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Essential Oil Extraction from Various Natural Sources: A Comprehensive Review of Methods, Phytochemistry, and Biological Activities

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ABSTRACT
Essential oil is volatile organic liquid compound extracted from different plant parts of various plant materials. Essential oil has been used in many industries like pharmaceuticals, perfumery, cosmetics, and food industries due to their natural properties like antifungal, anti-aging, antiseptic and many other activities. This work presents the impact of yield by conventional and non-conventional techniques including solvent extraction, soxlet extraction, hydrodistillation, steam distillation, microwave assisted extraction, ultrasound assisted extraction, microwave assisted hydrodistillation, ultrasound assisted hydrodistillation and supercritical fluid extraction on clove, lemon peels, orange peels, tulsi and nagod plants. The essential oils obtained are comprehensively characterized using analytical techniques including high-performance liquid chromatography, gas chromatography–mass spectrometry. This study it was observed that, for various plant material the traditional methods was able to achieve an extraction yield higher than the conventional method for the same amount of same amount of sample. Thus, the same yield of essential oils is obtained in less time by non-conventional techniques while conventional techniques take much longer time. The yield of essential oil also depends on the type of solvent used and the geographic origin of the plant materials. The paper presents the list out the various methods of extraction of essential oil from the different plant parts and their merits and demerits. The results obtained provide a fundamental basis for scaling up the extraction processes to an industrial level.
Keywords: *Essential oil, hydrodistillation, microwave assisted extraction, ultrasound assisted extraction, supercritical fluid extraction, high-performance liquid chromatography, gas chromatography–mass spectrometry*

INTRODUCTION

Essential Oils (EOs) or some of their components widely used in agricultural, dentistry, sanitary, perfumes, pharmaceutical, cosmetic and food industries as food preservers and additives, and as organic cures. Alternative therapies also make use of EOs. Analgesic, antimicrobial, sedative, anti-inflammatory, spasmolytic, bactericidal, virucidal, fungicidal, antiparasitical, insecticidal, and locally anesthesiatic effects are among the medical and cosmetic uses of EOs [1].
EOs are colorless, liquid, volatile, natural, limpid, complex molecules that have a strong odor. EOs are soluble in lipid and in organic solvents with densities that are typically lower than those of water. EOs are employed in nature to protect plants from herbivores by reducing their demand for certain plants and functioning as herbicides, antibacterials, insecticides, and antiviral agents. They may also draw some insects to help seeds and pollen move, or they may keep out unwanted insects.

Only 10% of the more than 3000 EOs currently known are employed in commerce [1]. EOs can be produced by the leaves, flowers, fruits, buds, stalks, twigs, seeds, roots, gums or oleoresin exudations, rhizomes, wood, or bark, among other plant organs. Different aromatic plants are used to make EOs. Various techniques can be used to extract EOs [1-2].
EOs usually obtained by conventional methods, including

- Cold pressing or Expression [3]
- Steam Distillation (SD) [4],
- Hydro-distillation (HD),
- Solvent Extraction [5],

- Extraction with Cold Fat (Enfleurage),
- Soxlet Extraction

Conventional extraction methods are user-friendly, avoid the use of organic solvents, and offer high reproducibility. Long extraction durations, high solvent and energy consumption, and the possibility of important bioactive chemicals degrading or hydrolyzing as a result of prolonged exposure to heat and steam are some of their disadvantages [6].

Advanced extraction methods of EOs Extraction having innovative methods for example,

- Supercritical fluid extraction (SFE) [2]
- Ultrasound assisted extraction (UAE),
- Microwave assisted hydrodistillation (MAHD) [5]
- Microwave assisted steam distillation (MASD) [5],
- Microwave assisted extraction (MAE),
- Microwave hydrodiffusion and gravity (MHDG)
- Solvent free microwave extraction (SFME)

EOs contain over 200 chemical constituents at varying concentrations. The major components typically include aromatic compounds, terpenes, terpenoids, and aliphatic molecules, which account for 20–70% of the total composition. The remaining fraction consists of minor constituents. The biological activity of EOs largely depends on the relative abundance of these major components [6].

Extraction of Essential Oils from Agricultural Biomass

EOs are extracted from different plants and from different plant parts such as leaves, stems, wood, bark, roots, seeds, rhizomes, flowers, fruits, and oleoresin exudates with their own chemical compositions and medicinal properties, EOs are extracted from a variety of plant parts, such as leaves (basil, mint), flowers (rose, jasmine), peels (orange, lemon), seeds (cumin, mustard), wood (sandalwood), bark (cinnamon), resins (guggul), rhizomes (ginger, turmeric), roots (vetiver), and berries (juniper, black pepper).[6]

Table 1. EOs produced by different parts of Plants

Leaves	Flowers	Peel	Seeds	Wood	Bark	Resin	Rhizome	Root	Berries
Basil	Rose	Orange	Black Cumin	Sandalwood	Cinnamon	Guggul	Ginger	Vetiver	Juniper
Lemongrass	Lotus	Lemon	Almond	Camphor	Cassia	Copal	Turmeric	Ashwagandha	Black Pepper
Mint	Jasmine	Lime	Coriander	Rosewood	Rosewood	Elemi	Spikenard	Aloe Root	Bayberry
Holi basi (tulsi)	Marigold (Calendula)	Grapefruit	Mustard	Agarwood	Sandalwood	Pine Resin	Ashwagandha	Marshmallow	Gooseberry
Neem	Lavender	Mandarin	Fenugreek	Cypress	Agarwood				

STRUCTURE OF THE INDUSTRY

EOs are composed of around 200 different components. EOs often consist of combinations of phenylpropanic or terpenes derivatives, with substances that have little chemical and structural variations [7].

One of the most used methods for identifying and separating the components of EOs is gas chromatography–mass spectrometry (GC-MS). The chemical composition and concentration of EOs can vary mainly dependent on factors like plant part used, harvest timing, drying and distillation methods, storage conditions, extraction technique, and environmental or climatic influences—even among closely related species. EOs contain diverse compounds such as alcohols, aldehydes, esters, hydrocarbons, ketones, phenols, and terpenes, each offering specific biological activities. These include antimicrobial, antiviral, anti-inflammatory, analgesic, sedative, antioxidant, and expectorant effects. The bioactivity of each EO depends on its chemical class and constituent concentration. EOs exhibit a wide range of biological activities due to their diverse chemical constituents. Alcohols like linalool and menthol are known for antimicrobial, antiviral, and anti-inflammatory properties. Aldehydes like citral and cinnamaldehyde display antiseptic, antifungal, and sedative effects. Esters and ketones contribute to spasmolytic, analgesic, and expectorant activities. Hydrocarbons, oxides, and phenols show antioxidant, stimulant, and immune-boosting properties. Additionally, monoterpenes and sesquiterpenes offer bactericidal, analgesic, and anti-allergic effects, while diterpenes like sclareol and phytol provide antifungal and hormonal balancing actions [7-8].

Table 2. Biological and chemical activities of EOs [7].

Chemical class	Name of the EOs composition	Biological activity
Alcohol	Citronellol, farnesol, fenchol, geraniol, linalool, menthol viridifloro, ascaridole, α-terpineol, β-nerolidol, borneol chrysanthenol, citronellol, etc.	antiviral, bactericidal, germicidal, anti inflammatory, antimicrobial, antiseptic anti-analgesic, etc.
Aldehyde	Citral, citronellal, cuminaldehyde, geranial, myrtenal neral, benzaldehyde, cinnamonaldehyde, etc.	Antimicrobial, antipyretic, antiviral hypotensive, spasmolytic, anti-fungal anti-inflammatory, anti-septic bactericidal, disinfectant, sedative, etc.
Ester	Menthofuran, 1, 8-cineole, geranyl formate, linalyl acetate eugenol acetate, geraniol acetate, bornyl acetate, etc.	sedative, spasmolytic, antifungal, anti inflammatory, anesthetic, etc.
Hydrocarbon	Myrcene, phellandrene, ocimene, terpinenes, p-cimene pinenes, α-phellandrene, pinenes-3-carene, cymene limonene, etc.	Antibacterial, antiviral, decongestant antioxidant, hepatoprotective, etc.
Ketone	Phenchone, pulegone, tegetone, thujone, carvone verbenone, pulegone, menthone, piperitone, nootkatone fenchone, camphor, etc.	Analgesic, antiviral, cell regenerating anti-catarrhal, cell proliferant expectorant, vulnery, digestive mucolytic, neurotoxic, sedative spasmolytic, etc.
Coumarin and lactone	Humulene epoxides, bergaptene, costuslactone nepetalactone, dihydronepetalactone, alantrolactone, etc	sedative, hypotensive, antiviral antibiotic, antipyretic, analgesic, etc.
Oxide	Caryophyllene oxide, linalool oxide, sclareoloxide ascaridole, bisabolone oxide, etc.	Anti-inflammatory expectorant stimulant, etc.
Phenol	Thymol, eugenol, carvacrol, chavicol, etc.	Anaesthetic, antimicrobial, immune stimulating, spasmolytic, etc.
Monoterpenes	Geraniol, Citronellol, Menthol, Camphor, Pinenes (α and β), Thujone, Borneol, Isoprene, Geraniol, Nerol Limonene, Geranial, Neral, Citronellal, Linalool Myrcene	Analgesic, Bactericidal, Expectorant and Stimulant.
Sesquiterpenes	B-bisabolene, Bergamotene, Cadinane, eudesmanolides eremophilanolides, Elemane, guaianolides pseudoguaianolides, xanthanolides, etc.	anti-inflammatory, anti-septic analgesic, anti-allergic
Diterpenes	Gibberellins, Sclareol and phytol	anti-fungal, expectorant, hormonal balancers, hypotensive

EXTRACTION TECHNIQUES

The various production sizes and extraction techniques for extracting EOs from various plants and their plant components are described in this section.

Steam Distillation

One technique for separating and purifying liquids with different boiling points is steam distillation. The liquid combination is frequently heated to a vapor state in order to streamline the distillation process. This makes it possible to use selective condensation to eliminate the right components. The foundation of steam distillation (SD) is the existence of two incompatible liquids: water and EOs. One popular technique for separating EOs from plants is to use SD to extract saturated vapors from immiscible liquids [9-10].

Hydrodistillation

EOs are usually extracted from various plant materials using hydrodistillation (HD). It is favored due to its simplicity, low operational cost, and ability to yield pure EOs. In this process, fresh or dried plant material is exposed to boiling water, initiating azeotropic distillation of water and volatile oil components. The resulting vapors are then condensed, allowing for easy separation of the EO from water. However, HD has certain limitations. It is energy-intensive due to the heating and cooling requirements, which also prolong the extraction time. Heat-sensitive parts of plant matter may lead to thermal degradation or hydrolysis when they come into direct contact with boiling water. Additionally, direct contact of plant material with boiling water [10].

Soxhlet Extraction

Soxhlet extraction one of the oldest and most well-known standard methods. It has been used for more than one hundred years. In a standard Soxhlet apparatus, plant material is placed in a thimble-holder, and fresh solvent is continuously condensed from a distillation flask. When a certain amount of solvent is reached in the extraction chamber, it siphons back into the flask with the compounds that were extracted. Solvent and solute are then separated via distillation, and the cycle repeats with fresh solvent passing through the plant matrix. This repeated cycling ensures thorough extraction. However, internal diffusion can make soxhlet extraction less effective. This is because it depends a lot on the physical properties and the size of the plant materials [8-9].

Supercritical Fluid Extraction

Supercritical fluid extraction (SFE) is one of the most effective and widely used method of extracting EOs. It utilizes supercritical fluids most commonly carbon dioxide (CO_2) as solvents. CO_2 is ideal because its critical temperature is low (31.3°C) and its pressure is high (73.8 bar). This makes the process safe and saves energy. CO_2 is also safe, non-toxic, non-flammable, and cheap. SFE does not use hazardous organic solvents and operates under mild conditions, minimizing thermal degradation and eliminating the need for post-extraction purification. However, CO_2 is less effective in the extraction of polar compounds as a result of its non-polar nature. In the supercritical state where temperature and pressure exceed a substance's critical point the fluid exhibits both gas-like diffusivity and liquid-like density. These properties enable superior penetration into plant matrices and tunable solvating power, as small pressure variations can significantly alter fluid density and extraction efficiency [10-11].

Microwave-Assisted Extraction

Microwave-Assisted Extraction (MAE) is used electromagnetic radiation in the microwave frequency range (0.3 to 300 GHz), where electric and magnetic fields interact synergistically. This energy gets into the sample and quickly heats it up and breaks up cells. This makes it easier for the target chemicals to escape into the extraction solvent. MAE has many benefits, such as using lesser solvent, shorter extraction times, and faster heating rates, all while minimizing thermal degradation of sensitive compounds. The efficiency of MAE is highly dependent on several factors: extraction temperature, sample properties, solid to- solvent ratio, extraction time and duration, microwave power, and agitation. Optimizing these parameters is critical to maximizing extraction yield and reproducibility [9-12].

Ultrasound-Assisted Extraction

Ultrasound-Assisted Extraction (UAE) enhances the efficiency of essential oil (EO) extraction when used in combination with conventional techniques like solvent extraction or HD. Ultrasound promotes the release of EOs by disrupting plant cell structures, facilitating the solvent's penetration and compound release. In food and plant processing, ultrasound has gained recognition as a valuable intensification technique. When ultrasonic waves are used, they speed up the rate of surface evaporation and create oscillating velocities at phase interfaces. These changes have an impact on mass transfer, boundary layer behavior, and diffusion rates. These effects contribute to improved extraction kinetics and higher yields of bioactive compounds [9-13].

Microwave-Assisted Hydrodistillation

Microwave-Assisted Hydrodistillation (MAHD) is an advanced method that integrates microwave energy with traditional HD to enhance the extraction of EOs. Studies have demonstrated that microwave energy effectively facilitates the release of active plant constituents. The electrical properties of plant material and the water have a big impact efficiency of MAHD. Conventional techniques often take a long time, use a lot of solvents, and require high temperatures. MAHD can remove compounds faster, use fewer solvents, and better protect compounds that are sensitive to heat (thermolabile). Additionally, MAHD contributes to environmental sustainability by lowering energy consumption and CO_2 emissions, making it a greener alternative for EO extraction [8-13].

Solvent-free microwave extraction

Solvent-Free Microwave Extraction (SFME) utilizes only water from the plant material for extracting EOs, without the use of organic solvents. Usually, plant matter is soaked in water for one to two hours before the extraction, and any extra water is taken away afterward. In a special oven, the plant material is then microwave-irradiated, and the collector collects released EOs. The extraction conditions, including microwave power, temperature, and duration, are controlled via a panel. After being extracted, the EOs are dried with dry sodium sulfate and kept at 4°C in the dark to keep them stable [13].

Microwave hydro-diffusion and gravity

Microwave Hydro Diffusion and Gravity (MHDG) is a cost-effective, efficient, and environmentally friendly extraction method that does not require water or solvents, reducing overall energy consumption. Compared to traditional hydrodistillation, which can take over 90 minutes, MHDG significantly shortens extraction time to just 20 minutes. This technique offers multiple advantages, including lower environmental impact and electricity savings, while maintaining high efficiency in extracting EOs[10].

The yield of EO is typically calculated using standard assessment formulas, which account for different plant materials and extraction methods. The EO yield can be expressed as a percentage by volume/weight (% v/w) using

Equation (1), or as a percentage by weight/weight (% w/w) using Equation (2). In these equations, V1 represents the volume of extracted EO, W1 is the mass of the extracted EO, and W2 is the mass of the dried plant material used in the extraction [10].

$$\%\text{ Extraction yield }\left(\%\,\frac{v}{w}\right) = \frac{V1}{W2}\times 100 - - - - - (1)$$

$$\%\text{ Extraction yield }\left(\%\,\frac{w}{w}\right) = \frac{W1}{W2}\times 100 - - - - - (2)$$

Table 3. Final examination of different raw biomass samples that have been pre-treated and its yield.

Sr. No	Plant Material / Waste	Methods	Extracted components	Optimum condition	Results	Reference
Sr. No	**Plant Material / Waste**	**Methods**	**Extracted components**	**Optimum condition**	**Results**	**Reference**
1.	Clove	SD	eugenol	S= 30 gm, t= 6 hr, Steam Generator = 1000 ml	49.15 %	11
2.	Clove	Soxlet	eugenol	S= 30 gm, t= 4 hr Solvent= Ethanol	31.9 %	11
3.	Clove	MAE	eugenol	T=70 °C, stirring=48(rpm, t=5 min, Solvent= Ethanol, S/L=1:16	47.5 %	11
4.	Clove	HD	Eugenol, α-Copaene, β Caryophyllene, α Humulene, δ-Cadinene Eugenyl acetate Phenylpropanoids, Sesquiterpenes	t=180, S/L=1:20 gm/ml extracted with CH_2Cl_2	12.93 %	12
5.	Clove	MAE	Eugenol, α-Copaene, β Caryophyllene, α Humulene, δ-Cadinene Eugenyl acetate Phenylpropanoids,	t=45, F=2450 MHz, P= 1000 W, S/L=1:2(gm/ml	15.83 %	12

			Sesquiterpenes			
6.	Clove	UAHD	Eugenol, α-Copaene, β Caryophyllene, α Humulene, δ-Cadinene Eugenyl acetate Phenylpropanoids, Sesquiterpenes	t=165, T=40 °C S/L=1:20 gm/ml	14.19 %	12
7.	Clove	MAE	eugenol	S= 30 g; V= 200 mL, t= 30 min, power — 600W S/L (w/w) =1:6.7 Solvent= water	13.11%	14
8.	Clove	HD	Eugenol,	S= 20 g; V= 500 mL, t= 180 min, S/L (w/w) =1:25, Solvent= water	12.45	14
9.	Clove	HD	Eugenol, β-caryophyllene eugenyl acetate	t= 240 min, T= 100°C V= 400 mL, S/L (w/w) =1:10, Solvent= H_2O,	12.98 %	15
10.	Clove	SD	Eugenol, β-caryophyllene eugenyl acetate	t= 240 min, T= 100°C V= 400 mL, S/L (w/w) =1:10, Solvent= Steam	11.54 %	15
11.	Clove	MAHD	Eugenol, β-caryophyllene eugenyl acetate	t= 80 min, T= 100°C, V= 400 mL, S/L (w/w) =1:10, Solvent= H_2O, P= 1000 W	13.94 %	15
12.	Clove	MASD	Eugenol, β-caryophyllene eugenyl acetate,	t= 80 min, V= 400 mL S/L (w/w) =1:10 Solvent= Steam, P= 1000 W	12.71 %	15
13.	Clove	SFE	eugenol, β-caryophyllene	S=150 gm, 240 min Solvent= SC-CO_2, Flow rate= 650 g/h, P= 10,000 kPa, T= 323.15K	14.2%	16
14.	Lemon Peels	HD	γ- Terpinene, β -Pinene Sabinene, β -Cymene Limonene, and 1R- α Pinene	S/L (w/w) =1:3, t= 60 min, Solvent= H_2O,	3.9% (v/w)	17
15.	Lemon Peels	HD	d-limonene	150 g, 95 °C, 200 min, Solvent= water	3.47%	18
16.	Lemon Peels	SD	d-limonene	150 g, 95 °C, 200 min Solvent= steam	4.4%,	18
17.	Lemon Peels	SE	d-limonene	150 g, 70 °C, 178 min Solvent= normal hexane	2.54%	18
18.	Lemon Peels	SFE	Limonene, α-pinene, γ terpinene, β-myrcene, and α-terpineol	t=317.51 min T=74.85°C, S/L=1:4 Solvent= CO_2	5.08%	19
19.	Lemon Peels	HD	Pinene, Myrcene Limonene, Neral Geraniol, Caryophellene	S=500 g, t= 180 min, V= 3 L, Solvent=water	1.3%	20
20.	Lemon Peels	MHG	Pinene, Myrcene Limonene, Neral Geraniol, Caryophellene	S=500 g, V= 3 L Solvent=water t= 15min P=500 W	1.2%	20
21.	Lemon Peels	HD	α-pinene, sabinene, β	S= 10 gm, t= 20 min	85.69	21

			phellandrene, and β myrcene		mg/g	
22.	Lemon Peels	UAE	α-pinene, sabinene, β phellandrene, and β myrcene	S= 10 gm, P= 400 W, t= 20 min, f= 455 kHz, a	115.072 mg/g	[21]
23.	Lemon Peels	UAHD	Limonene	S=100 g, 1:14 g/ml, f= 28 kHz, P= 150 W, T=95°C t=5.5 hr	0.99%	[22]
24.	Lemon Peels	MAHD	γ-terpinene, β-pinene	t= 80 min, S/L (v/w) =1:0.8, P= 700 W until 100°C, then 500 W	0.5%	[23]
25.	Lemon Peels	SFME	Limonene	S= 400 g, P= 797.844 W t= 30 min	0.757%	[24]
26.	Lemon Peels	UAME	Limonene	S= 400 g, T= 30°C, P= 797.844 W, t= 90 min, f= 40 kHz	1.06%	[24]
27.	Lemon Peels	MHDG	Myrcene, α-Pinene, β Pinene, β- Carene <Delta-3>, Limonene, γ-Terpinene	S/L (w/v) =1:6, P= 500W for 15 min.	1.1	[25]
28.	Orange Peels	HD	limonene, β-myrcene α-pinene	t= 210 min, S/L (V/w) =1:8.4, (g /mL) Solvent= 5.3%sodium chloride	2.14%	[26]
29.	Orange Peels	SD	Limonene, β-Myrcene Linalool	S=500 gm, V=1250 L Solvent=water, T= 120°C, t = 30 min	0.618%	[27]
30.	Orange Peels	UAE	Catechol, 2,2-diphenyl-1 picrylhydrazyl, 3 ethylbenzothiazoline-60-sulfonic acid	10 g, 100 ml ethanol solvent = ethanol, S/L= 1:10, 44 min at 50℃, 100 MHz	292.158 µg/g	[28]
31.	Orange Peels	Soxlet	limonene, linalool, β myrcene, decanal, α pinene, and valencene	S= 0.5g, Solvent= 36 ml 6 hours, methanol, methylene chloride. hexane + acetone. hexane	 0.420% 0.360 % 0.390 % 0.121 %	[29]
32.	Orange Peels	UAE	limonene, linalool, β myrcene, decanal, α pinene, and valencene	S= 0.5g, Solvent= 36 ml 60 minutes, P=100 W 25°C methanol, methylene chloride, hexane + acetone, hexane	 0.548 % 0.414 % 0.272 % 0.141 %	[29]
33.	Orange Peels	SFE	d-limonene, α-pinene, β pinene, myrcene terpinolene, citronellol and linalool	solvent = ethanol, P= 347.07 atm, T= 55°C, t= 30.16 min, and V= 147.05 µL	1.18% (w/w)	[30]
34.	Orange Peels	SD	d-limonene, oleic, linoleic hesperidin, narirutin	100 kg, t=120 min	4.16 %	[31]
35.	Orange Peels	MHG	d-limonene, oleic, linoleic hesperidin, narirutin	100 kg, 500 W, t=15 min	4.22 %	[31]
36.	Orange Peels	MAHD	β-myrcene	t= 60 min, S/L=1:0.8, P=	0.43%	[32]

				600 W until 100°C, then 500 W		
37.	Orange Peels	SD	n-Nonane, alpha-Pinene Sabinene, beta -Myrcene, n Decane, n-Octanal Limonene, p-Menthon-8 thiol, Dodecanal, Sinensal	S/L (w/V) =1:20 (g/ml) Solvent= Steam, T= 170°C, P= 12 bar, t= 4 min	1.25	[33]
38.	Orange Peels	SFME	Limonene, β-Myrcene Linalool	P=200 W, t= 10 min, T= 100°C	0.40%	[34]
39.	Orange Peels	HD	α-Pinene, Sabinene, β Myrcene, α-Phellandrene Limonene, γ-Terpinene Linalool, Citronellal Neral, Geraniol	S=200 g, t=3 h	0.40%	[35]
40.	Orange Peels	SFME	α-Pinene, Sabinene, β Myrcene, α-Phellandrene Limonene, γ-Terpinene Linalool, Citronellal Neral, Geraniol	S=200 g, V=500 mL solvent =water or organic solvent, P=1000 W t=30 min, T=100°C	0.40%	[35]
41.	Orange Peels	SFME	β-Limonene, β-Myrcene, α Pinene, Sabinene, E-Citral Z-Citral, Linalool L	P= 400 W, S/L (w/V) = 1:10 (g /mL), t= 60 min	1.67%	[36]
42.	Tulsi	HD	Eugenol, linalool Limonene, thymol, γ terpinene, and p-cymene.	V=6 L, Solvent= water, t= 270 min	0.028%	[37]
43.	Tulsi	SFME	Eugenol, linalool Limonene, thymol, γ terpinene, and p-cymene.	S=250 g P=500 W, t=30 min, T=100 ◦C	0.029%	[37]
44.	Tulsi	SD	Benzaldehyde, stearic acid phenolic compounds flavonoids, aesculectin aesculin, and volatile oil	S= 250 gm of the plant t= 420 min, Solvent= H_2O Steam	0.2 %	[38]
45.	Tulsi	Soxlet	Eugenol, Benzene, 1, 2 dimethoxy- 4- (2- propenyl) α - Farnesene and Cyclohexane,	S= 50 gm, V=700 ml Solvent= methanol, ethanol and distilled water	8%w/w,7 %w/w, and 5%w/w	[39]
46.	Tulsi (dry leaves)	SFE	Ursolic acid, β caryophyllene, eugenol methyl eugenol, and humulene	S=20 g, T=50°C, P=200 bar, t= 90 min, R= 2.5 L min^{-1} Fluid= CO_2	2.96 mg g	[40]
47.	Tulsi	MAE	Estragole, α-Bergamotene τ-Cadinol, and Linalool.	100 g, S/L=1:3, t= 60 min P= 450 W	0.6%	[41]
48.	Tulsi	UAE	methyl chavicol (estragole) and tetradecanoic acid eugenol, jasmonol, isobutyl salicylate and isopulegy acetate	S=10 g, V= 250 mL, t= 30 min, f= 40 kHz	1.05%	[42]
49.	Tulsi	MAHD	methyl chavicol, β bisabolene, eugenol, 1, 8 cineole	S= 100 g, t= 20 min at P= 300 W, S/L (v/w)= 1: 15 T= 105°C	0.5 % v/w	[43]
50.	Tulsi (dry leaves)	SD	methyl cinnamate cadino	S= 150 g, V=1500 mL o	0.15%	[44]

			linalool β-cubebene eucalyptol	Solvent= distilled water steam		
51.	Tulsi (dry leaves)	MAE	methyl cinnamate linalool eucalyptol β-cubebene cadinol	P=70%, t=30 min, V=400 mL, Solvent= water.	0.47%	[44]
52.	Tulsi	HD	Limonene, α-Pinene, β Myrcene, Sabinene Eugenol, Geraniol	S=180 gm, t= 240 min T_c=10°C, Solvent= Water	1.9%	[45]
53.	Tulsi	MHDG	Limonene, α-Pinene, β Myrcene, Sabinene Eugenol, Geraniol	S=180 gm, P=170 W t=50 min, V=150 mL T=60–80°C, Solvent= methanol	1.9%	[45]
54.	Nagod	HD	sesquiterpenes; α-Copaene five monoterpenes and two fatty acids	S= 1.5 kg, t=3 hours	1.6 % v/w	[46]
55.	Nagod	HD	terpinen-4 ol, sabinene and α-pinene	S=2 kg, V=4.5 L Solvent=Water, t= 4 h	0.4% v/w	
56.	Nagod (Root)	Soxlet	Protocatechuic acid oleanolic acid phydroxybenzoic acid, β sitosterol, n hentriacontanol	S= 10 gm, t= 24 hrs, V= each 200 ml Solvent= hexane, chloroform, ethyl acetate, and ethanol	0.52%, 0.22%, 1.02% & 3.35%	[47]
57.	Nagod (small branches)	Soxlet	Protocatechuic acid oleanolic acid phydroxybenzoic acid, β sitosterol, n hentriacontanol	S=10 gm, t= 24 hrs, V= each 200 ml Solvent= hexane, chloroform, ethyl acetate, and ethanol	0.51%, 0.82%, 1.56% & 7.43%	[47]
58.	Nagod	SFE	β-caryophyllene, epiglobulol, octadecanoic acid, linolenic acid and aliphatic hydrocarbons	S = 200 g, P= 414 bar, T= 40°C. CO_2 flow rate= 23.97 ml/min, ρ = 0.896 g/cm3, t= 201 min.	0.882 g/100 g dry material.	[48]
59.	Nagod	Soxlet	luteolin	t=2 h, T=50°C, S/L=1:10 (mL/g) Solvents= Ethanol, Methanol, Chloroform, Dichloromethane	14.5% 8.8% 8.6% 14.6%	[49]
60.	Nagod	UAE	luteolin	t=20 min, T=50°C, S/L= 1:10 (mL/g), Solvents= Ethanol, Methanol, Chloroform, Dichloromethane	5.2% 11.6% 4.1% 3.2%	[49]
61.	Nagod (fresh leaves)	HD	β-caryophyllen, eremophilene, eucalyptol α-terpinyl acetate, and	S= 300 g, V= 1L T_c=10oC, t= 2hr,	0.05% w/w	[45]

			sabinene			
62.	Nagod (dry leaves)	HD	β-caryophyllen, eremophilene, eucalyptol α-terpinyl acetate, and sabinene	S= 300 g, V= 1L T_c=10oC, t= 2hr,	0.35% w/w	45
63.	Nagod (fresh leaves)	MAHD	β-caryophyllen, eremophilene, eucalyptol α-terpinyl acetate, and sabinene	S= 300 g, V= 250L Solvent=distilled water P=1800W, t= 20 mins T_c= 10oC.	0.04% w/w	45
64.	Nagod (dry leaves)	MAHD	β-caryophyllen, eremophilene, eucalyptol α-terpinyl acetate, and sabinene	S= 300 g, V= 250L Solvent=distilled water P=1800W, t= 20 mins T_c= 10oC.	0.3% w/w	45
65.	Nagod	HD	α -Terpineol acetate, δ Himachalene and Tetrahydro Rimuene	S=50 g of dried, 350 g of distilled water, t= 4.5 hr	1.10 %	50
66.	Nagod	MAHD	α -Terpineol acetate, δ Himachalene and Tetrahydro Rimuene	S=70 g, V=1200 ml, P= 1000 W, t= 30 min	1.56 %	50

S= amount of solid sample, T= Temperature, Tc = Condenser temperature, V= Volume of Solvent, t=time, F=Frequency, P= Power, S/L = solid/liquid, R=Flow rate, SD = steam distillation; SE = solvent extraction; HD = hydrodistillation, MAE = microwave assisted extraction; MAHD = microwave assisted hydrodistillation; MASD = microwave-assisted steam distillation; SFME= solvent-less microwave extraction, SFME = solvent- free microwave extraction; SFE = Supercritical fluid extraction; UAE = ultrasound assisted extraction; MHDG= microwave hydro-diffusion and gravity , UAME= Ultrasound Assisted Microwave Extraction

ADVANTAGES, DISADVANTAGES OF EXTRACTION METHODS

Many methods exist for extracting EOs, each with its own set of pros and cons. Concerns about health and safety aside, the usual methods for extracting EOs from their natural sources include using a lot of solvent, which takes a long time, and can degrade compounds when subjected to high temperatures or ultrasonic. More and more people are opting to use green solvents to extract EOs instead of harmful organic solvents due to the worries about their effect on the human health and environment. The advantages and disadvantages of extraction technique are described in Table-4 [51 52]. Various EO extraction methods offer distinct advantages and drawbacks. Soxhlet Extraction (SE) provides high efficiency and cost-effectiveness but requires long extraction times and the use of high-purity solvents. HD is simple and economical but involves extended extraction periods and potential degradation of oils. SD is faster, reduces chemical changes, and decreases polar molecule loss but is costly and time-consuming. SFE uses moderate temperatures and avoids harmful solvents, but it is expensive and requires expertise. UAE speeds up extraction, while MAE offers quick, efficient results, though both methods require specialized equipment. MHDG and SFME are both energy-efficient, but they come with high maintenance costs.

Method of extraction	Advantages	Disadvantages
Method of extraction	• Advantages	• Disadvantages
Soxlet Extraction	• High efficiency • Low solvent usage • Complete extraction • Cost-effective	• Long extraction time • Requires high-purity organic solvents • Heat can degrade volatile and sensitive compounds
HD	• Easy construction, • Simple and economical	• extended extraction period (4-6 hours) • EOs degrade easily

	• suitable for use in the field EO extraction technique • No skilled labor needed • The oil deodorizes better. • Easy method implementation • Low equipment cost	• Produce wastewater
SD	• Shorter extraction duration • decrease in chemical changes • decrease in polar molecule loss	• A significant number of samples • Costly and time-consuming Steam volatile ingredients may evaporate
SE	• simple and efficient • Prevents changes and chemical side effects (cold extraction) • relatively simple and efficient	• time-consuming • The high solvent consumption • Usage of organic solvents • Produce costly oils than some other methods. • Inadequate repeatability • A time-consuming process • Oils are more costly than other procedures due to their high solvent usage. • suitable for costly, fragile, and thermally unstable mates
SFE	• Operates at moderate temperatures • Avoids organic solvents • Commonly uses non-toxic CO_2 • Higher yield • Eco-friendly	• Several factors that affect SFE's efficiency. • Expensive • Require a high level of expertise
Method of extraction	**Advantages**	**Disadvantages**
SFE	• Operates at moderate temperatures • Avoids organic solvents • Commonly uses non-toxic CO_2 • Higher yield • Eco-friendly	• Several factors that affect SFE's efficiency. • Expensive • Require a high level of expertise
UAE	• Easy and affordable • speeds up the EO's release • increased rate and efficiency of extraction • Lower extraction temperature • increased cell breakdown and mass transfer.	• Low selectivity • Impending high-temperature reaction • Special equipment demand • Filtration step required •
MAE	• Strongest EO extraction method • Quick, high repeatability • Reduce energy use • Reduced solvent use	• Low selectivity • Impending high-temperature reaction • Special equipment demand • Filtration step required • solvent must be able to absorb microwaves • Clean-up step needed Waiting time for the vessels to cool down
MAHD	• energy Saving • Reduced extraction time (42 mins) • Pure product • Higher yield • Green technology	• High maintenance cost • Expensive • Complicated process due to optimization of environmental conditions
SFME	• Energy Saving • Reduced extraction time (42 mins) • Final product purity high	• High maintenance cost

	• Higher yield • Green tech • Lower CO2 emissions • No degradation products	
MHDG	• Eco-friendly, affordable, and efficient without the use of solvents • Cut down on extraction time (20 minutes) • Reduced energy usage • Rapid Easy to handle • No filtration required	• Less dry extract yield results from improper extraction parameter selection which is a crucial phase.

APPLICATIONS OF EOs

India is a 3rd largest country which produces the EO in the world. Different EO from different plants has its different uses according to its biological properties. EOs can be used in pharmaceutical industries, food industries, cosmetics, perfumery industries, aromatherapy and in the many other sectors. EOs derived from various vegetal matter have numerous health and wellness applications. Clove oil is used in oral care products like antibacterial sprays and mouthwashes, and it helps relieve toothaches, gum infections, and muscle pain. Lemon oil brightens skin, fades scars, reduces scalp irritation, and aids in digestion while deterring mosquitoes. Orange oil promotes relaxation, improves digestion, and helps with constipation. Tulsi oil enhances immunity, reduces stress, and treats acne, while also supporting respiratory health. Nagod oil alleviates joint pain, reduces inflammation, treats infections, and acts as a natural insect repellent, promoting relaxation and stress relief. [51- 53]

Vegetal matter / Leaves	**Diseases and pathogen**
Vegetal matter / Leaves	**Diseases and pathogen**
Clove	oral antibacterial spray, mouthwash formulation, massage with aromatherapy, relieves toothaches and gum infections, control acne, benzimidazole derivative synthesis, streptococcus mutans toothbrush decontamination for kids, used in food and beverages as flavoring agent, relieves muscle pain, headaches, and toothaches.
Lemon	brigten skin, lesions and scars fade, reduces scalp irritation and flakes, enhances hair luster, fighters athlete's foot, deters mosquitoes and insects, used in household cleaners, uplifts mood, reduces stress, and improves concentration, aids digestion and detoxification, helps with inflammation related conditions.
Orange	anti-constipation, strengthens hair roots, brightens skin, prevents slow digestion, promotes relaxation and mood enhancement, reduces acne, protects against oxidative stress, improves digestion and reduces bloating, used in disinfectants and cleaners.
Tulsi	reduces blemishes, strengthens hair roots, reduces stress, promotes relaxation, enhances immunity and combats infections, protects against free radicals, reduces inflammation in the body, treats acne and skin irritations, curbs constipation, helps with respiratory conditions like colds, coughs etc. and speeds digestion.
Nagod	alleviates joint pain and muscle aches, reduces inflammation in the body, used to treat infections and fungal conditions, provides relaxation, helps with respiratory issues, natural insect repellent and relieves stress

BIOLOGICAL ACTIVITY

Antibacterial activity

EOs exhibit antibacterial activity by exhibiting bacteriostatic or bactericidal effects on bacteria. Thymol, carvacrol, eugenol, cinnamic aldehyde, p-cymene, and other chemical components of plant EOs have antimicrobial properties. The oils with the strongest antibacterial properties were discovered to be lavender, basil, rosemary, eucalyptus, manuka, and tea tree [54].

Antifungal activity

Our health and epidermis are adversely affected by fungus. Lemongrass oil, palmarosa oil, neroli oil, aegle oil, basil oil, citrus oil, Tea tree oil, fennel oil, lemongrass oil, cinnamon oil, oregano oil, rosemary oil, and thyme oil are among the EOs that possess potent fungicidal and fungistatic properties against dermatophytes and fungi[54].

Antiviral profile

EOs of dengue, herpes simplex, and junin contain viruses. Many diseases can be prevented by using oils of juniper, eucalyptus, rosemary, tea tree, basil, lavender, oregano, clove, ginger, thyme, hyssop, and sandalwood. Therefore, some EOs can be employed as specialists against viral infections and as antiviral medications[6-54].

Anti-inflammatory activity

A body experiences inflammation when its immune system is activated. Not all inflammation is beneficial. Some EOs that can reduce inflammation include eucalyptus oil, peppermint oil, helichrysum oil, and tea tree oil. These oils are used to reduce inflammation, edema, spasms, and tense muscles [54].

Antioxidant activity

The volatile matter concentration of activated carbon is determined using the Standard Test Procedure ASTM (American Society for Testing and Materials). The primary ingredient in EOs including citrus, lemon, peppermint, and rosemary oils is ascorbic acid, also referred to as vitamin C. It acts as an excellent antioxidant. Free radicals cause harm to the epidermis' cells. Antioxidants are compounds that stop free radicals created during oxidation from reacting chemically. The oxidation process is inhibited by antioxidants, which lead to an improved immune system and an enhanced skin radiance[54].

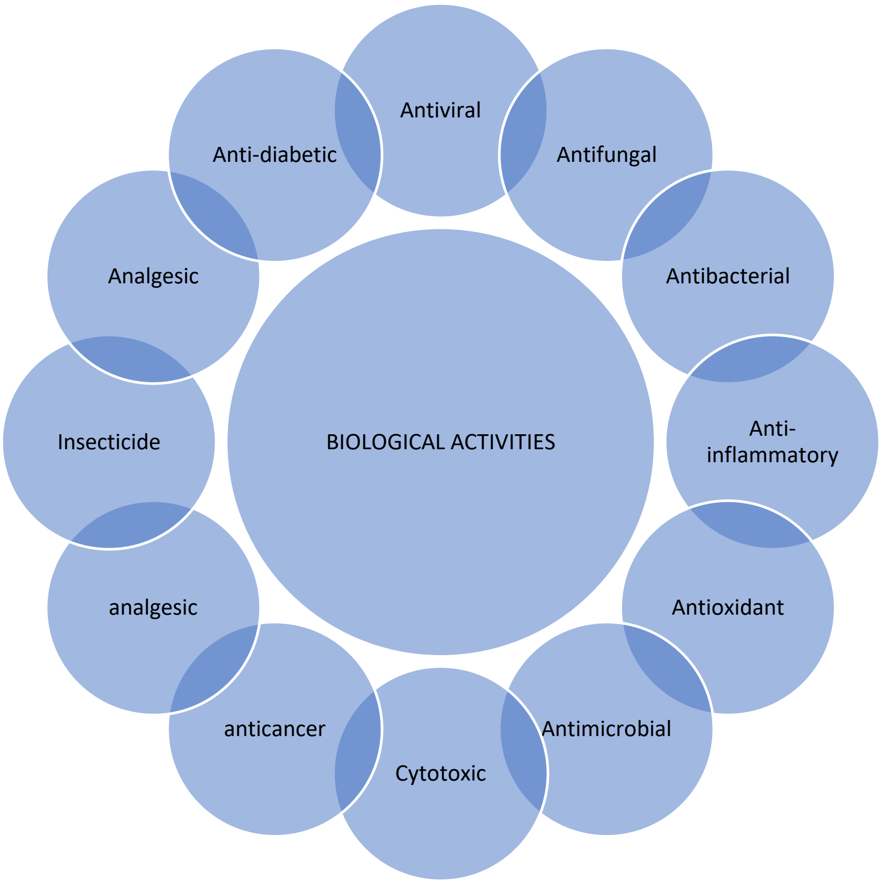

Figure 1. Different biological effects of EOs.

ANALYTICAL METHODS FOR EOs

GC-MS, Fourier Transform Infrared (FTIR) spectroscopy, gas chromatography with downstream flame ionisation detector (GC-FID), and head space gas chromatography mass spectrometry (HS-GC–MS) are used to analyze EOs. The chromatographic process is designed to separate mixtures with varying degrees of interaction with components of other substances. Comprise stationary phase-mobile phase transition. Sample components go through the stationary phase at different speeds and periods. Consequently, each component has a characteristic retention time. Chromatography separates volatile chemicals by molecular size, boiling point, and polarity [55].

CHALLENGES AND FUTURE SCOPE

Traditional methods like hydrodistillation and solvent extraction often require high energy consumption and long extraction times, which makes them less efficient and environmentally unfriendly. Solvent use in certain methods can lead to contamination of the oils and has environmental concerns. Moreover, achieving high selectivity during extraction without losing valuable volatile compounds is difficult, especially when using conventional methods. Some advanced techniques like ultrasound assisted extraction, supercritical fluid extraction and microwave assisted extraction show potential but come with high operational costs and the need for specialized equipment.

The extraction of essential oils faces challenges such as variability in yield due to factors like plant species, growing conditions, and extraction methods. In the future, focusing on sustainable extraction technologies like green solvents, eco-friendly microwave assisted techniques, and enzymatic treatments will likely improve both the efficiency and environmental impact of essential oil extraction. There are limited reseach for Comprehensive chemical analysis of various essential oil, exploring how factors like geographic diversity, seasonal variations, and plant part selection influence its chemical composition.

CONCLUSION

The extraction of essential oils from plant materials is a vital method that provides valuable compounds for use in aromatherapy, pharmaceuticals, cosmetics, and food. While traditional methods like hydrodistillation and solvent extraction are widely used, they present limitations such as long extraction times, energy consumption, and potential degradation of active compounds. The yield of essential oils produced by non-conventional methods was noticeably larger than that of the conventional method for the same amount of sample. Novel extraction techniques reduce extraction time, chemical risk, energy input and improves essential oil yield. This shows how the type of extraction solvent used can affect the yield of one component while increasing the yield of Essential oils in another approach. Essential oils have many uses, but they are sensitive to environmental variables.

REFERENCES

1. Bakkali, F., Averbeck, S., Averbeck, D. & Idaomar, M. Biological effects of essential oils - A review. Food and Chemical Toxicology vol. 46 446–475 Preprint at https://doi.org/10.1016/j.fct.2007.09.106 (2008).
2. Bährle-Rapp, M. Myroxylon balsamum. Springer Lexikon Kosmetik und Körperpflege 366–366 (2007) doi:10.1007/978-3-540-71095-0_6790.
3. Yang, C. et al. Antioxidant and anticancer activities of essential oil from gannan navel orange peel. Molecules **22**, 1–10 (2017).
4. Chemat, F. & Boutekedjiret, C. Extraction // Steam Distillation☆. in Reference Module in Chemistry, Molecular Sciences and Chemical Engineering (Elsevier, 2015). doi:10.1016/b978-0-12-409547-2.11557-4.
5. Haro-González, J. N., Castillo-Herrera, G. A., Martínez-Velázquez, M. & Espinosa-Andrews, H. Clove essential oil (Syzygium aromaticum l. myrtaceae): Extraction, chemical composition, food applications, and essential bioactivity for human health. Molecules **26**, (2021).
6. Erenler, R., Çarlik, Ü. E. & Aydin, A. Antiproliferative activity and cytotoxic effect of essential oil and water extract from origanum Vulgare L. Sigma Journal of Engineering and Natural Sciences **41**, 202–208 (2023).
7. Gökalp, F. A STUDY ON THE CHEMICAL PROPERTIES OF EUGENOL AND EUGENOL ACETATE, CLOVE ESSENTIAL OILS. Sigma J Eng & Nat Sci vol. 34 (2016).
8. Elyemni, M. et al. Extraction of Essential Oils of Rosmarinus officinalis L. by Two Different Methods: Hydrodistillation and Microwave Assisted Hydrodistillation. Scientific World Journal **2019**, (2019).
9. İŞçİMen, E. M. & Hayta, M. Optimization of ultrasound-assisted extraction of protein from the byproduct of the hazelnut oil industry using reverse micelles. Sigma Journal of Engineering and Natural Sciences **42**, 1202–1213 (2024).
10. Thakker, M. R., Parikh, J. K. & Desai, M. A. Isolation of Essential Oil from the Leaves of Cymbopogon martinii using Hydrodistillation: Effect on Yield of Essential Oil, Yield of Geraniol and Antimicrobial Activity. Journal of Essential Oil-Bearing

Plants **19**, 1943–1956 (2016).
11. A. Guntero, V., M. Mancini, P. & N. Kneeteman, M. Introducing Organic Chemistry Students to the Extraction of Natural Products Found in Vegetal Species. World Journal of Chemical Education **5**, 142–147 (2017).
12. Suttiarporn, P. et al. Enhanced extraction of clove essential oil by ultrasound and microwave assisted hydrodistillation and their comparison in antioxidant activity. Current Research in Green and Sustainable Chemistry **8**, (2024).
13. Kapadiya, S. M., Parikh, J. & Desai, M. A. A greener approach towards isolating clove oil from buds of Syzygium aromaticum using microwave radiation. Ind Crops Prod **112**, 626–632 (2018).
14. Kapadiya, S. M., Parikh, J. & Desai, M. A. A greener approach towards isolating clove oil from buds of Syzygium aromaticum using microwave radiation. Ind Crops Prod **112**, 626–632 (2018).
15. Golmakani, M. T., Zare, M. & Razzaghi, S. Eugenol enrichment of clove bud essential oil using different microwave-assisted distillation methods. Food Sci Technol Res **23**, 385–394 (2017).
16. Scopel, R. et al. Supercritical fluid extraction from Syzygium aromaticum buds: Phase equilibrium, mathematical modeling and antimicrobial activity. Journal of Supercritical Fluids **92**, 223–230 (2014).
17. Dao, T. P., Tran, N. Q., Tran, T. T. & Lam, V. T. Assessing the kinetic model on extraction of essential oil and chemical composition from lemon peels (Citrus aurantifolia) by hydro-distillation process. Mater Today Proc **51**, 172–177 (2021).
18. Giwa, S. O., Muhammad, M. & Giwa, A. Utilizing orange peels for essential oil production. ARPN Journal of Engineering and Applied Sciences **13**, 17–27 (2018).
19. Verma, A., Hartonen, K. & Riekkola, M. L. Optimisation of supercritical fluid extraction of indole alkaloids from Catharanthus roseus using experimental design methodology - Comparison with other extraction techniques. Phytochemical Analysis **19**, 52–63 (2008).
20. Bousbia, N., Vian, M. A., Ferhat, M. A., Meklati, B. Y. & Chemat, F. A new process for extraction of essential oil from Citrus peels: Microwave hydrodiffusion and gravity. J Food Eng **90**, 409–413 (2009).
21. Li, G. et al. Effect of Response Surface Methodology-Optimized Ultrasound-Assisted Pretreatment Extraction on the Composition of Essential Oil Released From Tribute citrus Peels. Front Nutr **9**, (2022).
22. Heydari, M. et al. Hydrodistillation ultrasound-assisted green extraction of essential oil from bitter orange peel wastes: Optimization for quantitative, phenolic, and antioxidant properties. J Food Process Preserv **45**, (2021).
23. Ciriminna, R. et al. High-Quality Essential Oils Extracted by an Eco-Friendly Process from Different Citrus Fruits and Fruit Regions. ACS Sustain Chem Eng **5**, 5578–5587 (2017).
24. Arafat, Y., Altemimi, A., Ibrahim, S. A. & Badwaik, L. S. Valorization of Sweet Lime Peel for the Extraction of Essential Oil by Solvent Free Microwave Extraction Enhanced with Ultrasound Pretreatment. Molecules **25**, (2020).
25. Bousbia, N., Vian, M. A., Ferhat, M. A., Meklati, B. Y. & Chemat, F. A new process for extraction of essential oil from Citrus peels: Microwave hydrodiffusion and gravity. J Food Eng **90**, 409–413 (2009).
26. Liu, K. et al. Extraction of 'Gannanzao' orange peel essential oil by response surface methodology and its effect on cancer cell proliferation and migration. Molecules **24**, (2019).
27. Fajardo Muñoz, S. E., Freire Castro, A. J., Mejía Garzón, M. I., Páez Fajardo, G. J. & Páez Gracia, G. J. Artificial intelligence models for yield efficiency optimization, prediction, and production scalability of essential oil extraction processes from citrus fruit exocarps. Frontiers in Chemical Engineering **4**, 1–7 (2022).
28. Shehata, M. G., Abd El Aziz, N. M., Youssef, M. M. & El-Sohaimy, S. A. Optimization conditions of ultrasound-assisted extraction of phenolic compounds from orange peels using response surface methodology. J Food Process Preserv **45**, (2021).
29. Xhaxhiu, K., Korpa, A., Mele, A. & Kota, T. Ultrasonic and Soxhlet Extraction Characteristics of the Orange Peel from 'Moro' Cultivars Grown in Albania. Journal of Essential Oil-Bearing Plants **16**, 421–428 (2013).
30. Ghadiri, K., Raofie, F., Qomi, M. & Davoodi, A. Response Surface Methodology for Optimization of Supercritical Fluid Extraction of Orange Peel Essential Oil. Pharmaceutical and Biomedical Research (2021) doi:10.18502/pbr.v6i4.5117.
31. Boukroufa, M., Boutekedjiret, C., Petigny, L., Rakotomanomana, N. & Chemat, F. Bio-refinery of orange peels waste: A new concept based on integrated green and solvent free extraction processes using ultrasound and microwave techniques to obtain essential oil, polyphenols and pectin. Ultrason Sonochem **24**, 72–79 (2015).
32. Ciriminna, R. et al. High-Quality Essential Oils Extracted by an Eco-Friendly Process from Different Citrus Fruits and Fruit Regions. ACS Sustain Chem Eng **5**, 5578–5587 (2017).
33. Golmohammadi, M., Borghei, A., Zenouzi, A., Ashrafi, N. & Taherzadeh, M. J. Optimization of essential oil extraction from orange peels using steam explosion. Heliyon **4**, (2018).
34. Aboudaou, M., Ferhat, M. A., Hazzit, M., Ariño, A. & Djenane, D. Solvent free-microwave green extraction of essential oil from orange peel (Citrus sinensis L.): effects on shelf life of flavored liquid whole eggs during storage under commercial retail conditions. Journal of Food Measurement and Characterization **13**, 3162–3172 (2019).
35. Aboudaou, M., Ferhat, M. A., Hazzit, M., Ariño, A. & Djenane, D. Solvent free-microwave green extraction of essential oil from orange peel (Citrus sinensis L.): effects on shelf life of flavored liquid whole eggs during storage under commercial retail conditions. Journal of Food Measurement and Characterization **13**, 3162–3172 (2019).
36. Qadariyah, L., Amelia, P. D., Admiralia, C., Bhuana, D. S. & Mahfud, M. Extraction of orange peel's essential oil by solvent-free microwave extraction. AIP Conf Proc **1840**, 1–8 (2017).
37. Lucchesi, M. E., Chemat, F. & Smadja, J. Solvent-free microwave extraction of essential oil from aromatic herbs: Comparison with conventional hydro-distillation. J Chromatogr A **1043**, 323–327 (2004).
38. Sharma, A., Manisha Dikshit, AC Pandey, Raj Kumar Singh & Praful Dikshit. Larvicidal activity of essential oils of Haridra and Tulsi against Aedes aegypti and Anopheles larvae. Journal of Ayurveda and Integrated Medical Sciences **8**, 13–20 (2023).
39. R, B. & S. P., B. Tulsi (Ocimum sanctum), excellent source of phytochemicals. International Journal of Environment, Agriculture and Biotechnology **3**, 1732–1738 (2018).

40. Chatterjee, D., Ghosh, P. K., Ghosh, S. & Bhattacharjee, P. Supercritical carbon dioxide extraction of eugenol from tulsi leaves: Process optimization and packed bed characterization. Chemical Engineering Research and Design **118**, 94–102 (2017).
41. Tran, T. H. et al. Optimization of microwave-assisted extraction of essential oil from Vietnamese basil (Ocimum basilicum L.) using response surface methodology. Processes **6**, (2018).
42. Ajmal, M. et al. Evaluation of basil essential oils for antifungal and anti-aflatoxigenic activity against Aspergillus flavus. Sci Rep **15**, (2025).
43. Golmakani, M. T., Niakousari, M., Keramat, M. & Khosravi, H. Protection of polyunsaturated fatty acids of fish oil from common Kilka (Clupeonella cultriventris caspia) using holy basil (Ocimum sanctum) essential oil. Iran J Fish Sci **19**, 217–233 (2020).
44. Cardoso-Ugarte, G. A., Juárez-Becerra, G. P., Sosa-Morales, M. E. & López-Malo, A. Microwave-assisted extraction of essential oils from herbs. Journal of Microwave Power and Electromagnetic Energy **47**, 63–72 (2013).
45. Thi My Dung, N. et al. CHEMICAL COMPOSITION OF ESSENTIAL OIL EXTRACTED FROM LEAVES OF VITEX NEGUNDO LINN. FROM BINH THUAN PROVINCE BY HYDRODISTILLATION AND MICROWAVE HYDRODISTILLATION. JOURNAL OF SCIENCE AND TECHNOLOGY (2018).
46. Verbenaceae, L. et al. Chemical composition and antimicrobial Activity of essential oil of leaves of Vitex negundo Linn . (Verbenaceae). (2010).
47. Meena, A. K. et al. Studies on physicochemical, phytochemicals, chromatographic profiling & estimation and in-silico study of Negundoside in roots & small branches of Vitex Negundo plant. Phytomedicine Plus **2**, 100205 (2022).
48. Singh, D. & Chaudhuri, P. K. A review on phytochemical and pharmacological properties of Holy basil (Ocimum sanctum L.). Ind Crops Prod **118**, 367–382 (2018).
49. Abidin, L., Mujeeb, M., Mir, S. R., Khan, S. A. & Ahmad, A. Comparative assessment of extraction methods and quantitative estimation of luteolin in the leaves of Vitex negundo Linn. by HPLC. Asian Pac J Trop Med **7**, S289–S293 (2014).
50. Farjam, M. H., Zardosht, M. & Joukar, M. Comparison of Microwave-Assisted Hydrodistillation and Traditional Hydrodistillation Methods for Extraction of the Vitex Pseudo-Negundo Essential Oils. Advances in Environmental Biology vol. 8 http://www.aensiweb.com/AEB/ (2014).
51. Suresh, A. & Velusamy, S. Techniques for essential oil extraction from kaffir lime and its application in health care products — A review. 1–17 (2020) doi:10.1002/ffj.3626.
52. Syafri, S. et al. The use of instrumental technique and chemometrics for essential oil authentication: A review. Results Chem **4**, 100622 (2022).
53. Kashyap, N., Kumari, A., Raina, N., Zakir, F. & Gupta, M. Phytomedicine Plus Prospects of essential oil loaded nanosystems for skincare. Phytomedicine Plus **2**, 100198 (2022).
54. El amrani, S. et al. Evaluation of antibacterial and antioxidant effects of cinnamon and clove essential oils from Madagascar. Mater Today Proc **13**, 762–770 (2019).
55. Rajguru, J. R., Dwivedi, J., Shirsat, M. R. & Tarke, S. R. FORMULATION DEVELOPMENT AND EVALUATION OF OIL AND EMULGEL OF VITEX NEGUNDO FOR ANTI-INFLAMMATORY ACTIVITY.