Annals of Phytomedicine 6(2): 5-46, 2017
DOI: 10.21276/ap.2017.6.2.2; Print ISSN : 2278-9839 and Online ISSN : 2393-9885

Ann. Phytomed., 6(2): 5-46 (2017)

Review article

Review on extraction methods, antioxidant and antimicrobial properties of volatile oils

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Received October 3, 2017: Revised November 14, 2017: Accepted November 25, 2017: Published online December 30, 2017

Abstract

A large range of technologies are available for the extraction (Conventional and Non-Conventional) of bioactive natural compounds and volatile oils from medicinal and aromatic plants. The choice depends on the economic feasibility and suitability of the process to particular situation. The various processes of production of volatile oils are reviewed in this paper including the advantages and disadvantages of different extracting methods. Volatile oils (VOs) have been used from ancient times as nutraceuticals because of its ease availability, cost effective and safety. Numerous studies have been demonstrated that antioxidant, antimicrobial, anticancer, antidiabetic, *etc*., properties of volatile oils obtained from various plants. Hopefully, this review on the VOs will help to academicians and researchers as well as scientists, working in industries to further explore the potentials of VOs as antioxidants and antimicrobials for development of new pharmaceuticals in future.

Key words: Volatile oils, extraction, antioxidants, antimicrobial, essential oil

1. Introduction

Volatile oils are odorous, volatile principles of plant and animal sources, evaporate when exposed to air at ordinary temperature and, hence known as volatile orethereal oils. These represent essence of active constituents of the plant and, hence also known as essential oils.

These are chemically derived from terpenes (mainly mono and sesquiterpenes) and their oxygenated derivatives. These are soluble in alcohol and other organic solvents, practically insoluble in water, lighter than water (clove oil heavier), have high refractive index and most of them are optically active. Volatile oils are colourless liquids but when exposed to air and direct sunlight these become darker due to oxidation. (Ahmad *et al*., 2012)

1.1 Sources of natural volatile oils

Different plant organs parts containing natural volatile oils are shown in (Handa *et al*., 1999) Figure 1.

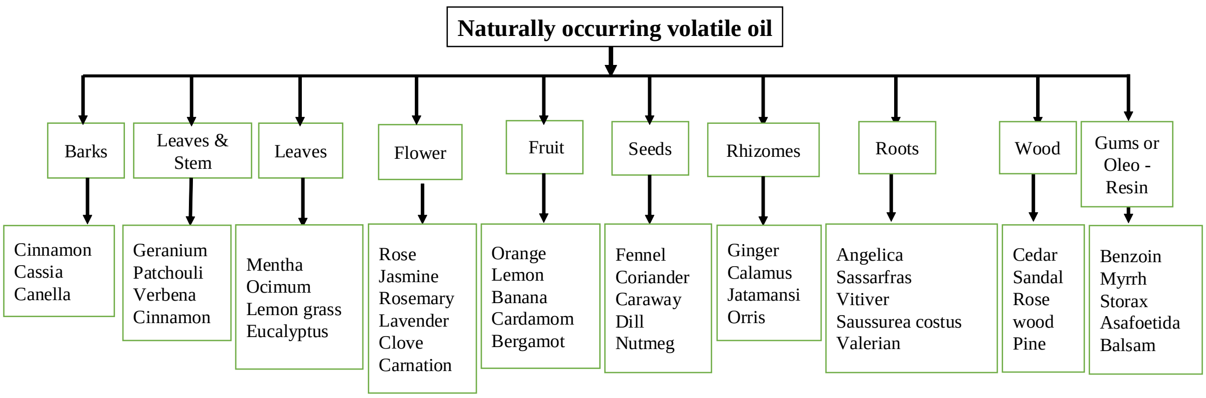

Figure 1: Plant organs parts containing natural volatile oils

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1.2 Specialized plant structures that produce and store volatile oils

Since times, the aromatic plants have been used by humans as therapeutic ailments due to the presence of the secondary metabolites (*i.e.*, volatile oils). These volatile oils (VOs) are important organic molecules because of natural essence and naturally synthesized in specialized cells of plants (Taylor *et al*., 2007.; Holopainen, 2004.; Elmadfa, 2003) such as glandular trichomes, osmophores, ducts and cavities. (Prod *et al*., 2016).

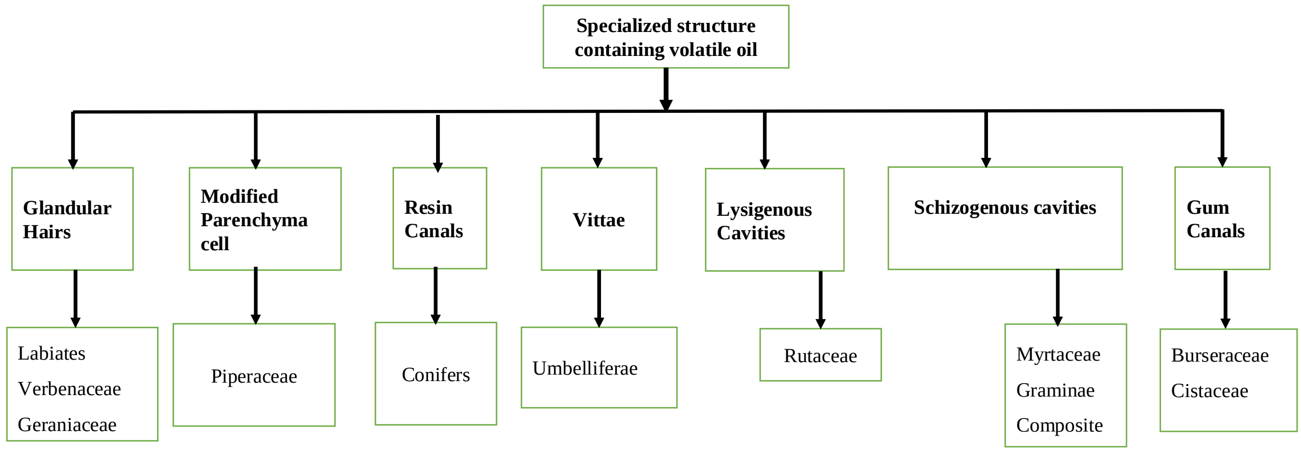

Figure 2: Families with specific plant tissues responsible for producing volatile oils

There are several plant families containing volatile oils in specialized parts shown in Figure 2.

It is well known that when a geranium leaf is lightly touched, an odour is emitted because the longstalked oil glands are fragile. Similarly, the application of slight pressure on a peppermint leaf rupture the oil gland and release oil. In contrast, pine needles and eucalyptus leaves do not release their oils until the epidermis of the leaf is broken. Hence, the types of structures in which oil is contained differ depending on the plant type and are plant family specific. (Handa *et al*., 1999).

2. Chemical constituents of volatile oil

Major constituents of volatile oils are shown in Figure 3, from which, it is clear that most volatile oils consist of hydrocarbons, alcohols, aldehydes, ketone, acids, phenols, phenol ethers, esters, oxides, lactones, and terpenes. Among these, the oxygenated compounds (alcohols, esters, aldehydes, ketone, lactones, and phenols) are principal odour source. They are most stable against oxidizing and resinifying influences than other constituents. On the other hand, unsaturated constituents like monoterpenes and sesquiterpenes have the tendency to oxidize or resinify in the presence of air and light (Bakkali *et al*., 2008; Mohamed *et al*., 2010).

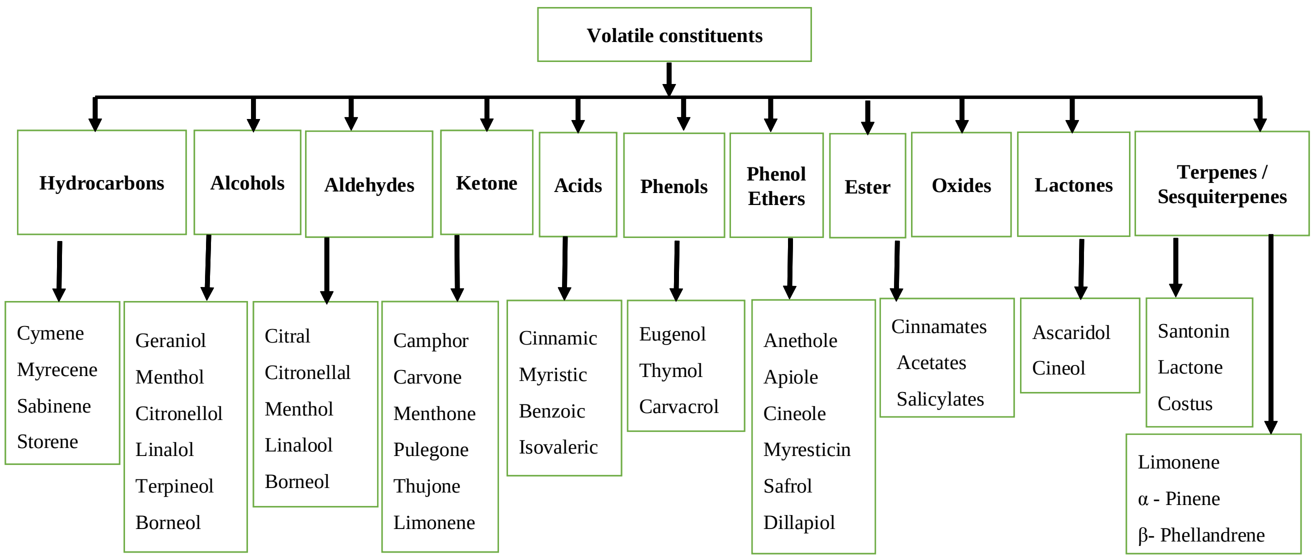

Figure 3: Chemical classification of volatile oils along with their examples

3. Extraction of volatile oils

Volatile oils can be extracted from several plants with different parts by various extraction methods. The manufacturing of volatile oils and the method used for extraction are normally dependent on botanical material used. Extraction method is one of prime factors that determine the quality of volatile oil. Extraction of volatile oils can be carried out by various means, as shown in Figure 4.

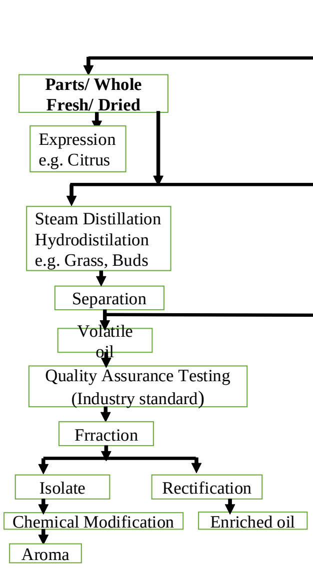

Figure 4: Methods of producing volatile oils from plant materials (DeSilva *et al.*, 1995)

3.1 Steam distillation

Steam distillation (Figure 5) is the most commonly used method for plant volatile oil extraction (Reverchon *et al.*, 1992). The proportion of volatile oils extracted by steam distillation is 93% and remaining 7% can further extracted by other methods (Masango, 2005). Basically, the plant material is placed in boiling water or heated by steam. The heat applied is the main cause of burst and break down of cell structure of plant material. As consequence, the aromatic compounds or volatile oils from plant material are released (Perineau *et al.*, 1992; Babu and Kaul, 2005). The temperature of heating must be enough to break down the plant material and release aromatic compound or volatile oil. A new process design and operation for steam distillation of volatile oils to increase oil yield and reduce the loss of polar compounds in waste water was developed (Masango, 2005). The system consists of a packed bed of the plant materials, with steam source and steam passes through it. Thus, it requires the minimum amount of steam in the process and the amount of water in the distillate is reduced. Also, water soluble compounds are dissolved into the aqueous fraction of condensate at a lower extent (Masango, 2005). Yildirim *et al.* (2004), reported that the 2, 2 diphenyl-1-picryl hydrazyl (DPPH) radical scavenging activity of volatile oils from steam distillation process were markedly higher than those of oils extracted using hydrodistillation. It is a simple method with high oil yield and low cost. The components of the oil are less susceptible to hydrolysis and polymerization. The loss of polar compounds is minimized by controlling refluxing oil quality is more reproducible.This method is time consuming and temperatures used may alter the chemistry compounds.

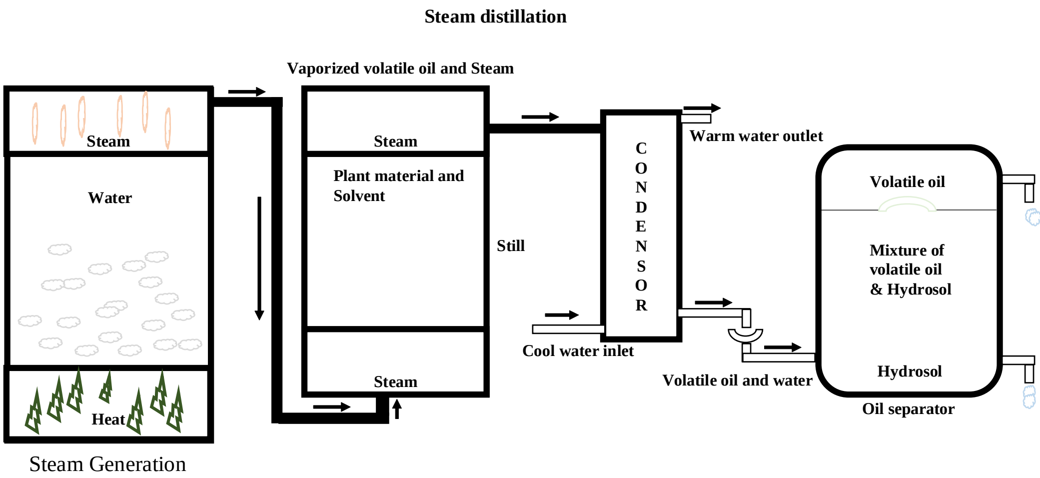

Figure 5: Schematic representation of steam distillation method

3.2 Hydrodistillation

Hydrodistillation (Figure 6) now becomes the standard method of volatile oil extraction from plant materials such as flower or wood, which is often used to isolate non-water soluble natural products with high boiling point. The process involves the complete immersion of plant materials in water, followed by boiling. This method protects the oils extracted to a certain degree since the surrounding water acts as a barrier to prevent it from overheating.

Hydrodistilation

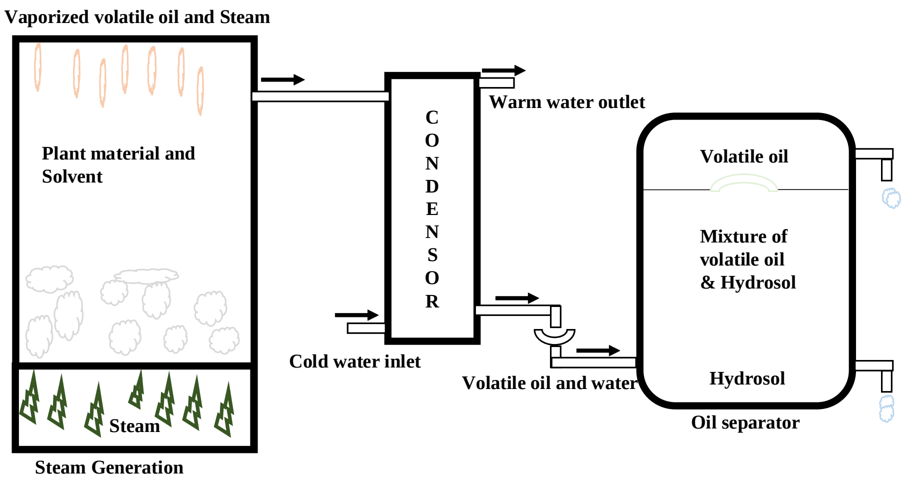

Figure 6: Schematic representation of hydrodistillation method

The steam and volatile oil vapour are condensed to an aqueous fraction (Denny, 1969), the material can be distilled at a temperature below 100°C, however, by this method, exhaustive extraction is not possible, some esters are partly hydrolyzed as well as sensitive compounds like aldehydes polymerized.

3.3 Traditional Indian Bhabkka method

The primitive, traditional Indian system of volatile oil distillation, that is bhabkka method, is also based on water distillation (Figure 7).

In this process, the plant material is entirely covered with water in a distillation still, which is made up of copper and is known as *deg*. This *deg* (boiler) is placed in a brick furnace. Another copper vessel with a long neck is placed in a water tank or natural pond to serve as a condenser. A bamboo pipe is used as the vapour connection and mud is used to seal the various joints. The water is boiled, the oil vapours along with steam are condensed in the copper vessel, and the oil is separated. The capacity of one *deg* is around 40 kg/batch. In India, these types of units are still being used in Kannauj (Uttar Pradesh) and in the Ganjam district of Orissa, for the preparation of *Rooh* and Attars of Gulab, Kewda, Khus, Rajnigandha and *Bela*. These units can easily be transported from one place to another, but are not suitable for large scale distillation of aromatic crops like grasses and mints (Kapoor, 1991; Rao *et al*., 1999).

Traditional Indian Bhabkka method

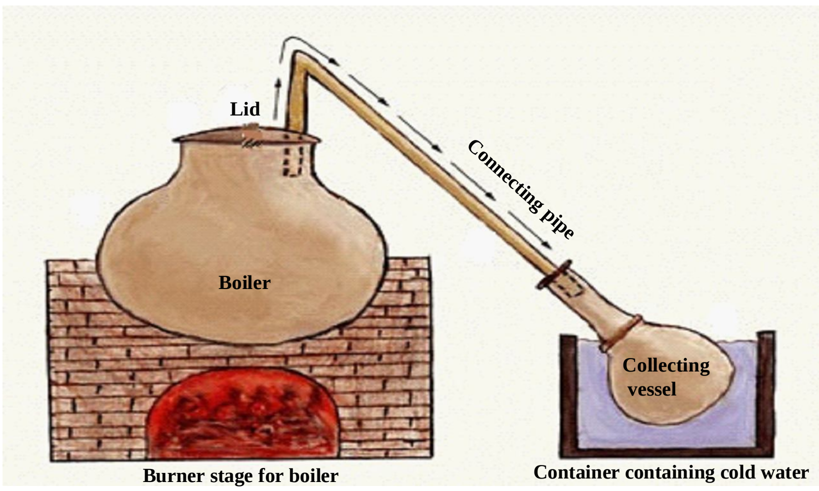

Figure 7: Traditional distillation unit (Bhabkka method)

The cost of process equipment is extremely low and design of the still, condensers and collection flask are very simple. There is no need of electricity where as plant materials used has tendency to agglomerate into impenetrable mass and, thus water distillation is preferred method. The plant material near the bottom of the still comes in direct contact with the fire from the furnace, which may char and impart an objectionable odour to the volatile oil. The prolonged use of hot water can cause hydrolysis of esters since, in this method heat control is difficult, which may lead to variable rates of distillation as well as process is slow and distillation times are much longer than those of steam distillation.

3.4 Hydrodiffusion

Legast and Peyron *et al.* (1983) first described the technique of oil isolation, which was called hydrodiffusion (Figure 8). Unlike traditional steam distillation, hydrodiffusion works on the diffusion principle of allowing steam to enter the top of the plant charge and diffuse through the charge by gravity. The process uses the principle of osmotic pressure to diffuse oil from the oil glands. The system is connected to a steam source, and low-pressure steam is passed into the plant material from a boiler. The condenser, which is directly under the basket within the still is of the tube type. The oil and water are collected below the condenser in a typical oil separator. It is an efficient process that is easy to use with higher yield. The process is beneficial because of the reduced steam consumption and hydrolysis due to shortened time. It utilizes higher energy, looses some volatile components, with low extraction efficiency and long extraction time.

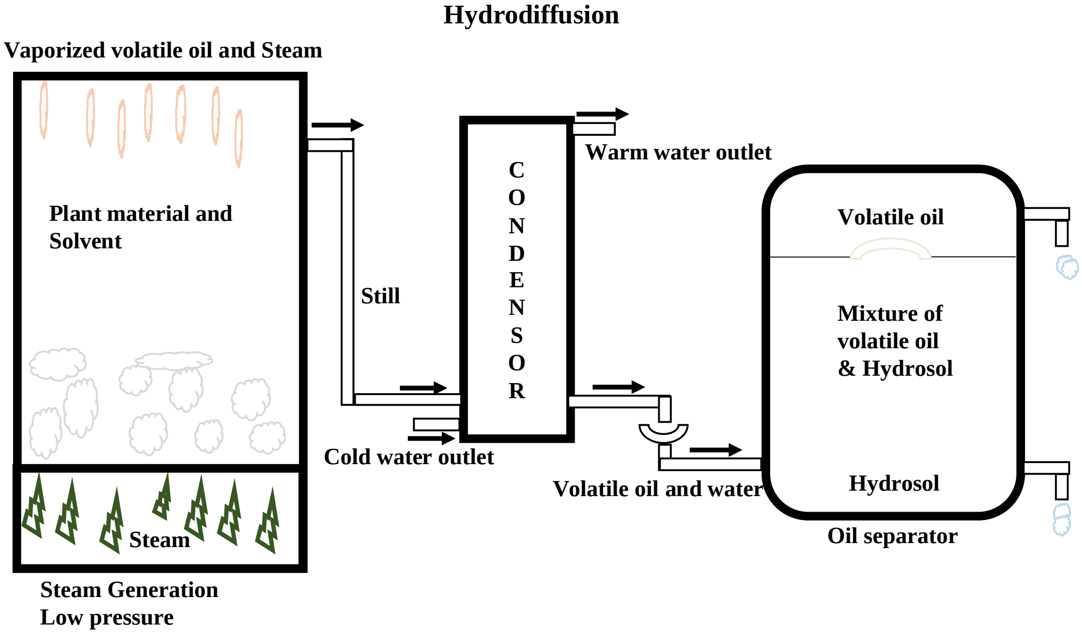

Figure 8: Schematic representation of hydrodifusion method

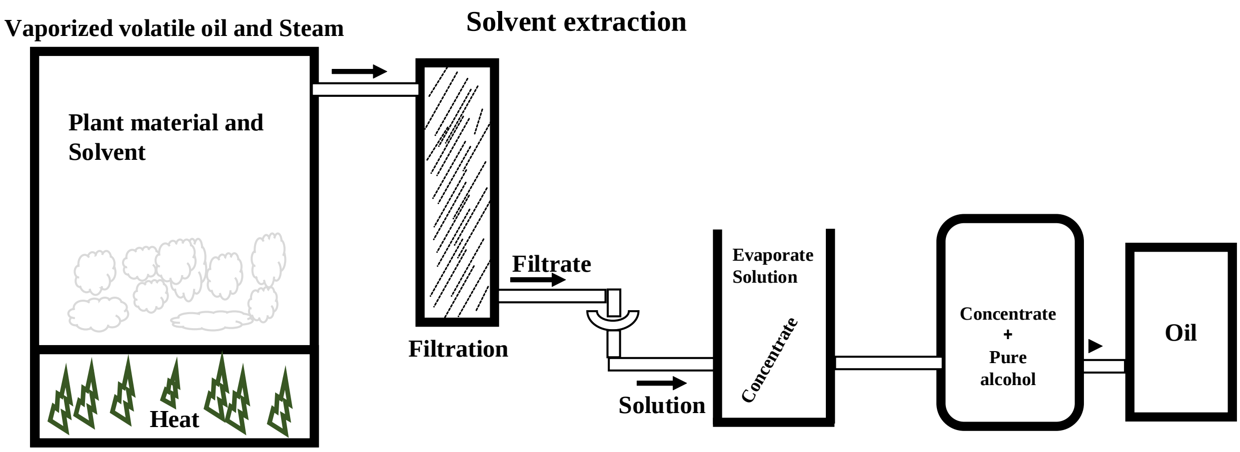

Figure 9: Schematic representation of solvet extraction method

3.5 Solvent extraction

Conventional solvent extraction (Figure 9) has been implemented for fragile or flowers which could not tolerate the heat of steam distillation. Different solvents including acetone, hexane, petroleum ether, methanol, ethanol, ethyl acetate and dichloromethane, can be used for extraction (Areias *et al*., 2000; Pizzale *et al*., 2002; Kosar *et al*., 2005). In general, the solvent is mixed with the plant material and then heated to extract the essential oil, followed by filtration. Subsequently, the filtrate is concentrated by solvent evaporation. The concentrate is resin (resinoid), or concrete (a combination of wax, fragrance, and essential oil), which is then mixed with pure alcohol to extract the oil and distilled at low temperature. The alcohols absorb the fragrance and when the alcohol is evaporated, the aromatic absolute oil is remained. However, this method is a relatively time-consuming process, thus making the oils more expensive than other methods (Li *et al*., 2009).This method is simple with higher yield, large selectivity and flexibility. However, it is a time consuming with emulsion formation and additional requirement of pre-concentration step.

3.6 Cold expression

This technique is an extraction without heating for essential oil of citrus family (Figure 10). The principle of this mechanic process is based on machine squeezing the citrus pericarps at room temperature for the release of essential oils which are washed in cold running water. The essence is then isolated by decantation or centrifugation. Although, this method retains a high value of citrus odour, the high consumption of water can affect essential oils quality as the result of the hydrolysis, the dissolution of oxygenated compounds and the transport of microorganism. Several new physical processes appear more popular for the reason of avoiding such deteriorations. The oleaginous cavities on the peel are pressed to burst by two horizontal ribbed rollers or a slow-moving Archimedean screw coupling to an abrasive shell, thus essential oils are bent to release. The oil in water emulsion is separated after rinse off with a fine spray of water. Besides the machines, which treat citrus peels only after removal of juices and pulps are known as sfumatric, while those which process the whole citrus fruit are called pelatrici (Guenther, 1948).

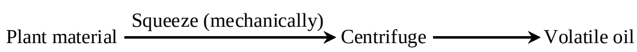

Figure 10: Schematic representation of cold expression methods for extraction of citrus fruits (Y.Li *et al*., 2014)

This is simple method with high oil yield of good quality. However,required long extraction time with high energy.

3.7 Green extraction methods

The green extraction (Figure 11) methods are either free from hazardous organic solvents, or require reduced quantity of solvents and, hence target compound are free from hazardous solvents. These extraction methods are employed under controlled temperature or without the involvement of heat, hence advantageous for extraction of thermolabile compounds, preventing them from degradation. Recently, clean techniques, such as solvent-free microwave, ultrasound-assisted extraction, microwave-assisted extraction, turbo distillation, simultaneous distillation extraction, pulsed electric field assisted extraction, sub-critical water extraction, super- critical fluid extraction are available. Green extraction for extracting volatile oils from complex matrices, have been developed where they can be used routinely (Aarti singh *et al*., 2015). This method is selective, nontoxic, and less time consuming, however required technical skills.

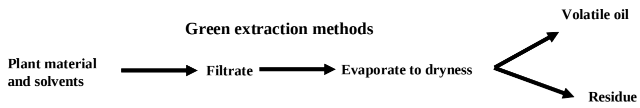

Figure 11: Schematic representationof green extraction method

3.8 Solvent free microwave extraction (SFME)

SFME (Figure 12) is a combination of microwave heating and dry distillation, performed at atmospheric pressure without any solvent or water. Isolation and concentration of volatile compounds are performed by a single stage (Lucchesi *et al*., 2004).

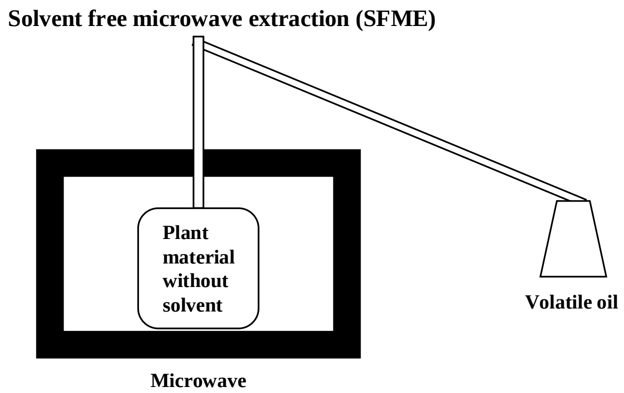

Figure 12: Schematic representation of solvent free microwave extraction method

Using oregano as a raw material, SFME offered significantly higher volatile oil yields (0.054 ml /g), compared to hydrodiffusion (0.048 ml/g) (Bayramoglu *et al*., 2008). When microwave power at 662W was used in SFME, process time was reduced by 80% compared with conventional process (Lopez Avila *et al*., 1994; Tomaniov *et al*., 1998). This method is environment friendly and rapid extraction of volatile oils from aromatic herbs, spices, and dry seeds. However, by this method, low boiling point hydrocarbon compounds may undergo decomposition.

3.9 Ultrasound extraction

In ultrasound extraction method (Figure 13),the sound waves of frequencies higher than 20 KHz, are used which causes rupture of the cell wall and diffusion of the solvent inside the cell, result in extraction of bioactive compounds (Takeuchi *et al*., 2009; Chemat *et al*., 2011).

This technique has been widely used for the extraction of nutritional material, such as lipids (Metherel *et al*., 2009), proteins (Zhu *et al*., 2009) flavouring components (Chen *et al*., 2007; Da Porto *et al*., 2009), essential oils (Kimbaris *et al*., 2006) and bioactive compounds, *e.g*., flavonoids (Ma *et al*., 2008), carotenoids (Sun *et al*., 2006; Yue *et al*., 2006) and polysaccharides (Iida *et al*., 2008; Chen *et al*., 2010; Wei *et al*., 2010; Yan *et al*., 2011).

Compared with traditional solvent extraction methods, ultrasound extraction can improve extraction efficiency, extraction rate, reduce extraction temperature and increase the selection ranges of the solvents (Vilkhu *et al*., 2008). Ultrasounds allow penetration of solvents to greater depths in sample matrices to facilitate the increased mass transfer of solutes to extraction solvent. However, high ultrasound waves bring about deleterious effects in bioactive constituents in plants by free radical formation and result in undesirable changes in extracted components.

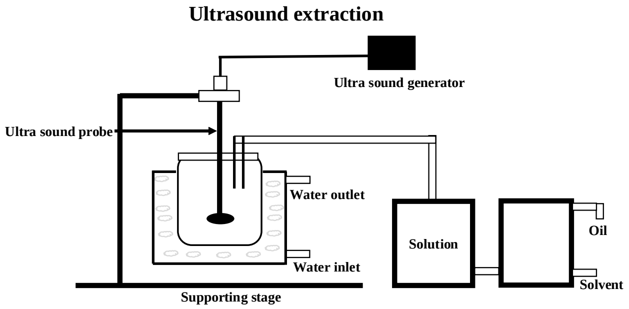

Figure 13: Schematic representation of ultra sound method

3.10 Microwave extraction

The use of microwaves extraction method (Figure 14) for isolating volatile oils has recently been reported (Deng *et al*., 2006). Microwave technology has allowed the development of rapid, safe and cheap methods for extracting volatile oil and does not require samples devoid of water (Chemat *et al*; 2006; Bousbia *et al*; 2009). Recently, extraction equipment that combines microwave energy with small volumes of solvent has appeared, resulting in the procedure known as microwave assisted extraction (Li *et al*., 2006). This method is use less energy, much lower solvent, and significantly faster extraction, though the efficiency of microwaves can be very poor, when either the target compounds are non-polar or when they are volatile.

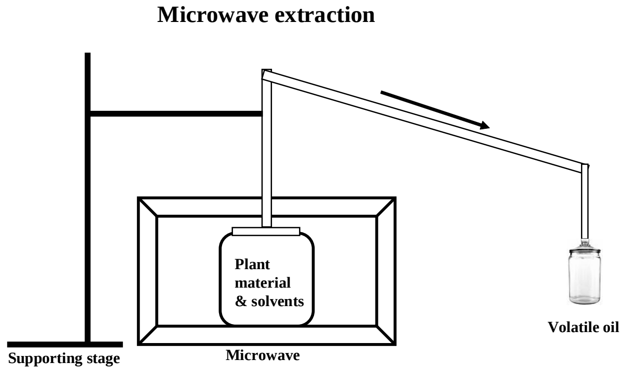

Figure 14: Schematic representation of green extraction method

3.11 Turbo distillation

This technique is developed to reduce energy and water consumption during boiling and cooling in hydrodistillation. The turbo extraction (Figure 15) allows a considerable agitation and mixing with a shearing and destructive effect on plant materials so as to shorten distillation time by a factor of 2 or 3. Furthermore, it is an alternative for extraction of essential oils from spices or woods, which are relatively difficult to distil. Besides, an ecoevaporator prototype could be added with aspect of the recovery and the reuse of the transferred energy during condensation for heating water in to steam (Chemat, 2010). This method is use less solvent, low energy consumption. However, high temperatures may alter the compounds.

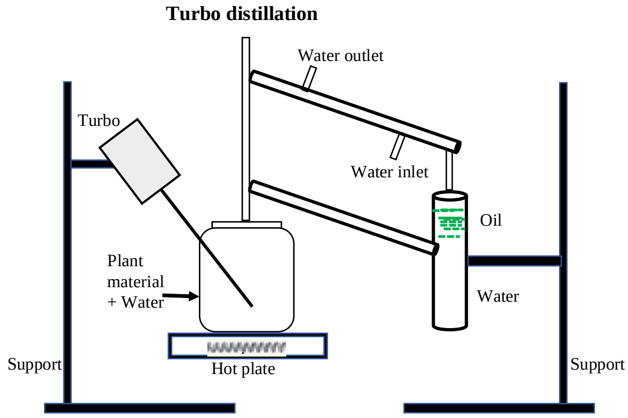

Figure 15: Schematic representation of turbo extraction method

3.12 Simultaneous distillation extraction (SDE)

In this technique, either hydrodistillation or steam distillation is combined with solvent extraction, which is frequently used for the isolation of volatile compounds from essential oils bearing plants. Solvent used should be insoluble in water and of high purity. SDE has been modified into several variants with the consideration of efficiency, scale and quality of end products (Jayatilaka *et al*., 1995; Blanch *et al*., 1996; Chaintreau, 2001; Altun and Goren, 2007; Teixeira *et al*., 2007) This method uses less solvent, However, loss of hydrophilic compounds.

3.13 Pulsed electricfield assisted extraction (PEF)

This technique applies short pulses at high voltage in order to create electro compression, which causes plant cells to be ripped open and perforated. The treatment chamber in PEF consists of at least two electrodes with an insulating region in between, where the treatment of plant materials happens (Jeyamkondan *et al*., 1999; Barbosa-Canovas *et al*., 2000; Fincan *et al*., 2004) This method is use low energy consumption, However only for pumpable materials.

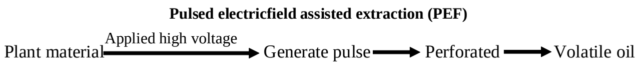

Figure 16: Schematic representation of turbo extraction method

3.14 Sub-critical water extraction

The hot water is used at temperatures between boiling (100°C) and critical point (374.1°C) of water. Water is maintained in its liquid form under the effect of high pressure. Under these conditions, the polarity of water decreases, which allows the extraction of medium polar and nonpolar molecules without using organic solvents.(Jimenez-Carmona *et al*., 1999; Ayala and Luque de Castro, 2001; Smith, 2002; Eikani *et al*., 2007; Giray *et al*., 2008). This method is simple, clean, safe adjustable the polarity of water and high ratio of oxygenated compounds can be extracted. However, expensive, and high energy consumption.

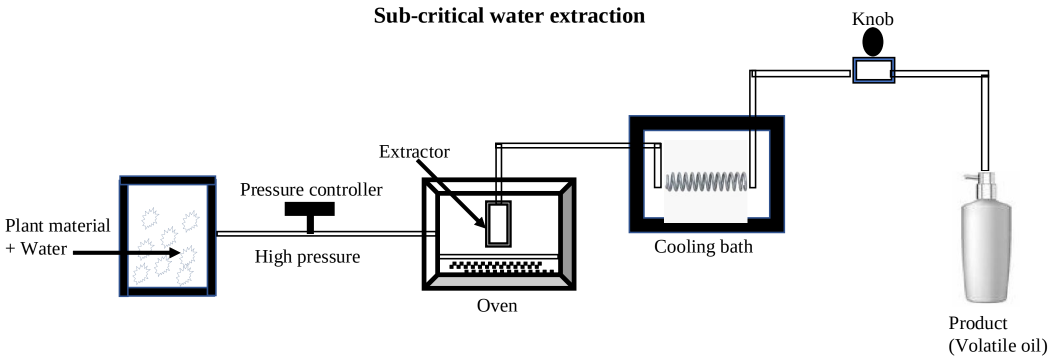

Figure 17: Schematic representation of sub-critical water extraction method

3.15 Supercritical fluid extraction

Supercritical fluid extraction (Figure 18) has been used for the extraction of fragrances from natural materials. The SFE is a separation technology that uses supercritical fluid as the solvent. Every fluid is characterized by a critical point, which is defined in terms of the critical temperature and critical pressure. Fluids cannot be liquefied above the critical temperature regardless of the pressure applied, but may reach a density close to the liquid state. A substance is considered to be a supercritical fluid when it is above its critical temperature and critical pressure. Several compounds have been examined as SFE solvents. For, *e.g.*, hydrocarbons such as hexane, pentane and butane, nitrous oxide, sulphur hexafluoride and fluorinated hydrocarbons (Brunner, 1994).

The main supercritical solvent used is carbon dioxide. Carbon dioxide (critical conditions 30.9°C and 73.8 bars) is cheap, environment friendly and generally recognized as safe. Supercritical CO_2 (SC-CO_2) is also attractive because of its high diffusivity and its easily tuneable solvent strength. Another advantage is that CO_2 is gaseous at room temperature and ordinary pressure, which makes analyte recovery very simple and provides solvent free analytes (Herrero *et al.*, 2010). Also, it is important for the sample preparation of food and natural products, and has the ability of SFE using CO_2 to be operated at low temperatures using a non-oxidant medium, which allows the extraction of thermallabile or easily oxidized compounds. The main drawback of SC-CO_2 is its low polarity, problem that can be overcome employing polar modifiers (Co solvents) to change the polarity of the supercritical fluid and to increase its solvating power towards the analyte of interest. The compounds that are added to the primary fluid to enhance extraction efficiency are known as co solvents. For, *e.g.*, the addition of 1 to 10% methanol or ethanol to CO_2 expands its extraction range to include more polar lipids. When the extraction is performed with SC-CO_2containing 20% ethanol, more than 80% of phospholipids are recovered from salmon roe (Tanaka *et al.*, 2004).

In a word, carbon dioxide is an ideal solvent for the extraction of natural products because it is non-toxic, non-explosive, readily available and easy to remove from the extracted product. SC-CO_2 extraction has been an excellent alternative method for seed oil extraction to replace conventional industrial methods. It becomes the focus of attention due to its chemical and physical properties. Furthermore, the extracted product has a good quality and scarcely needs any particular refining operation (Han *et al.*, 2009). Thus, SC-CO_2 technology has been applied to the extraction of oil from a large number of materials. This method is efficient and selective, though it is difficult to remove more polar compounds.

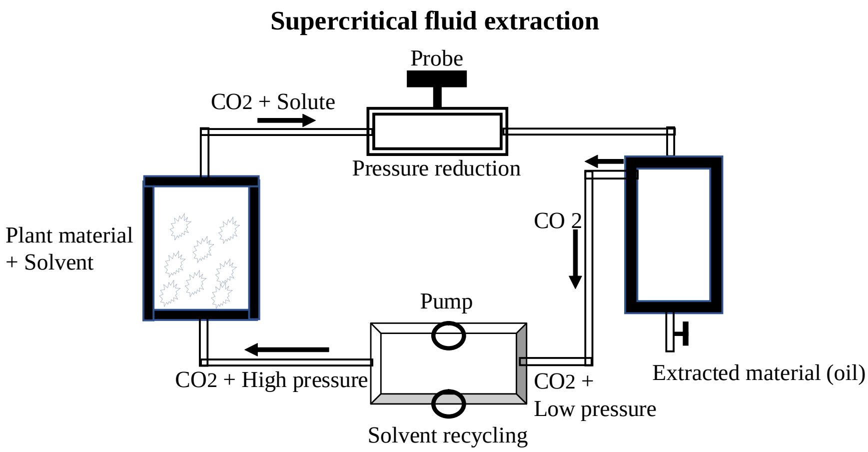

Figure 18: Schematic representation of supercritical fluid extractionmethod.

4. Comparison of different extracting method

Karl A.D. Swift *et al.* (1997) compared the two methods of extraction hydrodistillation hydrodiffusion in terms of oil yield and distillation times Table 1.

Table 1: Comparison of hydrodistillation and hydrodiffusion extraction method

Plant material	Hydrodistillation		Hydrodiffusion	
	Time(h)	% Yield	Time(h)	% Yield
Caraway fruits (Poland)	10	4.5	4	3.6
Cumin fruits (Poland)	12	3.7	4	5.0
Lavender (France)	1	0.75	0.5	0.73

Okoh *et al.* (2010), reported the effect of different extraction processes on yield properties of volatile oil from rosemary (*Rosmarinus officinalis* L.*)* by hydrodistillation and solvent free microwave extraction (SFME). The total yields of the volatile fractions obtained through hydrodistillation and SFME were 0.31% and 0.39%, respectively. The hydrodistillation oil contained more monoterpene hydrocarbons (32.95%) than SFME-extracted oil (25.77%), while higher amounts of oxygenated monoterpenes (28.6%) were present in the oil extracted by SFME in comparison with hydrodistillation (26.98%).

Golmakani *et al.* (2008), reported the microwave assisted hydro-distillation (MAHD), which is an advanced technique utilizing a microwave oven in the extraction process. The MAHD was superior in terms of saving energy and extraction time (75 min, compared to 4 hours in hydrodistillation).

Ohmicassisted hydrodistillation (OAHD) is another advanced technique (Gavahian *et al.*, 2012) reported which had the extraction time of 24.75 min, while hydrodistillation took 1 h for extraction of volatile oil from thyme. No change in compounds of the volatile oils obtained by OAHD was found in comparison with hydro-distillation.

Bousbia *et al.* (2009), compared the hydrodiffusion and innovative microwave hydrodiffusion and gravity methods for their effectiveness in the isolation of essential oil from rosemary leaves (*R. officinalis*). The microwave hydrodiffusion and gravity method exhibits the excellent advantages over traditional alternatives including shorter isolation times (15 min against 3 h for hydro-diffusion), environmental impact (energy cost is fairly higher to perform hydrodiffusion than that required for rapid microwave hydrodiffusion isolation), cleaner features (no residue generation and no water or solvent used), increased antimicrobial and antioxidant activities.

Farhat *et al.* (2011), studied the microwave steam diffusion, which is an advanced steam diffusion technique utilizing microwave heating process for extraction of essential oils from byproducts of orange peel. The essential oil extracted by microwave steam diffusion for 12 min had similar yield and aromatic profile to those obtained by steam diffusion for 40 min.

The microwave method offers the important advantages over traditional alternatives, such as shorter extractions times (30 min compared with 3 h for hydrodiffusion and 1h for cold pressing; better yields (0.24% compared with 0.21% for hydrodiffusion and 0.05% for cold pressing); environmental impact (energy cost is appreciably higher for performing hydrodiffusion and for mechanical motors (cold pressing) than that required for rapid microwave extraction); cleaner features (as no residue generation and no water or solvent used and high antimicrobial activities.(Farhat *et al.*,2007).

The list of volatile oils extracted by SC-CO_2 method from different plants is given in Table 2.

5. List of volatile oils extracted by supercritical fluid extraction using CO_2

Plant material	Analyte	Pressure (MPa)	Temperature(°C)	References
Daucus carota	Essential oil	10	40	Glisic *et al.*, 2007
Artemisia sieberi	Essential oil	30.4	50	Ghasemi *et al.*, 2007
Salvia lavandulifolia L.	Essential oil	90	40	Langa *et al.*, 2009
Valeriana officinalis L.	Essential oil	24.3 – 25.0	37	Safaralie *et al.*, 2010
Citrus reticulate	Peel oil	10.0	60	Danielski *et al.*, 2008
Coffea arabica	Green coffee oil	15.7	70	De Azevedo *et al.*, 2008
Juniperus communis L.	Essential oil	11.8	45	Orav *et al.*, 2010

6. Extraction of bio active and interesting compounds from plants by SFE

Source	Compound of interest	Extraction conditions	Reference
Coriandrum sativum	Volatile oil	CO_2, 90 bar, 40°C, 100 min	Grosso *et al.*, 2008
Hibiscus cannabinus	Oil	CO_2, 200 bar, 80°C, 150 min	Chan and Ismail., 2009
Hyssopus officinalis	Essential oil	CO_2, 90 bar, 40°C (dynamic)	Langa *et al.*, 2009
Salviahispanica	Oil	CO_2, 450 bar, 80°C, 300 min	Ixtaina *et al.*, 2010
Ramulus cinnamon	Volatile oil	$CO_{2,}$ 230 – 410 bar, 40-50°C	Liang *et al.*, 2008
Chrysobalanus icaco	Essential oil	$CO_{2,}$20kPa and 353.15 K	Vargas *et al.*, 2010
Vativeria zizanioides	Volatile oil	CO_2 + ethanol (5%) 200 bar, 40°C, 5 h	Talansier et al., 2008

7. Antioxidant activity of volatile oils (VOs)

Volatile oils (VOs) have been used from ancient times as nutraceuticals. VOs are substitute to synthetic additives for the food industry due to its ease availability, cost effective and safety. It is mainly obtained from several medicinal as well as aromatic plants by distillation method, shows good antioxidant properties and also used as food preservatives (Family and Nieto 2017). Numerous studies have been demonstrated that antioxidant properties of volatile oils. Antioxidant activity is depending on active constituent's present in volatile oil. The oxidative stress plays a key role to produce variety of diseases. The VOs extracted from different parts of plant are of vital importance to maintain health, might enhance human immune system and prevent diseases due to its antioxidant properties (Bessada, Barreira, and Oliveira 2015; Gramantieri and Bolondi 2002). Today's scenario, naturally occurring VOs are frequently used instead of synthetic antioxidants like BHA (butylated hydroxy anisole) or BHT (butyl hydroxy toluene) are suspected to be potentially harmful to human health (Opinion 2012; Red, 1996). The use of VOs as natural antioxidants is a field of growing interest, especially in food science and in complementary medicine.

9. Antimicrobial activity of volatile oils (VOs)

Since, plants and their products have been used for the primary resource of foods and medicines for human. The future medication exclusively depends on traditional medicine, specifically herbal medicines (Divya, 2015). Volatile oils (VOs), is one of the plant product have a wide application in traditional medicine, food flavouring, preservation as well as in fragrance industries(Kalemba and Kunicka, 2003). Some of the currently available synthetic drugs unable to inhibit many pathogenic organism, on other hand its produces carcinogenic effects, acute toxicity, and environmental hazard (Swamy *et al*., 2016). VOs are frequently used as antimicrobial agents from very ancient times because of thair feasibility and safety (Burt, 2004). Hopefully, future research on the bioactive natural products like VOs will help as antimicrobial agents.

8. Antioxidant compounds

Name of plant	Extraction method	Major constituents	Antioxidant method	IC50	Mechism of action	Reference
Boswellia dalzielii	Hydrodistillation	3-carene, α-pinene	DPPH	6.10 mg/l	Free radical scavenging capacity	Kohoude *et al*., 2017
Glycyrrhiza triphylla	_	β-caryophyllene, limonene	DPPH	100.40 ± 0.03 μg/ml	_	Shakeri *et al*., 2017
Anemopsis californica	_	Elemicin, methyleugenol	DPPH ABTS	_	_	Perez-Perez *et al*., 2017
Callistemon citrinus	Hydrodistillation	Eucalyptol, α-eudesmol	DPPH ABTS	1.49 mg/ml	Free radical	Larayetan *et al*., 2017
Gaillonia eriantha	Hydrodistillation	Camphor, octyl formate	DPPH Microplate method	_	_	Bahmanzadegan *et al*.,2017
Scutellaria immaculate	_	Acetophenone, eugenol	DPPH ABTS FRAP	2476.92 ± 15. 8 (mM Fe(II)/g).	Substantial reducing power	Mamadalieva *et al*., 2017
Thymus alternans	_	Nerolidol	DPPH ABTS FRAP	_	Weak inhibition on ABTS Radical and reducing power	Vitali *et al*., 2017
Porphyra tenera	Microwave hydrodistillation	Trans-beta-ionone, hexadecanoic acid	DPPH ABTS	177.83 μg/ml	Free radical, scavenging activity, Radical scavenging	Patra *et al*., 2017
Thymus spp.	_	Thymol, carvacrol	DPPH	339.22	_	Tohidi *et al*., 2017
Aphyllocladus Spartioides	_	α-pinene, cadinene	DPPH NO α-glucosidase	79 μg/ml 206 μg/ml 181 μg/ml	_	Celaya *et al*.,2017
Glycine max	_	Carvacrol	DPPH	162.35 μg/ml	Free radical scavenging capacity	Ghahari *et al*., 2017

Myrtus communis	_	α-pinene, 1,8-cineole,	DPPH FTC	375.23 µg/ml 249.41 µg/ml	Radical scavenging activity	Vafadar Shoshtari *et al.*, 2017
Rosmarinus eriocalyx	_	Rosmarinic acid, Carnosic acid	DPPH, ABTS FRAP, ORAC	_	_	Bendif *et al.*, 2017
Premna microphylla Turczaninow	Hydrodistillation	Blumenol C ß-cedrene	DPPH	451 mg/ml	Radical scavenging activity	Zhang *et al.*,2017
Leucas inflata Balf	_	Camphor Linalool	DPPH		Free radical	Mothana *et al.*, 2017
Solanum sisymbriifolium	Hydrodistillation	Hexadecanoic acid, Ambrettolide	DPPH	100 µg/ml	Free-radical-scavenging activity	Pasdaran *et al.*, 2017
Ammoides verticillate	Hydrodistillation	Thymol	DPPH	15.37µg/ml	-	Attou *et al.*, 2017
Foeniculum vulgare	_	Trans-anethole, limonene, α-pinene	DPPH β-carotene	74.2	_	Salami *et al.*, 2017
Artemisia absinthium	Hydrodistillation	Neryl isovalerate, geranyl isobutanoate	DPPH	_	Free radical scavenging activity	Hodaj-Çeliku *et al.*, 2017
Calamintha nepeta	Hydrodistillation	Pulegone	DPPH	_	Free radical scavenging activity	Hodaj-Çeliku *et al.*, 2017
Hypericum perforatum	Hydrodistillation	Caryophyllene oxide	DPPH	_	Free radical scavenging activity	Hodaj-Çeliku *et al.*, 2017
Sideritis raeseri	Hydrodistillation	Carvacrol	DPPH	_	Free radical scavenging activity	Hodaj-Çeliku *et al.*, 2017
Origanum vulgare	Hydrodistillation	Carvacrol	DPPH	76.5	Free radical scavenging activity	Hodaj-Çeliku *et al.*, 2017
Salvia officinalis	Hydrodistillation	Camphor, α-thujone	DPPH	_	Free radical scavenging activity	Hodaj-Çeliku *et al.*, 2017
Pituranthos scoparius	Hydrodistillation	Limonene, 1,8-cineole	DPPH β-carotene-linoleic acid	11.21 mg/ml	Free radical scavenging activity	Ksouri *et al.*, 2017
Mentha longifolia	Hydrodistillation	Carvone Limonene	DPPH	4.4-8.5 µg/ml	_	Anwar *et al.*,2017
Artemisia herba-alba	_	α-thujone, β-thujone	DPPH ABTS	6 µg/ml, 40 µg/ml	_	Bellili *et al.*, 2017
Artemisia judaica	Hydrodistillation	Piperitone, Davanone	DPPH ABTS FRAP	_	Radical-scavenging ability, Radical and for reducing power ability, Reduction of ferric cations	Hellali *et al.*,2017
Ferulago angulata	_	α-pinene, Cis-β-ocimene	DPPH	488 µg/ml	_	Ghasemi Pirbalouti *et al.*, 2016
Thymus spathulifolius	Hydrodistillation	Thymol, Borneol, Carvacrol	DPPH ABTS FRAP CUPRAC	3.82 and 0.22 mg/ ml,	Free radical scavenging, Reducing power	Ceylan *et al.*,2016

Eucalyptus globulus	Hydrodistillation	Sesquiterpenes	DPPH ABTS	27.0 ± 0.2 mg/ml,32.9 ±1.8 mg/ml	free radical scavenging, reducing power	Bey-Ould Si Said *et al.,* 2016
Thymus pannonicus	Headspace extraction	Citral	FRAP DPPH	68.09-124.58 mmol Fe_2^+/l	_	Arsenijevic *et al.,* 2016
Piper aequale	-	δ-elemene, β-pinene	DPPH	-	-	da Silva *et al.,*2016
Eruca longirostris	Hydrodistillation	Erucin, β-elemene	DPPH ABTS	_	_	Omri Hichri *et al* ., 2016
Juniperus rigida	_	Caryophyllene, α-caryophyllene	DPPH ABTS FRAP	_	_	Liu *et al.,* 2016
Blumea balsamifera	_	l-borneol	BCB DPPH	_	_	Yuan *et al.,* 2016
Artemisia absinthium	Maceration and SC-CO2	β-thujone, α-Farnesene	DPPH ABTS	_	_	Sidaoui *et al.,*2016
Ammi visnaga	Hydrodistillation	2-methylbutyl-2-methylbutyrate, linalool, limonene	DPPH	_	_	Keddad *et al.,* 2016
Citrus depressa	Cold centrifugation or Steam distillation	Limonene, γ-terpinene	DPPH	_	_	Asikin *et al.,* 2016
Nepeta sintenisii	Hydrodistillation	4aα,7α,7aβ-Nepetalactone, β-Farnesene	DPPH FRAP	7.16 mg/ml, 0.82 mM Fe_2^+/mg EO	_	Shakeri *et al.,* 2016
Rungia pectinate	Hydrodistillation	Trans-phytol, Hexahydrofarnesyl acetone	DPPH	_	_	Zhang *et al.,* 2016
Schinus areira	_	α-phellandrene	DPPH	-	-	Solis-Quispe *et al.,* 2016
Minthostachys spicate	_	Pulegone	DPPH	_	_	Solis-Quispe *et al.,* 2016
Hydnora abyssinica	-	Sabinene, α-terpinene	DPPH	-	-	Al-Fatimi *et al.,*2016
Syzygium aromaticum	_	Eugenol, β-caryophyllene, α-humulene	Superoxide anion radical, Hydroxyl radical	_	_	Kasai *et al.,* 2016
Vitex agnus-castus	Hydrodistillation	1,8-cineole, caryophyllene	DPPH	_	_	Habbab *et al.,*2016
Beilschmiedia pulverulenta	_	Eugenol	DPPH, β-carotene, FRAP	94.5 µg/ml	_	Salleh *et al.,*2016
Astrodaucus persicus	Hydrodistillation	ß-pinene, α-thujene	DPPH FRAP	_	_	Goodarzi *et al.,*2016
Lippia turbinate	_	Piperitenone oxide	ABTS DPPH BCB	_	Radical scavenger, inhibiting lipid peroxidation	Barbieri *et al.,* 2016
Lippia integrifolia	_	β-caryophyllene	_	_	_	Barbieri *et al.,* 2016
Clinopodium gilliesii	_	Pulegone	_	_	Highest hydrogen peroxide scavenging activity	Barbieri *et al.,* 2016
Prunus amygdalus	Hydrodistillation	9-octadecenoic acid, 3-eicosene	DPPH	_	Free radical inhibition	Bouaziz *et al.,*2016
Nandina domestica	_	3-hexen-1-ol	Reducing power, Metal chelating ability, Scavenging capacity	_	_	Bi *et al.,* 2016
Endlicheria arenosa	Hydrodistillation	Bicyclogermacrene	DPPH	_	Radical-scavenging	Da Silva *et al.,*2016
Rhanterium suaveolens	_	Perillaldehyde, caryophyllene oxide	β-carotene–linoleic acid assay,	17.97 ± 5.40 and 11.55 ± 3.39 µg /ml,	Lipid peroxidation inhibition activity	Chemsa *et al.,*2016
Gundelia tournefortii	Hydrodistillation	Thymol, γ-terpinene	DPPH	40.3 µg/ml	_	Dastan *et al.,* 2016
*Eucalyptus*spp.	Hydrodistillation	1,8-Cineole, α-pinene	DPPH	_	Radical scavenging activity	Ghaffar *et al.,* 2015
Teucrium pseudochamaepitys	Hydrodistillation	Hexadecanoic acid, caryophyllene oxide	DPPH	0.77 mg/ml	_	Hammami *et al.,* 2015
Laurus nobilis	Hydrodistillation	1,8-cineole, α-terpinyl acetate,	DPPH, ABTS	_	_	Boulila *et al.,* 2015

Salvia verticillate	_	1, 8-cineole, camphor	DPPH	_	_	Forouzin *et al.*, 2015
Salvia suffruticosa	_	1, 8-cineole, camphor	DPPH	_	_	Forouzin *et al.*, 2015
Pistacia atlantica	_	α-pinene, camphene, β-myrcene	DPPH, FRAP TBARS, β-carotene bleaching	_	_	Rezaie *et al.*, 2015
Voacanga africana	Hydrodistillation	Terpenoids	DPPH	25 mg/ml.	_	Liu *et al.*, 2015
Cedronella canariensis	_	Pinocarvone, β-pinene	ABTS	10.5 g/ml	_	Zorzetto *et al.*, 2015
Thymus capitatus	_	Carvacrol, Thymol	DPPH	119, 403 and 105 μg/ml	_	Dzamic *et al.*, 2015
Laminaria japonica	Microwave hydrodistillation	Tetradeconoic acid	DPPH ABTS Superoxide anion	_	Scavenging activity	Patra *et al.*, 2015
Anethum graveolens	Hydrodistillation	Phellandrene, Limonene	β-carotene bleaching	15.3 g/ml	_	Kazemi *et al.*, 2015
Veronica thymoides	_	Hexatriacontene, Linoleic acid	DPPH ABTS	15.32 ± 0.17 μg/ml, 9.15 ± 0.28 and 8.90 ± 0.14 μg/ml,	_	Ertas *et al.*, 2015
Achillea wilhelmsii	_	α-thujene, α-pinene	β-carotene bleaching	19 g/ml	_	Kazemi *et al.*, 2015
Lathyrus ochrus	Hydrodistillation	Phytol, Hexadecanoic acid	DPPH	_	_	Polatoglu *et al.*,2015
Satureja rechingeri	Hydrodistillation	Carvacrol, p-cymene	DPPH FRAP	46.2 to 50.2 mg/ml	_	Alizadeh *et al.*,2015
Hedychium spicatum	Hydrodistillation	1,8-cineole, β-eudesmol	DPPH	_	_	Koundal *et al.*, 2015
Helichrysum microphyllum	_	Neryl acetate, Rosifoliol	DPPH ABTS	_	Radical cation	Ornano *et al.*,2015
Daucus carota	_	Geranyl acetate, α-pinene, Sabinene	DPPH TBA	_	Radical scavenging activity, Lpid oxidation	Ksouri *et al.*,2015
Forsythia koreana	Hydrodistillation	Trans-phytol, cis-3-hexenol, β-linalool	DPPH, Nitric oxide, Superoxide	_	Scavenging activity, Anion radical scavenging	Yang *et al.*,2015
Rosmarinus officinalis	Hydrodistillation	α-pinene, Camphene, 1,8-cineole	DPPH	_	_	Ladan *et al.*,2015
Ocimum kilimandscharicum	Hydrodistillation	Camphor, 1,8 cineole, Limonene	DPPH	12.56 μg/ml	_	De Lima *et al.*, 2014
Calamintha origanifolia	Hydrodistillation	β-caryophyllene, Pulegone	DPPH FRAP	_	Radical scavenging, ferric ion reduction	Formisano *et al.*, 2014
Micromeria myrtifolia	Hydrodistillation	β-caryophyllene, Menthone	DPPH FRAP	_	Radical scavenging, ferric ion reduction	Formisano *et al.*, 2014
Rosmarinus officinalis	_	1,8-cineole, Camphor, α-pinene	DPPH	_	Free radical scavenging	Raskovic *et al.*, 2014
Eryngium tricuspidatum	Hydrodistillation	α-bisabolol	DPPH FRAP	510 g/ml	_	Merghache *et al.*, 2014
Piper nigrum	SC-CO_2, hydrodistillation	β-caryophyllene	DPPH	_	_	Bagheri *et al.*, 2014

Nigella sativa	_	Thymoquinone, p-cymene	DPPH	_	_	Singh *et al.*,2014
Tragopogon graminifolius	_	n -hexadecanoic acid, β-caryophyllene	DPPH FRAP	_	Radical scavenging activity	Farzaei *et al.*, 2014
Tagetes minuta	Hydrodistillation	(Z)-ocimenone, (E)-ocimenone	DPPH	36 µg/ml	Radical scavenging activity	Awadh Ali *et al.*,2014
Pavonia odorata	Hydrodistillation	β-caryophyllene	ORAC	_	_	Kashima *et al.*, 2014
Pterocarya fraxinifolia	_	Biotol, Aromadendrene	DPPH β-carotene	17.9 g/ml	_	Akhbari *et al.*, 2014
Bunium persicum	Hydrodistillation	p-cymene	DPPH β-carotene bleaching	4.47 (3.96 - 5.05) mg/ml 0.22 (0.16 - 0.31) mg/ml	Antilipid peroxidation	Nickavar *et al.*,2014
Brassica rapa	_	Dimethyl tetrasulfide	ORAC	_	_	Usami *et al.*, 2014
Ampelopsis megalophylla	_	Borneol, a-pinene	DPPH ABTS	_	_	Xie *et al.*, 2014
Panax ginseng	Hydrodistillation	β-farnesene, Phytol	DPPH ABTS	12.0 ± 0.4 mg/ml,1.6 ± 0.1 mg/ml	_	Jiang *et al.*,2014
Trifolium pratense	_	β-myrcene, p-cymene, Limonene	DPPH NO O_2	27.61 ± 0.12 µg/ml, 16.03 ± 0.11 µg/ml, 16.62 ± 0.29 µg/ml	_	Vlaisavljevic *et al.*,2014
Croton conduplicatus	Hydrodistillation	1,8-cineole, α-phellandrene	DPPH ABTS	_	_	Almeida *et al.*,2014
Tinospora cordifolia	Hydrodistillation	Hydroquinone, 2-hexenal,	DPPH	25±0.3 µg/ml	_	Naik *et al.*,2014
Azadirachta indica	Hydrodistillation	β-Elemene, Caryophyllene	DPPH	_	_	El-Hawary *et al.*, 2013
Liquidambar styraciflua	_	d-limonene, α-cadinol	DPPH Superoxide	3.17 and 2.19 mg/ml	Anion radical scavenging	El-Readi *et al.*, 2013
Citrus aurantium	_	Limonene	DPPH, Beta carotene	1.8 µg/ml 15.3 µg/ml	_	Hsouna *et al.*,2013
Callistemon viminalis	Hydrodistillation	1,8-cineole	DPPH	_	_	Salem *et al.*, 2013
Tetraclinis articulate	_	Bornyl acetate	DPPH	5.5 mg/ml	Strongest radical scavenging activity	Jemia *et al.*, 2013
Citrus aurantium	_	β-pinene, Limonene	DPPH	_	_	Sarrou *et al.*, 2013
Eremanthus erythropappus	Hydrodistillation	β-caryophyllene, α-bisabolol	DPPH	38.77 ± 0.76 to 102.24 ± 1.96 µg/ml	_	Silverio *et al.*, 2013
Tetraclinis articulate	Hydrodistillation	α-pinene, Bornyl acetate	DPPH	_	_	Chikhoune *et al.*,2013
Zanthoxylum alatum	_	Linalool, β-fenchol	DPPH	_	_	Guleria *et al.*,2013
Tagetes patula	Hydrodistillation	β-ocimene, α-terpinolene	DPPH	28.0 µg/ml	_	Negi *et al.*,2013
Gaillardia pulchella	Hydrodistillation	n-Hexadecanoic acid, Phytol	DPPH	_	_	Yao *et al.*,2013

Helichrysum oligocephalum	_	Ortho-vanillin, 1,8-cineole	DPPH β-carotene	_	_	Esmaeili *et al.*,2013
Feronia limonia	_	Thymol	DPPH H_2O_2 O_2 OH ABTS	41.35μg/ml, 45.49μg/ml, 30.86μg/ml, 25.05μg/ml, 30.28μg/ml	_	Senthilkumar *et al.*, 2013
Pulicaria gnaphalodes	Water distillation	Myrtenol, Citronellol	DPPH carotene bleaching	_	_	Kazemi *et al.*,2013
Achillea sieheana	Hydrodistillation	Camphor, 1.8-cineole	DPPH	87.04 μg/ml	_	Albayrak *et al.*, 2013
Carum copticum	_	Thymol	DPHH	40 and 60 μg/ml	_	Kavoosi *et al.*, 2013
Ferula asafoetida	_	β-pinene	DPPH	130 and 160 μg/ml	_	Kavoosi *et al.*,2013
Meconopsis oliverana	Steam distillation	n-hexadecanoic acid	DPPH OH	_	_	Gao *et al.*, 2013
Capsicum annum	_	Benzaldehyde, Z -ocimene	DPPH	10-60 g/ml	_	El-Ghorab *et al.*,2013
Salvia officinalis	Hydrodistillation, Microwave extracted	Trans-thujone, 1,8-cineole	DPPH	22 mg/ml	_	Bouajaj *et al.*, 2013
Citrus aurantium	_	Limonene, (E)-nerolidol	ABTS	672 mg/l	_	Haj Ammar *et al.*,2012
Syzygium aromaticum	_	Eugenol, Eugenyl acetate.	DPPH	_	_	El-Mesallamy *et al.*,2012
Murraya paniculate	Hydrodistillation	β-caryophyllene	DPPH	_		Rodríguez *et al.*,2012
Ajuga chamaeptys	Hydrodistillation	β-pinene α -pinene	DPPH ABTS	_	_	Yumrutas *et al.*,2012
Pogostemon paniculatus	_	α-guaiene, Caryophyllene	DPPH	18.5 μg/m	Free-radical scavenging activity	Manoj *et al.*,2012
Juglans regia	Hydrodistillation	β-pinene, α-pinene	DPPH	34.5 and 56.4 μg/m	_	Rather *et al.*,2012
Stachys lavandulifolia	Hydrodistillation	β-Phellandrene, α-pinene	DPPH	3.9 μg/m	Radical scavenging activity	Işcan *et al.*,2012
Stachys sylvatica	Steam distillation	α-pinene, β-pinene	DPPH FRAP	_	_	Hajdari *et al.*,2012
Plectranthus cylindraceus	_	Thymol	DPPH	34.5 μg/m	_	Awadh Ali *et al.*,2012
Meriandra benghalensis	_	Camphor	DPPH	935 μg/m	_	Awadh Ali *et al.*,2012
Solanum spirale	Hydrodistillation	(E)-Phytol	DPPH	41.89 mg/m	_	Keawsa-ard *et al.*,2012
Globba sessiliflora	_	α-cadinol myrcene	DPPH	_	_	Kumar *et al.*,2012
Juniperus oxycedrus	Hydrodistillation	α-pinene, Myrcene	ABTS DPPH	_	_	Hanène *et al.*,2012
Fortunella margarita	Hydrodistillation	d-limonene, β-myrecene	DPPH ABTS	_	_	Jayaprakasha *et al.*,2012

Cyperus alternifolius	Hydrodistillation	α-cyperone	DPPH	_	_	Ahmed *et al.*, 2012
Taiwania cryptomerioides	Hydrodistillation	α-cadinol	DPPH	90.8 ± 0.2 μg/ml	_	Ho *et al.*,2012
Machilus japonica	Hydrodistillation	α-phellandrene	DPPH	51.8 μg/ml	_	Ho *et al.*,2012
Artemisiae scopariae	Hydrodistillation	n-hexadecanoic acid, Caryophyllene oxide	DPPH FRAP	25-400 μg/ml	_	Jiang *et al.*,2012
Petasites albus	_	Euparin	DPPH	_	_	Mohammadi *et al.*,2012
Nasturtium officinale	_	Myristicin, Limonene	DPPH β-carotene-linoleic acid	_	_	Amiri *et al.*,2012
Pelargonium graveolens	_	Geraniol	DPPH	0.39 ± 0.04 mg/ml	_	Ćavar *et al.*, 2012
Morinda lucida	Hydrodistillation	α-terpinene	DPPH ABTS	_	_	Okoh *et al.*,2011
Piper krukoffii	_	Myristicin, Apiole	DPPH ABTS	_	_	Da Silva *et al.*,2011
Tornabenea bischoffii	_	Myristicin	DPPH TBARS	_	Free-radical scavenging, Prevention of lipid peroxidation	Ortet *et al.*,2011
Melaleuca armillaris	_	1,8-cineole	DPPH ABTS	247.3 ± 3.9 mg/l, 2183.6 ± 44.3 mg/l	_	Chabir *et al.*,2011
Nepeta laxiflora	_	α-pinene	DPPH	105.92 ± 1.39 μg/ml	_	Safaei-Ghomi *et al.*,2011
Nepeta sessilifolia	_	Spathulenol, Lavandulyl acetate	DPPH	99.71 ± 0.41μg/ml	_	Safaei-Ghomi *et al.*,2011
Juniperus phoenicea	_	Pinene, Camphene	DPPH ABTS	_	_	Medini *et al.*,2011
Echinophora platyloba	_	(Z)-β-ocimene	DPPH	71.2±1.11 μg/ml	_	Gholivand *et al.*,2011
Annona salzmannii	Hydrodistillation	(E)-caryophyllene	ORACFL DPPH	_	_	Costa *et al.*,2011
Annona pickelii	Hydrodistillation	(E)-caryophyllene	ORACFL DPPH	_	_	Costa *et al.*,2011
Gnaphlium affine	_	Eugenol	ABTS	_	_	Zeng *et al.*,2011
Origanum compactum	_	Carvacrol, Thymol	DPPH ABTS	2 ± 0.1 mg/l	_	Babili *et al.*,2011
Juniperus phoenicea	Hydrodistillation, steam distillation, Soxhlet	α-Terpinol	ABTS	22.6 ± 0.7 mg/l	_	Ennajar *et al.*,2011
Gymnema sylvestre	Hydrodistillation	Hydroquinone, Eugenol	DPPH ABTS	28 μg/ml	_	Naik *et al.*,2011
Pimenta dioica	Hydrodistillation	Eugenol	DPPH ABTS	4.82 ± 0.08, 5.14 ± 0.11 μg/ml, 50 2.27 ± 0.16, 2.94 ± 0.03 μg/ml	_	Padmakumari *et al.*,2011

Salvia lanigera	Hydrodistillation	Thymol	DPPH FRAP	_	_	Tenore *et al.*,2011
Etlingera elatior	_	β-pinene	DPPH	995.1 μg/ml	_	Abdelwahab *et al.*,2010
Cinnamomum pubescens	_	Cinnamaldehyde	DPPH	77.2 μg/ml	_	Abdelwahab *et al.*,2010
Atriplex undulata	Hydrodistillation	p-acetanisole carvone	DPPH Crocin bleaching inhibition	36.2 ± 1.6 μg/ml	Bleaching inhibition	Rodriguez *et al.*,2010
Bupleurum longiradiatum	Hydrodistillation	Thymol	DPPH inhibition of lipid peroxidation FeSO4 H2O2 CCl4	566.2 μg/ml, 275.2 μg/ml, 296.9 μg/ml, 118.7 μg/ml	radical scavenging inhibition of lipid peroxidation	Shi *et al.*,2010
Melaleuca leucadendra	_	1,8-cineol	DPPH TBARS ABTS	_	_	Pino *et al.*,2010
Cuminum cyminum	Hydrodistillation	Cuminlaldehyde	β-carotene bleaching	20 μg/ml	_	Hajlaoui *et al.*,2010
Origanum acutidens	_	Carvacrol	DPPH β-carotene/linoleic acid	_	_	Goze *et al.*,2010
Myrtus communis	_	α-pinene 1,8-cineole	DPPH, Reducing power and metal chelating activity	_	_	Aidi Wannes *et al.*,2010
Salvia eremophila	_	Borneol, α-pinene	DPPH β-carotene-linoleic acid	35.19 μg/ml	_	Ebrahimabadi *et al.*,2010
Citrus jambhiri	Hydrodistillation	D-limonene	DPPH	37.69±0.21 mg/ml	_	Hamdan *et al.*,2010
Citrus pyriformis	Hydrodistillation	D-limonene	DPPH	28.91±0.09 mg/ml	_	Hamdan *et al.*, 2010
Mangifera indica	Hydrodistillation	α-gurjunene, β-selinene	_	_	_	Simionatto *et al.*,2010
Mentha piperita	_	Menthol, menthone	DPPH, Hydroxyl (OH) radicals	860 μg/ml, 0.26 μg/ml	_	Schmidt *et al.*,2009
Marrubium deserti	Hydrodistillation	Germacrene D	DPPH ABTS	_	_	Laouer *et al.*, 2009
Caryophillus aromaticus	_	Eugenol	DPPH	_	_	Scherer *et al.*,2009
Magnolia liliflora	_	_	DPPH	10.11 μg/ml	_	Bajpai *et al.*, 2009
Achillea ligustica	_	Linalool, β-pinene	DPPH ABTS β-carotene bleaching	_	_	Maggi *et al.*,2009
Aucoumea klaineana	Hydrodistillation	δ-3-carene pcymene	DPPH	_	_	Koudou *et al.*, 2009
Bunium persicum	_	Caryophyllene	DPPH β-carotene bleaching	_	_	Shahsavari *et al.*, 2008

Satureja montana	Hydrodistillation	Thymol, Geraniol	DPPH	_	_	Ćavar *et al.*, 2008
Satureja subspicata	Hydrodistillation	Thymol, Spathulenol	DPPH	_	_	Cavar *et al.*, 2008
Discaria americana	Hydrodistillation	Eugenol α-terpineol	DPPH	_	_	Rodriguez *et al.*, 2008
Cinnamomum subavenium	Hydrodistillation	Methyl eugenol	_	_	_	Ho *et al.*, 2008
Dracocephalum heterophyllum	Hydrodistillation	Cineole	MDA	_	Inhibition of lipid peroxidation	Zhang *et al.*, 2008
Otostegia persica	Hydrodistillation	alpha- pinene, Diisooctyl phthalate	DPPH	19.8±1.8 µg/ml	_	Sharififar *et al.*, 2007
Salvia nilotica	_	Menthone	DPPH	_	_	Vagionas *et al.*, 2007
Eupatorium polystachyum	_	β-pinene, β-myrcene limonene	DPPH	_	_	Souza *et al.*, 2007
Capparis ovata	Steam distillation	Thymol	DPPH	_	_	El-Ghorab *et al.*, 2007
Origanum dubium	Hydrodistillation	Carvacrol	O_2	_	Scavenging O_2.	Karioti *et al.*, 2006
Achillea ligustica	Hydrodistillation	Borneol, Santolina alcohol	DPPH	_	_	Tuberoso *et al.*, 2005
Thymus vulgaris	_	Thyme	TBARS	_	_	Kulisic *et al.*, 2005
Thymus serpyllum	_	Thyme	TBARS	_	_	Kulisic *et al.*, 2005
Artemisia dracunculus	Hydrodistillation	(Z)-anethole, (Z)-β-ocimene	DPPH	_	_	Kordali *et al.*, 2005
Grammosciadium scabridum	_	γ-Terpinene, p-cymene	DPPH	6.6 mg/ml.	_	Sonboli *et al.*, 2005
Clausena anisate	Hydrodistillation	Estragole, (E)-anethole	DPPH	_	_	Avlessi *et al.*, 2004
Melissa officinalis	_	Neral,geranial, E-Caryophyllene	DPPH OH	7.58 µg/ml, 1.74 µg/ml	_	Mimica-Dukic *et al.*, 2004
Achillea millefolium	_	Eucalyptol, Camphor	DPPH OH	1.56 µg/ml, 2.7 µg/ml	_	Candan *et al.*, 2003
Cinnamomum zeylanicum	Steamdistillation	(E)-Cinnamyl acetate, (E)-caryophyllene	β-carotene-linoleate, Phosphomol ybdenum complex	_	Formation of the phosphomolybde num complex	Jayaprakasha *et al.*, 2003
Thymus pectinatus	Hydrodistillation	γ-terpinene p-cymene	DPPH Superoxide radical scavenging, Lipid peroxidation	_	_	Vardar-unlu *et al.*, 2003
Eucalyptus camaldulensis	Hydrodistillation	Aromadendrene α-pinene	thiocyanate	_	_	El-Ghorab *et al.*, 2002
Ocimum sanctum	_	Cirsimaritin, Eugenol, Apigenin	_	_	_	Kelm *et al.*, 2002
Rosmarinus officinalis	Mechanical extraction	Carnosic acid	_	_	_	Tymoschuk *et al.*, 1999
Petroselinum crispum	_	Apiol, Miriszticin	DPPH H_2O_2 OH	_	_	Fejes *et al.*, 1998

10. Antimicrobial compounds

Name of Plant	Extraction Method	Major Constituent	Anti-micrbial Method	MIC	Reference
Scrophularia spp.	Hydrodistillation	Carvacrol	agar well diffusion	-	Renda *et al.*,2017
Glycyrrhiza triphylla	_	β-caryophyllene	_	2.7 μg/ml	Shakeri *et al.*,2017
Callistemon citrinus	Hydrodistillation	Eucalyptol	-	-	Larayetan *et al.*,2017
Epilobium parviflorum Schreb.	Hydrodistillation	Linoleic acid, α-linolenic acid	microdilution	10–40 μg/ml	Bajer *et al.*,2017
Mentha spicate	Supercritical fluid	Carvone	_	_	Shrigod *et al.*,2017
Thymus alternans	_	Nerolidol	disc diffusion	_	Vitali *et al.*,2017
Ocotea	_	α-pinene, p-cymene β-caryophyllene,	_	19.5 μg/ml	Da Silva *et al.*,2017
Ammodaucus leucotricus	Hydrodistilled	D-limonene	disk diffusion	_	Gherraf *et al.*, 2017
Pulicaria incisa	_	Carvotanacetone, Chrysanthenone	agar well diffusion	0.49 – 15.63 μg/ml	Shahat *et al.*,2017
Alpinia zerumbet	Hydrodistillation	_	_	_	Kerdudo *et al.*,2017
Aphyllocladus spartioides	_	α-pinene	_	0.3 – 0.6 mg/ml	Celaya *et al.*,2017
Glycine max	_	Carvacrol	disk diffusion	25 μg/ml	Ghahari *et al.*,2017
Nigella sativa	Hydraulic and screw pressing techniques	Thymoquinone	_	40 μl	Hamed *et al.*,2017
Citrus sinensis	steam distillation	d-limonene	_	_	Geraci *et al.*,2017
Ocimum gratissimum	Hydrodistillation	Linalool, 1,8-cineole	broth microdilution	31.25 to 125 μg/ml	Mohr *et al.*,2017
Baccharis parvidentata	Hydrodistillation	Sabinene	_	78 μg/ml to 2500 μg/ml.	Perera *et al.*,2017
Hyptis monticola	Hydrodistillation	trans-caryophyllene	_	_	Perera *et al.*,2017
Lippia origanoides	Hydrodistillation	(E)-methyl cinnamate	_	78 μg/ml to 2500 μg/ml	Perera *et al.*, 2017
Leucas inflate	_	Camphor	broth micro-dilution	0.81 mg/ml.	Mothana *et al.*,2017
Solanum sisymbriifolium	Hydrodistillation	Hexadecanoic acid	well diffusion	60 and 80 μg/ml	Pasdaran *et al.*,2017
Premna microphylla	Hydrodistillation	Blumenol C, ß-cedrene	_	0.15 mg/ml	Zhang *et al.*,2017
Ammoides verticillate	Hydrodistillation	Thymol, p-cymene	disc diffusion	0.78 and 2.34 μl/ml	Attou *et al.*,2017
Zanthoxylum zanthoxyloides	_	(E)-β-ocimene	_	_	Tine *et al.*,2017
Iris persica	Hydrodistillation	Phenylethanol, Phenylacetaldehyde	_	_	Amin *et al.*,2017
Artemisia judaica	Hydrodistillation	Piperitone, Davanone	agar diffusion	_	Hellali *et al.*,2017
Mentha longifolia	Hydro distillation	Carvone, Limonene	_	_	Anwar *et al.*,2017
Pituranthos scoparius	Hydro-distillation	Limonene, 1,8-cineole	disk diffusion	2.000 to 0.019 mg/ml	Ksouri *et al.*,2017
Rosa damascene	_	Alcoholic monoterpene	Microdilution	_	Moein *et al.*,2017
Geranium robertianum	Hydrodistillation	_	_	_	Barowska *et al.*,2017
Bunium persicum	_	γ-terpinene	agar diffusion	0.375-1.5 mg/ml	Rustaie *et al.*,2016

Geranium spp.	SPME	Sabinen, caryophyllene, germacrene D	_	_	Renda *et al.*,2016
Genista quadriflora	Hydrodistillation	α-cadinol, caryophyllene oxide	dilution and disc diffusion	0.9 ± 0.1 and 1.7 ± 0.3 mg/mL	Kacem *et al.*,2016
Ferulago angulate	_	α-pinene, cis-β-ocimene	_	62 to 250 µg/mL	Ghasemi Pirbalouti *et al.*,2016
Eugenia uniflora	_	Spathulenol, β-caryophyllene	broth microdilution	0.63 mg/mL	Sobeh *et al.*,2016
Verbena officinalis	_	Carvacrol, thymol	Microplate	_	Elshafie *et al.*,2016
Majorana hortensis	_	Carvacrol, thymol	Microplate	_	Elshafie *et al.*,2016
Salvia officinalis	_	Carvacrol, thymol	Microplate	_	Elshafie *et al.*,2016
Citrus sinensis	_	Sabinene, δ-3-carene	disk diffusion	_	Yovo *et al.*, 2016
Eucalyptus globulus	Hydrodistillation	_	_	3 and 4 mg/mL	Bey-Ould Si Said et al 2016
Thymus pannonicus	static headspace	Citral, 1,8-cineole	broth microdilution	31.25-62.50 µL/mL	Arsenijevic *et al.*,2016
Thymus bovei	_	Trans-geraniol, α-citral	_	_	Jaradat *et al.*,2016
Aloysia gratissima	Hydrodistillation	E-caryophyllene, germacrene B	micro-dilution	_	Santos *et al.*,2016
Eruca longirostris	Hydrodistillation	Erucin, β-elemene	96-well microplates	0.125 to 0.31 mg/mL	Omri Hichri *et al.*,2016
Hyptis atrorubens	Hydrodistillation	caryophyllene oxide, β-caryophyllene	_	_	Kerdudo *et al.*,2016
Citrus medica	_	Limonene, Camphene	_	_	Aliberti *et al.*, 2016
Anthemis gayana	Hydrodistillation	caryophyllene oxide, 1,8-cineole	_	128 µg/ mL	Aboee-Mehrizi *et al.*, 2016
Rhaphiodon echinus	_	β-caryophyllene	Microdilution	_	Duarte *et al.*,2016
Nepeta sintenisii	Hydrodistillation	Nepetalactone, β-Farnesene	_	_	Shakeri *et al.*, 2016
Salvia multicaulis	Hydrodistillation	Nerolidol	Microdilution	_	Fahed *et al.*, 2016
Origanum ehrenbergii	Distillation	Carvacrol	_	400 to 1200 µg/mL	Al Hafi *et al.*, 2016
Origanum syriacum	Distillation	Carvacrol	_	400 to 1200 µg/mL	Al Hafi *et al.*, 2016
Pyrrosia tonkinensis	_	trans-2-hexenal, limonene	_	_	Xin *et al.*, 2016
Vitex agnus-castus	Hydrodistillation	1,8-cineole, Cedrelanol	well-diffusion	_	Habbab *et al.*,2016
Macleaya cordata	Hydrodistillation	_	_	125 to 500 g/mL	Li *et al.*,2016
Coriandrum sativum	_	Linalool	_	2 and 8 µL/mL	Alves *et al.*,2016

Beilschmiedia indicates	_	Eugenol	disk diffusion, microdilution	62.5 µg/ml	Salleh *et al.*,2016
Nepeta alpina	Hydrodistillation	Germacrene D, Spathulenol	_	32 µg/ml	Aboee-Mehrizi *et al.*,2016
Lippia thymoides	Hydrodistillation	β-caryophyllene, borneol		0.004 mg/ml	Silva *et al.*,2016
Tetraclinis articulate	_	α-pinene	_	_	Bahri *et al.*,2016
Litsea cubeba	Hydrodistillation	1,8-cineole, citral, limonene	paper disc diffusion	_	Su *et al.*,2016
Piper amalago	Hydrodistillation	β-phellandrene	paper discs	_	Santos *et al.*,2016
Ocimum tenuiflorum	Distillation	Camphor, Eucalyptol, Eugenol	Broth microdilution		Yamani *et al.*,2016
Juniperus phoenicea	Hydrodistillation	α-pinene	_	_	Bouyahyaoui *et al.*,2016
Endlicheria arenosa	Hydrodistillation	Bicyclogermacrene , β-caryophyllene, Limonene	_	19.5 µg/ml	Da Silva *et al.*,2016
Pelargonium asperum	_	Citronellol, geraniol	broth microdilution	_	Chraibi *et al.*,2016
Perovskia artemisioides	Hydrodistillation	1,8-cineole, camphor	_	_	Hafez Ghoran *et al.*,2016
Pycnocycla bashagardiana	_	Myristicin, E-β-ocimene	agar diffusion, broth macro dilution	_	Hafezian *et al.*,2016
Clinopodium macrostemum	SPME	Menthone	_	0.145 g/l	Villa-Ruano *et al.*,2015
Allium neapolitanum	_	(E)-chrysanthenyl acetate, (Z)-chrysanthenyl acetate, Camphor	_	_	Casiglia *et al.*,2015
Phoenix dactylifera	_	Linalool, β-fenchyl alcohol	_	_	Faridi *et al.*,2015
Pistacia atlantica	_	α-pinene, camphene	_	6 and 12.5 µg/ml,	Rezaie *et al.*, 2015
Artemisia annua	Hydrodistillation	Camphor, α-pinene	_	0.51 to 16.33mg/ml	Marinas *et al.*,2015
Satureja intermedia	_	γ-terpinene, thymol	microbroth dilution	_	Sharifi-Rad *et al.*,2015
Thymus capitatus	_	Carvacrol	Microdilution	_	Dzamic *et al.*, 2015
Mentha spicate	_	Carvone, limonene	disc diffusion, microdilution	_	Snoussi *et al.*, 2015
Ruta graveolens	Hydrodistillation	2-nonanone, 2-undecanone	_	0.75-1.40 µg/ml	França *et al.*,2015
Eremanthus erythropappus	_	δ-elemene, α-bisabolol	broth microdilution	_	Dos Santos *et al.*,2015
Plectranthus barbatus	_	(Z)-caryophyllene	broth microdilution	_	Dos Santos *et al.*, 2015
Plectrantuns amboinicus	_	Carvacrol, p-cymene	broth microdilution	_	Dos Santos *et al.*,2015
Lavandula coronopifolia	_	Carvacrol, E-caryophyllene	broth micro-well dilution	_	Ait Said *et al.*, 2015

Psammogeton canescens	Hydrodistillation	β-bisabolene, α-pinene, apiole	_	_	Kazemi *et al.*, 2015
Artemisia stricta	_	Capillene, spathulenol, β-caryophyllene	_	0.625 mg/ml	Manika *et al.*,2015
Ajania semnanensis	Hydrodistillation	1,8-cineole, bornyl acetate	_	_	Salehi *et al.*,2015
Dietes bicolor	Hydrodistillation	Spathulenol, cubenol	microbroth dilution	115 and 460 μg/ml	Ayouba *et al.*,2015
Laserpitium latifolium	Steam distillation	α-pinene, sabinene	broth-microdilution	13.0-73.0 μg/ml	Popovic *et al.*,2015
Laserpitium ochridanum	Steam distillation	Limonene, sabinene	broth-microdilution	_	Popovic *et al.*, 2015
Myrtus communis	-	Limonene, linalool	-	-	Hennia *et al.*,2015
Diospyros discolour	Hydrodistillation	(2Z,6E)-farnesol, α-cadinol, τ-cadinol	disc diffusion, micro-broth dilution	31.25-62.5 g/ml	Su *et al.*,2015
Foeniculum vulgare	Hydrodistillation	Fenchone, estragole, trans-anethole	disc diffusion agar, broth macrodilution	62.5 to 2000 μg/ml	Mota *et al.*, 2015
Thymus serpyllum	Hydrodistillation	Carvacrol, γ-terpinene, β-caryophyllene	Microdilution	0.025 μl/ml	Wesołowska *et al.*,2015
Thymus serpyllum 'Aureus'	Hydrodistillation	Carvacrol, γ-terpinene, β-caryophyllene	Microdilution	0.05 μl/ml	Wesołowska *et al.*,2015
Origanum hypericifolium	_	Thymol, Borneol, Carvacrol	Agar diffusion	_	Fakir *et al.*,2015
Vismia macrophylla	Hydrodistillation	δ-bisabolene, germacrene-D	_	150 μl/ml to 740 μl/ml	Buitrago *et al.*,2015
Pluchea dioscoridis	_	Farnesol, nuciferol, trans-cadinol	agar well diffusion	_	El-Ghorab *et al.*,2015
Lallemantia royleana	_	Pinocarvone, trans-pinocarvyl acetate	disk diffusion, microbroth dilution	3.1 and 2.5μg/ml, 5.6, 4.8 and 3.5μg/ml	Sharifi-Rad *et al.*,2015
Magydaris tomentosa	Hydrodistillation	Cembrene, β-springene, (E)-nerolidol		25 and 12.5 μ/mL	Khaoukha *et al.*,20014
Convolvulus althaeoides	_	Germacrene D, T-cadinol, verbenone	_	_	Hassine *et al.*,2014
Lavandula coronopifolia	Hydrodistillation	Carvacrol	_	_	Hassan *et al.*,2014
Nigella sativa	_	Thymoquinone, cymene, α-thujene	agar well diffusion	_	Singh *et al.*,2014
Tragopogon graminifolius	_	β-caryophyllene, n -hexadecanoic acid	_	_	Farzaei *et al.*,2014

Tagetes minuta	Hydrodistillation	(Z)-ocimenone, (E)-ocimenone	_	_	Awadh Ali *et al.*,2014
Cuscuta reflexa	Hydrodistillation	(E)-nerolidol, limonene	_	313 g/ml	Paudel *et al.*,2014
Schinus mole	_	α-phellandrene, β-phellandrene	agar disc diffusion	_	Martins *et al.*,2014
Glossogyne tenuifolia	_	Linalool, 4-terpineol, ρ-cymene	_	0.75 to 12 mg/ml	Yang *et al.*,2014
Ampelopsis megalophylla	_	Borneol, a-pinene, b-elemene	disc diffusion, broth microdilution		Xie *et al.*,2014
Cinnamomum zeylanicum	_	Anethole, carvacrol, eugenol	broth dilution	_	Sleha *et al.*,2014
Pinus peuce	_	α-pinene, camphene, β-pinene	disk diffusion, broth dilution	15-125 µl/ml	Karapandzova *et al.*,2014
Juniperus excels	Hydrodistillation	α-pinene, α-cedrol, δ-car-3-ene.	broth microdilution	64 and 128 µg/ml	Khoury *et al.*,2014
Plectranthus mollis	Hydrodistillation	Fenchone	tube dilution	_	Joshi *et al.*,2014
Ammodaucus leucotrichus	Hydrodistillation	Perillaldehyde, limonene	_	.5-1.0 µl/ml	El-Haci *et al.*,2014
Melampodium divaricatum	_	(E)-Caryophyllene, germacrene D	Microdilution	below 100 µg/ml	Duarte Moreira *et al.*,2014
Myrtus communis	_	Myrtenyl acetate, 1,8-cineol	_	0.078-2.5 mg/ml	Ben Hsouna *et al.*,2014
Sclerorhachis leptoclada	_	(E)-nerolidol, terpinen-4-ol, camphor	_	1.8 mg/ml	Sonboli *et al.*,2014
Artemisia phaeolepis	_	Eucalyptol, Camphor, Terpine-4-ol	_	_	Ben Hsouna *et al.*,2013
Daucus carota	_	β-bisabolene, Sabinene, Geranyl acetate	disk-diffusion	_	Rokbeni *et al.*, 2013
Aristolochia delavayi	Hydrodistillation	(E)-dec-2-enal	_	3.9 to 62.5 µg/ml	Li *et al.*,2013
Citrus aurantium	_	Limonene, E-nerolidol	agar diffusion, broth microdilution		Hsouna *et al.*,2013
Callistemon viminalis	Hydrodistillation	1,8-cineole, α-pinene	agar disc diffusion, 96-well micro-plates	_	Salem *et al.*,2013
Artemisia integrifolia	Hydrodistillation	Camphor, eucalyptol, artemisia ketone	disc diffusion, broth micro dilution	62.5 to 250 µg/ml	Zhu *et al.*,2013
Eremanthus erythropappus	Hydrodistillation	β-caryophyllene, germacrene-D	disc diffusion, microdilution	0.01 to 0.50 mg/ml	Silvério *et al.*,2013
Mentha suaveolens	Hydrodistillation	Menthone, pulegone	_	_	Kasrati *et al.*,2013
Cyclotrichium leucotrichum	Hydrodistillation	1,8-cineol, elemol	_	0.5 to 64 mg/ml	Mirjalili *et al.*,2013
Citrus reshni	_	Linalool, limonene,	_	_	Hamdan *et al.*,2013
Artemisia indica	_	Artemisia ketone, Germacrene, Borneol	_	_	Rashid *et al.*,2013

Machilus mushaensis	Hydrodistillation	n-decanal, α-cadinol	Disc diffusion, Micro-broth dilution	375-500 µg/ml	Su *et al.*,2013
Chromolaena laevigate	_	Laevigatin, spathulenol	_	500 and 125 µg/ml	Murakami *et al.*,2013
Cassia bakeriana	_	Linalool, (E)-nerolidol	Microdilution	62.5 and 125 µg/ml	Cunha *et al.*,2013
Feronia limonia	_	Thymol	_	31.25 µg/ml	Senthilkumar *et al.*,2013
Ocimum gratissimum	Steam distillation	Bornyl acetate, β-pinene	Cup plate	_	Katara *et al.*,2013
Pulicaria gnaphalodes	water distillation	Myrtenol, citronellol	Disc diffusion	_	Kazemi *et al.*,2013
Achillea sieheana	Hydrodistillation	Camphor, 1.8-cineole	_	_	Albayrak *et al.*,2013
Prangos peucedanifolia	Hydrodistillation	β-pinene, α-pinene, m-cresol	Micro- and Macrodilution	≤1.9×103 µg/ml	Brusotti *et al.*,2013
Daucus aureus	Hydrodistillation	Germacrene D, Caryophyllene oxide	_	0.125-4.6 mg/ml	Meliani *et al.*,2013
Nepeta binaludensis	Hydrodistillation	1,8-cineol	Broth dilution	3.125 mg/ml	Mohammadpour *et al.*,2013
Citrus aurantium	_	Limonene	Agar-well-diffusion		Haj Ammar *et al.*,2012
Myrica esculenta	Hydrodistillation	n-hexadecanol, eudesmol acetate	_	_	Agnihotri *et al.*,2012
Murraya paniculate	Hydrodistillation,	β-caryophyllene	_	_	Rodriguez *et al.*,2012
Kochia scoparia	Hydrodistillation	α-thujaplicin	_	_	El-Shamy *et al.*,2012
Chrysanthellum americanum	Hydrodistillation	Caryophyllene oxide, α-pinene	_	_	Mevy *et al.*,2012
Pogostemon paniculatus	_	Caryophyllene, α-guaiene, β-guaiene	Disc diffusion	_	Manoj *et al.*,2012
Cunninghamia lanceolata	Hydrodistillation	Cedrol	Disc diffusion, Micro-broth dilution	31.25-62.5 µg/ml	Su *et al.*,2012
Salvia x jamensis.	_	β-caryophyllene	_	_	Fraternale *et al.*,2012
Lippia grandis	Hydrodistillation	Carvacrol, ρ-cymene	Agar disk diffusion	0.57 - 1.15 mg/ml	Sarrazin *et al.*,2012
Plectranthus cylindraceus	_	Thymol	Disc diffusion, Broth Microdilution	0.39, 0.18, and, 0.18 µl/ml	Awadh Ali *et al.*,2012
Meriandra benghalensis	_	Camphor	Disc diffusion, Broth Microdilution	_	Awadh Ali *et al.*,2012
Heracleum rigens	Hydrodistillation	Bornyl acetate, α-pinene	Disc diffusion	_	Jagannath *et al.*,2012
Tridax procumbens	Hydrodistillation	(Z)-falcarinol, limonene	_	_	Joshi *et al.*,2012
Phyllanthus muellerianus	Hydrodistillation	(E)-isoelemicin	_	13.5 to 126 µg/ml.	Brusotti *et al.*,2012
Plectranthus marrubatus	Hydrodistillation	Thymol, p-cymene, γ-terpinene	Disc diffusion	10 to 800 µg/ml,	Asres *et al.*,2012
Machilus japonica	Hydrodistillation	α-phellandrene, α-pinene, thymol	Disc diffusion, Micro-broth dilution	16.12~ µg/ml	Ho *et al.*,2012
Satureja thymbra	_	γ-terpinene, thymol, p-cymene, carvacrol	_	_	Giweli *et al.*,2012
Artemisia annua	Hydrodistillation	Artemisia ketone, camphor	Agar diffusion	_	Cavar *et al.*,2012

Piper officinarum	_	β-caryophyllene, α-phellandrene	_	250 µg/ml	Salleh *et al.*,2012
Acorus calamus	Hydrodistillation	(Z)-asarone, (Z)-methyl isoeugenol	Disc diffusion	_	Bisht *et al.*,2011
Cinnamomum tamala	Hydrodistillation	(E)-cinnamaldehyde	Disc diffusion	_	Bisht *et al.*,2011
Origanum vulgare	Hydrodistillation	p-Cymene, Thymol, Carvacrol	Disc diffusion	_	Bisht *et al.*,2011
Rosmarinus tournefortii	Hydrodistillation	Camphor, 1,8-cineole	Muller Hinton agar plates	_	Bendeddouche *et al.*,2011
Satureja kitaibelii	_	Limonene, p-cymene, Borneol	_	6.25-50.0 µg/ml	Mihajilov-Krstev *et al.*,2011
Senna alata	Hydrodistillation	Ar-turmerone, β-caryophyllene	_	_	Essien *et al.*,2011
Senna hirsute	Hydrodistillation	(E)-phytol	_	_	Essien *et al.*,2011
Senna occidentalis	Hydrodistillation	(E)-phytol	_	_	Essien *et al.*,2011
Piper caninum	_	Safrole	_	62.5 to 250 µg/ml	Salleh *et al.*,2011
Litsea akoensis	Hydrodistillation	Limonene, Thymol, β-phellandrene	_	_	Ho *et al.*,2011
Gnaphlium affine	_	Eugenol, Linalool	_	0.2-1.56 µg/ml	Zeng *et al.*,2011
Heracleum siamicum	Hydrodistillation	n-octyl acetate, o-cymene	Agar diffusion	_	Kuljanabhagavad *et al.*,2011
Anthriscus nemorosa	Hydrodistillation	β-pinene, δ-cadinene, n-nonane	Broth microdilution	_	Pavlovic *et al.*,2011
Feronia elephantum	_	β-pinene, Z-anethole	_	0.31±0.06 mg/ml	Joshi *et al.*,2011
Alpinia pahangensis	Hydrodistillation	γ-selinene, β-pinene, α-pinene	Broth microdilution	0.08 and 0.31 µg/µl	Awang *et al.*,2011
Pinus nigra	_	α-pinene	Disc-diffusion, Broth-microdilution	0.03-0.50% (v/v))	Politeo *et al.*,2011
Eucalyptus oleosa	Hydrodistillation	1,8-cineole, Spathulenol, γ-eudesmol	_	_	Marzoug *et al.*,2011
Paeonia daurica	_	Linalool	_	_	Tosun *et al.*,2011
Allium sphaerocephalon	_	Shyobunol, β-caryophyllene	Broth microdilution	0.08 mg/ml	Lazarevic *et al.*,2011
Salvia lanigera	Hydrodistillation	Thymol, Carvacrol, α-thujone	Broth dilution method	_	Tenore *et al.*,2011
Datura metel	_	α-phellandrene, p-cymene, 1,8-cineole	_	_	Essien *et al.*,2010
Cinnamomum zeylanicum	_	(E)-cinnamaldehyde	Disc diffusion	_	Unlu *et al.*,2010
Ferulago campestris	Hydrodistillation	Myrcene, α-pinene	Agar diffusion, microdilution	39-78 µg/ml	Cecchini *et al.*,2010
Bupleurum longiradiatum	Hydrodistillation	Thymol	Disc diffusion, 96-well dilution	250 -500 µg/ml	Shi *et al.*,2010
Laserpitium zernyi	Hydrodistillation	α-pinene, α-bisabolol	Microdilution	_	Popovic *et al.*,2010
Ocimum basilicum	Hydrodistillation	Methyl chavicol, Caryophyllene	_	62.5500 µg/ml	Hossain *et al.*,2010
Stachys byzantine	Hydrodistillation	Nerolidol, Thymol	Agar diffusion	_	Manafi *et al.*,2010
Cuminum cyminum	_	β-pinene, Cuminic aldehyde	Agar diffusion	_	Wanner *et al.*,2010
Mangifera indica	Hydrodistillation	α-gurjunene, β-selinene, β-caryophyllene	_	_	Simionatto *et al.*,2010

Pulsatilla albana	Hydrodistillation	Pulegone, Piperitenone, Menthone	_	_	Shafaghat *et al.*,2010
Calycopteris floribunda	_	Caryophyllene oxide, β-caryophyllene, n-hexadecanoic acid	Disk diffusion	_	Liu *et al.*,2009
Litsea nakaii	Hydrodistillation	α-humulene, (E)-β-ocimene	_	_	Ho *et al.*,2009
Litsea kostermansii	Hydrodistillation	β-eudesmol, γ-eudesmol	_	_	Ho *et al.*,2009
Artemisia incana	Hydrodistillation	Camphor, Borneol, 1,8-cineole	_	_	Cetin *et al.*,2009
Marrubium incanum	Hydrodistillation	(E)-caryophyllene	Agar diffusion, Broth microdilution		Petrovic *et al.*,2009
Achillea ligustica	_	Linalool, β-pinene	Broth micro-dilution	_	Maggi *et al.*,2009
Abies holophylla	_	δ3-carene, α-pinene	Agar disc diffusion, Microdilution	5.5-21.8 mg/ml	Lee *et al.*,2009
Abies koreana	_	Bornyl ester,Camphene	Agar disc diffusion	0.5-2.2 mg/ml	Lee *et al.*,2009
Phyllanthus emblica	Hydrodistillation, SFE	β-caryophyllene, β-bourbonene, Thymol	_	_	Liu *et al.*,2009
Machilus obovatifolia	Hydrodistillation	β-caryophyllene, β-phellandrene	_	_	Ho *et al.*,2009
Hypericum cordatum	Hydrodistillation	Myrcene, α-pinene, Limonene	_	_	Ladeira *et al.*,2009
Acronychia pedunculata	_	α-pinene, (E)-β-caryophyllene	_	_	Lesueur *et al.*,2008
Curcuma longa	_	Linalool, 1,8-Cineole	_	_	Gerige *et al.*,2008
Lavandula angustifolia ‘Lavender’	SFE-CO2	Linalyl acetate	Agar disc diffusion, Agar dilution	0.63-3. 33 g/l	Chen *et al.*,2008
Lavandula angustifolia ‘Lavender’	Hydrodistillation	Linalyl acetate	Agar disc diffusion, Agar dilution	_	Chen *et al.*,2008
Salmonella spp.	_	d-limonene, Myrcene	Disc diffusion	_	O'Bryan *et al.*,2008
Salvia aramiensis	_	β-pinene, 1,8-cineole	Disc diffusion	_	Kelen *et al.*,2008
Salvia aucheri	_	1,8-cineole, Camphor	Disc diffusion	_	Kelen *et al.*,2008
Salvia pilifera	_	α-thujene, α-pinene	Disc diffusion	_	Kelen *et al.*,2008
Cinnamomum subavenium	Hydrodistillation	Methyl eugenol, p-cymene,	_	_	Ho *et al.*,2008
Baccharis articulate	_	β-pinene	Broth microdilution	2.5 mg/ml	Simionatto *et al.*,2008
Artemisia feddei	_	1,8-cineole	_	0.025 to 0.05 mg/ml	Cha *et al.*,2007
Calamintha origanifolia	Hydrodistillation	Pulegone, Isomenthone	_	_	Formisano *et al.*,2007
Teucrium ramosissimum	_	Caryophyllene oxide, β-eudesmol	_	0.24-0.36 mg/ml	Sghaier *et al.*,2007
Satureja spp.	Hydrodistillation	α-bisabolol oxide-B, linalool, Spathulenol, Thymol	Agar dilution	_	Vagionas *et al.*,2007
Artemisia afra	Hydrodistillation	Camphor, α-thujone,	_	_	Vagionas *et al.*,2007
Leonotis ocymifolia	Hydrodistillation	Germacrene D, (Z)-β-ocimene	_	_	Vagionas *et al.*,2007
Salvia officinalis	_	Camphor, α-thujone, β-thujone	_	_	Edris *et al.*,2007
Artemisia kopetdaghensis	Hydrodistillation	Methyleugenol, Geranial, Davanone, Camphor	Agar dilution	_	Ramezani *et al.*,2006
Origanum dubium	Hydrodistillation	Carvacrol	_	_	Karioti *et al.*,2006
Amomum cannicarpum	Hydrodistillation	β-terpineol, β-pinene, α-pinene	_	_	George *et al.*,2006
Thymbra spicate	Hydrodistillation	Carvacrol, Trans-caryophyllene	_	_	Kiliç *et al.*,2006
Equisetum arvense	_	Cis-geranyl acetone, Thymol, trans-phytol	Disk diffusion	_	Radulovic *et al.*,2006

Solidago virgaurea	_	α-pinene, Myrcene, β-caryophyllene	Disc diffusion	_	Tkachev *et al.*,2006
Azadirachta indica	Steam distillation	α-cubebene, Copaene, Humulene	_	_	Aromdee *et al.*, 2006
Juniperus communis	_	α-pinene, β-pinene	_	_	Pepeljnjak *et al.*, 2005
Salvia suffruticosa	Hydrodistillation	Camphor, 1,8-cineol	_	_	Norouzi-Arasi *et al.*, 2005
Rosmarinus officinalis	Supercritical CO_2	α-pinene, 1,8-cineole,	Disc diffusion	_	Santoyo *et al.*, 2005
Chrysanthemum indicum	Hydrodistillation	1,8-cineole, Camphor, Borneol	Disc paper, Broth microdilution	_	Shunying *et al.*, 2005
Lavandula stoechas	_	Fenchone, Camphor	_	_	Bouzouita *et al.*, 2005
Cuminum cyminum	_	Cumin aldehyde, β-pinene, p-cymene	_	_	Jirovetz *et al.*, 2005
Croton hieronymi	_	Camphor, Borneol, γ-asarone	_	_	de Heluani *et al.*, 2005
Artemisia khorassanica	Hydrodistillation	1,8-cineol, Camphor, Davanone, Isogeraniol	Agar dilution	_	Ramezani *et al.*, 2004
Nepeta crispa	_	1,8-cineol, 4aα,7α,7aβ-nepetalactone	_	_	Sonboli *et al.*, 2004
Pistacia vera	Hydrodistillation	α-Pinene, β-pinene, Camphene	Agar-disk diffusion	_	Alma *et al.*, 2004
Psiadia lucida	Hydrodistillation	Terpinolene, Limonene	_	_	Andriamanantoanina *et al.*, 2004
Anethum graveolens	_	D-limonene, D-carvone	_	_	Jirovetz *et al.*, 2003
*Thymus*spp.	Hydrodistillation	Linalool, 1,8-cineole	Disc agar diffusion	_	Faleiro *et al.*, 2003
Thymus pectinatus	Hydrodistillation	Thymol, Carvacrol	_	_	Vardar-Unlu *et al.*, 2003
Pimpinella tirupatiensis	_	β-bisabolene, Cis-carveol, elemol	_	_	Bakshu *et al.*, 2002
Calea clematidea	Hydrodistillation	Clemateol, α-terpinene, Thymol methyl ether, o-cymene	_	> 3.57 mg/m	Flach *et al.*, 2002
Halimium voldii	_	Z-caryophyllene, Nonanal, Thymol	_	_	Demetzos *et al.*, 2001
Thymus revolutus C.	_	Carvacrol	_	_	Karaman *et al.*, 2001
Phlomis lanata	_	α-pinene, Limonene, Trans-caryophyllene	_	_	Couladis *et al.*, 2000
Scutellaria albida	Steam distillation	Linalool, Trans-nerolidol	_	_	Skaltsa *et al.*, 2000
Ocimum gratissimum	_	Eugenol	-	3 to 12 µg/ml	Nakamura *et al.*, 1999
Origanum dictamnus	_	Carvacrol	_	_	Economakis *et al.*, 1999
Pittosporum senacia	_	δ-cadinene, α-muurolol, α-cadinol	_	_	Mananjarasoa *et al.*, 1998
_	_	Cineole, Citral, Geraniol, linalool, Menthol	_	_	Pattnaik *et al.*,1997
Musca domestica L.	_	Myrcene, p-cymene, γ-terpinene, Linalool	_	_	Maganga *et al.*,1996
Tea-tree oil	_	Terpinen-4-ol, α-terpineol, α-pinene	_	_	Raman *et al.*,1995
Melaleuca alternifolia	_	1,8 - cineole, Linalool, ρ - cymene	Disc Biffusion, Broth microdilution	_	Carson *et al.*,1995
*Bystropogon*spp.	_	Pulegone, Menthone,	_	_	Economou *et al.*,1991
Achillea fragrantissima	_	Terpinen-4-ol	_	_	Barel *et al.*,1991
Ducrosia anethifolia	_	α-Pinene, Limonene, n-decanol	_	_	Janssen *et al.*,1984
Nigella sativa	_	Thymohydroguinone	_	_	El Alfy *et al.*,1975
Pogostemon cablin	Azeotropic distillation	Patchouli oilpogostone and (-)-patchouli alcohol	Broth dilution	_	Yang *et al.*, 2013

11. Conclusion

The medicinal properties of volatile oil have been described in the Traditional medicine. This review presents various distillation method for extraction of volatile oil, and its activity such as antioxidant, antimicrobial. Distillation is the most widely used method for the extraction of volatile oils. Proper selection of the distillation technique, design and material of fabrication of the equipment, and processing parameters all play vital roles in determining the quality and yield of a volatile oil. The evaluation of volatile oils isessential in order to explore their enormous potential as anti-oxidants and as antimicrobial agents, which can be used further for the welfare of human being.

Conflict of interest

We declare that we have no conflict of interest.

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