Essential Oils Extracted from Medicinal Plants and Their Applications

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Contents

Abstract

Essential oils (EOs) are extracted from flowers, leaves, barks, roots, and fruits of the medicinal plants using hydrodistilation or steam distillation and continuous solvent extraction. EOs are mixture of chemical constituents which have less molecular weight substances, such as alcohols, polyphenols, terpenoids, carbonyl compounds, and aliphatic compounds which provide smell and possess

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biological properties. EOs have been used as folk medicine throughout the history. Nowadays, EOs are widely used as an alternative medicine in varied industries such as pharmaceutical, agricultural, sanitary, and food industries due to their antibacterial, antifungal, antiviral, antiparasitical, antidiabetic, anticancer (cytotoxic), insect repellent, food industry (flavoring), aromatherapy, antioxidant, perfume, and cosmetic properties. EOs have a great demand and interest as cosmetic and pharmaceutical substances. The isolation, identification, and characterization of major components of EOs have a premier significance. Individual compounds present in EOs mixture such as thymol, camphor, limonene, α-pinene, terpinolene, menthol, menthone, etc. exhibit wide-ranging biological properties. Commercially, still synthetic chemicals are widely used as biological activities than the EOs from the plants. However, EOs from natural sources are more effective and safe for human health and the environment compared to the synthetic chemicals. The aim of the present chapter is to discuss the specific chemical compounds occurring in EOs, their medical applications, and economic importance.

Keywords
Essential oils · Natural products · Antibacterial · Antifungal · Anticancer

9.1 Introduction

Essential oils (EOs) are obtained from aromatic and medicinal plants as a volatile mixture of chemical compounds with strong odor. EOs are extracted from the aromatic and medicinal plants using steam or hydrodistillation or Soxhlet extraction (solvent extraction or continuous extraction) methods developed in the middle ages by Arabs (Bakkali et al. 2008; Raut and Karuppayil 2014). EOs are considered as one of the most predominant plant products in agriculture, as they exhibit antifungal, antibacterial, antioxidant, anticancer, antidiabetic, antiviral, insect repellent, and anti-inflammatory properties (Buchbauer 2010; Teixeira et al. 2013; Raut and Karuppayil 2014; Said et al. 2016; Swamy et al. 2016).

Research on artificial pharmaceutical substances reveals the significance of EOs extracted from medicinal and aromatic plants, as their therapeutic properties have numerous applications. Consequently, researchers and farmers have been motivated to expand the cultivation and market these substances (Swamy and Sinniah 2015, 2016). Presently, about 100 herbs are known for their EOs, while more than 2000 herbs scattered across 60 families, such as Umbelliferae, Lamiaceae, Lauraceae, Myrtaceae, etc., could produce medicinally valued EOs. In global markets, only 300 among 3000 known types of EOs are deemed to be of commercial importance. EOs have found application in agricultural sectors and can be potentially used in other industries, such as pharmaceuticals, drugs, food, perfumes, makeup products, sanitary products, dentistry, food preservatives, additives, cosmetics, and natural remedies (Swamy et al. 2016; Mahmoudi 2017). EOs, in perfumes, creams, soaps, in flavor and fragrance for foods, sanitary products and industrial solvents

phytocompounds, such as limonene, patchoulol, geranyl acetate, etc., derived from have been widely used. Moreover, essential oil blends are used in bath products and in aromatherapy. Further, many EOs are particularly valued for their medicinal properties (Swamy and Sinniah 2015, 2016; Arumugam et al. 2016). For example, menthol EOs are used as natural bug repellent, as well as for treating joint pain, respiratory allergies, muscle pain, headache, hair growth, and fever relief, as well as in cancer treatment (menthol protects against cell death and DNA damage).

EOs or natural products are widely used as fragrances. However, their application in human health, agricultural industry, and environmental protection requires better understanding of their biological properties. Some of the EOs and their chemical constituents are viable as alternatives to the synthetic compounds, presently widely used in the chemical industry. This is because EOs are not associated with harmful side effects (Carson and Riley 2003). In nature, EOs play an important role in providing plant protection against pathogenic bacteria, viruses, and fungi and preventing the attack by insect pests. In addition, EOs can attract or repel insects when present in pollen and seeds. To protect chemical compounds' ecological equilibrium, the use of EOs in pharmaceutical, food, bactericidal, and fungicidal is becoming more prevalent in recent times. EOs yielding medicinal and aromatic plants are normally native to warm countries, where they represent an important traditional pharmacopeia (Arumugam et al. 2016). EOs are less dense than water. They are volatile and mostly colorless, as well as soluble in organic solvents. All plant parts, such as buds, leaves, fruits, bark, root, stems, twigs, and flowers, can contain EOs.

Different methods can be applied for essential oil extraction, such as hydrodistillation, steam distillation, and solvent extraction (including liquid carbon dioxide or microwave extraction). For example, hydrodistillation or steam distillation is typically used for Citrus and Lamiaceae family members. Various factors, such as the extraction method, geographical conditions, type of soil, plant material, and harvesting stage, are being reported to influence on the occurrence of number of chemical constituents in EOs and variations in EO quality and yield (Masotti et al. 2003; Angioni et al. 2006; Swamy and Sinniah 2015; Swamy et al. 2016). In order to ensure a constant chemical composition, quality, and quantity, EOs should be extracted under the same conditions, such as using same plant organs, extraction method, harvesting period or season, and growing plants in the same soil types. Many of the EOs are commercialized and chemotyped by gas chromatography mass spectrometry (GC-MS), and the results have been published in international organizations like the ISO, WHO, EP (European pharmacopoeia), and Council of Europe (Smith et al. 2005) to protect good grade and amount of EOs.

Apiaceae, Lamiaceae, Myrtaceae, Poaceae, and Rutaceae families are of particular importance for medicinal applications. For example, some of the EOs, like anise, caraway, black caraway, clove, oregano, cumin, coriander, sage, basil, dill, lemon balm, peppermint, thyme, and tea oils, already have widespread medicinal applications. Some of the essential oil containing plant families, like Liliaceae, Fabaceae, Pinaceae, Piperaceae, Cupressaceae, and Hypericaceae, also exhibit a considerable medicinal potential (Hammer and Carson 2011). The aim of the present chapter is to discuss the specific chemical compounds occurring in EOs, their medical applications, and economic importance.

9.2 Chemical Composition of Essential Oils

EOs are volatile liquids that are rarely colored. They are complex mixtures comprising of different concentrations, quantities, and compositions of 20–60 chemical components (Bakkali et al. 2008). Among these, two to three major chemical compounds are known to occur in prominent concentrations (20–70%), while other components are present in less concentration. For example, menthone (39.55%) and isopulegone (30.49%) are the major components of *Mentha longifolia* essential oil (Nagarjuna et al. 2017), while cinnamyl acetate (41.98%) is extracted from *Cinnamomum zeylanicum* Blume (Jayaprakash et al. 2000). Similarly, eugenol (86.02%) is obtained from *Cinnamomum verum* (Patel et al. 2013), whereas linalool (46.97%) and 1,8-cineole (14.97%) are the major components of *Ocimum basilicum* (Santoro et al. 2007a, b). Likewise, *Pogostemon cablin* essential oil possesses mainly the patchouli alcohol, also called as patchoulol (32–37%), a tricyclic sesquiterpene (Swamy and Sinniah 2015). While, the leaf essential oil of *Plectranthus amboinicus* is rich in carvacrol (43%), thymol (7%) (a phenolic monoterpenes) (Arumugam et al. 2016). Mainly, higher concentrations of chemical constituents govern the biological properties of the EOs. Most of the EOs also constitute low molecular weight chemical components, such as terpenes and terpenoids (Croteau et al. 2000; Betts 2001; Bowels 2003; Pichersky et al. 2006; Swamy and Sinniah 2015; Arumugam et al. 2016). Terpenes and terpenoids, along with other of aliphatic and aromatic chemical constituents, are shown in Fig. 9.1.

Terpenes are biosynthetically derived isoprene (2-methyl 1,3-butadiene) units. The molecular formula of isoprene unit is C_5H_8. Thus, the basic molecular formula of terpenes comprises of multiples of isoprene units, such as $(C_5H_8)n$, where n denotes the number of isoprene units. This is known as biogenetic rule or C_5 rule. The isopentenyl diphosphate (IPP) molecule has a major role in the terpenes biosynthesis. As chains of IPP units accumulate (acyclic or cyclic), the resulting terpenes are classified based on the size into hemiterpenes (C_5), monoterpenes (C_{10}), sesquiterpenes (C_{15}), diterpenes (C_{20}), triterpenes (C_{30}), and tetraterpenes (C_{40}). Terpene that is having oxygen is called oxygenated terpenoid. EOs consist of 90% monoterpene (a combination of two isoprene units) molecules, thus allowing for a variety of structures and functions. Sesquiterpenes are also present in EOs, but they are not like monoterpenes as main. Sesquiterpenes can also assume a variety of structures and functions, as shown in Table 9.1. When a chemical constituent is optically active, the two optical isomers are frequently obtained in various plants. For example, optical isomers of (+)-α-pinene and (−)-β-pinene can be obtained from *P. palustris* and *P. caribaea,* respectively, while optical isomers of linalool obtained (−)linalol is sourced from *C. sativum* and (+)linalool from a few *C. camphora* plants. Sometimes, a racemic mixture is also encountered, whereby (±)-citronellol is very common. In particular, (+) citronellol from *Eucalyptus citriodora* and the rose and geranium EOs (−) citronellol form is common.

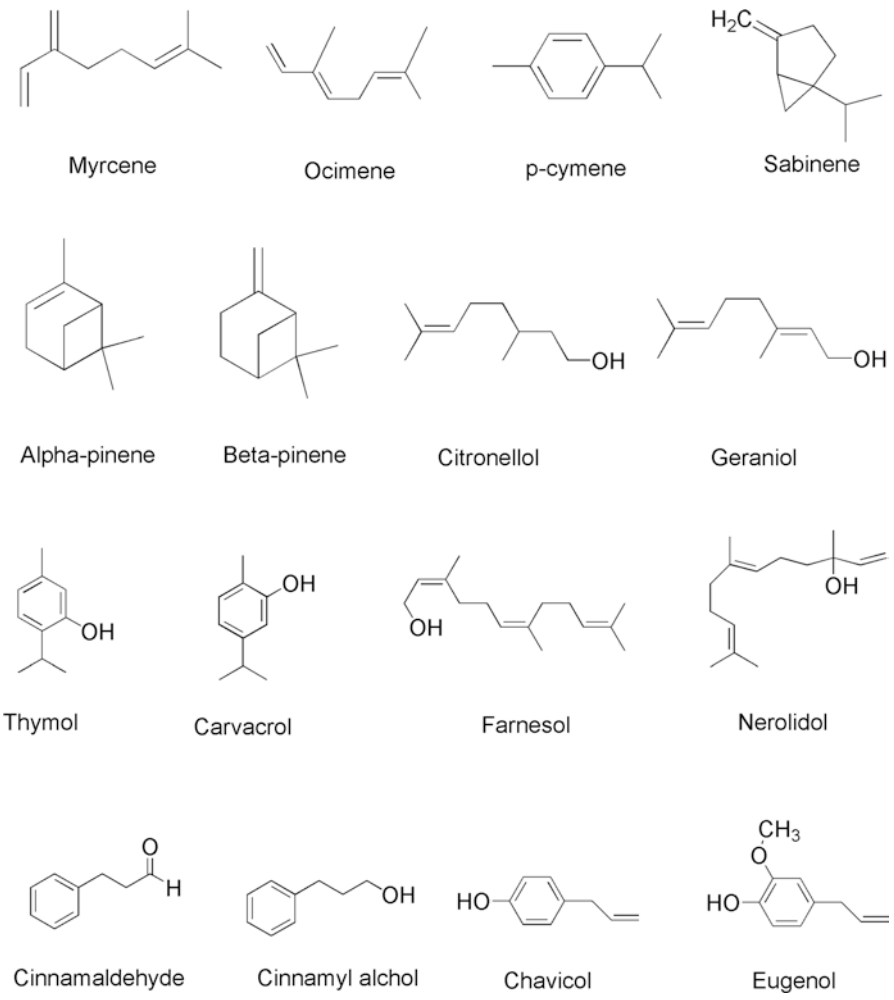

Fig. 9.1 Chemical structures of selected components of essential oils

The EOs terpenes are major chemical constituents than aromatic hydrocarbons. In plants, the biosynthetic pathways of aromatic hydrocarbons (phenyl propane) and terpene derivatives are completely different. For example, cinnamaldehyde is a major compound in cinnamon and clove oil, while eugenol is a minor constituent. Aromatic hydrocarbons generally occur in plants, namely, *C. sativum*, *S. aromaticum*, *P. anisum*, *F. vulgare*, *M. fragrans*, *P. crispum*, *S. albidum*, and *L. verum*, and some plant families, such as Myrtaceae, Rutaceae, and Lamiaceae. In addition, EOs constitute aldehydes (cinnamaldehyde, cuminic aldehyde, perillaldehyde, etc.), alcohols (cinnamic alcohol, terpinenol, menthol, etc.), phenols (eugenol, carvacrol, etc.), and methoxy derivatives (anethole, estragole, etc.); compounds occur on aromatic hydrocarbons.

Table 9.1 Essential oils major chemical class with few examples of phytocompounds

Class	Functional group	Structure type	Examples
Terpenes	Carbures	Acyclic	Myrcene, ocimene, etc.
		Monocyclic	Terpenes, *p*-cymene, phellandrenes, etc.
		Bicyclic	Pinenes, 3-carene, camphene, sabinene, etc.
	Alcohols	Acyclic	Geraniol, linalol, citronellol, lavandulol, nerol, etc.
		Monocyclic	Menthol, α-terpineol, carveol, etc.
		Bicyclic	Borneol, fenchol, chrysanthenol, thuyan-3-ol, etc.
Monoterpenes	Aldehydes	Acyclic	Geranial, neral, citronellal, etc.
	Ketone	Acyclic	Tegetone, etc.
		Monocyclic	Menthones, carvone, pulegone, piperitone, etc.
		Bicyclic	Camphor, fenchone, thuyone, ombellulone, pinocamphone, pinocarvone, etc.
	Esters	Acyclic	Linalyl acetate or propionate, citronellyl acetate, etc.
		Monocyclic	Menthyl or α-terpinyl acetate, etc.
		Bicyclic	Isobornyl acetate, etc.
	Ethers	Bicyclic	1,8-cineole, menthofuran, etc.
	Peroxides	Bicyclic	Ascaridole, etc.
	Phenols	Monocyclic	Thymol, carvacrol, etc.
Sesquiterpenes	Carbures	Acyclic	Farnesenes, etc.
		Monocyclic	β-bisabolene, curcumenes, elemenes, zingiberene, etc.
		Bicyclic	Azulene, cadinenes, b-caryophyllene, etc.
		Tricyclic	Longifolene, etc.
	Alcohols	Acyclic	β-nerolidol, farnesol, etc.
		Monocyclic	Bisabolol, etc.
		Bicyclic	Carotol, β-santalol, etc.
		Tricyclic	Cedrol, patchoulol, viridiflorol, etc.
	Ketones	Monocyclic	Germacrone, cis-longipinan-2,7-dione, turmerones, etc.
		Bicyclic	Nootkatone, β-vetinone, etc.
	Epoxides	Bicyclic	Humulene epoxides, etc.
		Tricyclic	Caryophyllene oxide, etc.

9.3 Biological Effects of Essential Oils

At present, around 60 plant families are known to produce EOs, which are valued in medicinal, pharmaceutical, flavor and fragrance, and agricultural industries. Several plant species belonging to the Apiaceae, Alliaceae, Asteraceae, Lamiaceae, Myrtaceae, Poaceae, and Rutaceae family produce EOs with medicinal and industrial values (Vigan 2010; Hammer and Carson 2011). Details of EOs produced from medicinal and aromatic plants and their medicinal importance are mentioned in

Table 9.2. EOs are rich in terpenes, while phenylpropanoids more frequently occur in Apiaceae, Alliaceae, Lamiaceae, Myrtaceae, and Rutaceae plant families (Chami et al. 2004). These family plants are used for the commercial level manufacture of EOs. For example, patchoulol, coriander, anise, dill, and fennel EOs are extracted from *P. cablin, C. sativum, P. anisum, A. graveolens* and *F. vulgare,* respectively. These EOs are well known for their antimicrobial and anticancer activities. The plants belonging to the Lamiaceae and Apiaceae family are popular for antimicrobial, anticancer, antibacterial, antimutagenic, anti-inflammatory, and antioxidant activities (Swamy and Sinniah 2015; Swamy et al. 2016). Some of the plants from Lamiaceae family produce EOs (Burt 2004; Hammer et al. 2006; Hussain et al. 2008), such as *M. piperita, R. officinalis, O. basilicum, S. officinalis, M. officinalis, S. hortensis, T. vulgaris, L. angustifolia,* and *O. vulgore* (Swamy and Sinniah 2015; Swamy et al. 2016). Likewise, EOs from Lauraceae and Myrtaceae families also exhibit antimicrobial, antitumor, anticancer, antibacterial, and antiviral activities (Burt 2004; Hammer et al. 2006). *Cinnamomum verum* (Lauraceae) and *Syzygium aromaticum* (Myrtaceae) EOs are particularly rich in eugenol. Many EOs have been screened for their pharmacological potential, and in the following sections, studies showing different pharmacological activities of EOs are discussed.

9.3.1 Essential Oils as Antibacterial Agents

Many essential oils have been investigated for their antibacterial and antifungal activities, as well as their potential against Gram-positive and Gram-negative bacteria (Swamy et al. 2016). EOs show good antibacterial properties against *Salmonella*, *Staphylococcus,* and other bacterial pathogens. Thus, it is essential to study their effects as very good alternatives to antibiotics (Fujita et al. 2015; Karbach et al. 2015; Sienkiewicz et al. 2015). *O. basilicum* essential oil exhibits good antibacterial properties against Gram-positive bacteria (Al Abbasy et al. 2015; Avetisyan et al. 2017). In the investigations of antibacterial effects, manuka oil has been shown to exhibit good antibacterial activity. Similarly, eucalyptus, rosmarinus, *Lavandula* oil, and tree oil were found effective against *Streptococcus mutans, S. sobrinus, Fusobacterium nucleatum,* and *Porphyromonas gingivalis* (Takarada et al. 2004). Tea tree (*Melaleuca alternifolia*) oil is demonstrated to be sensitive to 15 genera of oral bacteria, indicating its potential applications in oral hygiene (Hammer et al. 2003). *Pittosporum undulatum* and *Hedychium gardnerianum* EOs show the highest antibacterial activities against *Staphylococcus epidermis* and *S. aureus*.

Despite the discovery of new antibiotics, bacterial infectious/diseases still pose a serious threat to human health, predominantly due to the appearance of antibiotic-resistant strains. In addition, as the global people continues to expand, this will result in a greater prevalence of bacterial diseases, low immunity, and increased drug resistance. Therefore, bacterial infections will be more likely to be fatal (Ahmad and Beg 2001; Hall-Stoodley et al. 2004; Swamy et al. 2016; Rudramurthy et al. 2016). To decrease the risk of infectious diseases, high concentrations of

Table 9.2 Essential oils from different plant families and their major medicinal importance

Essential oil sources	Plant family	Medicinal importance	References
Origanum vulgare (oregano); *Melissa officinalis* (lemon balm); *Salvia officinalis* (sage); *Mentha* sp.; *Mentha longifolia* (wild mint); *M. piperita* (peppermint); *M. spicata* (spearmint); *Ocimum basilicum* (sweet basil); *O. sanctum*; *Rosmarinus officinalis* (rosemary); *Lavandula officinalis* (lavender); *Lavandula* sp.; *Salvia sclarea* (sage Clary)	Lamiaceae/ Labiatae	Antibacterial; antifungal; anticancer; antiviral; antidiabetic; antimutagenic; antiprotozoal; anti-inflammatory; antioxidant	Bakkali et al. (2008), Raut and Karuppayil (2014), Swamy et al. (2016) and Nagarjuna et al. (2017)
Cinnamomum sp. (cinnamon)	Lauraceae	Antimicrobial; anti-inflammatory; antimutagenic	Raut and Karuppayil (2014) and Toscano-Garibay et al. (2017)
Allium sativum (garlic); *Allium cepa* (onion)	Liliaceae	Antifungal; antiviral; antiprotozoal	Raut and Karuppayil (2014) and Swamy et al. (2016)
Syzygium aromaticum (clove); *Thymus vulgaris* (thyme);*Thymus* sp.; *Melaleuca alternifolia* (tea tree); *Eucalyptus globulus* (blue gum); *Myristica fragrans* (nutmeg)	Myrtaceae	Antibacterial; antifungal; anticancer; antiviral; antimutagenic; anti-inflammatory; antiprotozoal	Bakkali et al. (2008), Raut and Karuppayil (2014) and Swamy et al. (2016)
Foeniculum vulgare (fennel); *Carum nigrum* (black caraway); *Anethum graveolens* (dill); *Cuminum cyminum* (cumin); *Pimpinella anisum* (anise); *Apium graveolens* (celery); *Coriandrum sativum* (coriander)	Apiaceae	Antidiabetic; anticancer; antibacterial; antifungal; antiviral	Bakkali et al. (2008), Raut and Karuppayil (2014) and Swamy et al. (2016)
Artemisia judaica; *A. annua*; *A. absinthium* (wormwood); *A. dracunculus* (tarragon)	Asteraceae	Antifungal; anticancer; antiviral	Bakkali et al. (2008), Raut and Karuppayil (2014) and Swamy et al. (2016)
Pelargonium graveolens (rose geranium)	Geraniaceae	Antibacterial	Raut and Karuppayil (2014) and Swamy et al. (2016)
Jasminum sp.; *Olea europaea* (olive)	Oleaceae	Antibacterial, anticancer	Raut and Karuppayil (2014)

(continued)

Table 9.2 (continued)

Essential oil sources	Plant family	Medicinal importance	References
Piper nigrum (black pepper)	Piperaceae	Antibacterial; antifungal; anticancer; antiprotozoal	Bakkali et al. (2008) and Raut and Karuppayil (2014)
Cedrus libani (cedarwood oil)	Pinaceae	Antifungal	Bakkali et al. (2008), Raut and Karuppayil (2014) and Swamy et al. 2016
Cymbopogon martini (palmarosa); *Cymbopogon citrates*(lemongrass); *Cymbopogon nardus* (citronella grass)	Poaceae	Antifungal; anticancer	Bakkali et al. (2008), Raut and Karuppayil (2014) and Swamy et al. 2016
Citrus sp. (lemon); *C. paradisi* (grape fruit)	Rutaceae	Antibacterial; antifungal; anticancer	Bakkali et al. (2008), Raut and Karuppayil (2014) and Swamy et al. 2016
Rosa sp.	Rosaceae	Antifungal	Bakkali et al. (2008), Raut and Karuppayil (2014) and Swamy et al. 2016
Santalum sp.; *Santalum album* (sandalwood)	Santalaceae	Antiviral	Bakkali et al. (2008) and Raut and Karuppayil (2014)
Zingiber officinale (ginger); *Zingiber montanum*; *Curcuma longa* (turmeric); *Elettaria cardamomum* (cardamom)	Zingiberaceae	Antifungal; anticancer; antioxidant; antimutagenic	Bakkali et al. (2008), Raut and Karuppayil (2014) and Swamy et al. 2016

antibacterial drugs are usually employed, resulting in toxicity and adverse side effects. Hence, there is a need to explore alternative approaches and develop new molecules against human pathogenic bacteria (Galvao et al. 2012; Rudramurthy et al. 2016). In this context, plant EOs exhibit a good potential due to their proven activity against both Gram-positive and Gram-negative bacteria as shown in Table 9.3 (Edris 2007; Lang and Buchbauer 2012; Hassanshahian et al. 2014; Teixeira et al. 2013). Some EOs show potential antibacterial activity against Gram-positive bacteria only, such as *Santalum album*, *Leptospermum scoparium,* and *Chrysopogon zizanioides* (Hammer and Carson 2011). According to the available

Table 9.3 Essential oils as antibacterial agents

Essential oil sources	Bacteria	References
Origanum vulgare (oregano); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Syzygium aromaticum* (clove); *Thymus vulgaris* (thyme); *Thymus* sp.	*Aeromonas hydrophila* *Alcaligenes faecalis*	Dorman and Deans (2000), Tepe et al. (2004), Lopez et al. (2005, 2007), Bozin et al. (2006) and Rosato et al. (2007)
Carum nigrum (black caraway); *Santolina rosmarinifolia* (cotton lavender)	*Bacillus cereus*	Singh et al. (2006) and Ioannou et al. (2007)
Juglans regia (common walnut); *Melissa officinalis* (lemon balm); *Myristica fragrans* (nutmeg); *Origanum vulgare* (oregano); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Rosa* sp.; *Syzygium aromaticum* (clove); *Ziziphora clinopodioides* (blue mint); *Thymus vulgaris* (thyme); *Thymus* sp.	*Bacillus subtilis*	Dorman and Deans (2000), Mimica-Dukic et al. (2004), Tepe et al. (2004), Lopez et al. (2005,2007), Bozin et al. (2006), Sonboli et al. (2006), Rosato et al. (2007), Hirulkar and Agrawal (2010) and Rather et al. (2012)
Anethum graveolens (dill); *Apium graveolens* (celery); *Eucalyptus robusta* (swamp mahogany); *E. saligna*; *E. globulus* (blue gum); *Juglans regia* (common walnut); *Melaleuca alternifolia* (tea tree); *Melissa officinalis* (lemon balm); *Mentha longifolia* (wild mint); *M. piperita* (peppermint); *M. spicata* (spearmint); *Pimpinella anisum* (aniseed); *Myristica fragrans* (nutmeg); *Origanum vulgare*(oregano); *Pelargonium graveolens* (rose geranium); *Pinus densiflora* (Japanese red pine); *Pinus koraiensis* (Korean pine); *Piper nigrum* (black pepper); *Rosa* spp.; *Salvia sclarea* (sage clary); *S. officinalis* (sage); *S. lavandulifolia*; *S. rosifolia*; *Santolina rosmarinifolia* (cotton lavender); *Syzygium aromaticum* (clove); *Tamarix boveana* (salt cedar); *Ziziphora clinopodioides* (blue mint); *Thymus vulgaris* (thyme); *Thymus* sp.	*Escherichia coli*	Dorman and Deans (2000), Delaquis et al. (2002), Singh et al. (2002), Dryden et al. (2004), Hong et al. (2004), Mimica-Dukic et al. (2004), Rota et al. (2004), Tepe et al. (2004), Bozin et al. (2006), Carson et al. (2006), Sonboli et al. (2006), Fabio et al. (2007), Lopez et al. (2005,2007), Ioannou et al. (2007), Rafii and Shahverdi (2007), Rosato et al. (2007), Sartorelli et al. (2007), Saidana et al. (2008), Roller et al. (2009), Hirulkar and Agrawal (2010), Baananou et al. (2013), Djenane et al. (2012), Galvao et al. (2012) and Rather et al. (2012)
Mentha longifolia (wild mint)*; M. piperita* (peppermint); *M. spicata* (spearmint); *Origanum vulgare* (oregano); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Rosa* spp.; *Syzygium aromaticum* (clove)	*Enterobacter aerogenes; E. cloacae*	Dorman and Deans (2000), Singh et al. (2002), Tepe et al. (2004), Lopez et al. (2005), Bozin et al. 2006), Fabio et al. (2007), Rafii and Shahverdi (2007), Rosato et al. (2007), Hirulkar and Agrawal (2010) and Djenane et al. (2012)

(continued)

Table 9.3 (continued)

Essential oil sources	Bacteria	References
Melaleuca alternifolia (tea tree); *Origanum vulgare* (oregano); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Syzygium aromaticum* (clove); *Ziziphora clinopodioides* (blue mint); *Thymus vulgaris* (thyme); *Thymus* sp.	*Enterococcus faecalis*	Dorman and Deans (2000), Singh et al. (2002), Dryden et al. (2004), Tepe et al. (2004), Lopez et al. (2005, 2007), Bozin et al. (2006), Carson et al. (2006), Sonboli et al. (2006), Fabio et al. (2007), Rosato et al. (2007) and Shan et al. (2007)
Eucalyptus robusta (swamp mahogany); *E. saligna; E. globulus* (blue gum); *Eugenia caryophyllus* (clove); *Melaleuca alternifolia* (tea tree); *Mentha longifolia* (wild mint); *M. piperita* (peppermint); *M. spicata* (spearmint); *Salvia sclarea* (sage clary); *S. officinalis* (Sage); *S. lavandulifolia; S. rosifolia*	*Haemophilus influenzae*	Rota et al. (2004), Carson et al. (2006), Fabio et al. (2007), Sartorelli et al. (2007), Shan et al. (2007), Rafii and Shahverdi (2007), Roller et al. (2009), Djenane et al. (2012) and Galvao et al. (2012)
Anethum graveolens (dill); *Eucalyptus robusta* (swamp mahogany); *E. saligna; E. globulus* (blue gum); *Eugenia caryophyllus* (clove); *Juglans regia* (common walnut); *Mentha longifolia* (wild mint*); M. piperita* (peppermint); *M. spicata* (spearmint); *Myristica fragrans* (nutmeg); *Origanum vulgare* (oregano); *Pelargonium graveolens* (rose geranium); *Pinus densiflora* (Japanese red pine); *Pinus koraiensis* (Korean pine); *Piper nigrum* (black pepper); *Rosa* spp.*; Salvia sclarea* (sage clary); *S. officinalis* (sage); *S. lavandulifolia; S. rosifolia; Syzygium aromaticum* (clove); *Ziziphora clinopodioides* (blue mint); *Thymus vulgaris* (thyme); *Thymus* sp.	*Klebsiella pneumoniae*	Dorman and Deans (2000), Delaquis et al. (2002), Hong et al. (2004), Rota et al. (2004), Tepe et al. (2004), Bozin et al. (2006), Carson et al. (2006), Sonboli et al. (2006), Fabio et al.(2007), Lopez et al. (2005,2007), Rafii and Shahverdi (2007), Rosato et al. (2007), Shan et al. (2007), Roller et al. (2009), Hirulkar and Agrawal (2010), Djenane et al. (2012), Galvao et al. (2012) and Rather et al. (2012)
Melaleuca alternifolia (tea tree)	*Mycobacterium avium*	Dryden et al. (2004) and Carson et al. (2006)
Lantana fucata; L. trifolia	*Mycobacterium tuberculosis*	Juliao et al. (2009)
Juglans regia (common walnut); *Myristica fragrans* (nutmeg); *Pelargonium graveolens* (rose geranium); *Rosa* sp.; *Syzygium aromaticum* (clove); *Thymus vulgaris* (thyme); *Thymus* sp.	*Proteus vulgaris*	Dorman and Deans (2000), Hirulkar and Agrawal (2010) and Rather et al. (2012)

(continued)

Table 9.3 (continued)

Essential oil sources	Bacteria	References
Apium graveolens (celery); *Carum nigrum* (black caraway); *Juglans regia* (common walnut); *Melaleuca alternifolia* (tea tree); *Origanum vulgare* (oregano); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Rosa* spp.*; Syzygium aromaticum* (clove); *Tamarix boveana* (salt cedar); *Ziziphora clinopodioides* (blue mint); *Thymus vulgaris* (thyme); *Thymus* sp.	*Pseudomonas aeruginosa*; drug-resistant *P. aeruginosa*	Dorman and Deans (2000), Singh et al. (2006), Dryden et al. (2004), Tepe et al. (2004), Bozin et al. (2006), Carson et al. (2006), Sonboli et al. (2006), Lopez et al. (2005,2007), Rosato et al. (2007), Saidana et al. (2008), Hirulkar and Agrawal (2010), Baananou et al. (2013) and Rather et al. (2012)
Apium graveolens (celery); *Croton cajucara; Eucalyptus robusta* (swamp mahogany); *E. saligna; E. globulus* (blue gum); *Eugenia caryophyllus* (clove); *Juglans regia* (common walnut); *Lavandula angustifolia* (common lavender); *L. latifolia; L. luisieri; Melaleuca alternifolia* (tea tree); *Melissa officinalis* (lemon balm); *Mentha longifolia* (wild mint); *M. piperita* (peppermint); *M. spicata* (spearmint); *Myristica fragrans* (nutmeg); *Origanum vulgare* (oregano); *Pelargonium graveolens* (rose geranium); *Pinus densiflora* (Japanese red pine); *Pinus koraiensis* (Korean pine); *Piper nigrum* (black pepper); *Rosa* spp.; *Rosmarinus officinalis* (rosemary); *Salvia sclarea* (sage clary); *S. officinalis* (sage); *S. lavandulifolia; S. rosifolia; Santolina rosmarinifolia* (cotton lavender); *Skimmia laureola; Syzygium aromaticum* (clove); *Tamarix boveana* (salt cedar); *Ziziphora clinopodioides* (blue mint); *Thymus vulgaris* (thyme); *Thymus* sp.	*Staphylococcus aureus; methicillin-resistant Staphylococcus aureus* (MRSA)	Dorman and Deans (2000), Delaquis et al. (2002), Dryden et al. (2004), Mimica-Dukic et al. (2004), Rota et al. (2004), Tepe et al. (2004), Alviano et al. (2005), Bozin et al. (2006), Carson et al. (2006), Sonboli et al. (2006), Fabio et al. (2007), Lopez et al. (2005,2007), Ioannou et al. (2007), Rafii and Shahverdi (2007), Rosato et al. (2007), Sartorelli et al. (2007), Shan et al. (2007), Saidana et al. (2008), Roller et al. (2009), Hirulkar and Agrawal (2010), Tohidpour et al. (2010), Baananou et al. (2013), Djenane et al. (2012), Galvao et al.(2012), Rather et al. (2012) and Shah et al. (2013)
Juglans regia (common walnut); *Skimmia laureola; Tamarix boveana* (salt cedar); *Ziziphora clinopodioides* (blue mint)	*S. epidermidis*	Sonboli et al. (2006), Saidana et al. (2008), Rather et al. (2012) and Shah et al. (2013)
Eucalyptus robusta (swamp mahogany); *E. saligna; E. globulus* (blue gum); *Eugenia caryophyllus* (clove); *Melaleuca alternifolia* (tea tree); *Mentha longifolia* (wild mint); *M. piperita* (peppermint); *M. spicata* (spearmint); *Rosa* spp.; *Salvia sclarea* (sage clary); *S. officinalis* (sage); *S. lavandulifolia; S. rosifolia; Thymus vulgaris* (thyme); *Thymus* sp.; *Coriandrum sativum* (coriander)	*Streptococcus pneumonia; S. pyogenes; S. agalactiae; S. haemolyticus*	Delaquis et al. (2002), Singh et al. (2002), Dryden et al. (2004), Lo Cantore et al. (2004), Rota et al. (2004), Carson et al. (2006), Fabio et al. (2007), Rafii and Shahverdi (2007), Sartorelli et al. (2007), Shan et al. (2007), Roller et al. (2009), Hirulkar and Agrawal (2010), Djenane et al. (2012), Galvao et al. (2012), Rather et al. (2012) and Shah et al. (2013)

(continued)

Table 9.3 (continued)

Essential oil sources	Bacteria	References
Coriandrum sativum (coriander); *Juglans regia* (common walnut); *Melissa officinalis* (lemon balm); *Pinus densiflora* (Japanese red pine); *Pinus koraiensis* (Korean pine); *Rosa* spp.; *Salvia sclarea* (sage clary); *S. officinalis* (sage); *S. lavandulifolia; S. rosifolia; Tamarix boveana* (salt cedar)	*Salmonella typhimurium*	Delaquis et al. (2002), Singh et al.(2002), Hong et al.(2004), Lo Cantore et al.(2004), Mimica-Dukic et al. (2004), Rota et al. (2004), Fabio et al. (2007), Roller et al. (2009), Hirulkar and Agrawal (2010) and Saidana et al. (2008)
Myristica fragrans (nutmeg); *Origanum vulgare* (oregano); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Syzygium aromaticum* (clove); *Thymus vulgaris* (thyme); *Thymus* sp.	*Serratia marcescens*	Dorman and Deans (2000), Tepe et al. (2004), Lopez et al. (2005,2007), Bozin et al. (2006) and Rosato et al. (2007)
Juglans regia (common walnut); *Ocimum basilicum* (sweet basil); *O. gratissimum* (African basil)	*Shigella dysenteriae*	Iwalokun et al. (2003), Bozin et al. (2006) and Rather et al. (2012)
Coriandrum sativum (coriander); *Pinus densiflora* (Japanese red pine); *Pinus koraiensis* (Korean pine)	*Listeria monocytogenes*	Delaquis et al. (2002), Singh et al. (2002), Hong et al. (2004) and Lo Cantore et al.(2004)
Myristica fragrans (nutmeg); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Syzygium aromaticum* (clove); *Tamarix boveana* (salt cedar); *Thymus vulgaris* (thyme); *Thymus* sp.	*Micrococcus luteus*	Dorman and Deans (2000) and Saidana et al.(2008)
Myristica fragrans (nutmeg); *Origanum vulgare* (oregano); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Syzygium aromaticum* (clove); *Thymus vulgaris* (thyme); *Thymus* sp.	*Moraxella* sp.	Dorman and Deans (2000), Tepe et al. (2004), Lopez et al. (2005,2007), Bozin et al. (2006) and Rosato et al. (2007)
Myristica fragrans (nutmeg); *Pelargonium graveolens* (rose geranium); *Piper nigrum* (black pepper); *Syzygium aromaticum* (clove); *Thymus vulgaris* (thyme); *Thymus* sp.	*Yersinia enterocolitica*	Dorman and Deans (2000)

evidence, cinnamon, lemongrass, thyme, clove, rosewood, orange, rosemary, peppermint, bay, basil, and eucalyptus EOs exhibit the most effective antimicrobial activity. EOs are very active at ˂1% minimum inhibition concentrations (MICs). *Escherichia coli* exhibits zone of inhibition at 0.02, 0.04, and 0.06% concentrations against clove, grass, oregano, bay, and thyme EOs, respectively (Hammer and Carson 2011). Some EOs show less activity, but their major constituent molecules are observed to possess higher activity. For example, eugenol, carvacrol, and 4-terpinenol display greater antibacterial activity than their corresponding EOs. In extant literature, phenols and aldehydes are reported potential antimicrobial activity (Lambert et al. 2001; Ultee et al. 2002; Carson et al. 2006). A large number of the EOs have been shown to be successful against drug-resistant strains, antibiotics, and biofilms (May et al. 2000; Bozin et al. 2006; Galvao et al. 2012). EOs of *A. fragrantissima*, *A. ligustica*, *A. absinthium*, *A. biennis*, *A. cana*, *A. dracunculus*,

A. longifolia, *A. frigida*, *C. officinalis*, *C. sativum*, *C. cyminum*, *C. longus*, *D. littoralis*, *E. erythropapps*, *E. rostkoviana*, *F. margarita*, *L. nobilis*, *L. angustifolia*, *L. longifolia*, *J. excelsa*, *M. suaveolens*, *N. sativa*, *O. vulgare*, *T. vulgaris*, *O. basilicum*, *P. cablin*, *T. kotschyanus*, *S. cumini*, *T. ammi,* and *S. sparganophora* show potential antibacterial activity against *S. aureus*, *S. epidermidis*, *E. coli*, *S. mutans*, *B. thermosphacta*, *L. innocua*, *L. monocytogenes*, *P. putida*, *B. cereus*, *B. subtilis*, *N. gonorrhoeae*, *K. pneumoniae*, *C. botulinum*, *C. perfringens*, *S. sonnei*, *S. lutea*, *P. putida*, *M. flavus*, *L. innocua*, *E. faecalis*, and *S. putrefaciens* (Lopes-Lutz and Alviano 2008; Maggi et al. 2009; Matasyoh et al. 2009; Begnami et al. 2010; Runyoro et al. 2010; Ait-Ouazzou et al. 2012; Bejaoui et al. 2013; Teixeira et al. 2013; Yang et al. 2013; Amatiste et al. 2014; Andrade et al. 2014; Bilcu et al. 2014; Bisht et al. 2014; Flores et al. 2014; Kasim et al. 2014; Khoury et al. 2014; Petretto et al. 2014; Pullagummi et al. 2014; Santurio et al. 2014; Singh et al. 2014;; yousefbeyk et al. 2014; Zeedan et al. 2014; Ahmadi et al. 2015; Beatovia et al. 2015; Santos et al. 2015; Ibrahim et al. 2015a, b; Novy et al. 2015).

9.3.2 Essential Oils as Antioxidant Agents

Modern era has brought about different health problems, such as noncommunicable diseases (e.g., cancer, diabetes, and Alzheimer's, Parkinson's, and heart diseases) which are attributed to oxidative stresses. EOs exhibit a significant antioxidant activity due to their phtocompounds, such as flavonoids, terpenoids, and phenolic compounds (McCord 2000; Tomaino et al. 2005; Edris 2007; Ferguson and Philpott 2008; Ruan et al. 2008; Miguel 2010; Cavar et al. 2012; Andrade et al. 2013; Sanchez-Vioque et al. 2013; Aleksic and Knezevic 2014; Bouzabata et al. 2015). Among many EOs, *O. majorana*, *T. filifolia*, *B. monnieri*, *C. longa*, *S. cryptantha*, *A. millefolium*, *S. multicaulis*, *M. officinalis*, *M. alternifolia*, *Ocimum*, and *Mentha* sp. have been reported to possess significant antioxidant activity (Mau et al. 2003; Tepe et al. 2004; Kim et al. 2004; Maheshwari et al. 2006; Maestri et al. 2006; Gulluce et al. 2007; Tripathi et al. 2007; Politeo et al. 2007; Hussain et al. 2008; Aqil et al. 2012; Mohamed et al. 2013; Toscano-Garibay et al. 2017;). Thymol and carvacrol containing EOs in particular show strong antioxidant properties (Tepe et al. 2004; Miguel 2010). Likewise, EOs of *Cuminum cyminum*, *Petroselinum sativum*, *S. cumini*, and *Coriandrum sativum* also exhibit efficient antioxidant (Romeilah et al. 2010; Eshwarappa et al. 2014). In addition, clove oil shows a much stronger antioxidant and radical scavenging activity compared to cinnamon, basil, oregano, nutmeg, and thyme EOs (Tomaino et al. 2005).

9.3.3 Essential Oils as Anticancer Agents

As cancer is a growing problem globally, many curing and preventive therapies have been developed over the years. In the human body, cancer is characterized by uncontrolled proliferation of abnormal cells. The malignant cells have the potential to be

metastatic, requiring urgent treatment, such as radiotherapy, and chemotherapy. Among these, chemotherapy treatment is most challenging and can be difficult for patients to tolerate due to extreme side effects. Therefore, many alternative treatments and therapies have been explored. In both developed and developing countries, herbal medicines have been historically used for traditional medicinal treatments. For thousands of years, African and Asian populations have used medicinal plants in folk medicine. Even developed nations are starting to recognize the health benefits medicinal plants, according to the WHO. Plants identified for their anticancer properties have been chemically characterized to reveal the occurrence of many bio-active compounds, such as polyphenols, taxols, brassinosteroids, etc.

Flavonoids, tannins, curcumin resveratrol, and gallocatechins are some of the plant-derived polyphenolic compounds possessing anticancer properties. A regular intake of healthy diet can improve the human health as they are rich in natural antioxidants and can thus reduce the risk of developing cancer. For example, gallocatechins found in green tea and resveratrol found in peanuts, grapes, and red wine are effective in preventing cancer (Azmi et al. 2006; Apostolou et al. 2013). Polyphenols have been shown to regulate cancer cell growth through modifications of acetylation, methylation, or phosphorylation processes involved in the regulation of chromatin function. For example, *C. longa* EOs has been treated various cancer cell lines shown to suppression the tumor necrosis factor (TNF) impression along interaction with various stimuli (Gupta et al. 2014). Flavonoids, another class of plant secondary metabolites, possess therapeutic efficacy and scientifically prove to impart health benefits to humans. In traditional Chinese medicine, litchi leaf (*Litchi chinensis*) is used in cancer treatment (Cao et al. 2013; Wen et al. 2014). Litchi leaf is rich in flavonoids, such as flavones, flavonols, and chalcones (Wen et al. 2014). The essential oil of *Dryopteris erythrosora* showed potential anticancer activity against human lung cancer cells (A456 cell line) (Kloog and Cox 2004; Cao et al. 2013).

Plant-derived compounds also show potential activity against cancer cell lines. These compounds occur naturally and are easily available and nontoxic to the healthy human cells. Thus, they could be administrated to patients orally (Cornblatt et al. 2007; Amin et al. 2009). Still, there are a few exceptions, such as glycosides, lectins, saponins, lignans, lectins, and taxanes (Unnati et al. 2013). BR compounds, such as sulforaphane, isothiocyanates, isoflavones, and pomiferin, are considered histone deacetylase (HDAC) inhibitors. For example, sulforaphane has been used against breast cancer proliferation (Pledgie-Tracy et al. 2007; Seidel et al. 2012). In the studies on inhibition of cancer cell proliferation, taxols (plant molecules) were shown effective against different types of malignancies, like colon cancer, gastric cancer, breast cancer, leukemia, and human liver and pulmonary tumors (Edris 2007; Kaefer and Milner 2008; Hamid et al. 2011). In Table 9.4, details of different medicinal and aromatic plant EOs possessing anticancer properties are cited. For example, *Cymbopogon martini* EOs are rich in geraniol. Geraniol is used against ion homeostasis which interferes with membrane function as well as cancer cell line signaling. *Atractylodes lancea* oils are used for the treatment of malignant tumors (Tsuneki et al. 2005), whereas *Myristica fragrans* (*M. fragrans*) oils contain myristicin and are used for their hepatoprotective activities (Morita et al. 2003).

Table 9.4 Anticancer and antitumor activities of essential oils

Essential oil sources	Antitumor/anticancer	References
Alpinia officinarum (galangal/China root); *Citrus hystrix* (Thai lime); *C. paradise* (grape fruit tree); *Curcuma longa* (turmeric); *Cymbopogon nardus* (citronella grass); *Cymbopogon martini* (palmarosa); *Lavandula angustifolia; Mentha spicata; Ocimum basilicum; O. americanum; O. sanctum; Piper nigrum; P. betle* (beetle leaf); *Zingiber montanum; Vetiveria zizanioides* (Khus)	Inhibition of proliferation of murine leukemia and human mouth epidermal carcinoma cell lines	Hata et al. (2003), Carnesecchi et al. (2004), Koo et al. (2004), Manosroi et al. (2006)
Artemisia annua	Induction of apoptosis in cultured hepatocarcinoma cells	Li et al. (2004)
Atractylodes lancea	Anti-angiogenesis properties	Tsuneki et al. (2005)
Curcuma longa (turmeric)	Inhibition of primary liver cancer	Koo et al. (2004) and Manosroi et al.(2006)
Elettaria cardamomum (cardamom); *Eucalyptus globulus* (eucalyptus)	Induction of apoptosis in human leukemia cells	Moteki et al. (2002)
Allium sativum; Elaeis guineensis (palm oil)	Chemoprevention of various cancers	Milner (2001) and Luk et al. (2011)
Eugenia caryophyllata (i.e., *Syzygium aromaticum*)	Inhibition of proliferation of cancerous cells	Yoo et al. (2005)
Foeniculum vulgare; Myristica fragrans	Hepatoprotective activity	Ozbek et al. (2003), Morita et al. (2003) and Lee et al. (2005)
Foeniculum vulgare	Inhibition of growth of different human cancer cell lines like breast cancer and liver cancer	Ozbek et al. (2003)
Matricaria chamomilla	Induction of apoptosis in highly malignant glioma cell	Cavalieri et al. (2004)
Melaleuca alternifolia	Induction of caspase dependent apoptosis inhuman melanoma	Calcabrini et al. (2004)
Myrica gale (myrtle/bayberry)	Activity against lung and colon cancer cell lines	Sylvestre et al. (2005,2006)
Melissa officinalis	Activity against a series of human cancer cell lines and a mouse cell line	De Sousa et al. (2004)
Myristica fragrans	Induction of apoptosis in human neuroblastoma	Morita et al. (2003) and Lee et al. (2005)

(continued)

Table 9.4 (continued)

Essential oil sources	Antitumor/anticancer	References
Nigella sativa	Inhibition of cancer proliferation in rats	Salim and Fukushima (2003); Mansour et al. (2001)
Olea europaea (olive oil)	Protection against colorectal cancer	Gill et al. (2005)

Lemongrass oil mainly consists of citral, which is used for in vivo studies on the initial phases of hepatocarcinogenesis (Puatanachokchai et al. 2002). EOs extracted from *E. ciliata* shows potential anticancer activity against human glioblastoma (U87), pancreatic cancer (Panc-1), and triple negative breast cancer (MIDA-MB231) (Pudziuvelyte et al. 2017). *A. fragrantissima* EOs show potential anticancer activity against human breast cancer cell line (MCF-7) and colon cancer cell line (HCT116) and the IC_{50} (μg/ml) MCF7 for 0.51 and HCT116 for 0.62 μg/ml. Compared to solvent extracts, EOs have shown better anticancer activity (Choucry. 2017), and also *A. aucheri*, *M. communis,* and *O. vulgare* EOs show efficient anticancer activity against human promyelocytic leukemia cell lines (HL-60, NB4), lymphocytes, tumor HeLa cells, and Ehrlich ascites carcinoma cells (EACC) (Taherkhani 2015; Romeilah 2016). Orange peel EOs have been investigated by 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay against lung cancer cell line (A549) and prostate cancer cell line (22RV-1); it showed good inhibition of the proliferation of a lung and prostate cancer cell lines (Yang et al. 2017).

Individual chemical constituents in EOs show potential anticancer and antitumor activity such as D-limonene (in vivo), geraniol (in vitro and in vivo), thymol and carvacrol (in vitro), thymoquinone (in vitro *and* in vivo), farnesol (in vivo and in vitro), (−)-α-bisabolol (in vitro and in vivo), (−)-β-elemene (in vitro and in vivo), (−)-β-caryophyllene (in vitro), α-humulene (in vitro), nerolidol (in vitro), germacrone (in vitro), and eugenol (in vitro and in vivo) studies which show efficient anticancer activity against stomach (mice), lung (mice), breast (rats, MCF-7), prostate (PC3, mice), skin (B16F10, rats, SCC VII, A431), colon (Caco-2, mice, rats, V79), pancreas (MIAPaca-2, hamsters), kidney (rats), mouth (hamsters), bones (MG63), brain (DBTRG-05MG), liver (HepG2, Caco-2), and blood (HL60) cancer types (Malíková et al. 2008; Lesgards et al. 2014; Bayala et al. 2014; Gautam et al. 2014) respectively.

9.3.4 Essential Oils as Antifungal Agents

Many EOs have been investigated for their antifungal activities. Fungi are very difficult to target because of cellular and molecular levels, human pathogenic fungi, and eukaryotes which are very similar with their host. However, eukaryotes and human pathogenic fungi and their hosts have similarities at molecular and cellular levels (Routh et al. 2011). Some of the human fungal pathogens, such as *Aspergillus*

spp., *Cryptococcus* sp., and *Candida* spp., are very problematic for immunocompromised patients. Hence, limited numbers of antifungal drugs are available against fungi (Kathiravan et al. 2012). Currently, the prescribed drugs are resistant to fungal strains and may lead to cause biofilm infections and adverse side effects. Consequently, fungal infections are associated with high morbidity and mortality rates (Sardi et al. 2013; Swamy et al. 2016). Plant EOs that are effective against human pathogenic fungi, plant fungi, and yeast are mentioned in Table 9.5. Based on the EO efficiency, the zone of inhibition to different the targeted organisms varies. For instance, EOs of plants, such as coriander, anise, and fennel, though belonging to the same family, i.e., Apiaceae, show differences in their antifungal activity against *Candida albicans* with MICs (minimum inhibitory concentrations) of 0.25%, 0.5%, and 1%, respectively. Among the EOs, Japanese mint, ginger grass, cinnamon, lemongrass, clove, anise, and geranium oils are particularly encouraging against *C. albicans* and the essential concentration range between 0.01% and 0.15% (Devkatte et al. 2005; Hammer and Carson 2011). EOs can rapidly inhibit growth of dermatophytes and their spores. This is an attribute to the occurrence of high levels of phytocompounds, i.e., α-bisabolol (an alcohol) and eugenol (a phenylpropanoid), in their EOs (Bajpai et al. 2009; Maxia et al. 2009; Pragadheesh et al. 2013). *C. citratus* EOs show a potential activity against many filamentous fungi at the concentration range of 0.006–0.03%. Also, it inhibits the growth of *Aspergillus niger*, *A. flavus*, *P. chrysogenum*, and *P. verrucosum* below 1% concentration (Viuda-Martos et al. 2008). Eucalyptus oil rich in citral, geraniol, geranyl acetate, and citronelol components was found to inhibit the growth of *C. albicans* by blocking the S phase of its life cycle (Zore et al. 2011a). All chemical constituents of tea tree (*Melaleuca alternifolia*) oil, except β-myrcene, exhibit in vitro antifungal activity. Tea tree oils show potential antifungal activity against dermatophytes and filamentous fungi (Hammer et al. 2003). Likewise, the growth of *A. niger* was significantly by the EOs of *Melaleuca ericifolia* fresh leaves. EOs from various plants that are generally used for the flavor and fragrance including *Mentha piperita*, *Brassica niger*, *Angelica archangelica*, and *Cymbopogon citratus* have been tested for their antifungal activity and found that they exhibit very strong antifungal activity. EOs extracted from *A. marmelos*, *C. sativum*, *D. foetidum*, *E. erythropappus*, *E. rostkoviana*, *F. vulgare*, *G. spathulata*, *M. alternifolia*, *M. pulegium*, *M. communis*, *N. sativa*, *O. vulgare*, *P. graveolens*, *P. cablin*, *R. officinalis*, *S. sclarea*, and *S. aromaticum* show efficient antifungal activity of *C. albicans*, *A. niger*, *F. oxysporum*, *C. gattii*, *C. neoformans*, *S. cerevisiae*, *A. alternate*, *F. oxysporum*, *A. flavus*, *T. rubrum*, *E. floccosum*, *C. neoformans*, *M. furfur*, *M. canis*, *M. sympodialis*, *M. gypseum*, *R. rubra*, *T. rubrum*, *T. tonsurans*, *C. zemplinina*, *K. apiculata*, *T. phaffii*, *F. moniliforme*, *F. graminearum*, *P. viridicatum*, *T. violaceum*, *B. cinerea*, *P. oryzae*, *C. tropicalis*, *C. krusei*, and *C. glabrata* (Hammer et al. 2002; Matasyoh et al. 2009; Begnami et al. 2010; Hammer and Carson 2011; Berka-zougali et al. 2012; Wang et al. 2012;

Table 9.5 Essential oils as antifungal agents

Essential oil sources	Fungi	References
Cedrus libani (cedarwood oil); *Cymbopogon martini* (ginger grass); *C. citrates* (lemongrass); *Tamarix boveana; Rosmarinus officinalis* (rosemary); *Foeniculum vulgare* (fennel)	*Alternaria alternata*	Mimica-Dukic et al. (2004), Rota et al. (2004), Ozcan and Chalchat (2008), Rosato et al. (2007), Rasooli et al. (2008), Saidana et al. (2008) and Peighami-Ashnaei et al. (2008)
Allium sativum (garlic); *Artemisia judaica* (wormwood); *A. absinthium; A. biennis; Carum nigrum* (black caraway); *Cedrus libani* (cedarwood oil); *Chenopodium ambrosioides; Cymbopogon martini* (ginger grass); *C. citrates* (lemongrass); *Eugenia caryophyllus* (clove); *Foeniculum vulgare* (fennel); *Juniperi aetheroleum* (juniper); *Matricaria chamomilla* (chamomile); *Zingiber officinale* (ginger); *Tamarix boveana*	*Aspergillus niger*	Saikia et al. (2001), Benkeblia (2004), Mimica-Dukic et al. (2004), Kordali et al. (2005), Pepeljnjak et al. (2005), Kumar et al. (2007), Agarwal et al. (2008), Bansod and Rai (2008), Lopes-Lutz and Alviano (2008), Saidana et al.(2008), Singh et al. (2008), Cetin et al. (2009), Irkin and Korukluoglu (2009), Peighami-Ashnaei et al. (2008) and Tolouee et al. (2010)
Satureja hortensis (summer savory); *Rosmarinus officinalis* (rosemary)	*Aspergillus parasiticus*	Rota et al. (2004), Rosato et al. (2007), Ozcan and Chalchat (2008), Rasooli et al. (2008) and Razzaghi-Abyaneh et al. (2008)
Carum nigrum (black caraway); *Cedrus libani* (cedarwood oil); *Cuminum cyminum* (cumin); *Nigella sativa* (black cumin); *Zingiber officinale* (ginger); *Satureja hortensis* (summer savory)	*Aspergillus flavus*	Singh et al. (2006), Singh et al. (2010), Razzaghi-Abyaneh et al. (2008) and Khosravi et al. (2011)
Cedrus libani (cedarwood oil); *Chenopodium ambrosioides; Cuminum cyminum* (cumin); *Eugenia caryophyllus* (clove); *Nigella sativa* (black cumin)	*Aspergillus fumigatus*	Kumar et al. (2007), Bansod and Rai (2008) and Khosravi et al. (2011)
Rosmarinus officinalis (rosemary); *Foeniculum vulgare* (fennel); *Artemisia judaica* (wormwood); *A. absinthium*; *A. biennis*; *other Artemisia* sp.	*Botrytis cinerea; Botrytis fabae*	Rosato et al. (2007), Ozcan and Chalchat (2008), Lopes-Lutz and Alviano (2008), Rasooli et al. (2008), Cetin et al. (2009), Irkin and Korukluoglu (2009) and Peighami-Ashnaei et al. (2008)

(continued)

Table 9.5 (continued)

Essential oil sources	Fungi	References
Cinnamomum sp.; *Croton cajucara*; *Cymbopogon martini* (ginger grass); *C. citrates* (lemongrass); *Eucalyptus saligna* (saligna); *Eugenia caryophyllus* (clove); *Juniperi aetheroleum* (juniper); *Lavandula* sp.; *Melaleuca alternifolia; Melissa officinalis; Mentha piperita; M. longifolia; M. viridis; Ocimum* sp.; *Ocimum sanctum* (holy basil/tulsi); *Pimpinella anisum; Piper nigrum* (black pepper); *Ziziphora clinopodioides; Santolina rosmarinifolia*	*Candida albicans; C. glabrata; Candida* sp.	Saikia et al.(2001), Singh et al. (2002), Dryden et al. (2004), Mimica-Dukic et al.(2004), Alviano et al. (2005), Devkatte et al. (2005), Pepeljnjak et al. (2005), Carson et al. (2006), Ioannou et al. (2007), Sartorelli et al. (2007), Agarwal et al. (2008), Bansod and Rai (2008), Irkin and Korukluoglu (2009), Mkaddem et al. (2009), Khosravi et al. (2011), Zore et al. (2011b), Zuzarte et al. (2011,2012) and Rabadia et al. (2012)
Cedrus libani (cedarwood oil); *Artemisia judaica* (wormwood); *A. absinthium; A. biennis; Artemisia* sp.	*Cladosporium cladosporioides; C. herbarum*	Kordali et al. (2005), Lopes-Lutz and Alviano (2008), Cetin et al. (2009) and Irkin and Korukluoglu (2009)
Lavandula sp.; *Ziziphora clinopodioides*	*Cryptococcus neoformans*	Khosravi et al. (2011) and; Zuzarte et al. (2011,2012)
Allium sativum (garlic); *Artemisia judaica* (wormwood); *A. absinthium; A. biennis;* other *Artemisia* sp.; *Tamarix boveana; Carum nigrum* (black caraway); *Cymbopogon martini* (ginger grass); *C. citrates* (lemongrass)	*Penicillium cyclopium; P. purpurogenum; P. madriti; P. viridicatum; P. roqueforti; Penicillium* sp.	Saikia et al. (2001), Benkeblia (2004), Kordali et al. (2005), Singh et al. (2006), Agarwal et al. (2008), Lopes-Lutz and Alviano (2008); Saidana et al. (2008), Cetin et al. (2009) and Irkin and Korukluoglu (2009)
Allium sativum (garlic); *Artemisia judaica* (wormwood); *A. absinthium; A. biennis; other Artemisia* sp.; *Chenopodium ambrosioides; Cymbopogon martini* (ginger grass); *C. citrates* (lemongrass); *Tamarix boveana; Rosmarinus officinalis* (rosemary); *Zingiber officinale* (ginger); *Salvia fruticosa; S. officinalis; S. rosifolia*	*Fusarium oxysporum; F. moniliforme; F. solani; F. proliferatum*	Saikia et al. (2001), Benkeblia (2004), Rota et al. (2004), Kordali et al. (2005), Fabio et al. (2007), Kumar et al. (2007), Rosato et al. (2007), Agarwal et al. (2008), Lopes-Lutz and Alviano (2008), Ozcan and Chalchat (2008), Rasooli et al. (2008), Saidana et al. (2008), Singh et al. (2008), Cetin et al. (2009),; Irkin and Korukluoglu (2009) and Ozek et al. (2010)
Artemisia judaica (wormwood); *A. absinthium; A. biennis; and* other *Artemisia* sp.	*Fonsecaea pedrosoi*	Kordali et al. (2005), Lopes-Lutz and Alviano (2008), Cetin et al. (2009) and Irkin and Korukluoglu (2009)
Artemisia judaica (wormwood); *A. absinthium; A. biennis*; other *Artemisia* sp.	*Geotrichum candidum*	Kordali et al. (2005), Lopes-Lutz and Alviano (2008); Cetin et al. (2009) and Irkin and Korukluoglu (2009)

(continued)

Table 9.5 (continued)

Essential oil sources	Fungi	References
Artemisia judaica (wormwood); *A. absinthium; A. biennis*; other *Artemisia* sp.	*Rhizoctonia solani*	Kordali et al. (2005), Lopes-Lutz and Alviano (2008), Cetin et al. (2009) and Irkin and Korukluoglu (2009)
Chenopodiumam brosioides	*Macrophomina phaseolina*	Kumar et al.(2007)
Artemisia judaica (wormwood); *A. absinthium; A. biennis; other Artemisia* sp.; *Cinnamomum* sp.; *Croton argyrophylloides; C. zehntneri; C. cajucara; Syzygium aromaticum; Daucus carota* (wild carrot)	*Microsporum canis; Microsporum gypseum*	Dorman and Deans (2000), Alviano et al. (2005), Kordali et al. (2005), Fontenelle et al. (2008), Lopes-Lutz and Alviano (2008), Tavares et al. (2008), Cetin et al. (2009), Irkin and Korukluoglu (2009) and Pinto et al. (2009)
Mentha piperita; M. longifolia; M. viridis	*Mucor ramannianus*	Agarwal et al. (2008) and Mkaddem et al. (2009)
Artemisia judaica (wormwood); *A. absinthium; A. biennis;* other *Artemisia* sp.	*Pythium debaryanum*	Kordali et al. (2005), Lopes-Lutz and Alviano (2008); Cetin et al. (2009) and Irkin and Korukluoglu (2009)
Artemisia judaica (wormwood); *A. absinthium; A. biennis; Artemisia* sp.	*Trichophyton rubrum T. mentagrophytes; T. roseum*	Dorman and Deans (2000), Kordali et al. (2005), Lopes-Lutz and Alviano (2008), Cetin et al. (2009), Irkin and Korukluoglu(2009) and Pinto et al. (2009)

Santos et al. 2015; Hammer et al. 2012; Hristova et al. 2013; Kocevski et al. 2013; Petretto et al. 2014; Pullagummi et al. 2014; Singh et al. 2014; Ibrahim et al. 2015a, b; Latifah-Munirah et al. 2015; Novy et al. 2015; Papajani et al. 2015;; Venturi et al. 2015; Souza et al. 2016). Most research on the antifungal activity is in the initial phases of clinical trials. Thus, EOs are functioning as an alternative for the existing antifungal drugs (Samber et al. 2015).

9.3.5 Essential Oils and Their Antiviral Activity

In addition to antimicrobial and anticancer activity, EOs also exhibit antiviral activity (see Table 9.6). EOs show potential inhibition against viral replication, as they consist of monoterpenes, sesquiterpenes, and phenylpropanoid chemical constituents (Astani et al. 2011). Eucalyptus, thyme, and *M. alternifolia* (tea tree oil) EOs show potential antiviral activity against herpes virus. Their activity has also been established against viral envelope structures (Carson et al. 2001; Reichling et al. 2005; Schnitzler et al. 2007, 2011). For example, oregano oils exhibit potential antiviral activity against herpes simplex virus (HSV) and yellow fever virus (Meneses et al. 2009). Monoterpenes of EOs, such as isoborneol, have been shown

Table 9.6 Essential oil exhibiting antiviral activities

Essential oil	Antiviral effect	References
Artemisia arborescens; A. vulgaris; Lippia origanoides (wild marjoram); *Origanum vulgare*	Inactivation of yellow fever virus	Sinico et al. (2005), Meneses et al.(2009)
Artemisia arborescens; A. vulgaris; Allium cepa (onion); *A. sativum* (garlic); *Coriandrum sativum* (cilantro/dhania); *Cuminum cyminum; Ocimum basilicum; O. americanum; O. sanctum*	Activity against herpes simplex virus type 1 (HSV-1)	Sinico et al.(2005), Meneses et al. (2009) and Romeilah et al. (2010)
*Eugenia caryophyllata (*i.e. *Syzygium aromaticum); Eucalyptus globulus* (eucalyptus oil); *Leptospermum scoparium* (manuka oil); *Melaleuca alternifolia; M. armillaris; Origanum vulgare; Santalum* sp. (sandal wood)	Activity against HSV-1 and HSV-2	Benencia and Courreges (2000), Schnitzler et al. (2001), Reichling et al. (2005), Cermelli et al. (2008), Garozzo et al.(2009) and Meneses et al. (2009)
Eucalyptus globulus (eucalyptus oil)	Activity against respiratory viruses	Schnitzler et al.(2001) and Cermelli et al. (2008)
Houttuynia cordata (fishwort/chameleon plant); *Melaleuca alternifolia*	Virucidal effect on influenza virus and HSV-1	Garozzo et al. (2009,2011)
Cymbopogon citrate and other species	Inhibition of HSV-1 replication	Minami et al. (2003)
Mentha piperita	Virucidal activity against HSV-1 and HSV-2	Schuhmacher et al. (2003)
Melissa officinalis L.	Prevention of Replication of HSV-2	Allahverdiyev et al. (2004)
Santolina insularis	Inactivation of viral particles of HSV-1 and HSV-2	De Logu et al. (2000)
Thymus sp.	Inhibition of replication of Epstein-Barr virus (EBV)	Hamid et al. (2011)

effective against HSV-1 virus (Armaka et al. 1999). HSV-2 virus is more delicate than HSV-1 virus to the pine, tea tree, manuka, lemon balm, and santolia EOs in small concentrations, i.e., in the range between 0.0001 and 0.0009% of the IC_{50} value (Garcia et al. 2003; Saddi et al. 2007; Koch et al. 2008; Schnitzler et al. 2011). In a report published by Benencia and Courreges (2000), clove oil eugenol was used against HSV-induced keratitis. Antiviral activity through plaque reduction assay against African green monkey, EOs such as *Melaleuca armillaris* (*M. armillaris*), *Melaleuca ericifolia* (*M. ericifolia*), and *Melaleuca styphelioides* (*M. styphelioides*)

showed 99%, 91.5% and 92% effectiveness, respectively (Deans and Ritchie 1987). *A. fragrantissima*, *A. arborescens*, *F. margarita*, *G. marifolia*, *H. mutabilis*, *L. salviifolia*, *M. officinalis*, *M. mollis*, *O. campechianum*, *P. cablin*, and *T. ammi* EOs show potential antiviral activity against ORF virus (a parapox virus), HSV-I, avian influenza A virus (H5N1), HSV-1, HSV-2, avian influenza virus (AIV), subtype (H9N2), influenza A (H2N2) virus, and Japanese encephalitis virus (JEV) (Allahverdiyev et al. 2004; Sinico et al. 2005; Wu et al. 2011, 2013; Kiyohara et al. 2012; Zeedan et al. 2014; Ibrahim et al. 2015a, b; Venturi et al. 2015 Roy et al. 2015; Brand et al. 2016).

9.3.6 Essential Oils as Antidiabetic Agents

Diabetes mellitus (DM), generally known as diabetes, is a metabolic disorder that is becoming increasing prevalent in modern society due to unhealthy lifestyle. Insulin-dependent diabetes is called Type-I diabetes, its causes do not produce insulin, and it damages the pancreas. Type-II diabetes is non-insulin diabetes, it causes insulin resistance in the liver, peripheral tissues, and reduced β-cell mass (Srinivasan and Ramarao 2007; Matthaei et al. 2000), respectively. Diabetes causes changes in metabolism of carbohydrates, fats, and proteins, which results in hyperglycemia, glycosuria, and hyperlipidemia (Baradaran et al. 2013; Behradmanesh et al. 2013; Mirhoseini et al. 2013). Diabetes can be successfully managed with a proper diet and consuming drugs. Also, the use of traditional medicines can effectively control the risk of diabetes with reduced side effects. The essential oil of *Vaccinium arctostaphylos* containing high levels of anthocyanoside myrtillin is used in the traditional medicine for diabetes control (Murray 1997). In mouse models, *Securigera securidaca* essential oil had significantly found effective in reducing the blood glucose level (Hisseinzadeh et al. 2002). Likewise, *Gymnema sylvestre* essential oil has been reported to be effective against both Type 1and Type 2 diabetes. It influenced the absorption of glucose in the digestive track and regenerated and proliferated β-cells (Lirussi et al. 2002; Amini et al. 2012; Madihi et al. 2013; Nasri et al. 2013; Nasri and Shirzad 2013; Rafieian-Kopaei et al. 2013). Similarly, *Atriplex halimus* has been used for Type 2 diabetes treatment in animal models, as it contains fibers, proteins, and other trace elements, such as chromium. Consumption of *A. halimus*, 3 grams dried leaves can reduce blood sugars in Type 2 diabetes patients (Bahmani et al. 2014). *Camellia sinensis* seed oil containing flavonoids like catechin, epicatechin, epigallocatechin, and gallocatechin can increase insulin levels, and their polyphenolic compounds act as antioxidants (Asadi et al. 2013; Parsaei et al. 2013). EOs or natural products have had major impact on diabetes, whereby flavonoids, metformin, anthocyanin, catechin, quercetin, flavone, phenylpropanoids, lipoic acids, and coumarin metabolites are particularly effective (Arabbi et al. 2004; Rafieian-Kopaei et al. 2013; Singab et al. 2014).

Foeniculum vulgare (*F. vulgare*) EOs show potential antidiabetic activity in rates corrected the hyperglycemia from 162.5 ± 3.19 mg/dl to 81.97 ± 1.97 mg/dl and also high activity of serum glutathione peroxide from 59.72 ± 2.78 U/g Hb to

99.60 ± 6.38 U/g Hb (El-Soud et al. 2011). Yen et al. (2015) from Taiwan described that different families of commercial EOs purchased from local market such as (Lamiaceae, Rutaceae, Myrtaceae, Cupressaceae, Piperaceae, Burseraceae, Zingiberaceae, Geraniaceae, Apiaceae, Asteraceae, Pinaceae, and Lauraceae) show potential antidiabetic activity after 24 hrs in culture medium of 3 T3-L1 adipocytes. Alpha amylase inhibition assay shows efficient antidiabetic activity with *S. aromaticum* and *C. cyminum* EOs (Tahir et al. 2016).

9.3.7 Essential Oils as Insect Repellents

Insect repellent is a substance applied to the surface of skin or on clothing to prevent insect bites (Blackwell et al. 2003; Choochote et al. 2007; Nerio et al. 2010). Generally, repellents work as vapor barriers, preventing the insects from coming into contact with the surface. Currently, many synthetic chemicals are used to control insects and arthropods; however, they are causing concerns regarding human health and environmental pollution. Plant molecules or plant EOs are an alternative to this and are used as insect and arthropod repellants. Because of their natural origin, they are relatively safe for human health and environmental friendly. These insect repellent plant molecules have been isolated from a large number of plants, mainly from their essential oils. Some of them have been commercialized in certain formulations as insect repellents (Chaubey 2007). Synthetic insect repellents are widely used to prevent infestation of stored grains, fruits, and other cellulosic materials by different pests, mostly arthropods. Similar circumstances occur for animals and human health. To control insects different insecticides have been used; these insecticides transmit to human pathogens. These days many of these insects are resistant to the chemicals, and it should be applied to larger amounts, due to the temperature changes, global warming, etc.; actually global warming has moved the mosquitoes to transmit malaria, dengue, and yellow fever into high altitude, some temperatures affecting these diseases. EOs are volatile and complex mixtures of hydrocarbons (monoterpenes and sesquiterpenes) with different functional groups (ethers, alcohols, aldehydes, esters, ketones, phenols, and phenol ethers). However, these chemicals can act as insect repellents, in particular if combined with other natural products. For example, to increase protection time, vanillin could be used with *C. winterianus* EOs. Among plant families, *Ocimium* spp., *Eucalyptus* spp., and *Cymbopogon* spp. are widely used as insect repellents. Similarly, some major compounds, such as citronellol, camphor, thymol, α-pinene, and limonene, have shown good insect repellent activity. Among the plant families that contain about 3000 EOs, approximately 10% of these EOs have commercial importance in pharmaceutical, food, and cosmetics industries. The United States Food and Drug Administration (FDA) considers EOs as insect repellents that are safe for human health and environmentally friendly (Trongtokit et al. 2005; Nerio et al. 2010). EOs from a large number of plant families showing the potential insect repellent activity are shown in Table 9.7.

Table 9.7 Essential oils exhibiting insect repellent activities

Family	Insect scientific name	Essential oil sources	References
Diptera	*Anopheles annularis; Anopheles culicifacies; C. quinquefasciatus*	*Mentha piperita*	Ansari et al. (2000)
Diptera	*A. aegypti*	*Z. piperitum*	Choochote et al. (2007)
Diptera	*Culex pipiens*	*Pimpinella anisum; O. basilicum; Eucalyptus camaldulensis*	Erler et al. (2006)
Diptera	*A. aegypti*	*Baccharis spartioides, Aloysia citriodora*	Gillij et al. (2008)
Diptera	*Mansonia*	*Eucalyptus maculata citriodora*	Hadis et al. (2003)
Diptera	*A. gambiae*	*Croton pseudopulchellus, Mkilua fragrans, Endostemon tereticaulis, Ocimum forskolei, Ocimum fischeri, Plectranthus longipes*	Odalo et al. (2005)
Diptera	*A. gambiae*	*Conyza newii, Tarchonanthus camphoratus, Tetradenia riparia, Lippia javanica, Lippia ukambensis, Plectranthus marrubioides*	Omolo et al. (2004)
Diptera	*A. aegypti*	*C. citratus*	Oyedele et al. (2002)
Diptera	*A. braziliensis*	*O. selloi*	Padilha de Paula et al. (2003)
Diptera	*Anopheles stephensi, A. aegypti, C. quinquefasciatus,*	*O. basilicum*	Prajapati et al. (2005)
Diptera	*Anopheles stephensi, A. aegypti, C. quinquefasciatus,*	*Rosmarinus officinalis*	Prajapati et al. (2005)
Diptera	*Anopheles stephensi, A. aegypti, C. quinquefasciatus*	*Cinnamomum zeylanicum*	Prajapati et al. (2005)
Diptera	*C. quinquefasciatus*	*C. citratus*	Pushpanathan et al. (2006)
Diptera	*C. quinquefasciatus*	*Zingiber officinalis*	Pushpanathan et al. (2008)
Diptera	*C. quinquefasciatus*	*Moschosma polystachyum*	Rajkumar and Jebanesan (2005)
Diptera	*C. quinquefasciatus*	*Solanum xanthocarpum*	Rajkumar and Jebanesan (2005)
Diptera	*A. dirus, C. quinquefasciatus*	*Curcuma longa L, C. winterianus, O. americanum*	Tawatsin et al. (2001)

(continued)

Table 9.7 (continued)

Family	Insect scientific name	Essential oil sources	References
Diptera	*A. dirus, C. quinquefasciatus*	*Z. limonella*	Trongtokit et al. (2005)
Diptera	*A. aegypti, C. quinquefasciatus, A. dirus*	*Pogostemon cablin*	Trongtokit et al. (2005)
Diptera	*A. aegypti, C. quinquefasciatus, A. dirus*	*Syzygium aromaticum*	Trongtokit et al. (2005)
Diptera	*A. aegypti*	*Z. limonella, C. nardus*	Trongtokit et al. (2005)
Diptera	*A. albopictus*	*E. globulus*	Yang and Ma (2005)
Diptera	*A. aegypti*	*D. caryophyllum*	Tunón et al. (2006)
Coleoptera	*T. castaneum*	*Nigella sativa, Trachyspermum ammi, Anethum graveolens,*	Chaubey (2007)
Coleoptera	*T. castaneum*	*B. salicifolia*	García et al. (2005)
Coleoptera	*T. castaneum*	*Artemisia annua*	Goel et al. (2007)
Coleoptera	*L. serricorne*	*Perilla frutescens, Thymus vulgaris, Satureia hortensis, Mentha piperita, Cinnamomum cassia, Litsea cubeba, Perilla frutescens*	Hori (2003)
Coleoptera	*Acanthoscelides obtectus*	*Laurus nobilis, Rosmarinus officinalis, E. globulus, Juniperus oxycedrus, Lavandula hybrid, Mentha microphylla, Mentha viridis, Apium graveolens*	Papachristos and Stamopoulos (2002)
Coleoptera	*Callosobruchus maculatus*	*O. basilicum*	Pascual and Ballesta (2003)
Coleoptera	*T. castaneum*	*Artemisia vulgaris*	Wang et al. (2006)
Phthiraptera	*P. humanus capitis*	*Mentha pulegium*	Toloza et al. (2006)
Isoptera	*Coptotermes formosanus*	*Calocedrus macrolepis, Cryptomeria japonica, Chamaecyparis obtusa*	Cheng et al. (2007)
Thysanoptera	*Thrips tabaci*	*Rosmarinus officinalis*	Koschier and Sedy (2003)

Worldwide, *Cymbopogon* spp. produce the most widely used natural insect repellent. In tropical or forest regions, these families are used as mosquito repellents (Trongtokit et al. 2005; Moore et al. 2007). EOs extracted from these plant families

have been tested against the arthropod, *Cymbopogon excavates*. The results showed that EOs were 100% efficient for insect repellent activity up to 2 hrs. Likewise, when applied against *Anopheles arabiensis*, the repellent efficacy of these oils was decreased by 59.3% after 4 h (Govere et al. 2000). Vanillin (5%) mixed with *C. winterianus* EOs shows 100% efficacy up to 6 hrs against *A. aegypti*, *C. quinquefasciatus*, and *A. dirus* (Tawatsin et al. 2001). However, *C. nardus* and *C. flexuosus* oils were inactive against *Cydia pomonella* (Lepidoptera) and *Lasioderma serricorne* (cigarette beetle) (Landolt et al. 1999). Eucalyptus oils show high repellent activity against Mansonia mosquitoes, *Pediculus humanus capitis*, *Ixodes ricinus*, and *Aedes albopictus* (Hadis et al. 2003; Yang and Ma 2005; Jaenson et al. 2006; Toloza et al. 2008), as well as moderate activity against *A. aegypti* and *C. pomonella* (Trongtokit et al. 2005; Gillij et al. 2008), but no activity against *L. serricorne* (Hori 2003). *Ocimum* spp. EOs are also found as an efficient insect repellent (Padilha de Paula et al. 2003). The insect pests, such as *A. aegypti, A. dirus*, and *C. quinquefasciatus*, were potentially repelled by the *O. americanum*) essential oil (Tawatsin et al. 2001). Similarly, *O. selloi*, *O. basilicum*, and *O. gratissimum* EOs were potentially effective repellents against *A. braziliensis* (Padilha de Paula et al. 2003) while exhibiting no repellent activity against *L. serricorne* and *C. pomonella* (Landolt et al. 1999; Hori 2003). Fresh leaves of EOs extracted from *O. sanctum, M. piperita*, *E. globulus*, and *P. amboinicus* oils show potential insect repellent against *Aedes aegypti* (Lalthazuali and Mathew 2017). Some of the EOs such as *J. procera*, *C. citrates*, *C. zeylanicum*, *R. officinalis*, *Z. officinale*, *A. marmelos*, *L. acidissima*, *S. indicus*, *S. amaranthoides*, *C. odorata*, *D. elata*, *C. longa*, *P. heyneanus*, and *Z. limonella* show against *Anopheles arabiensis*, *Culex tritaeniorhynchus*, *Anopheles subpictus*, *Culex quinquefasciatus* (mosquitoes), *Aedes aegypti* (mosquitoes), *Anopheles stephensi* (malaria), and *Aedes albopictus* (mosquitos) strong insect repellent activity in laboratory level, respectively (Govindarajan 2011; Govindarajan et al. 2015; Karunamoorthi et al. 2014; Reegan et al. 2015; Das et al. 2015).

9.3.8 Antimutagenic Properties of Essential Oils

Antimutagenic properties arise due to the inhibition of diffusion of the mutagens into the cells, antioxidant and direct radical scavenging activity, inactivation of mutagens and produced by a mutagen, antioxidant activity of enzyme cell activation, and inhibition of metabolic conversation of P450 of promutagens into mutagens, for instance, by plant extracts (Sharma et al. 2001; Ipek et al. 2005). Plant extract constituents, such as superoxide dismutase (enzyme), glutathione, N-acetylcysteine, retinoids, carotenoids, flavonoids, and other polyphenols, are known to function as reactive oxygen species (ROS) scavengers that can prevent mutagenesis (Racchi 2013; Toscano-Garibay et al. 2017). EOs or their individual components, such as α-bisabolol, aflatoxin B1, 2-aminoanthracene, benzo-a-pyrene, and 2-aminofluorene, potentially inhibit induced mutagenesis and moderate N-oxide, 4-nitroquinoline, and 2-nitrofluorene induced mutagenesis while having less or no induced mutagenesis for sodium azide and nitro-o-phenylenediamine

(Gomes-Carneiro et al. 2005). The antimutagenic effect of α-bisabolol is due to the interaction of it with promutagen biotransformation enzymes. *Salvia officinalis* EOs show the potential inhibition of UVC-induced mutagenesis in *Salmonella typhimurium*, *E. coli*, and *Saccharomyces cerevisiae* (Dudai et al. 2005; Vukovic-Gacic et al. 2006). In an experiment, Idaomar et al. (2002) treated *Drosophila melanogaster,* with EOs of *Ledum groenlandicum*, *Ravensara aromatica,* and *Helichrysum italicum* significantly reduced the induced mutation frequency. Likewise, *Origanum compactum* EOs showed a potential antimutagenic effect against the mutagen, urethane (Mezzoug et al. 2007). *O. majorana*, *C. sinensis*, *C. latifolia*, *A. aucheri*, *A. ciniformis*, and *J. leptoloba* EOs show potential antimutagenic activity against *S. typhimurium* strains TA97a, TA98, TA100, TA100, and TA1535 (Fernandesa et al. 2015; Taherkhani. 2015, 2016; Dantas et al. 2016; Toscano-Garibay et al. 2017).

9.3.9 Phototoxicity

Plant molecules, such as furanocoumarins and coumarins present in grapefruit peel oil and citrus plants oils, are photoactive in nature. For example, citrus EOs contain psoralen (a furocoumarin) that binds with DNA under ultraviolet A (UVA) light, causing it to become highly cytotoxic and mutagenic due to the formation of mono and diadducts in DNA (Lang and Buchbauer 2012; Raut and Karuppayil 2014). However, in dark conditions, cytotoxic and mutagenic activity is not detected (Dijoux et al. 2006; Bakkali et al. 2008). Cytotoxicity and phototoxicity depend on the EOs which contain the chemical constituents that produce free radicals according to the sunlight exposure. Wood oil (*Fusanus spicatus*) is cytotoxic but not phototoxic (Dijoux et al. 2006; Bakkali et al. 2008; Raut and Karuppayil 2014). EOs producing reactive oxygen species (ROS) destruct the cellular and organelle membranes, prooxidants on proteins, and DNA. Under sunlight, oxygen singlets occur, due to reactive oxygen species producing energy on excitation. This may be due to the destruction of the polysaccharides, nucleic acids proteins, and enzymes and, in some times, causes the formation of adducts with DNA and lipid membranes. With or without light, free radical generation depends on the chemical constituents present in the EOs. *Citrus aurantium* and *Cymbopogon citratus* EOs show potential cytotoxic and phototoxic activity (Dijoux et al. 2006). Thus, these photoactive compounds find their application in biomedicine fields including photochemotherapy.

9.3.10 Carcinogenicity of Essential Oils

EOs are potentially cytotoxic without being mutagenic. Thus, carcinogenicity of EOs and their constituents are considered carcinogenic as they are involved in the metabolic activation of secondary carcinogens (Guba 2001). EOs like *S. sclarea* and *M. quinquenervia* produce estrogen secretions, which could induce estrogen-dependent cancer. Major chemical compounds, such as flavins, porphyrins,

hydrocarbures, and cyanins, are photosensitive molecules that could cause skin cancer. Under ultraviolet A radiation, EOs containing psoralen are also photosensitive to light and therefore could induce cancer and DNA adducts (Lesgards et al. 2014; Romeilah. 2016; Choucry. 2017). EOs of *Mentha* species containing pulegone as one of the major constituents is known to induce carcinogenicity through metabolism generating glutathione (Zhou et al. 2004). *Sassafras albidum* and *Ocotea pretiosa* EOs contain safrole, and *Laurus nobilis* and *Melaleuca leucadendron* EOs contain methyl eugenol as the major constituent. Safrole and methyl eugenol (phenylpropenes) could induce carcinogenic metabolites in rodents (Burkey et al. 2000; Liu et al. 2000; Gautam et al. 2014). D-limonene from citrus and estragole from *O. basilicum* EOs could induce carcinogenic mutations in male rats and mouse models (Anthony et al. 1987; Miller et al. 1983; Bayala et al. 2014; Chen et al. 2017).

9.3.11 Essential Oils as Antiprotozoal Agents

Different protozoan diseases are very important to public health, such as malaria, trichomoniasis, giardiasis, and leishmaniasis caused by *Plasmodium* sp., *Entamoeba histolytica*, and *Trypanosoma cruzi* species, respectively. Availability of antiprotozoal drugs is limited, and their prolonged use causes side effects (Sauter et al. 2012). Hence, plant extracts and EOs could be a safer treatment alternative for protozoal diseases (Sauter et al. 2012). For example, *Thymus vulgaris* essential oil, thymol, is the major component that inhibits trypanosomal parasite through damage of plasma membrane (Santoro et al. 2007a, b; Saeidnia and Gohari 2012). Compared to *T. vulgaris*, *C. citrates* and *O. gratissimum* EOs show a better antitrypanosomal activity. Terpenoids like thymol, carvacrol, and linalool are known to inhibit *Entamoeba histolytica*. EOs from *M. alternifolia*, *C. copticum,* and *L. angustifolia* show potential protozoal effects (Carson et al. 2006; Mansoor et al. 2011). *C. citrates*, *Origanum* spp., *L. multiflora*, *O. gratissimum*, and *S. thymbra* EOs exhibit a potential antimalarial activity (Tchoumbougnang et al. 2005; El babili et al. 2011). Specifically, *C. cajucara*, *C. citrates*, *O. gratissimum*, *A. millefolium*, *A. abrotanum*, *C. ambrosioides*, *P. caribaea*, and *Piper* spp. EOs show antileishmanial activity (Santin et al. 2009; Santos et al. 2010; Ahmed et al. 2011; Tariku et al. 2011).

9.4 Economic Importance of Essential Oils

In the global markets, EOs and their derived molecules are widely used, such as in perfumes and cosmetics, as well as in food, pharmaceutical, and agricultural industries. Throughout Europe, Africa, and Asia, as well as in the USA, EOs have been used in cosmetics (skin creams, body lotions, soaps, perfumes, shampoos, etc.), medicinal industry (pharmaceutical and bulk drug industry, aromatherapy products, and medicinal supplements), and food industry (herbs, spices, and additives) (Nakatsu et al. 2000; Hussain et al. 2008; Teixeria et al. 2013; Swamy and Sinniah 2015, 2016). Essential oil production has exceeded 70,000 tons per annum,

and the main producers are the USA, Brazil, China, India, Australia, Indonesia, Malaysia, Thailand, Sri Lanka, South Africa, Italy, Russia, Nepal, Bangladesh, Germany, and Pakistan. For example, clove, celery, basil, and lemongrass EOs are mainly produced in India; rosemary and lavender EOs are usually grown in Spain and France; geranium and rose geranium EOs are endemic to Africa; and tea oils are grown mostly in Australia and South Wales (Bedi and Tanuja 2010). Among 3000 EOs, only 10% have been commercially exploited (Djilani and Dicko 2012). EOs such as basil, orange oil, corn mint, peppermint, eucalyptus, citronella, lemon, clove, camphor, and cumin oils are medicinally important worldwide (Hussain et al. 2008; Bedi and Tanuja 2010). Based on purity, composition, and material sources, their market value can vary considerably. Globally, more than 80% of the people are depending on the plant-based traditional medicine (Akhtar et al. 2014; Arumugam et al. 2016; Swamy and Sinniah 2015; Swamy et al. 2012). Generally, anise and coriander oil cost $20 to $30 per pound, while thyme, dill, and calendula might cost >$100. Moreover, sweet basil, fennel, clary sage, lavender, and caraway EOs could cost $50–$80 per pound. World wide EOs in global markets estimate more than 62 billion USD per year, and it is imagined by the year 2050 to grow up to 5 trillion USD per year. World wide, plant-based (Natural Products) molecules have high demand in the food industry, perfumes, and cosmetic and pharmaceutical substances. Internationally, more than 250 EOs trade at the value of 1.2 billion USD per year (Akhtar et al. 2014; Arumugam et al. 2016; Bhattacharya et al. 2014; Swamy et al. 2016). Still there are wide differences between low- and high-income peoples in the worldwide annual economic demand of pharmaceutical substances. An average spending by each person on pharmaceutical substances per year in low-income countries, such as India, Nigeria and Sri Lanka is about 0.75 US$, 1.2 US$, 0.58 US$, respectively. While, the same in high-income countries like Japan, the USA, and Germany is 38.5 US$, 35.10 US$, and 53.4 US$, respectively. This indicates clearly that there is a significant difference in the expenditure for pharmaceutical products between low- and high-income nations. This is because people in low-income nations largely depend on herb-based medicines (Lu et al. 2011; Bukar et al. 2016).

9.5 Conclusions and Future Prospects

The EOs could act as antimicrobial agents in personal hygiene, air purification, internal use, insecticides and preservations of crops, and food products because of its non-genotoxic risks. However, some EOs showed antimutagenic, anticarcinogenic, photosensitive, and antidiabetic activities. Recent studies on EOs and their chemical constituents, such as polyphenols, flavonoids, and alcohols, showed their potential in reducing tumor cell proliferation, and murine leukemia. They have also been used in cosmetic, food, and pharmaceutical industries, chemotherapy, and prevention of drug resistance against infectious and noninfectious diseases. Although lot of works have been done on the EOs, but still future researches are needed to optimize their doses in combination with existing drugs for the safer use as a medicine for patients.

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