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Innovative methods for extraction of essential oils from medicinal plants

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Abstract: Essential oils are concentrated liquids of intricate combinations of volatile substances, extracted from various plant parts. Several bioactive substances with antibacterial and antioxidant activities are abundant in essential oils. Some essential oils have also been employed in medicine. Due to the risk associated with employing synthetic preservatives, the use of essential oils as natural additives for extending the shelf life of food products has also drawn considerable attention. They are used in the pharmaceutical, cosmetic, and food industries for their functional properties. There are various methods for extraction, but both the quality and the percentage yield of essential oil never remain the same. So, innovative and non-conventional techniques of essential oils extraction from medicinal plants were evoled to get quantitative and qualitative yield. In the present article, we searched and reviewed innovative techniques used for the extraction of essential oils from medicinal and aromatic plants through electronic searches of PubMed, Medline, Wiley, Scopus, and Google Scholar. For the extraction of essential oils, several innovative/non-conventional techniques have been reported in literature. Extraction of essential oil by using innovative techniques retards the risk of losing the essential components of plants, maintains the quality, reduces chemical risk, extraction time, acts eco-friendly, and increases the percentage yield of the essential oils. This paper presents the success story of innovative extraction methods of essential oils in accordance with sustainable development and environmental protection.

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1. INTRODUCTION

Essential oils (volatile oils) are aromatic liquids that have been extracted from various plant parts, including leaves, flowers, seeds, and bark, when introduced to a solvent that dissolves volatile oil. They are good resources of numerous biologically active constituents which possess many pharmacological activities and have a significant role in the growth and development of aromatic herbs. Volatile oils confer fragrance to reproductive organs and fruits that attract pollination animals. To save plants, they resist phytophagous organisms, including viruses and phytoplasma vectors (Iriti & Faoro, 2009). They also contain different carbon- and hydrogen-

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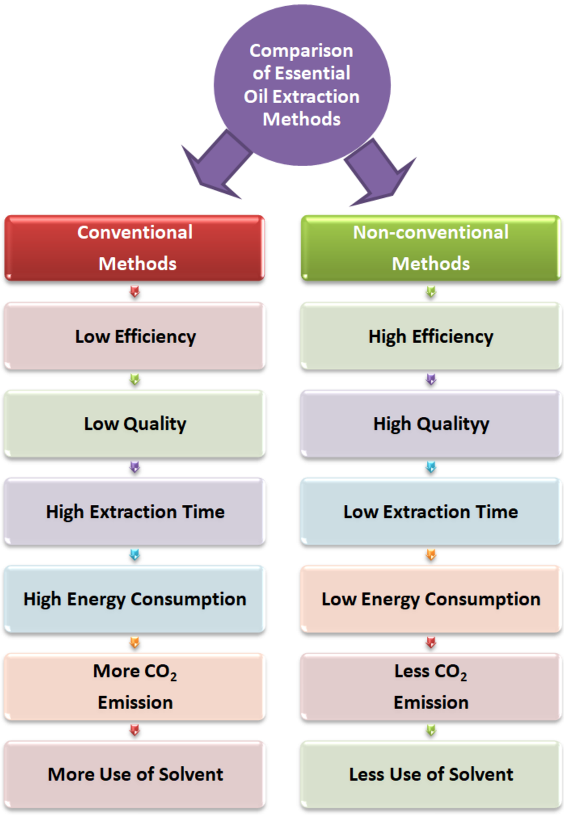
based compounds called terpene hydrocarbons. A basic hydrocarbon found in essential oils is isoprene. Mono-, sesqui-, and diterpenes are the result of combination of two, three and four isoprenes joined together respectively. The constituents of essential oils may be broadly classified as volatile and non-volatile fractions. Volatile oils are categorized into mono-/ sesquiterpene components and oxygenated derivatives along with esters, aliphatic aldehydes, and alcohols. The oxygenated derivatives of hydrocarbons are derived from isoprenoid pathways. These chemical moieties help determine the physicochemical properties, including solubility, nature, appearance, stereochemistry, and biological activities such as antimicrobial, antiviral, antioxidant, hepatoprotective, spasmolytic, analgesic, antidiabetic, and protect against cardiovascular diseases including atherosclerosis, thrombosis, and carminative (Edris, 2007; Reichling *et al.*, 2009). Many preclinical studies of essential oils have been published on various cell and animal models.

Figure 1. Comparison of conventional and non-conventional extraction methods of essential oils.



The conventional methods employed to extract volatile oils are being used worldwide owing to the fact that the essential oils are widely consumed. Selection of extraction method plays a critical role in the percentage yield of essential oils; it may affect the physiochemical properties as well. Some extraction methods are best suited to particular plant types and parts. Modern technologies have constantly been developed to overcome the limitation of traditional methods and enhance extraction efficacy, such as steam distillation, hydrodistillation, solvent extraction, maceration, carbon dioxide extraction, cold-press extraction, enfleurage, etc. However, innovations are required in conventional techniques to get the quantitative and qualitative yield of essential oils from medicinal plants. The comparison of conventional and non-conventional extraction methods of essential oils is shown in Figure 1.

2. INNOVATIVE TECHNIQUES

Innovative/ non-conventional techniques are "green" in concept. Various innovative extraction methods have been proposed (Figure 2) to overcome the limitations of traditional methods. These are less time-consuming, environmentally friendly, improve yields and quality of essential oils with less utilization of solvents and energy (Figure 3), and help avoid toxic chemicals. The conventional technology involves the transfer of heat energy via conduction and convection mechanisms which ultimately may cause variations in the temperature gradient within the product. Therefore, several novel heating techniques that contain more efficiency have been developed as summarized in Table 1 (Neetoo & Chen, 2014). Table 1 also entails the source, plant parts used, secondary metabolites of volatile oils, and their pharmaceutical importance.

Figure 2. Non-conventional and conventional extraction methods of essential oils.

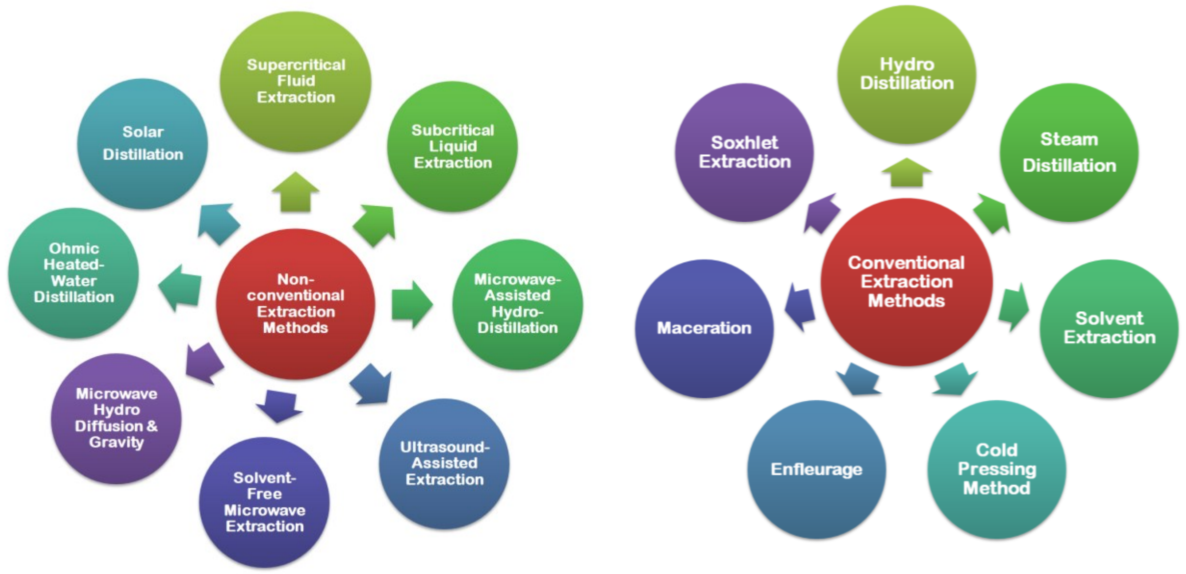


Figure 3. Advantages of innovative extraction techniques of essential oils.

2.1. Supercritical Fluid Extraction

Supercritical fluid extraction (SFE) is a sophisticated method of isolating one component from a combination utilizing a supercritical fluid as an extracting solvent composed of gases or liquids. Their dissolving power is controlled by temperature and/or pressure. However, it is employed to isolate those chemical classes of volatile oils, which cannot be advisable to extract through the steam distillation method. The schematic representation of SFE system is shown in Figure 4. The most commonly used solvent is carbon dioxide (CO_2) for several practical reasons like low critical pressure (73.8 bar) and temperature (31°C), nonflammable, noncorrosive, safe, cheap, and availability in high purity. Using the press release, it may be easily extracted from plant material (Rozzi *et al.*, 2002). One drawback is that CO_2 is nonpolar, so it cannot extract polar analytes (Pourmortazavi & Hajimirsadeghi, 2007) alone but can be used as a supercritical fluid with co-solvents such as dimethyl ether, ethane, ethylene ethanol, freons, methanol, nitrous oxide, propane, ethylene, etc. The SFE method of essential oils from various plants has been listed in Table 1. Additional benefits of this method include providing a high-quality range with advanced biological and functional properties compared to other products obtained (Cappuzzo *et al.*, 2013) by using the hydrodistillation method. This method is environmentally friendly because the nontoxic solvents used in the extraction process leave no harmful residue. The extracting solvent can be quickly recovered from the extract because of its high volatile nature. The components with high boiling points get easily extracted at low temperatures considered suitable for thermolabile components. The principal limitation of this method is the complexity of the system, which increases the cost of the equipment. Another disadvantage is that elevated pressure requires a more considerable upfront capital expenditure.

Figure 4. Schematic representation of the supercritical fluid extraction (SFE) system.

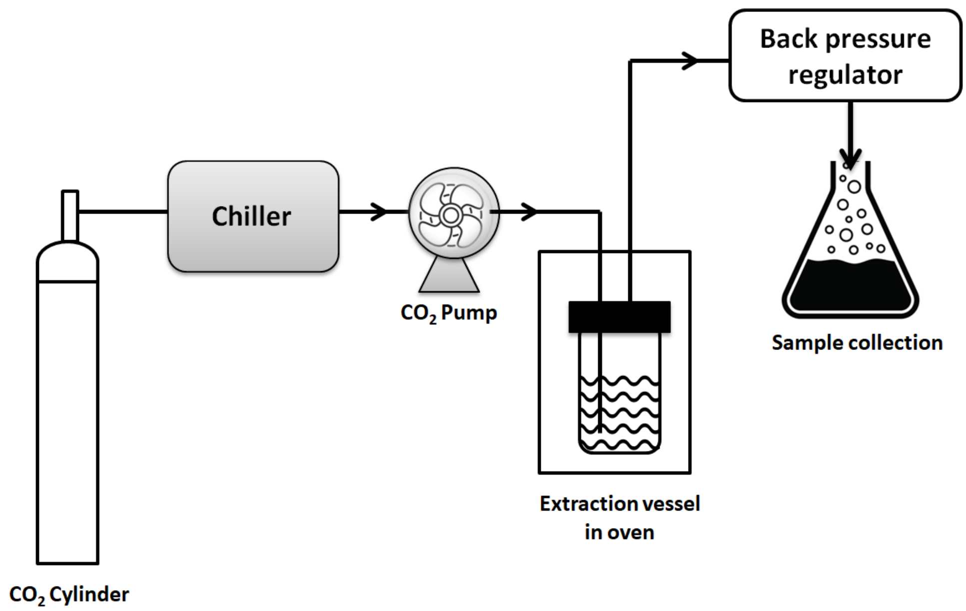


Table 1. Supercritical fluid extraction (SFE) of essential oils from various sources.

Sources (Part Used)	Common Name	Chemical Constituents	Pharmaceutical Application	References
Santolina chamaecyparissus L.; Asteraceae (Flower heads)	Cotton Lavender	1,8-Cineole, *β*-eudesmol, terpinen-4-ol, terpinolene, borneol and isobornyl acetate	Anticandidal, antibacterial and antifungal activity	(Grosso *et al.*, 2009A; Suresh *et al.*, 1997; Salah-Fatnassi *et al.*, 2017)
Mentha pulegium L.; Lamiaceae (Flowers and leaves)	Pennyroyal	*α* & *β*-Pinene, pulegone, menthol, piperitenone, isomenthol, menthone, isomenthone, neomenthol and neoisomenthol	Anti-cholinesterase, anti-Alzheimer and antioxidant activity	(Reis-Vasco *et al.*, 1999; Bektašević *et al.*, 2021)
Foeniculum vulgare Mill. subsp. *piperitum*; Umbelliferae (Flowers and unripe and ripe fruits)	Fennel	*α* & *β*-Pinene, myrcene, *p*-cymene, limonene, linalool, fenchone, estragol, camphor, *α*-phellandrene, (*E*)-anethole	Antifungal activity	(Coelho *et al.*, 2003; Ozcan *et al.*, 2006)
Coriandrum sativum L.; Apiaceae (Leaves and seeds)	Coriander	Linalool, *γ*-terpinene, *α*-pinene camphor, geranyl acetate, geraniol, and limonene	Antibacterial, antifungal, and antioxidant activity	(Grosso *et al.*, 2008; Mandal and Mandal, 2015)
Satureja montana L.; Lamiaceae (Leaves and flowers)	Winter Savory	Carvacrol, thymol, *p*-cymene, thymoquinone, *γ*-terpinene and *β*-bisabolene	Anti-cholinesterase, anti-Alzheimer, antioxidant, cytotoxic, antibacterial, and antidiarrhoeal activity	(Grosso *et al.*, 2009B; Silva *et al.*, 2009; Grosso *et al.*, 2009C; Miladi *et al.*, 2013; Skočibušić and Nada, 2008)
Satureja fruticosa Béguinot; Lamiaceae (Leaves and flowers)	Savory	Piperitenone, piperitenone oxide, pulegone and isomenthone	-	(Coelho *et al.*, 2007)
Thymus vulgaris L.; Lamiaceae (Aerial flowering parts)	Thyme	*γ*-Terpinene, linalool, thymol, *p*-cymene, and carvacrol	Antioxidant and antiviral, antiproliferative activity	(de Melo *et al.*, 2000; Grosso *et al.*, 2010; Catella *et al.*, 2021 Niksic *et al.*, 2021)
Origanum majorana L.; Lamiaceae (Leaves)	Marjoram	Terpinen-4-ol, *α* & *β*-pinene, *γ*-terpinene, camphene, *α*-terpineol, linalool, *α*-terpinene, *p*-cymol, *cis*-sabinene hydrate, spathulenol, *β*-caryophyllene,	Antimicrobial, antioxidant, anti-coagulant and antidepressant activity	(Reverchon, 1992; Va'gi *et al.*, 2005; Bağci1 *et al.*, 2017; Busatta *et al.*, 2008; Abbasi-Maleki *et al.*, 2019)

Zataria multiflora Boiss; Lamiaceae (Arial branches)	Shirazi thyme	Thymol, carvacrol, linalool, *λ*-terpinene and *p*-cymene	Antimicrobial, antioxidant and scolicidal activity	(Ebrahimzadeh *et al.*, 2003; Shafiee and Javidnia, 1997; Mahmoudvand *et al.*, 2017)
Eucalyptus loxophleba ssp. *Lissophloia;* Myrtaceae (Leaves)	*Eucalyptus*	1,8-Cineole, *α*-pinene, aromadendrene, trans-pinocarveol, and methyl amyl acetate	Antioxidant and antimicrobial activity	(Zhao and Zhang, 2014; Assareh *et al.*, 2007; Rahimi-Nasrabadi *et al.*, 2012; Aldoghaim *et al.*, 2018)
Lippia alba; Verbenaceae (Leaves & flowers)	Anise verbena	Carvone, limonene, elemol, γ-muurolene, guiaol, bulnesol and citral	Antimicrobial, antioxidant, and cytotoxic activity	(Reyes-Solano *et al.*, 2017; Stashenko *et al.*, 2004; Braga *et al.*, 2005; Lima Juiz *et al.*, 2015; Santos *et al.*, 2016; Saroj *et al.*, 2019)
Pimpinella anisum; Apiaceae (Fruits)	Aniseed	*γ* -Himachalene, trans-anethole, methylchavicol, 2-methylbutyrate, trans-pseudoisoeugenyl	Antimicrobial, antiviral, antioxidant, analgesic, muscle relaxant, antifungal, and anticonvulsant activity	(Rodrigues *et al.*, 2003; Gende *et al.*, 2009; Shojaii and Fard, 2012)
Artemisia sieberi Besser Asteraceae (Aerial parts)	Artemisa	Camphene, 1,8-cineole, *γ*-terpinene, camphor, chrysanthenone, *cis & trans*-thujone, and *cis*-chrysanthenone	Antioxidant, antimicrobial, and antifungal activity	(Ghasemi *et al.*, 2007; Ghasemi *et al.*, 2020; Mahboubi and Farzin, 2009; Aghajani *et al.*, 2014; Asgharpour and Honarvar, 2016)
Anacardium occidentale L.; Anacardiaceae (Leaves)	Cashew	Cardanol, *α*-copane, *β*-caryophyllene, cardol, *γ*-cadinene, germacrene B & D, dimethylanacardate	Antioxidant and antimicrobial activity	(Patel *et al.*, 2006; Janet *et al.*, 2015; Baptista *et al.*, 2018; Dzamic *et al.*, 2009)
Eugenia caryophyllata Thunb; Myrtaceae (Buds, leaves, and stems)	Clove	Eugenol, eugenol acetate, *trans*-caryophyllene	Antioxidant, antimicrobial and anti-inflammatory activity	(Sohlait, 2015; Wenqiang *et al.*, 2007; Ivanovic *et al.*, 2011; Mahboubi and Mahboubi, 2015; Sohilait *et al.*, 2018; Öztürk and Özbek, 2005).

2.2. Subcritical Liquid Extraction

SLE takes place when liquid reaches a pressure greater than Pc (critical pressure) but less than Tc (critical temperature). This condition is said to be in the subcritical stage. The schematic representation of the SLE system is shown in Figure 5. The solvents used to extract essential oils in this process are H_2O and CO_2. The fluid's subcritical condition has several advantages: decreased density, lower viscosity, and improved gas-liquid diffusivity. Because this extraction procedure is performed at a moderate working temperature, it is regarded as the best alternative strategy for thermolabile components. Compared to other traditional ways, this process takes 15 minutes to complete (Khmelinskii & Woodcock, 2020). The subcritical liquid extraction method of essential oils from various plants is listed in Table 2. The advantages of this method include their being simple, less time-consuming, cost-efficient, and environmentally friendly. It is a powerful alternative to the essential oils extraction technique as it enables a fast essential oil isolation process (Shirsat *et al.*, 2004). The major disadvantage of this extraction technique is that it requires high pressure to maintain the solvent in the subcritical state, which increases the operating costs.

Figure 5. Schematic representation of the subcritical liquid extraction (SLE) system.

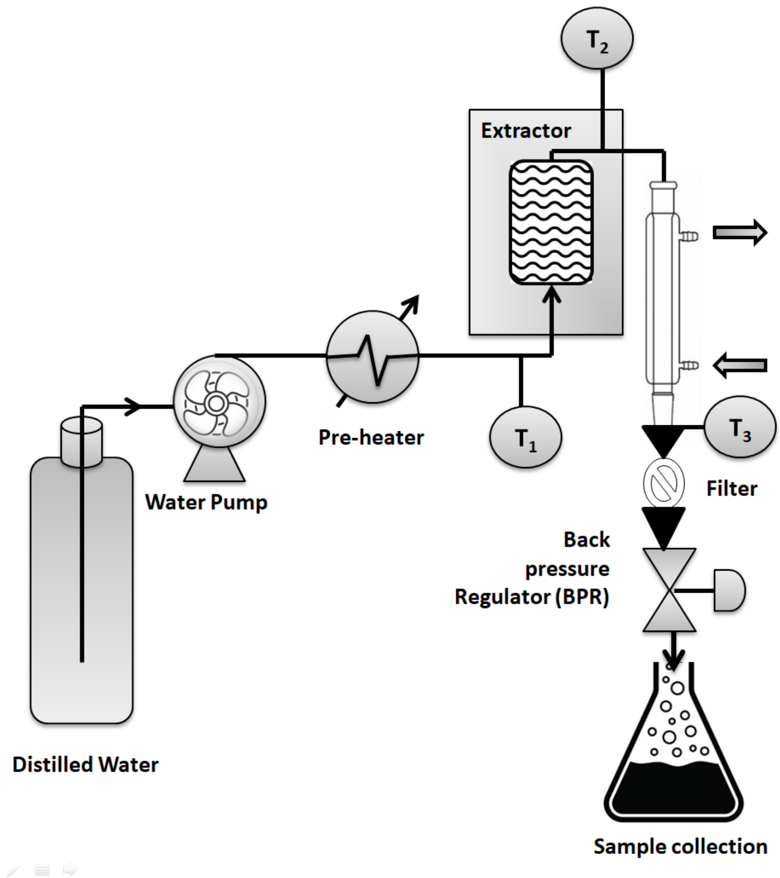


Table 2. The subcritical liquid extraction (SLE) of essential oils from various sources.

Sources (Part Used)	Common Name	Chemical Constituents	Pharmaceutical Application	References
Lavandula angustifolia Mill.; Lamiaceae (Flowers)	Lavender	*β*-Pinene, *β*-phellandrene, borneol, camphor, linalool, terpineol, linalyl acetate and 1,8-cineole	Antimicrobial, anti-inflammatory, and antioxidant activity	(Reverchon *et al.*, 1995; Zhi-linga *et al.*, 2011; Akgu *et al.*, 2000; Lakušić *et al.*, 2014; Danh *et al.*, 2012; Wells *et al.*, 2018)
Lavandula hybrida; Lamiaceae (Flowers)	Lavandin	1,8-Cineole, camphor, linalool, and linalyl acetate	Antinociceptive and gastroprotective activity	(Kamali *et al.*, 2015; Barocelli *et al.*, 2004)
Rosmarinus officinalis L.; Lamiaceae (Leaves)	Rosemary	1,8-Cineole, verbenone, α-pinene, borneol, camphor, *β*-caryophyllene	Antioxidant, antimicrobial, anti-Alzheimer, and hepatoprotective activity	(Khalili *et al.*, 2017; Nieto *et al.*, 2018; Habtemariam, 2016; Rašković *et al.*, 2014)
Zingiber officinale; Zingiberaceae (Rhizomes)	Ginger	*α*-Zingiberene, geraniol, neral, *α*-curcumene, (*Z*)-*α*-bisabolene, *β*-phellandrene and geranial	Anti-inflammatory antibacterial, antifungal, analgesic, anti-ulcer, immunomodulatory and relaxant activity	(Junior *et al.*, 2020; Mahboubi, 2019; Akinyemi and Adeniyi, 2018; Funk *et al.*, 2016)
Citrus sphaerocarpa Tanaka; Rutaceae (Peel)	Kabosu	*β*-Farnesen, auraptene, limonene and myrcene, decanal, nerol and neryl acetate	Antioxidant activity	(Suetsugu *et al.*, 2013; Minh *et al.*, 2002; Kamal *et al.*, 2013)
Chamaecyparis obtusa (Siebold & Zucc.) Endl.; Cupressaceae (Leaves)	Hinoki cypress	Bornyl acetate, elemol, *α*-pinene, 1-muurolol, (+)-limonene, and *α*-terpinyl acetate	Antibacterial, antifungal, anti-inflammatory, antioxidant, and also promote hair growth	(Jina *et al.*, 2010; Yang *et al.*, 2007; Suh *et al.*, 2016; Lee *et al.*, 2010)
Coriandrum sativum L. (Seeds)	Coriander	*γ*-Terpinene, terpin-4-ol, linalool, *α* & *β*-pinene, and borneol	Antioxidant and antimicrobial activity	Eikani *et al.*, 2007; Ghazanfari *et al.*, 2020)
Origanum majorana L.; Lamiaceae	Marjoram	Terpinen-4-ol, *γ*-terpinene, *α* & *β*-pinene, *p*-cymol, *α*-terpineol, *α*-	Antimicrobial, antioxidant,	(Busatta *et al.*, 2008; Abbasi-Maleki *et al.*, 2019; Jiménez-

(Leaves)		terpinolene, *α*-terpinene, camphene, *β*-caryophyllene, spathulenol and *cis*-sabinene hydrate	anti-coagulant and antidepressant activity	Carmona *et al.*, 1999; Va'gi *et al.*, 2005; Bağci1 *et al.*, 2017)
Zataria multiflora Boiss; Lamiaceae (Arial branches)	Shirazi thyme	Thymol, carvacrol, linalool, *λ*-terpinene and *p*-cymene	Antimicrobial, antioxidant and scolicidal activity	(Shafiee and Javidnia, 1997; Mahmoudvand *et al.*, 2017; Khajenoori *et al.*, 2009)
Laurus nobilis L.; Lauraceae (Leaves & fruits)	Bay	1.8-Cineole, sabinene, *β*-elemene, bornyl acetate, *α*-terpinyl acetate, *α* & *β*-phellandrene and trans-*β*-osimen	Antimicrobial, antifungal, and antioxidant activity	(Fernández-Pérez and Jiménez-Carmona, 2000; Sangun *et al.*, 2007; Fidan *et al.*, 2019; Caputo *et al.*, 2017; Mssillou *et al.*, 2020)
Aquilaria malaccensis Lamk.; Thymelaeaceae (Leaves)	Agar Wood	Agarospirol, guaiacol, cyclotene, mequinol, *γ*-himachalene, *α*-guaiene, *β*-agarofuran, *α*-bulnesene, kusunol, creosol, jinkoheremol, and oxoagarospirol	Antibacterial, antifungal, anti-inflammatory, analgesic, anti-diabetes, antioxidant and anticancer activity	(Samadi *et al.*, 2019; Samadi *et al.*, 2020; Tajuddin and Yusoff, 2010; Gunasekera *et al.*, 1981; Wang *et al.*, 2018)

2.3. Microwave-Assisted Hydrodistillation

This microwave-assisted hydrodistillation (MWHD) technique is used to heat the solvent in place of regular electric heating. This approach works by changing the polarity of water and then heating it with microwaves. Electromagnetic energy is converted into heat energy utilizing microwave energy directly generated through molecular interaction between aromatic plants (materials) and the electromagnetic field (Eskilsson & Björklund, 2000; Routray & Orsat, 2012; Thostenson & Chou, 1999). These waves may cause some structural alterations within the plant cells. The schematic representation of the MWHD system is shown in Figure 6. Heat and mass transfer occur in the same direction, *i.e.*, from the inner cells to the outside. The factors affecting the efficiency of this technique include time, temperature, physicochemical properties of the extracted compounds, dielectric properties of the sample mixture, and solvent type. The MWHD extraction method of essential oils from various plants has been reported in the literature (Table 3). This method is used in industry, and it provides an excellent versatile tool that covers a wide range of plant materials under suitable conditions. This method shows speedy extraction performance with low solvent consumption. It is an ecofriendly method due to the less CO_2 emission from the atmosphere (Lucchesi *et al.*, 2004; Moradi *et al.*, 2018; Ferhat *et al.*, 2006). This method offers protection from thermolabile compounds, and the efficiency is firmly based on the dielectric constant of plant material and water, respectively (Brachet *et al.*, 2002). There is only one disadvantage: the microwave technique can lead to changes in the stereochemistry of compounds and can convert them from one isomer to another (Fadel *et al.*, 2011; Norfatirah *et al.*, 2013; Jeyaratnam *et al.*, 2016).

Figure 6. Schematic representation of the microwave-assisted hydrodistillation (MWHD) system.

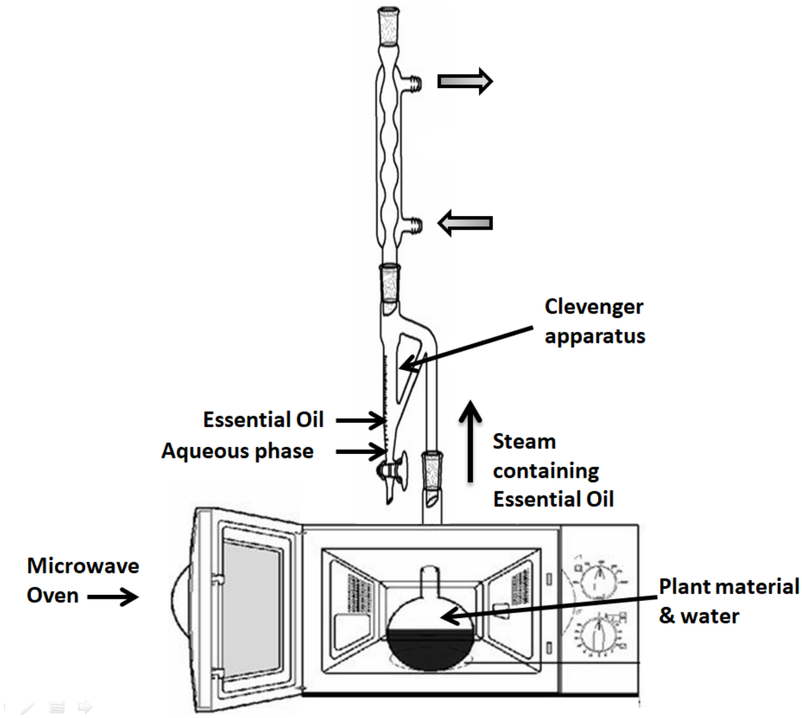


Table 3. The microwave-assisted hydrodistillation (MWHD) based extraction of essential oils from various sources.

Sources (Part Used)	Common Name	Chemical Constituents	Pharmaceutical Application	References
Rosmarinus officinalis L.; Lamiaceae (Leaves)	Rosemary	*α*-Pinene, *β*-myrcene, fenchol camphene, 1,8-cineole, linalool, camphor and borneol	Antioxidant, antimicrobial, anti-Alzheimer, and hepatoprotective activity	(Nieto *et al.*, 2018; Habtemariam, 2016; Rašković *et al.*, 2014; Moradi *et al.*, 2018; Elyemni *et al.*, 2019)
Coriandrum sativum L.; Apiaceae (Seeds)	Coriander	Linalool, *γ*-terpinene, terpin-4-ol, *α* & *β*-pinene and borneol	Antioxidant and antimicrobial activity	(Ghazanfari *et al.*, 2020)
Cinnamomum camphora L.; Lauraceae (Leaves)	Camphor tree	Sabinene, *β*-pinene, *β*-myrcene, *α* & *δ* -terpineol, 3-heptanone, 1,8-cineole, D-camphor, linalool, and *β*-thujene	Antimicrobial, anti-inflammatory, and antioxidant activity	Shang *et al.*, 2020; Lei *et al.*, 2020; Zhang *et al.*, 2019)
Pimpinella anisum; Apiaceae (Fruits)	Aniseed	*γ*-Himachalene, methylchavicol, trans-anethole, *cis* & *trans*-pseudoisoeugenyl and 2-methylbutyrate	Antimicrobial, antiviral, muscle relaxant, analgesic, antifungal, antioxidant and anticonvulsant activity	(Shojaii and Fard, 2012; Boumahdi *et al.*, 2021)
Anethum graveolens. L.; Apiaceae (Seeds)	Dill	Carvone, myristicin, *cis*-isodihydrocarvone, *cis* & *trans*-carveol, limonene, and dillapiole	Antioxidant and antimicrobial activity	(Kosar *et al.*, 2005; Ljiljana *et al.*, 2016)

2.4. Ultrasound-Assisted Extraction

The UAE method permits highly selective and escalation of volatile oils to get separated from plant material. The principle behind this method is that it develops cavitation of some tiny bubbles within the solvent system due to the passage flow of ultrasound waves which usually allow a more significant percentage of a solvent system within the plant material that enhances the surface area (Garcı´a-Pe´rez, 2006). Plant raw materials are immersed in water or another solvent (such as methanol or ethanol) and subjected to ultrasound (Figure 7) (Assami &Pingret, 2012). This technique involves extracting essential oil components from leaves, seeds, and flowers (Sereshti *et al.*, 2012). Factors that significantly affect the percentage yield and quality of the essential oils are ultrasonic frequency, duration of ultrasound treatment, immersion time, extraction temperature, the duty cycle of ultrasound, features, and size of plant materials (Sun *et al.*, 2019). The ultrasound-assisted extraction method of essential oils from various plants has been listed in Table 4. This technique is advantageous for heat-sensitive combinations due to mean temperature and saving energy. It is a suitable method of extraction to get high valuable volatile oils. The efficiency of extraction can be enhanced using this technique which may cause disruption of plant cell walls and improved mass transfer through the formation of cavitation babble effects (Entezari, 2004). The disadvantages of this method include poor purity, low efficiency, and lengthy process (Lu *et al.*, 2012; Mura *et al.*, 2015).

Figure 7. Schematic representation of the ultrasound-assisted extraction (UAE) system.

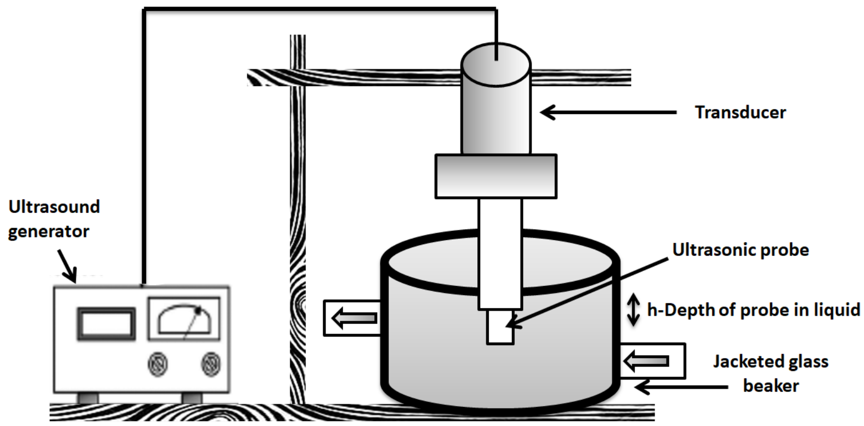


Table 4. Ultrasound-assisted extraction (UAE) of essential oils from various plant sources.

Sources (Part Used)	Common Name	Chemical Constituents	Pharmaceutical Application	References
Lavandula angustifolia and *L. latifolia;* Lamiaceae (Flowering stems)	Lavandin	Linalool, terpinen-4-ol, linalyl acetate, camphor, borneol, *β*-caryophyllene, lavandulyl acetate, and 1,8-cineole	Antimicrobial, antioxidant, carminative, sedative, neuroprotective, anti-depressive activity, and effective for burns and insect bites	(Périno-Issartier *et al.*, 2013; Lesage-Meessen *et al.*, 2015; Cavanagh and Wilkinson, 2002; Hancianu *et al.*, 2013)
Apium graveolens L.; Apiaceae (Seeds)	*Celery*	Limonene, *α* & *β*-selinene, sedanenolid and 3-butylphtalide	Antimicrobial and antioxidant activity	(Zorga *et al.*, 2020)
Trichoderma africanum L.; Boraginaceae (Leaves)	African barbell	Caryophyllene oxide, *γ*-eudesmol, elemol, *α*-muurolene, carvone, *β*-caryophyllene and *α*-pinene	Antimicrobial and antioxidant activity	(Jaradat *et al.*, 2016; Ahmed *et al.*, 2015)
Thymus vulgaris L.; Lamiaceae (leaves)	Thyme	Carvacrol, thymol, *p*-cymene and *γ*-terpinene	Antioxidant, antiproliferative and antiviral activity	(Grosso *et al.*, 2010; Catella *et al.*, 2021; Niksic *et al.*, 2021; Kowalski and Wawrzkowski; 2009)
Carum carvi L.; Apiaceae (Seeds)	Caraway	Carvone, limonene, *β*-myrcene, trans-carveole, γ-terpinene, trans-dihydrocarvone, *α*-pinene, sabinene, trans-*β*-ocimene, and linalool	Antibacterial, fungicidal, antioxidant, anti-acetylcholinesterase, antidiabetic and diuretic activity	(Assami *et al.*, 2012; Raal *et al.*, 2012; Begum *et al.*, 2008; Hajlaoui *et al.*, 2021)
Lavandula intermedia; Lamiaceae (Flowers)	Lavender	Linalool, cineole, camphor, 1,8- limonene, linalyl acetate and (*Z* & *E*)-*β*-ocimene	Antibacterial, antioxidant, and anti-inflammatory activity	(Ahmed *et al.*, 2015; Garzoli *et al.*, 2020; Tardugno *et al.*, 2019; Lane and Mahmoud, 2008; Wells *et al.*, 2018)
Elettaria cardamomum L. Maton; Zingiberaceae (Seeds)	Cardamom	*α*-Terpinyl acetate, *α* & *β*-pinene, *β*-myrcene and 1,8-cineole	Antimicrobial, antidiarrhoeal, and antispasmodic activity	(Morsy, 2015; Noumi *et al.*, 2018; Alam *et al.*, 2021

Origanum majorana L.; Lamiaceae (Leaves)	Sweet marjoram	Carvacrol, *o*-cymene, *α* & *β*-pinene, *β*-myrcene, *γ*-terpinene, limonene and linalool	Antimicrobial, antioxidant, anti-coagulant and antidepressant activity	(Bağcil *et al.*, 2017; Busatta *et al.*, 2008; Abbasi-Maleki *et al.*, 2019; Ebrahimzadeh *et al.*, 2003; Kowlski *et al.*, 2015)
Chamomilla recutita L.; Asteraceae (Flowers)	Chamomile	*α*-Bisabolol oxide A, *α*-bisabolol, *β*-bisabolene *α*-bisabolol oxide B, *cis*-enynebicycloether, bisabolol oxide A, chamazulene, spathulenol and (*E*)-*β*-farnesene	Anti-inflammatory, anticancer and gastroprotective activity	(Pino *et al.*, 2002; Orav *et al.*, 2010; Srivastava *et al.*, 2010)
Apium graveolens L.; Apiaceae (Seeds)	Celery	Limonene, *β*-selinene, sedanenolid, *α*-selinene, 3-butylphtalide	Antimicrobial and antioxidant activity	(Begum *et al.*, 2008; Dinç Zor *et al.*, 2017)
Allium sativum L.; Amaryllidaceae (Bulbs)	Garlic	Diallyl trisulfide, allyl methyl trisulfide, allyl methyl disulfide, allyl (*E*)-1-propenyl disulfide and diallyl sulfide	Antioxidant, anti-hypertensive, anticoagulant and anti-Alzheimer activity	(Boubechiche *et al.*, 2017; Satyal *et al.*, 2017; Hashemi *et al.*, 2019)
Mentha spicata; Lamiaceae (Leaves)	Spearmint	Limonene, carvone, menthol, carveol, isocaryophyllene, germacrene D and *β*-farnesene	Antibacterial, antidermatophytic, anticholinesterase and anti-Alzheimer activity	(Porto and Decorti, 2009; Ali-Shtayeh *et al.*, 2019)
Citrus limetta; Rutaceae (Peel)	Sweet lime	D-Limonene, bergamol, α & β-pinene, linalool, 1,8 cineole and α-terpineol	Antimicrobial, antioxidant, anti-inflammatory and anxiolytic activity	(Arafat *et al.*, 2020; Mahmud *et al.*, 2009)

2.5. Solvent-Free Microwave Extraction

Dry distillation and microwave heating energy in combination are used in this process (Chemat *et al.*, 2003; Chemat *et al.*, 2004). In this method, the moisture present in the plant material is used as a solvent (Lucchesi *et al.*, 2007). Before undergoing the extraction process, the herbal materials are moistened with water for approximately 2 hrs. The moistened materials are microwaved, and a condenser is used to collect the essential oils. The thermal stress and pressure generated within the plant tissues being treated in the case of microwave heating may cause their disruption more rapidly when compared with the traditional methods. The panel embedded within the instrument controlled the temperature, pressure, and irradiation power (Figure 8). The essential oil is dried in the desiccator and stored in a dark place. This method is used to quickly isolate volatile oils from herbs, spices, and seeds, as listed in Table 5. The main advantage of this method is the single-stage isolation and concentration of essential oil (Lucchesi *et al.*, 2004; Bayramoglu *et al.*, 2008). Other benefits of this green technique include efficiency, selectivity, and shorter time (Boubia *et al.*, 2009; Lopez-Avila *et al.*, 1994).

Figure 8. Schematic representation of the solvent-free microwave extraction (SFME) system.

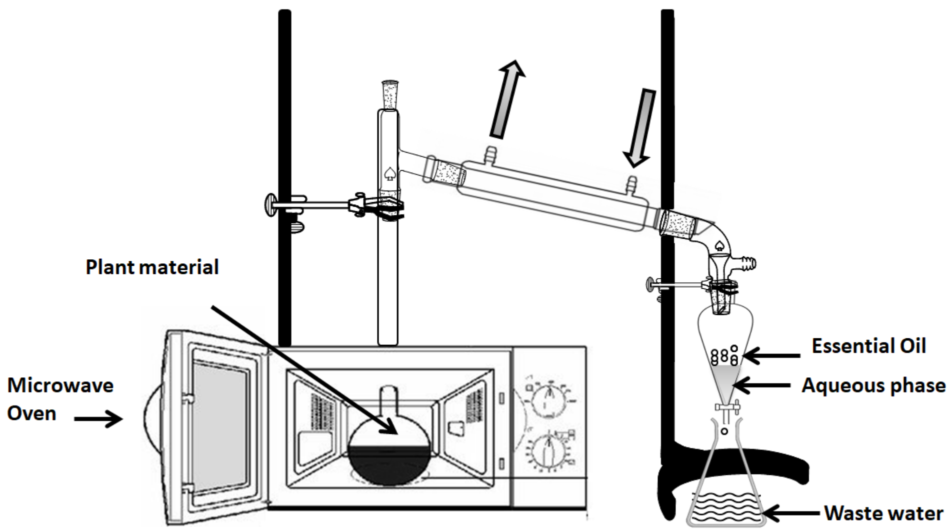


Table 5. Solvent-free microwave extraction (SFME) of essential oils from various sources.

Sources (Part Used)	Common Name	Chemical Constituents	Pharmaceutical Application	References
Ocimum basilicum L.; Lamiaceae (Leaves)	Egyptian sweet basil	Camphor, limonene, linalool, *β*-selinene, methyl chavicol and 1,8-cineole	Antioxidant and antimicrobial activity	(Chenni *et al.*, 2016)
Amomum tsaoko; Zingiberaceae (Seeds)	Chinese black cardamom	Geranial, eucalyptol, neral, Geraniol, (2*E*)-decenal and 4-indanecarbaldehyde	Antioxidant and antimicrobial activity	(Cui *et al.*, 2017; Sim *et al.*, 2019)
Foeniculum vulgare Mill.; Apiaceae (Seeds)	Fennel	*α* & *β*-Pinene, *α*-fenchene, 3-methylnonane, carvone, eucalyptol, camphor, *α*-terpinolene, *γ*-terpinene, and *cis*-anethole	Antioxidant and antimicrobial activity	(Benmoussa *et al.*, 2019; Khammassi *et al.*, 2018)
Cuminum cyminum L.; Apiaceae (Seeds)	Cumin	*α*-Thujene, *γ*-terpinene, geraniol, *α*-pinene, sabinene, (*E*)-ocimene, linalool, trans-carveole, *α*-terpinyl acetate, neryl acetate and *α*-campholenal	Antimicrobial, anti-vomiting, anti-asthma and anti-spasm activity	Wang *et al.*, 2006; Wannera *et al.*, 2010; Esmaeili, 2015)
Zanthoxylum bungeanum; Rutaceae (Fruit)	Sichuan pepper	Terpinen-4-ol, Linalool, limonene, 1,8-cineole, *γ*-terpinene, *α*-terpineol, and terpinyl acetate	Antibacterial, antifungal and anticancer activity	Wang *et al.*, 2006, Gong *et al.*, 2009; Lan *et al.*, 2014A; Lan *et al.*, 2014B; Zhu, 2011)
Melissa officinalis L.; Lamiaceae (Leaves)	Lemon balm	Geranial, neral, caryophyllene, *γ*-caryophyllene oxide, *μ*- pinene, citronella and sabinene	Anti-inflammatory, anticancer and antioxidant activity	Uysal *et al.*, 2010; Fernández *et al.*, 2020; Bounihi *et al.*, 2013; de Sousa *et al.*, 2004)
Laurus nobilis L.; Lauraceae (Leaves & fruits)	Bay	1.8-Cineole, bornyl acetate, *β*-elemene, sabinene, *α*-terpinyl acetate, *α*-pinene, trans-*β*-osimen, *α* & *β*-phellandrene	Antimicrobial, antifungal and antioxidant activity	(Sangun *et al.*, 2007; Fidan *et al.*, 2019; Caputo *et al.*, 2017; Mssillou *et al.*, 2020; Uysal *et al.*, 2010)
Melaleuca leucadendra L.; Myrtaceae (Leaves)	Cajuput	(*E*)-Nerolidol, viridiflorol, *β*-caryophyllene, (*E*)-*β*-farnesene, *α*-humulene and 1,8-cineole	Antimicrobial, antikinetoplastid, antiproliferative and cytotoxic activity	(Ismanto *et al.*, 2018; Rajendra *et al.*, 2015; Pino *et al.*, 2002; Monzote *et al.*, 2020)

Elletaria cardamomum L.; Zingiberaceae (Seeds)	Cardamom	1,8-Cineole, linalool, *α*-terpineol, *α* -terpinyl acetate, linalyl acetate	Antibacterial, antiseptic, carminative and antispasmodic activity	(Lucchesi *et al.*, 2007; Al-Zuhair *et al.*, 1996)
Origanum vulgare L.; Lamiaceae (Leaves and flowers)	Oregano	Thymol, *γ*-terpinene, Carvacrol, *β*-caryophyllene, terpinen-4-ol, *β*-myrcene, and *trans*-sabinene hydrate	Antimicrobial, antioxidant, anti-inflammatory, antidiabetic and anticancer activity	(Lucchesi *et al.*, 2008; Leyva-López *et al.*, 2017)
Dryopteris fragrans; Dryopteridaceae (Leaves and stems)	Fragrant woodfern	Esculetin, isoscopoletin, methylphlor-butyrophenone, aspidinol and albicanol	Antioxidant, anticancer and anti-inflammation activity	(Li *et al.*, 2012; Zhao *et al.*, 2014; Zhang *et al.*, 2018)
Rosmarinus officinalis L.; Lamiaceae (Leaves)	Rosemary	1,8-Cineole, *α*-pinene, verbenone, borneol camphor and *β*-caryophyllene	Antioxidant, antimicrobial, anti-Alzheimer and hepatoprotective activity	(Nieto *et al.*, 2018; Habtemariam, 2016; Rašković *et al.*, 2014; Okoh *et al.*, 2010)
Haplophyllum robustum Bge; Rutaceae (Aerial parts)	-	Sabinene, *β*-phellandrene, 1,8-cineole, camphor, terpinene-4-ol, *β*-pinene, 3,5-dimethoxy toluene	Antioxidant activity	(Moradalizadeh *et al.*, 2013; Gholivand *et al.*, 2012)

2.6. Microwave Hydro-diffusion and Gravity

Microwave hydro-diffusion and gravity (MHG) is one of the novel green methods of extracting volatile oils. This technology utilizes microwaves and earth gravity to harvest and extract volatile oils that hydro diffuse from the inner cell areas to the exterior of the plant material. The schematic representation of the MHG extraction system is shown in Figure 9. It is typically carried out at atmospheric pressure with no solvent added. It was designed for small-scale experimentation and processing (Vian *et al.*, 2008). This technique is used for expeditious isolation of volatile oils, as listed in Table 6. The advantage of this method is that it is economical, requires less energy, is highly efficient and does not require any solvent/water (Lucchesi, 2005). The extraction time is in minutes compared to hydrodistillation, which takes hours (Vian *et al.*, 2008).

Figure 9. Schematic representation of the microwave hydro-diffusion and gravity (MHG) extraction system.

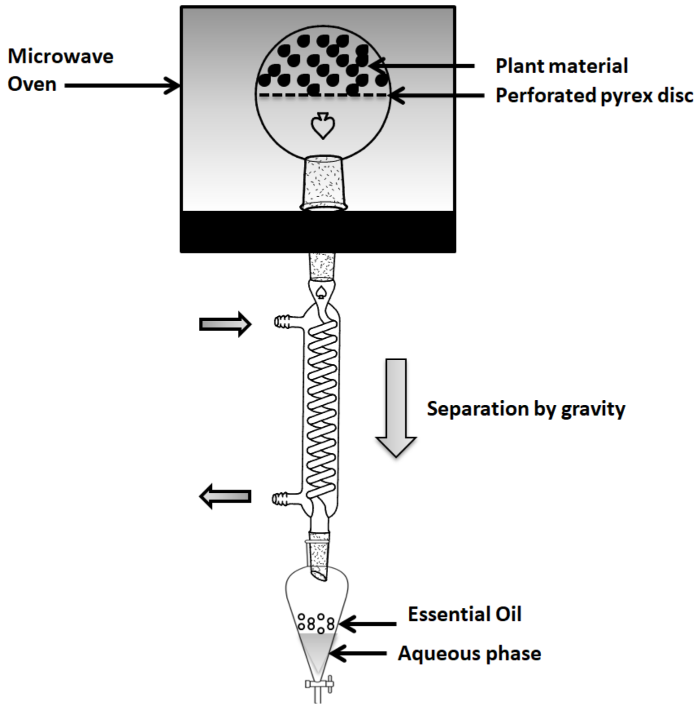


Table 6. Microwave hydro-diffusion and gravity (MHG) method of extraction of essential oils from various sources.

Sources (Part Used)	Common Name	Chemical Constituents	Pharmaceutical Application	References
Mentha spicata L.; Lamiaceae (Leaves)	Spearmint	Limonene, carvone, menthol, carveol, isocaryophyllene, germacrene D and *β*-farnesene	Antibacterial, antidermatophytic, anticholinesterase and anti-Alzheimer activity	(Ali-Shtayeh *et al.*,2019; Vian *et al.*, 2008)
Mentha pulegium L.; Lamiaceae (Flowers and leaves)	Pennyroyal	*α* & *β*-Pinene, pulegone, piperitenone, menthol, iso & neo-menthol, menthone, iso-menthone, and neoiso-menthol	Anti-cholinesterase, anti-Alzheimer and antioxidant activity	(Bektašević *et al.*, 2021; Vian *et al.*, 2008)
Zingiber officinale; Zingiberaceae (Rhizomes)	Ginger	Geraniol, geranial, *β*-phellandrene, neral, *α*-curcumene, *β*-sesquiphellandrene, (*Z*)-*α*-bisabolene and *α*-zingiberene	Anti-inflammatory antibacterial, anti-ulcer, antifungal, analgesic, immunomodulatory and relaxant activity	(Mahboubi, 2019; Akinyemi and Adeniyi, 2018; Funk *et al.*, 2016; Asofiei *et al.*, 2017)
Calophyllum inophyllum L; Calophyllaceae (Seeds)	Tamanu	*α*-Thujen, *α* & *β*-pinene, camphene, limonene, *γ*-terpinene, myrcene and *p*-cymene	Anti-inflammatory, antibacterial, wound healing, anti-HIV and antioxidant activity	(Raharivelomanana *et al.*, 2018; Emmanuel *et al.*, 2019)
Cuminum cyminum L.; Apiaceae (Seeds)	Cumin	*α*-Thujene, 1,8-cineole, *α*-pinene, sabinene, limonene, terpinolene, (*E*)-ocimene, geraniol, *γ*-terpinene, linalool, *α*-campholenal, trans-carveole, linalyl acetate, *α*-terpinyl acetate and neryl acetate	Antimicrobial, anti-vomiting, anti-asthma and anti-spasm activity	(Wannera *et al.*, 2010; Esmaeili, 2015; Benmoussa *et al.*, 2018)

2.7. Ohmic Heated Water Distillation

Ohmic heated water distillation (OHWD) is a revolutionary process for isolating essential oils that use ohmic or Joules' heating (Shirsat *et al.*, 2004), and it requires less power (per mL) (Gavahian *et al.*, 2012). Controlling treatment homogeneity necessitates the most accurate modeling inputs. The schematic representation of the OHWD extraction system is shown in Figure 10. The heating rate is proportional to the square of the electric field strength and the conductivity of the medium. This technique is used for expeditious isolation of various volatile oils, as listed in Table 7. Ohmic heating is a highly energy-efficient and safe technology. It gives rapid and relatively homogenous heating. The quality of essential oils extracted by this method is good. The main disadvantage of ohmic heating is the high cost, the corrosion in the electrodes, and constant cleaning (Zareifard *et al.*, 2003; Goullieux & Pain, 2005).

Figure 10. Schematic representation of the Ohmic heated water distillation (OHWD) extraction system.

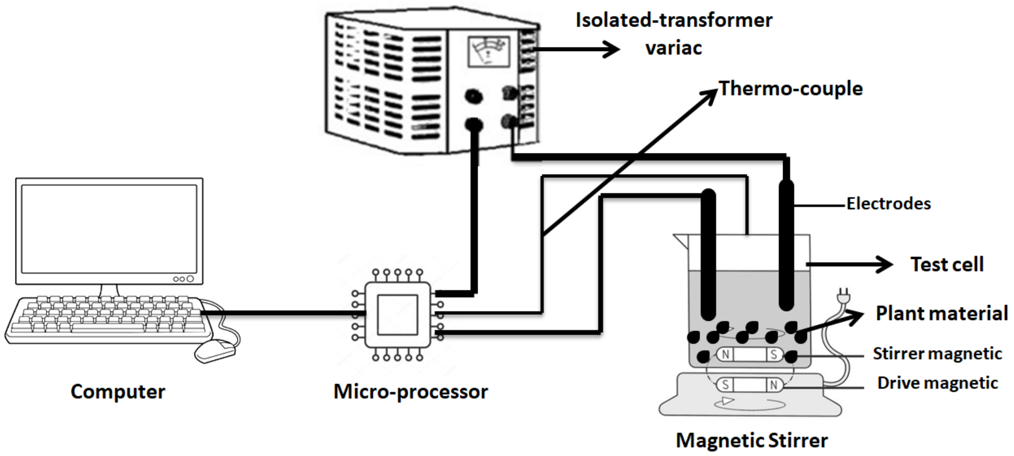


Table 7. Ohmic heated water distillation (OHWD) method of extraction of essential oils from various sources.

Sources (Part Used)	Common Name	Chemical Constituents	Pharmaceutical Application	References
Thymus daenensis Celak; Lamiacae (Aerial parts)	Thyme	Thymol, carvacrol,*γ*-terpinene and *p*-cymene	Antimicrobial, antioxidant, insecticidal and immunomodulatory activity	(Tavakolpour *et al.*, 2017; Pirbalouti *et al.* 2013; Hadipanah and Khorami, 2016; Mohammad and Krenn, 2015)
Cymbopogon nardus; Poaceae (Grass)	Citronella	Citronellal, citronellol, neral, geraniol, linalool, *γ*-cadinene, trans-*β*-caryophyllene and citronellyl acetate	Antimicrobial, anthelmintic, antioxidant, anticonvulsant antitrypanosomal and wound healing activity	(Hazwan *et al.*, 2012; Sharma *et al.*, 2019)
Carum copticum L.; Umbelliferae (Seeds)	Ajowan	*α*-Thujen, *p*-cymene, thymol, *α* & *β*-pinene, 1,8-cineole, carvacrol and *γ*-terpinene	Antioxidant and antiaflatoxigenic activity	(Hashemi *et al.*, 2016; Ghadimian and Esmaeili, 2016; Kahkha *et al.*, 2014)
Melaleuca leucadendra L; Myrtaceae (Leaves, twigs and flowers)	Weeping paperbark	(*E*)-Nerolidol, (*E*)-*β*-farnesene, viridiflorol, *β*-caryophyllene, and *α*-humulene	Antimicrobial, antifungal, antikinetoplastid and antiproliferative activity	(Rajendra *et al.*, 2015; Monzote *et al.*, 2020; Iswahyono *et al.*, 2021; Zhang *et al.*, 2019)
Mentha piperita; Lamiaceae (Leaves)	Peppermint	Menthol, 1,8-cineole, menthone, *β*-pinene, (+/-)-menthyl acetate, *β*-caryophyllene and limonene	Antioxidant and antimicrobial activity	(Gavahian *et al.*, 2017; Gavahian *et al.*, 2015; Schmidt *et al.*, 2009; Mimica-Dukić *et al.*, 2003)
Lavandula angustifolia; Lamiaceae (Flowers)	Lavender	*β*-Pinene, linalool, camphor, terpineol, *β*-phellandrene, borneol, linalyl acetate and 1,8-cineole	Antimicrobial, anti-inflammatory and antioxidant activity	(Akgu *et al.*, 2000; Lakušić *et al.*, 2014; Danh *et al.*, 2012; Wells *et al.*, 2018; Gavahian and Chu, 2018)
Thymus vulgaris L.; Lamiaceae (Aerial flowering parts)	Common thyme	*p*-Cymene, linalool, thymol, *γ*-terpinene and carvacrol	Antioxidant, antiviral and antiproliferative activity	(Grosso *et al.*, 2010; Catella *et al.*, 2021; Niksic *et al.*, 2021; Gavahian *et al.*, 2012)
Zataria multiflora Boiss; *Lamiaceae* (Arial branches)	Shirazi thyme	Thymol, carvacrol, linalool, *λ*-terpinene and *p*-cymene	Antimicrobial, antioxidant and scolicidal activity	(Shafiee and Javidnia, 1997; Mahmoudvand *et al.*, 2017; Gavahian *et al.*, 2011)
Syzygium aromaticum (L.) Merrill et L.M. Perry; Myrtaceae (Buds)	Clove	Eugenol, eugenyl acetate, *δ*-cadinene *α*-caryophyllene, and *β*-elemene	Antioxidant, antifungal and antimicrobial activity	(Tunç and Koca, 2019; Selles *et al.*, 2020; Kaur *et al.*, 2019)

2.8. Solar Distillation

Solar energy serves in the agriculture field by saving money and reducing the environmental pollution. New technology has been developed to improve the efficiency of the distillation process by utilizing renewable energy sources such as sunlight. This method is used about the same amount of heat energy per unit weight of plant material (Garg & Prakash, 2006). A Scheffler fixed steam receiver, condenser, focus concentrator, oil separator, distillation still, and other components are used in solar distillation (Figure 11). The amount of energy available for the distillation process is determined by the sun intensity and the solar distillery's thermal and optical efficiency. It is a low-cost method for extracting essential oils from medicinal plants. Essential oils from different plant sources are extracted using a solar distillation system like eucalyptus leaves, peppermint leaves, clove buds, fennel seeds, basil, lavender, cumin, cardamom, orange, lemon, rosemary, citrus, Cymbopogon, etc. (Table 8) (Al-Hilphy *et al.*, 2022; Radwan *et al.*, 2020; Afzal *et al.*, 2017; Yen and Lin, 2017).

Figure 11. Schematic representaiton of the solar distillation (SD) extraction system.

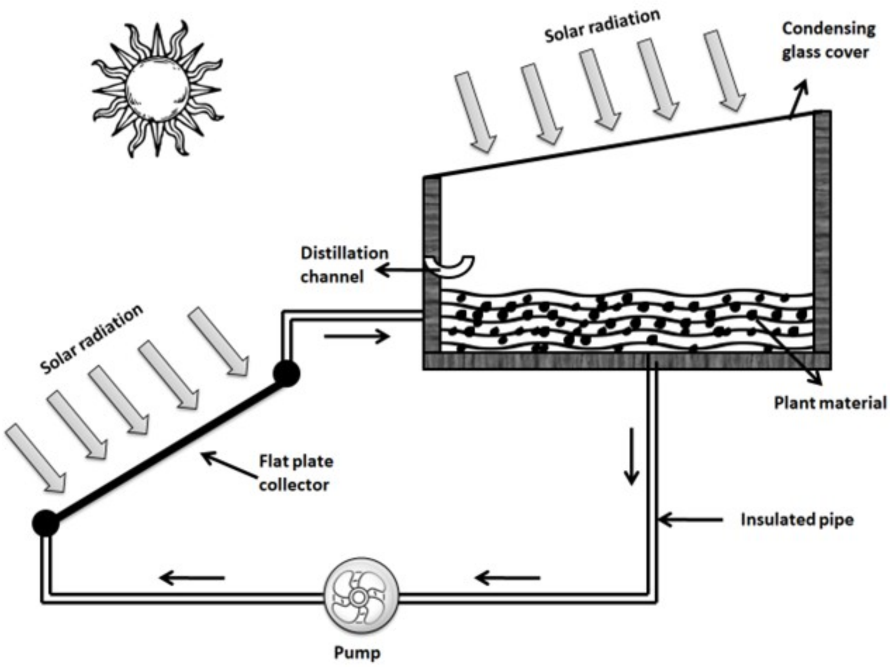


Table 8. Solar distillation (SD) method of extraction of essential oils from various sources.

Sources (Part Used)	Common Name	Chemical Constituents	Pharmaceutical Application	References
Eucalyptus camaldulensis; Myrtaceae (Leaves)	River red gum	Eucalyptol, *α*-phellanderene, *β*-pinene, arommadenderene, terpineol-4-ol	Antimicrobial activity	(Al-Hilphy et al., 2022; Afzal *et al.*, 2017; Lima *et al.*, 2013)
Mentha piperita; Lamiaceae (Leaves)	Peppermint	Menthol, 1,8-cineole, menthone, *β*-pinene, (+/-)-menthyl acetate, *β*-caryophyllene and limonene	Antioxidant and antimicrobial activity	(Afzal *et al.*, 2017; Schmidt *et al.*, 2009; Mimica-Dukić *et al.*, 2003)
Pinus (Roxburghii)		*α*-Pinene		(Afzal *et al.*, 2017)
Lavandula angustifolia; Lamiaceae (Flowers)	Lavender	*β*-Pinene, *β*-phellandrene, borneol, camphor, linalool, terpineol, linalyl acetate, terpineol-4-ol, cymene and 1,8-cineole	Antimicrobial, anti-inflammatory, and antioxidant activity	(Radwan *et al.*, 2020; Lakušić *et al.*, 2014; Danh *et al.*, 2012; Wells *et al.*, 2018)
Cymbopogon citratus (DC) Stapf..*;* Poaceae (Leaves)	Lemon grass, oil grass	Geranial (citral a), neral (citral b), myrcene	Antioxidant, antileishmanial, antispasmodic, analgesic, anti-inflammatory, anti-pyretic, diuretic, anticonvulsant, and sedative activity	(Yen and Lin, 2017, Hanaa *et al.*, 2012, Santin *et al.*, 2009, Blanco *et al.*, 2009)
Syzygium aromaticum; Myrtaceae (Buds)	Clove	Eugenol, eugenyl acetate, *δ*-cadinene *α*-caryophyllene, and *β*-elemene	Antioxidant, antifungal and antimicrobial activity	(Al-Hilphy *et al.,* 2022, Selles *et al.*, 2020; Kaur *et al.*, 2019)
Rosmarinus officinalis L.; Lamiaceae (Leaves)	Rosemary	1,8-Cineole, verbenone, α-pinene, borneol, camphor, *β*-caryophyllene	Antioxidant, antimicrobial, anti-Alzheimer, and hepatoprotective activity	(Hilali *et al.*2018, 2018; Habtemariam, 2016; Rašković *et al.*, 2014)
Ocimum basilicum; Lamiaceae (Leaves)	Egyptian sweet basil	Camphor, limonene, linalool, *β*-selinene, methyl chavicol and 1,8-cineole	Antioxidant, and antimicrobial activity	(Nannaware *et al.*, 2022)
Elettaria cardamomum; Zingiberaceae (Seeds)	Cardamon/ cardamum	1,8-Cineole, *α*-terpinyl acetate, sabinene, *β*-linalool, *α* & *β*-pinene, and *β*-myrcene	Antimicrobial, aphrodisiac, astringent, digestive, stomachic, stimulant, and diuretic activity	(Al-Hilphy *et al.*, 2022, Alam *et al.*, 2021; Noumi *et al.*, 2018)

3. CONCLUSION

Various essential oils can be utilized as natural food additives and emanate from various sources. Many researchers have proven the effectiveness of innovations in traditional methods to extract volatile oils from various plant materials. The creation, improvement, and scale-up of these advances from the laboratory to pilot and industrial-scale all need modeling the experimental data. Reverchon *et al.*, 1999 and Sovová, 2005 provided some of the most successful ways. The objective of research scientists in the twenty-first century is to stimulate advances in traditional essential oil extraction processes that increase the yield and quality of volatile oils for aromatherapy and pharmaceutical uses. Essential oils' mechanisms of action must be understood to determine their efficacy as phytotherapeutic agents. On the other hand, innovative approaches, including microwave, ultrasound, ohmic heat, and solar energy-assisted extraction, can be coupled with conventional extraction methods for efficacious production of essential oils. Further research is necessary to find essential oils with novel bioactivities or functionalities.

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Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in IJSM belongs to the authors.

Authorship Contribution Statement

Yogesh Murti and Divya Jain: Equally contributed to conceiving the presented idea for the article, performed the literature search, analyzed the data, and wrote the original draft. **Bhupesh Chander Semwal and Sonia Singh**: Drew the figure and tables and edited the manuscript. **Pracheta Janmeda**: Provided critical feedback. **Pranav Bhaskar**: Provided critical feedback, edited the paper, and helped shape the final draft for submission.

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