. For this reason, it is used in food packaging to increase the shelf life of food products (Mohsin et al. 2017).

Lavender (*Lavandula dentata* L.) belongs to the Lamiaceae family and grows native to the Mediterranean region. Natural hybrid "lavandin" (*L. x intermedia*) and lavender (*L. angustifolia*) are the most produced species and oil is obtained from fresh flowers with a rate of 1.0-1.5% and dried flowers as 5.0-6.0% (Kara and Baydar 2012; Silva et al. 2017). It is cultivated throughout the world for ornamental and decorative purposes in addition to its economic and therapeutic properties (González- Coloma et al. 2011; Touati et al. 2011). It has been determined that lavender essential oil has significant clinical effects on the central nervous system (anticovulsant, analgesic, anxiolytic, sedative, local anesthetic activity) and also antimicrobial, anti-inflammatory, spasmolytic, antioxidant, and carminative properties (Hassiotis et al. 2010). Due to their content in essential oils (EOS), Lavandula species is one of the most aromatic and medicinal plants of great economic value for the aromatherapy, food and flavor industries, perfumery, cosmetics, and pharmaceutical (Zuzarte et al. 2009).

The essential oil obtained from *Citrus aurantium* flowers is called neroli. Neroli oil is produced in many countries. The best and most expensive of neroli oil are produced in Algeria, Morocco, Egypt, France, Spain and Tunisia (Haj Ammar et al. 2012). Neroli, a non-toxic plant material, has been used in traditional medicine for different purposes for years. The U.S. Food and Drug Administration (FDA) consider Neroli essential oil safe for consumption (GRAS) (Tisserand and Balacs 1995; Khodabakhsh et al. 2015). Neroli oil has many therapeutic properties such as soothing, calming, tonie, cytophylactic, aphrodisiac, anti-depressant and antispasmodic (Jeannot et al. 2005). Neroli essential oil that is produced from the flower of *Citrus aurantium* var amara L. also known as bitter orange. It is an extremely expensive essential oil because 850 kg of bitter orange blossoms are required to produce 1 kg of oil (Sarkic and Stappen 2018).

Chia seed contains about 0.32 g oil/g seed 0.28 g of fibres/g seed 0.21 g protein/g of seed, and 0.05 g ash/g seed and chia oil (about 0.6 g/g oil of a-linolenic acid) (Ayerza and Coates 2004). Chia seed oil (CSO) has a high content of essential fatty acids (EFAs), a-linolenic acid (ALA) and linoleic acid (LA). These two EFAs make up more than 80% of the fatty acid composition, making CSO one of the healthiest fats (Segura-Campos et al. 2014). The composition of monounsaturated fatty acids such as oleic acid or saturated fatty acids such as palmitic and stearic in chia seeds varies by 2.9%-16.2%, 6.5%-7.5% and 0.3-3.0%, respectively (Timilsena et al. 2017). Polyunsaturated fatty acids (PUFAs) play an important role in the prevention or treatment of non-communicable diseases (NCDs), also known as chronic diseases such as cancer, hypertension, diabetes, and coronary artery disease (Ferereidoon 2009; Poudyal et al. 2012; Bodoira et al. 2017). However, the antioxidant capacity of this oil is relatively low because the phenolic compounds found in the seed owing to mostly hydrophilic in nature (da Silva Marineli et al. 2014).

One of the most popular and widely used medicinal plants all over the world is rose (Family Rosaceae). Although it is known to be of Middle Eastern origin, it is grown all over the world (Krussman, 1981). Today this essential oil produce most countries such as Turkey, Bulgaria and Morocco. This oil is semi-solid, pale, yellow and very expensive (Baydar 2005). Rose oil compounds are glycosides, terpenes, flavonoids and anthocyanins (Almasirad et al. 2007; Knapp et al. 1998; Schiber et al. 2005; Mohebitabar et al. 2017). Rose oil, rose water and concentrated rose are among the most important raw materials of the cosmetics industry. 3500-4000 kilograms of rose flower is required to produce 1 kg of rose oil. Because of its expensive industrial production and its importance in the cosmetics industry, rose oil is often referred to as "liquid gold" (Mohamadi et al. 2013).

Safflower oil is used in Korea as a condiment oil with red pepper, sesame and perillar oils (Kim et al. 1998; Yoshida and Takagi 1997; Lee et al. 2004). Traditionally, this seasoning oil is produced by extracting the seeds by applying a mechanical press expeller after roasting at suitable temperatures. Various studies conducted recently include the positive effects of safflower oil on health (Shimomura et al. 1990). It has a balanced fatty acid profile in its oil and has been found to reduce fat accumulation in rats compared to the beef tallow diet. In addition, clinical studies have shown us that the conjugated linoleic acid in its oil effectively reduces body weight (Norris et al. 2009). It has also been stated that safflower oil is effective in oil-induced insulin resistance (Neschen et al. 2002; Khalid et al. 2017).

Immortelle EO (*Helichrysum italicum* (Roth) G. Don) is very popular in traditional medicine (used as expectorant, diuretic and choleretic) besides having antimicrobial activity (Djihane et al. 2017). This essential oil is used successfully in inflammatory conditions, scars and allergies (Viegas et al. 2014; Odak et al. 2018). In addition, its antiproliferative effect has also been proven on human dermal fibroblasts (Han et al. 2017; Mesic et al. 2021). This essential oil has a strong honey-like aroma and is an oily liquid ranging from pale green color to red. *H. italicum* (Roth) G. Don's flower does not fade and its flowers are known to retain their color even when picked and dried.

Hence, the name "Immortelle" is used as immortal. In Europe, this oil is mostly consumed as a tea to treat respiratory infections such as asthma and chronic bronchitis, and has also been used to treat migraines, headaches, allergic conditions and skin burns (Sarkic and Stappen 2018).

9. USAGE AREAS IN FOOD INDUSTRY

In our rapidly developing world, consumer expectations are constantly changing in the light of new technologies used in the food industry. They prefer foods that are microbially safer, have a long shelf life, have high appeal, higher quality, organic and do not contain additives (Yangılar and Kabil 2013). For this purpose, the use of essential substances that are considered natural in food production has become more prominent in recent years (Buchbauer 2000; Dhakad et al. 2018). In addition, since years ago, EOs have been used in oral care products without any negative effects due to their medicinal properties, food preservation, perfumery, aromatherapy, spice and therapeutic properties (Anastasiou and Buchbauer 2017; Chen et al. 2017; Yang et al. 2019). EOs have a variety of immunomodulatory properties. To date, limited studies have been conducted on the immunomodulatory effects of EOs. It has been reported that monoterpenes show a strong immunobiological effect with their effects on thromboxane, leukotriene production and tumor necrosis factor (TNF)-interleukins (ILs) (Andrade and De Sousa 2013). This immunomodulatory activity also provides an opportunity to use EOS as a component in functional foods (Valdivieso-Ugarte et al. 2019). While the food industry fulfills the demands of consumers for quality food expectations without increasing the sensory and nutritional costs, on the other hand, by reducing the use of synthetic preservatives, it ensures the production of foods in a more reliable way for the consumer.

Fungi can develop as unpalatable or unsafe in various foods, causing undesirable taste in foods, acidity, fermentation, discoloration, breakdown, rotting and nutritional losses due to the formation of pathogenic or allergenic toxins (Filtenborg et al. 1996; Pitt and Hocking 2009). For centuries, herbs and spices have been used in food preservation, but a new area of research has emerged mostly in the last two years (Kalemba and Kunicka 2003). It was emphasized that some compounds that contain more antimicrobial properties than their own essential oils (Burt 2004; Friedman et al. 2002; López et al. 2007). For this reason, bioactive compounds obtained from essential oils are used in order to reduce the additives to be used for antimicrobial activity. In addition, many independent components of essential oils are categorized by the European Commission as flavoring agents and are generally considered safe (GRAS) by the United States Food and Drug Administration (FDA) (Balaguer et al. 2013).

Essential oils are also widely used in the food industry as antimicrobial food packaging. The use of antimicrobial agents prevents the development of pathogenic and spoilage microorganisms and extends the shelf life of fresh and packaged foods (Franssen et al. 2004). Despite advances in food security, foodborne diseases continue to be common worldwide and pose a growing threat to global public health. Essential oils, known for their antimicrobial and antioxidant activities, are widely used in the food industry (Bakkali et al. 2008; Calo et al. 2015; Falowo et al. 2014; Jayasena and Jo 2013; Sanches-Silva et al. 2014; Silva and Domingues 2017; Duarte et al. 2016). Some studies have reported that the use of essential oils extends the shelf life of fish and meat. Especially, they been reported to have effects lemon EOs on salted sardines (Alfonzo et al. 2017), chitosan coatings enriched with cinnamon oil on rainbow trout (*Oncorhynchus mykiss*), thyme oil on poultry meat, and clove, cumin and mint oils on red sea bass (Huang et al. 2017; Valdivieso-Ugarte et al. 2019).

In recent years, studies have been carried out to use new packaging techniques that can prevent microbial proliferation or sensory property change in the preservation of food in the storage process (Imran et al. 2010). Antimicrobial food packaging is an active packaging process in which natural antimicrobial substances are used as packaging material in order to eliminate undesirable changes in the quality of foods (Sung et al. 2013). Smart packaging is prepared from a variety of materials that keep track of the packaged food or the surrounding environment. It detects environmental changes such as temperature and pH of the food or its surroundings, thus improving the functionality of traditionally used packaging materials (Realini and Marcos 2014; Sharma et al. 2021). Generally, the US Food and Drug Administration have recognized natural extracts of EOs as safe for food safety. They are more alternative compounds to synthetic antioxidants such as butylated hydroxytoluene (BHT) or butylated hydroxyaniol (BHA), which may have a carcinogenic effect in food preparation (Li et al. 2012). In addition, synthetic packaging film may create adverse effects on the environment due to its inability to biodegrade. Consumers' concerns about environmental protection have led manufacturers to increase research on biodegradable food packaging materials. Thus, biopolymers can form an alternative solution in the development of packaging materials due to their biodegradability (Fajardo et al. 2010). The most commonly used polymers, as active packaging materials are commercial synthetic petroleum-based ones that are not biodegradable. After the food products are consumed, the packaging material is discarded, but the accumulation of these non-biodegradable wastes causes environmental damage. To prevent this, natural polymers used in active packaging are biodegradable (Arfat et al. 2017). To achieve this, there is the use of essential oils, antimicrobial compounds and plant extracts by consumers as an alternative application of natural preservatives instead of synthetic preservatives (Bazargani-Gilani et al. 2015). Researchers found four essential oils (basil, clove, thyme, and casia oil) with high antimicrobial activity. This result is a promising application for packaging studies in food preparation.

Antimicrobial agents are applied to foods by different methods such as dipping, spraying or brushing to stop microbial growth. Due to the rapid loss of activity of the antimicrobial agents of this application, they provide limited benefits (Ture et al. 2011). Recently, the research community and food industry have shown increasing interest in active edible films that support antimicrobials in order to improve food safety and extend food shelf life due to their potential to reduce the rate of antimicrobial diffusion from the surface to the bulk of the product. This process also allows the active ingredient to be protected and show its effect for a long time. One of the most important benefits is that edible films are seen as a good source in the development of packaging material due to their biodegradability properties (dos Santos Pires et al. 2008; Fajardo et al. 2010; Kristo et al. 2008; Ollé Resa et al. 2013; Ture et al. 2011; Ollé Resa et al. 2014). These films allow the controlled release of gases such as carbon dioxide, ethylene and oxygen, which are necessary for the respiration of foods, and thus create a natural fine structure to reduce aroma, moisture losses and prevent loss of solubility from the food surface (Embuscado and Huber 2009; Dehghani et al. 2018). Figure 5 shows the effects of edible films and coatings against environmental factors such as gas, steam, chemical, physical and biological (Salgado et al. 2015).

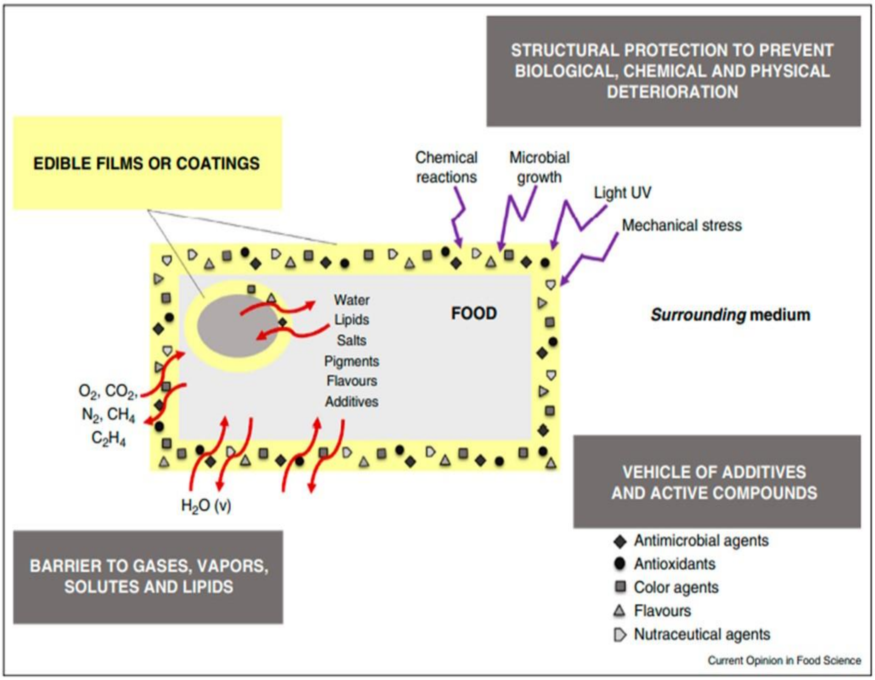


Figure 5. Functions of edible films and coatings

Among the coating methods, the dipping process is mostly recommended in laboratory applications due to its low cost, easy application and use on irregular food surfaces. In addition, the dipping method causes a high rate of coating material residue and the microbiological load in the application tank is also the negativity of this method (Andrade et al. 2012; Hirlekar et al. 2010). In addition, the continuity of production is included with process control (Karnjanolarn and McCarthy 2006). EOS consists of a thin layer of edible film coatings containing protein, lipids, modified starch and natural gum oil carrier biological polymers. This application both prevents the exchange of oxygen, carbon dioxide and water of the atmosphere surrounding the food and improves the decay times. It can be eaten with food or removed by washing. The methods of using EOs in foods are given in Figure 6 (Ju et al. 2019).

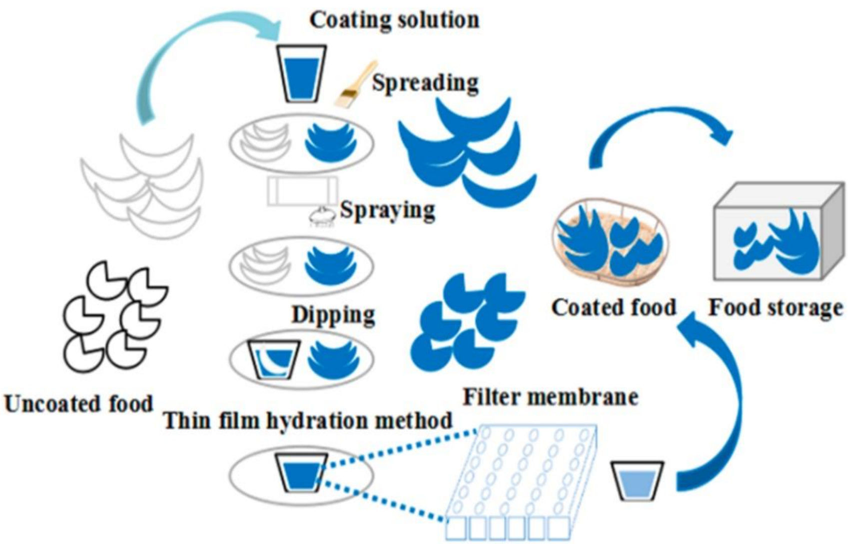


Figure 6. The methods of using EOs-edible coating in foods.

EOs can be used very easily in herbs and spicy foods. The synergistic effect between essential oils and the biological active compounds in the herb/spice and the concentration to be achieved for the desired biological effect will prevent the formation of undesirable changes in taste (Burt 2004). At the same time, this interaction can improve the bioactivity of edible films, especially in order to extend the shelf life of foods with high fat content. It has been used in last years because it has been accepted as an effective solution to achieve this. The concentrations that these oils should be used are very important and may cause changes in the sensory properties of the products and toxic problems (Sánchez-González et al. 2011; Al-Hashimi et al. 2020). When applied at a concentration of 0.05-0.1% of essential oils, it has been shown to be effective against pathogenic microorganisms (Tajkarimi et al. 2010). The basis of application actually depends on the food, its method, preparation processes and of course the sensory properties (Ghabraie et al. 2016).

We can share that the research of consumers and manufacturers on edible coatings also creates an increasing demand due to the environmental impact of non-biodegradable packaging material. EO edible coating material can be selected according to the purpose of use. For this, proteins, lipids and polysaccharides are preferred as coating materials (Donhowe and Fennema 1993; Pan et al. 2013). EO edible coatings prepared from these materials are successfully applied in food packaging. This is the reason why these coatings have been developed especially in recent years. Potential foods suggested for coating applications are given in Figure 7 (Ju et al. 2019).

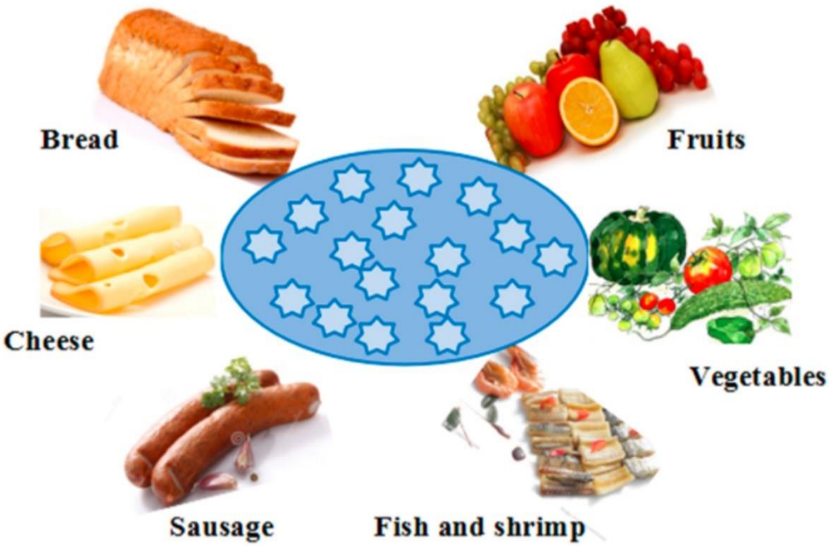


Figure 7. Potential foods recommended for edible coating applications

Encapsulation technique is one of the most effective methods for solving all problems that may arise with active food packaging applications or direct addition of EOs to foods. In the encapsulation process of foods, oil-based nanocarriers (nanostructured lipid carriers, nanoliposomes, nanoemulsions, solid lipid nanoparticles etc.) and nano/micro coating materials (polysaccharides, proteins or capsules prepared with their use) are used (Fathi et al. 2014; Hemmatkhah et al. 2020). In the encapsulation technique, the release management of the essential oil is made and antimicrobial activity is ensured when applied both directly and in the headspace of the package. In aqueous film dispersions of polymers, we can say that essential oils are first emulsified and then controlled drying process as one of the encapsulation process into polymer structure. Previous studies have reported that the casting method causes various losses in essential oil during film formation (Sánchez-González et al. 2011; Perdones et al. 2016). Current literature reviews have shown us that the best method of protecting the active compounds of essential oils from environmental parameters such as light, pH, oxygen and moisture in the encapsulation technique is microencapsulation. In addition, it is very important that the material to be coated is solid, liquid, gas, and the method to be used. For example, solid lipid microparticle application has been proposed in the encapsulation of juniper oil to prevent volatility of the antimicrobial compound (Gavini et al. 2005).

10. EXTRACTION METHODS

EOs extracted from plants are complex mixtures of volatile compounds and insoluble in water (Dima and Dima 2015). The production technique used to obtained essential oils depends on the components and the properties of the herbal extract (Aziz et al. 2018). Essential oils are produced from the roots, leaves, seeds, flowers and bark of the plant. Essential oils are unique and differ even in the same plants, also have a variety of applications (Butnariu and Sarac 2018). For example, the essential oil obtained from coriander seeds differs from that obtained from immature coriander (*Coriandrum sativum* L.) leaves.

Different extraction methods are used in essential oil production (Delaquis et al. 2002). Steam and hydrodistillation methods are used more than distillation methods in obtaining essential oil with traditional methods. In addition, microwave assisted hydrodistilation, ohmic assisted hydro distillation and supercritical liquid extraction methods are among the recent extraction techniques (Okoh et al. 2010). These traditional and newly developed methods are successfully used to extract essential oils from their sources. Researchers prefer steam distillation, solvent extraction or hydrodistillation method in the preparation of aromatic plant essential oils (Gavahian et al. 2011; Gavahian et al. 2012; Gavahian et al. 2015; Gavahiaen et al. 2017; Stratako and Koidis 2016; Hashemi et al. 2018; Pateiro et al. 2018). Because these methods are cheap, but some fragrance compounds can be damaged in heat treatment, dissolution and hydrolysis. Essential oils extracted with solvents may cause some residues in foods. All these negativities can be eliminated using the supercritical liquid extraction (SFE) process (Reverchon 1997; Khajeh et al. 2004; Wenqiang et al. 2007). In addition, with this method, the environment is not harmed in the processes of separating essential oils from plant raw materials. An advantage of this method is that the extracts obtained with SFE preserve their organoleptic properties at their source (Damjanović et al. 2005).

Extraction methods for essential oils especially used in food industry are given in Figure 8 (Pateiro et al. 2018). Widely used extraction method is steam distillation method (Figure 8a). According to Masango (2005), 93% of the extraction is obtained using steam distillation. In the beginning, the heating process is done with a generator that provides steam. Then the steam interacts only with the plant without coming into contact with the boiling water. The heat provided by the steam provides the structural changes of the plant material while allowing the essential oil to be released. In this process, the amount of wastewater decreases.

Another extraction method is the treatment of plant material in solvent such as ether, hexane, acetone and ethanol and slightly heating, filtration and finally solvent is evaporated. The mixture obtained in the filtering process is mixed with alcohol at a certain concentration to produce essential oil and distillation is carried out at low temperature (Tongnuanchan and Benjakul 2014). It is known that particle size, type of solvent used, temperature and agitation speed affect the solvent extraction rate in these methods. In the choice of solvent, it should be a good selective solvent and low viscosity is important (Atabani et al., 2012; Atabani et al., 2013; Keneni and Marchetti 2017).

The determination of the appropriate technique and method provides a significant effect on the preparation of an essential oil with the desired properties. The advances made everyday in technology have given the opportunity to apply new extraction techniques in addition to the known methods (Figure 8b; Asl et al. 2018; Hashemi et al. 2018). Another extraction method, which is most used in the production of essential oil found in different parts of plants and is more cost-effective, is the traditional hydro-distilation (HD) technique using the modified Clevenger apparatus (Figure 8c). In this method, the essential oil is collected in the vapor then condensed back into the liquid. The heat in this method can cause damage to some sensitive compounds, especially those with therapeutic properties. The volatile nature of essential oils is the reason why hydrodistillation is preferred for extraction. This ensures that the number of unwanted compounds is low and a much higher yield (Arora et al. 2016).

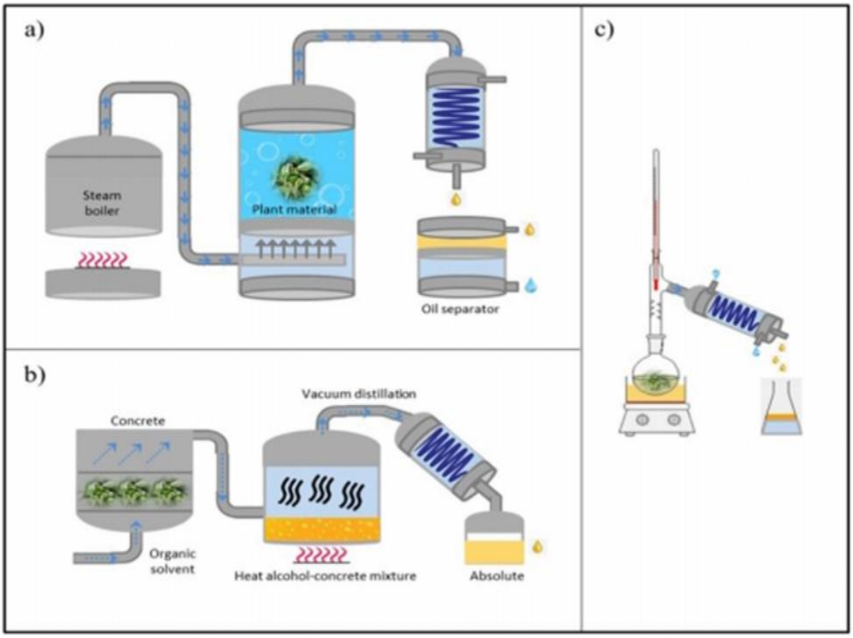


Figure 8. Main essential oils extraction methods used in food industry. **a)** Steam distillation, **b)** solvent extraction, **c)** hydrodistillation

The use of supercritical fluids (SF) in essential oil extraction has gained importance in recent years. It provides a fast and effective extraction, it is used at medium temperature and it does not need harmful organic solvents. Since it is non-explosive and non-toxic, carbon dioxide (CO_2) is the most suitable solvent for extraction and isolation processes (Pourmortazavi and Hajimirsadeghi 2007). Thus, the loss of thermolabile compounds and degradation of volatile compounds is prevented. The high molecular weight and coloring compounds (chlorophyll) are recovered together with the fragrance components due to the high-pressure application. For example, Gopalakrishnan et al. (1990) reported that when the extraction pressure increased from 10 MPa to 50 MPa at 40ºC, it caused an increase in the chlorophyll content in the collected extract (Wenqiang et al. 2007). This technique has the principle of working both off-line and on-line. Process information of off-line SFE is given in Figure 9a (Fornari et al. 2012; Yousefi et al. 2019). In this method, when using supercritical liquids as solvents, it can be shown that they have good dissolving properties, fast mass transfer, low viscosity and high diffusivity, together with a very fast extraction (Yamini et al. 2002). In addition, high quality extract production, lower extraction material cost, less solvent consumption (Herrero et al. 2006) and being an environmentally friendly method are among the advantages compared to traditional methods (Figure 9b; el Asbahani et al. 2015).

Vian et al. (2008), Microwave hydrodiffusion and gravity (MHG) technique has been designed as a new technique for essential oil extraction and is used as a green technique (Figure 9c). Apart from these techniques, ultrasound-assisted ohmic extraction (UAOE), ohmic extraction (OE) and ultrasound-assisted hydrodistilation (UAHD) methods are also used in essential oil production (Knirsch et al. 2010; Xu et al. 2011; Tavakolpour et al. 2017). When applied together with ultrasound hydro-distilation/solvent extraction methods, it accelerates the release of essential oils from the plant material and ensures that the extraction process is completed selectively and intensively. In this method, the plant material is treated in water and solvent and then exposed to the effect of ultrasound. This method is preferred mostly in the production of essential oil from the seed section (Assami et al. 2012; Sereshti et al. 2012; el Asbahani et al. 2015). Ultrasound has advantages such as shorter and more effective processes in terms of emulsification, sterilization, pasteurization, filtration, extraction, washing/cutting, freezing/thawing processes (Chemat et al. 2004). Another important aspect is that the extracts are carried out at a low temperature that can prevent thermal damage and minimize the loss of bioactive compounds (Figure 9d; Hromadkova et al. 1999; Zhang et al. 2008).

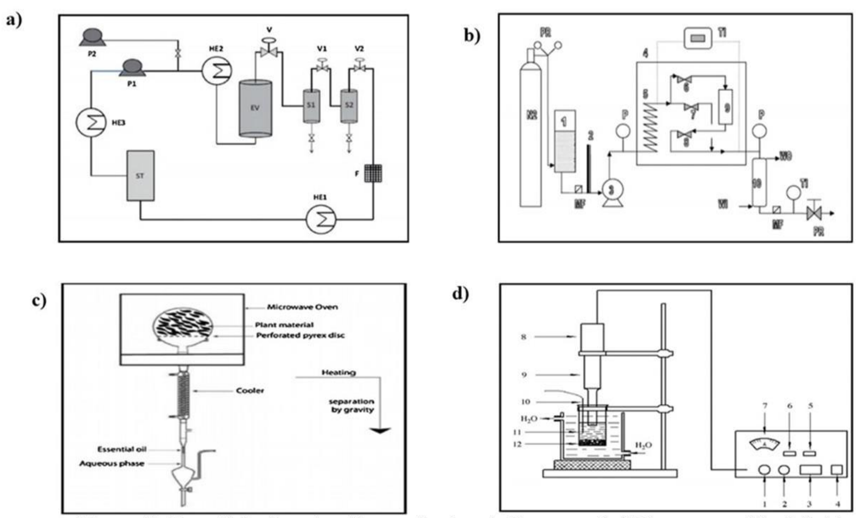


Figure 9. Essential oils extraction methods: **a)** diagram of off-line supercritical fluid extraction; **b)** diagram of subcritical water extraction system; **c)** diagram of microwave hydrodiffusion and gravity;**d)** diagram of the apparatus of the ultrasound-assisted extraction

In the solvent-free microwave extraction method (SFME) is a method works with a combination of dry distillation or microwave heating energy based on the principle of microwave dry distillation of the plant under atmospheric pressure without the use of organic solvents and water (Filly et al. 2014). SFME process is given in Figure 10 (Lucchesi et al. 2004a; Lucchesi et al. 2004b; Filly et al. 2014). Bousbia et al. (2009) reported that at least 60% of the initial moisture was designed for the extraction of volatile compounds from fresh plant material using a microwave dry diffusion and gravity process. The principle of this technique is that it works without the need to use any solvent/water since microwave is used as energy. The basis of the process is based on the warming of the water present in the fresh plant tissues and the occurrence of changes and disintegration in the cell structures and thus the fall of the sap by the effect of gravity (Farhat et al. 2010).

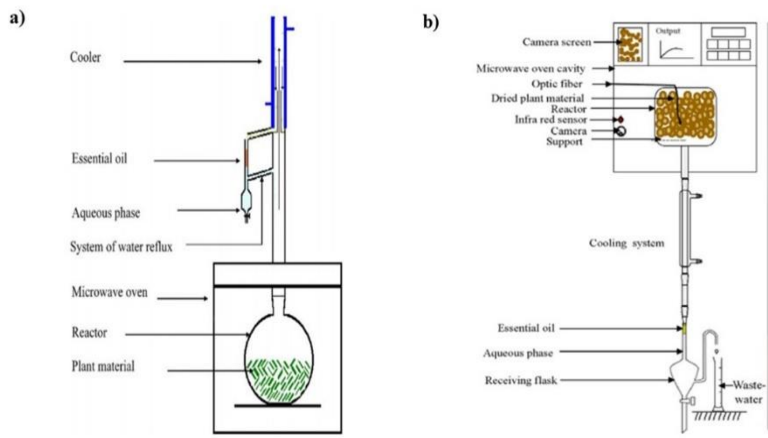


Figure 10. a) Solvent-free microwave extraction (SFME); **b)** Schematic diagram of Microwave dry-diffusion and gravity process.

Gas chromatography (GC) is a powerful separation technique. Since there is MS in GC-MS, it provides additional resolution power and thus the resolving power can be increased. Therefore, GC-MS is one of the major effective and important methods in the analysis of EOs. The general advantages of GC-MS are to identify separated components and analyse complex mixtures using low limits of detection or high precision mass spectra (Jalali-Heravi and Parastar 2011; Jalali-Heravi et al. 2011; Marriott et al. 2001; Sereshti et al. 2012).

11. CONCLUSIONS

EOs play important roles in product protection and food industry with their wide variety of applications. They are bioactive compounds suitable for active packaging because of their ability to prevent the growth of foodborne pathogens and protect food products. EOs and their compounds can be added to food or included in packaging. Natural additives such as EOs are substances with proven antioxidant capacity and antimicrobial properties and have been accepted as GRAS. It is a very important issue to standardize EOs so that they can be used without being biologically damaged. In addition, more studies should be conducted in addition to the existing information on EOs to evaluate their use for food purposes, their safety and the interactions between the food used in its preparation and the consumer.

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