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A COMPREHENSIVE REVIEW ON LEMONGRASS (*CYMBOPOGON CITRATUS*) OIL EXTRACTION AND ITS APPLICATIONS

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ABSTRACT
This article presents a comprehensive review of methods of extraction, properties, compositions and industrial application of lemongrass essential oil. Lemongrass (Cymbopogon citratus) essential oil has been used traditionally since ancient days in medicine as remedy to improve blood circulation, treat fever and malaria, promote digestion and as well used to increase immune system of the human body. Essential Oils of lemongrass are used in various industries. Some of the industries in which they are used extensively include Aromatherapy, Food and drink industry, Pharmaceuticals industry, Fragrance and Flavour industry, Agriculture and Livestock industry, Cosmetic and Soaps industry, House hold and Domestic. The quality of the essential oil from lemongrass strongly depends on the extraction method and operating conditions. Basically lemongrass essential oil can be obtained by various extraction methods, such as steam distillation, conventional solvent extraction, Soxhlet extraction, ultrasound-assisted extraction (UAE), hydrodistillation (HD), microwave-assisted hydrodistillation (MAHD), Simultaneous-distillation-extraction technique (SDE), Solvent-Free-Microwave-Extraction Technique (SFME) and supercritical fluid extraction (SFE) with CO_2. The composition of essential oil of Cympobogon citratus contains α-pinene, β-pinene, delta-3-catrene, myrcene dipentene, β-phellandrene, β-cymene , methyl heptanene, citronellal, β-elemene, β-caryophyllene, citronellyl acetate, geranyl acetate , citral A , citral B, geraniol, elemol , and β-caryophyllene oxide, etc. In addition, lemongrass oil also contains essential minerals such as Fe, Zn, Mg, Na, K, Ca, Mn, P etc. The most important physicochemical properties of lemongrass oil includes specific gravity, Optical rotation, refractive index, percentage of citral, freezing point, moisture content, acid value, ester value, carbonyl value and phenol content . Nevertheless, the chemical composition of the essential oil of Lemongrass also varies with the geographical origin, cultivation practices, plant age, photoperiod, harvest period, cultivars, and extraction methods. However, for extraction of lemongrass oil, green technology such SFE, SDE, SFME and MAHD that are consumer and environmental friendly in industrial-scale essential oil production should be considered as a method to overcome the limitations of traditional distillation methods.

KEYWORDS: ***Essential Oil, Lemongrass, Microwave-Assisted-Hydrodistillation. Solvent Extraction, Steam Distillation, Supercritical Fluid Extraction***

1.0 INTRODUCTION
Lemongrass is a tropical perennial and aromatic plant which belongs to the family *Graminae* (Poaceae) and the genus *Cymbopogon*. The name *Cymbopogon* came from Greek words *'kymbe'* (boat) and *'pogon'* (beard) meaning arrangement of flower spike (Shah *et al.*, 2011). The herb is cultivated and distributed in sub regions of Africa, Asia, North America, South America, Australia, Oceania till present day (New Directions Aromatics, 2017; Suryamanshi *et al*., 2016; Chantal *et al*., 2012;). There are about 55-80 species of lemongrass already identified which includes *Cymbopogon citratus* (West Indian lemongrass), *Cymbopogon flexuosus* (East Indian lemongrass), and *Cymbopogon pendulus* (Jammu lemongrass) (Jayasinha *et al*., 1999; Lawal *et al.*, 2017; Chowdury *et al.*,2015). Out of all the species identified, only two have economic importance as cultivated plants namely *C. citratus* and *C. flexuosus* (Avoseh *et al*., 2015). According to Directorate Plant Production (2012), *Cymbopogon citratus* as shown in Figure 1 is a fast-growing, lemon-scented, perennial herb having average height of about 1m. It has distinct bluish-green leaves and usually does not produce seed. It produces many bulbous stems that increase the clump diameter as the plants mature.

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Figure 1: West Indian Lemongrass (*Cymbopogon citratus*)

On the other hand, *Cymbopogon flexuosus* which is the second most important lemongrass specie is a tall, fast-growing, lemon-scented, perennial grass reaching an average height of about 1.5 m. It has distinct, dark-green foliage and also produces seed. Lemongrass plants persist for many growing season and it produces essential oil. It contains many phytochemical compounds like phenol, citral, geranial, terpenoids, benzenoids and other nitrogenous compounds which help in metabolic process of plant. The leaves of lemongrass and its oil possess lemon-like odour characteristic aromatic flavours due to its citral contents which is the most dominant constitutes. Dry leaves of lemongrass contain approximately 1-2 percent essential oil (Carlson *et al*., 2001). Lemongrass extracts has found industrial application in pharmaceutical, cosmetics, food processing and perfumery industries (Ganjewala and Luthra, 2010; Joy *et al*., 2006). Scientific studies have showed that *Cymbopogon citratus oil* possesses various pharmacological properties such as antibacterial, anti-amoebic, anti-filarial, antidiarrheal, anti-inflammatory, antifungal, antimalarial, anti-mycobacterial, anti-mutagenicity, hypoglycemic, antioxidants and neurobehavioral. antiprotozoal, anti-carcinogenic, antioxidant, anti-rheumatic and cardio-protective (Aly, 2021; Ajayi *et al.*, 2016; Chukwuocha *et al.*, 2016; Ekpenyong *et al*., 2015; Avoseh *et al*., 2015; Akono *et al*., 2014). For instance, in India, China, Thailand among other countries, lemongrass is generally used as food flavoring agent, ingredient in beverages because its ability to aid digestion, boost body immunity and blood circulation. Also, Okpo and Edeh (2022) has reported that in some parts of Nigeria, lemongrass is use for the treatment of fever, convulsion in children, throat inflammations, stomach upset, skin diseases, and ears/eyes infections. Particularly, in Isoko part of Nigeria, lemongrass is used as ingredient in pepper soup, curries, and local drink. Lemongrass extract have been reportedly used for treatment of diarrhea, skin infections and painful irregular menstruation in females. In sub-regions of the world, lemongrass is reportedly used to reduce blood pressure (Rodriques and Carlini, 2004). Devi, *et al*., (2011) affirmed the use of lemongrass extracts for local treatment of gastrointestinal discomfort. In Guatemala, an extract of lemongrass leaves have been reportedly applied for various purposes (Selvi *et al*., 2011; Jayasinha, 1999a). For other application of lemongrass especially in the manufacturing industries, it had been reportedly used as a major ingredient of perfumery, cosmetics, soaps, tea, cleansing agent and confectionary products (Ganjewala, 2008; Akhila, 2010). It is also said that lemongrass oil can help accelerate the healing of scratches and cuts, but Karma (2006) confirmed a burning sensation from direct application of lemongrass oil on the skin. The essential oil of lemongrass is in high demand due to its commercial value. Extracting and characterizing bioactive molecules from medicinal plant is very important for drugs with high therapeutic value. This review is aimed to provide information on harnessing the existing extraction methods of lemongrass essential oil, its chemical composition and its application in pharmaceutical, cosmetics, food processing and perfumery industries.

2.0. PHYSICOCHEMICAL PROPERTIES OF ESSENTIAL OIL

The chemical compositions of lemongrass oil vary with the age of the grass. Fresh lemongrass contains 0.67% of essential oil, which has substantial amount of citral (Maiti *et al.*, 2006). Lemongrass oil can be regarded as a semi viscous liquid with darkish-yellowish or darkish-amber colour that change to red as it gets older. Presence of moisture in the oil makes the oil have a turbid appearance. The most important physicochemical properties of lemongrass oil usually considered includes specific gravity(SG), refractive index(RI), percentage of citral, freezing point, moisture content, acid value, ester value, carbonyl value and phenol content (Pushpakumari, 1987).

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However, Standard Organization has specified standard reference characteristics/properties for Lemongrass oil. International standards Organization(ISO) and Indian Standards Institute (ISI) for physico-chemical standards for Cymbopogon citratus and Cymbopogon flexuosus are presented in Table 1.

Table 1: Physico-chemical properties standards for *Cymbopogon citratus* and *Cymbopogon flexuosus (*Rajeswara Rao, 2013)

Parameter	ISO 3217:1974 standard for *Cymbopogon citratus*	IS:327:1961 standard for *Cymbopogon flexuosus*
Colour	Yellow	Dark yellow to light broenish-red mobile liquid
Odour	Lemon-scented	Intense lemon-like
Specific gravity	0.872-0.897(at 20^{o}C)	0.888-0.898 (at 30^{o}C)
Refractive index	1.4830-1.4890(20^{o}C)	1.4786-1.4846 (at 30^{o}C)
Optical rotation	-3^o to+1^o	-3^o to+1^o
Carbonyl value as citral	Not less than 75%	75%
Solubilty	Fresh oil soluble in 70% (v/v) alcohol at 20^{o}C. Insoluble in 90%(v/v) alcohol	Soluble in 3 volumes of 70% alcohol by volume Occasionally with slight turbidity

Furthermore, Table 2 presents various physico-chemical properties of lemongrass oil that have been reported in literatures by researchers.

3.0:COMPOSITION OF LEMONGRASS AS OBTAINED BY DIFFERENT INVESTIGATORS

Many researchers have reported that lemongrass oil contains so many compounds, functional and elemental minerals (Okpo and Edeh, 2022; Okpo and Otaraku, 2020).

3.1. Chemical compositions of the essential oil of Lemongrass

Lemongrass oil is majorly composed of citral. The percentage citral content varies with locality of the plant (Ranade, 2004; Tasldnen *et al.*, 1983; Nath *et al.*, 1994). Citral is used as crude material for vitamin A, confectionery and perfumery products (Viabhav *et al*., 2013; Singh et al., 2011; Carlson, *et al*., 2001; Suryawansh *et al.*, 2016).

Table 2. Physico-chemical properties for *Cymbopogon citratus* researchers

Parameter	Abera (2020)	Benoudjit, etal.,(2022)	Dao, et al.,(2020)	Mustapha (2018)	Olayemi, etal.,(2018)
Appearance		Mobile, clear liqiud	Liquid	-	
Acid value	2.805	1.402±0.036	2.948	4.09	0.55
Boiling point	212			299	
Colour		Pale yellow	Light yellow	Dark yellow	
Iodine value		69.795±1.521			105
Ester value			6.402		189.21
Moisture contents	20.7				
Odour		Fresh with strong lemon odour	Specific		
Optical rotation		4±1			
Peroxide value		3±0.082		6.0	6.0
$_P$H	5.5				
Refractive index		1.488±0.001		n20/D2.487	1.4838
Residue on evaporation at 100oC					10%
Saponification value	140.25		9.35	143	189.76
Solubility		Immiscible		Insoluble in water	
Specific gravity		0.891±0.001	0.8865	0.896	0.8960

The composition of *C. citratus* essential oil varies widely depending on genetic diversity, habitat and agronomic treatment of the culture (Ranitha *et al*., 2014), as well as on the part of the plant (Olayemi, 2017), maturity stage (Tajidin *et al*., 2012) and

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extraction method (Bossou et al., 2015). The oil of West India lemongrass (*Cymbopogon citratus)* grown in Kaduna Nigeria shows that the lemongrass contains about 34, 26 and 16 compounds respectively for root, stalk and leaf (Olayemi, 2017). Jayasinha *et al.*, (1999b) identify about 70 constituents of essential oil of the three (3) species of lemongrass. Okpo and Otaraku (2020) established and nineteen (19) different components in *Cympobogon citratus* oil sample as presented in Table 3.

Table 3: Composition of lemongrass essential oil (Okpo and Otaraku, 2020)

Component	% Composition
α-pinene	12.9
2- nonanone	10.3
Acetonitrile	7.5
β-cedrenes	6.6
Camphor	6.4
Citronellal	6.0
4- nonanone	5.9
Terpinolene	5.4
Decanal	5.3
α-cedrol	5.3
Citral A	5.0
β-pineane	4.4
Atlantone	3.6
Pentane	3.3
p-cymene	3.1
γ-terpinene	2.8
α-cedrenes	2.6
Thujopsene	2.0
Genaniol	1.7
Total	100.0

As reported in the work of Joy *et al.*, (2006), various researchers have also reported on the composition of three (3) species of lemongrass oil. For East Indian lemongrass oil, Weiss (1997); Ranade (2004) asserted that the oil contains 75-85% of aldehydes consisting largely of citral, linalool (1.34%), geraniol (5.00%), citronellol, nerol (2.20%), 1,8 cineole, citronellal (0.37%), linalyl acetate, geranyl acetate (1.95%), α-pinene (0.24%), limonene (2.42%), caryophyllene, β-pinene, β-thujene, myrcene (0.46%), β-ocimene (0.06%), terpenolene (0.05%), methyl heptanone (1.50%) and α-terpineol (0.24%). Likewise, the composition of essential oil of West Indian lemongrass oil Cympobogon citratus contains approximately α-pinene (0.13%), β-pinene, delta-3-catrene (0.16%), myrcene (12.75%), dipentene (0.23%), β-phellandrene (0.07%), β-cymene (0.2%), methyl heptanene (2.62%), citronellal (0.73%), β-elemene (1.33%), β-caryophyllene (0.18%), citronellyl acetate (0.96%), geranyl acetate (3.00%), citral b (0.18%), citral a (41.82%), geraniol (1.85%), elemol (1.2%) and β-caryophyllene oxide (0.61%) (Saleem et al, 2003a; Saleem et al, 2003b). And that of C. pendulus oil is reported to contain pinene (0.19%), camphene (0.01%), β- pinene (0.16%), car-3-ene (0.04%), myrcene (0.04%), dipentene (0.35%), phellandrene (0.3%), pcymene (0.36%), methyl heptanone (1.05%), citronellal (0.49%), linalool (3.07%), β-elemene (0.7%), β-caryophyllene (2.15%), citronellyl acetate (0.72%), geraniol acetate (3.58%), citral b (32.27%), citral a (43.29%), geraniol (2.6%), elemol (2.29%) and β-caryophyllene oxide (1.56%) (Shahi, 1997; Sharma et al, 2002). Similarly, olayemi (2017) discovered 34,24 and16 compounds respectively for the root, stalk and leaf of oil lemongrass.

3.2. Functional group composition of lemongrass

It has been reported that lemongrass oil contains different functional groups which include halo-compound, alkene, alkane, sulphate, aldehyde, thiol, isothiocyanate, carboxylic acid,primary amide, amine, ketone, ester, carboxylic acid, alcohol, and aromatic compound in lemongrass oil (Benoudjit, et al., 2022; Okpo and Otaraku ,2020; Olayemi et al., 2018,)

3.3. Mineral composition

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The mineral content of lemongrass oil has also been reported in literatures. Cymbopogon citratus contains importants elemental minerals such as Soduim, Magnesium, Potassium, manganese, zinc, Phylate, phosphorus, calcium among. Table 4 presents results of mineral/heavy metal contents of lemongrass oil in comparison with W.H.O. and Indian standard for medicinal plants.

Table 4. Mineral contents of lemongrass by various researchers

Mineral	Indian specification (mg/100g)	WHO specification (mg/kg)	Okpo & Edeh (2022).	Nimenibo-Uadia and Nwosu (2020)	Uraku et al., (2015)	Sulaiman et al., (2019)
Cadmium			0.080			
Calcium				40.08±0.00 x10^{-2}	2.14±0.02	1.00±0.002
Chromium			0.530			0.05±0.002
Cobalt					0.39±0.01	
Copper	0.05-0.07	20-150	0.267	4.45±0.46 x10^{-3}	0.39±0.01	0.08±0.002
Iron	1.5-1.98	261-1239	0.167	7.45±0.25x10^{-2}	0.11±0.02	
Lead	0.14	10	1.379			
Magnesium			14.159	13.77±0.40 x10^{-2}		
Manganese	0.0.19-0.27	20-150	0.009		2.57±0.04	
Mecury			0.728			
Phosphorus				11.20±0.65x10^{-2}		
Potassium				38.50±1.85 x10^{-2}	0.64±0.01	2.55±0.015
Sodium				2.70±0.21x10^{-2}	0.41±0.01	6.63±0.034
Zinc	2.23	50	0.844		0.03±0.03	0.08±0.002

Similarly, for sample of lemongrass leaves analyzed in Nigeria by Asaolu *et al*., (2009) revealed that lemongrass leaves were rich in essential mineral elements, while the recorded concentrations of Fe, Zn, Mg, Na, K, Ca, Mn, P and Se were 43, 16, 226, 323, 298, 242, 25, 1245 and 2 mg/kg. In addition, analysis of lemongrass leaves extract done by Aftab *et al*., (2011) from Punjab province of Pakistan also revealed high contents of K (53.40%), Ca (26.19%) and Si (10.01%) while 2.57% and 2.05% were recorded for sodium and Magnesium respectively.

4.0. METHODS OF EXTRACTIONS OF LEMONGRASS

Extracting and characterizing bioactive molecules from medicinal plant is very important for drugs with high therapeutic value. Dutta *et al*., 2014 has suggested that distillation method is the best approach to extract essential oil of lemongrass. However common methods reported by researchers to extract essential oil from medicinal plants including Lemongrass *(Cymbopogon Citratus)* are hydrodistillation (HD), steam distillation, steam and water distillation, maceration, destructive distillation and expression (Dhobi *et al*., 2009; Abderrahmane *et al*,.2013). A lot of studies have showed that essential oils quality depends mainly on its constituents which is significantly influenced by the extraction techniques (Desai and Parikh, 2015; Abderrahmane *et al*., 2013; Ashgari *et al*., 2012; Schaneberg and Khan, 2002). Besides, methods involving heating may induce degradation, hydrolysis and water solubililization of some fragrance and volatile constituents (Dhobi *et al*., 2009; Karakaya *et al*., 2014). Additionally, the oil obtained through solvent aided extraction contains residues that may pollute the foods fragrances to which they serve as additive. As a means to overcome this drawbacks, some advance and improved techniques which includes microwave-assisted extraction (Hong *et al*., 2010), ohmic-assisted hydrodistillation (Mohsen *et al*., 2012), supercritical fluid extraction, subcritical water extraction and ultrasound-assisted extraction (Porto and Decorti, 2009) have been suggested researchers to shorten extraction time, improve the extraction yield and reduce the operational costs among other advantages. Below is the description of various methods;

4.1. Steam Distillation

According to Hesham *et al.* (2016), steam distillation is widespread method for isolating essential oils commercially. About 80 to 90% of vital plant constituents are obtained using steam distillation method. The technique is good for fresh plant materials that have a high boiling point most especially roots and seeds. In this method, the plant matrix(solid) is placed in the perforated grid, steam is released from steam boiler to the extraction still(pot) passing through the plant matrix(solid) and oil is removed from the plant matrix by diffusion process and comes out with steam to the condenser, then to the separation unit. Generally, Clevenger steam distillation apparatus in Figure 2 is used for recovering small quantities of solid plant material. Advantages of this method includes easy control of steam quality and quantity at any instance, low risk of thermal degradation as temperature is generally not above 100°C. Its only disadvantage is that of high level of technicality, repairs and maintenance.

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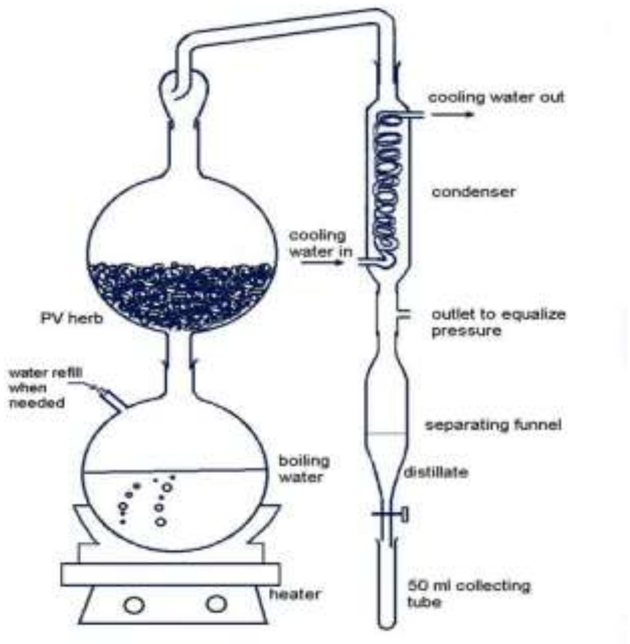

Figure 2. Steam distillation apparatus (Mak and Walsh, 2021)

4.2. Water (Hydro) Distillation

Li *et al.* (2014) have stated that, hydro-distillation differs from steam distillation. Hydro-distillation is used to bring out aromatic plants oil via boiling water. This method has some disadvantages which include slow distillation process resulting into long distillation time thereby leading to consuming more energy that makes the process uneconomical, extraction of herbs (leaves) is not always complete, Long stay of plant materials in hot water may cause changes in composition, The plant raw material very close to bottom walls of the pot have direct contact with the heat source, therefore, there is likelihood of plant material getting burned resulting to bad odour to the oil. Figure 3 is a typical schematic hydro-distillation apparatus.

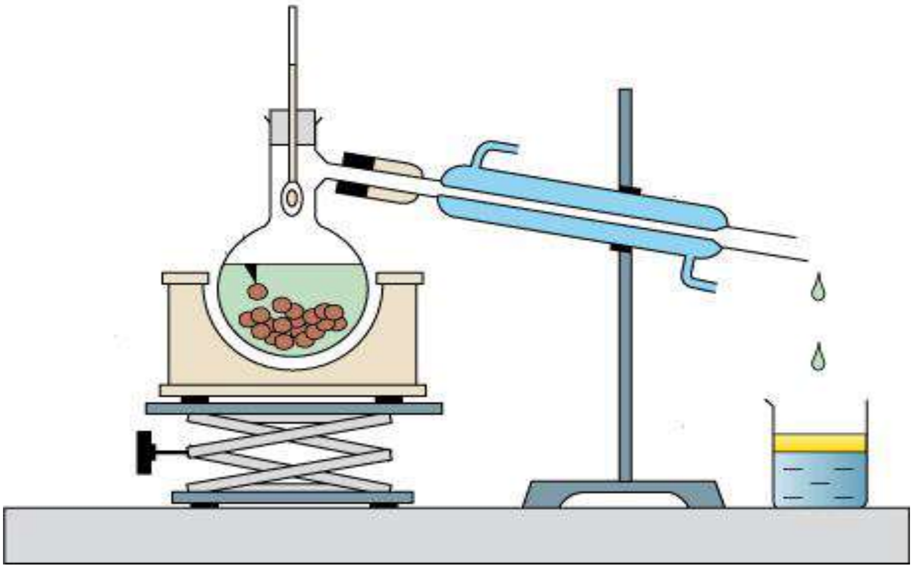

Figure 3. Hydro-distillation apparatus (Hesham *et al.*, 2016)

4.3. Effleurage

Effleurage method of extraction has its origin from Grasse, a southern part of France where it was first used for extraction of flower oils. In this method, the glass plate is covered with thin-layer of purified fixed oil or fat upon which fresh flowers are spread. In effleurage process, the volatile oil is recovered in a fatty base. In this method, the essential oil is usually separated from fatty compounds by adding alcohol. After a time, the alcohol evaporates leaving the essential oils. Effleurage is highly labor-intensive method of extraction (Trease and Evans, 1978).

4.4. Maceration
This method involves soaking (macerating) the sample plant material in solvent, then after a while, filtering and concentration of the extract will take place. This method uses very cold solvent that reduces the chances of decomposition. But, it has a disadvantage of taking longer time as well consuming a lot of solvent (Joy *et al.*, 2006).

4.5. Solvent extraction
In solvent- extraction, raw materials are placed in a glass vessel and soaked in either of petroleum ether, hexane or benzene etc. In this method, as soon as extraction is completed, the solids are separated from the liquid mixture. The latter is heated so that the more readily vaporizing (diffusing) component of the oil can be evaporated, then subsequently condensed. Solvent extraction uses very little heat as a result; it is advantageous to obtained oils with whole fragrances that would have been otherwise destroyed by excess heat and steam. One disadvantages associated with the solvent-extraction method is that of solvent residues which often contaminate the product thereby resulting to side effects that makes the use of essential oil undesirable for skin applications but may still be used in cosmetics and household products (Ndou, 1986). Reports have shown solvent extraction method has a higher yield than steam distillation and effleurage method of obtaining essential oil of lemongrass (Suryawanshi *et al.*, 2016; Shetty *et al.*, 2017).

4.6. Soxhlet Extraction
Soxhlet extraction is one of commonly used method for extraction of nutraceuticals, but has its own limitations which include use of a large quantity of solvent and the process can be quite time consuming, taking from a few hours up to several weeks (Kaur, 2016). Castro and Priego-Capote, 2010; Luque de-Castro and García-Ayuso, 1998 explained Soxhlet extraction that, sample solid material containing desired compound is placed inside a thimble made from thick filter paper that is loaded into the main chamber of the Soxhlet extractor as depicted in Figure 4. The Soxhlet extractor is placed onto a flask containing the extraction solvent. The Soxhlet is then connected to a condenser. The solvent is heated to reflux. The solvent vapor travels up a distillation arm and floods into the receiving chamber housing the thimble of solid. The condenser ensures that any solvent vapor cools and drips back down into the chamber housing the solid material. The chamber containing the solid material slowly fills with warm solvent. Some of the desired compound will then dissolve in the warm solvent. When the Soxhlet chamber is almost full, the chamber is automatically emptied by a siphon side arm, with the solvent running back down to the distillation flask. This cycle may be allowed to repeat many times over hours or days.

4.7. Supercritical Fluids Extraction
Supercritical fluid extraction (SFE) involves separating one component(extractant) from another (plant matrix) using supercritical fluid(CO_2) as solvent (Kaur, 2016). One of the most common supercritical fluids employed in this extraction technique is CO_2. Supercritical extraction is quicker and more effective than ordinary solvent extraction; besides, supercritical fluid solvents are more easily removed. Recovery is usually accomplished when pressure is reduced to release the solvent from the extracted analytes. Figure 5 is a typical Supercritical fluid extraction (SFE) process. In this method, CO_2 is used as solvent. These desirable properties of CO_2 makes the essential oils that are produced have organoleptic properties closely resembling those of the plant from which the oil was extracted**.** CO_2 is inexpensive, safe and abundant.

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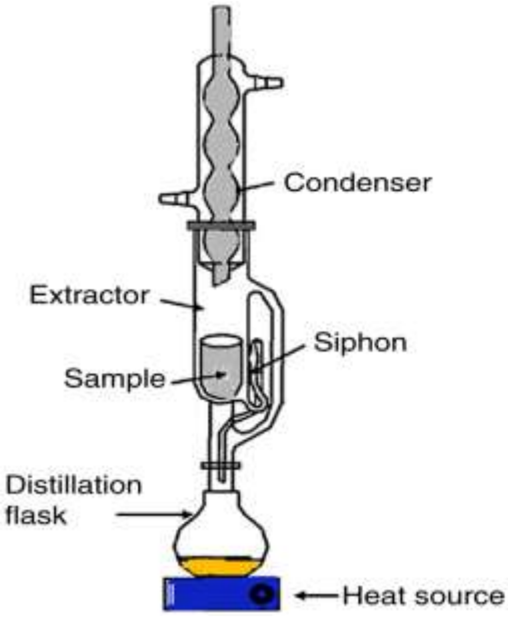

Figure 4. Soxhlet Extractor Apparatus (Kaur, 2016)

4.8. Ultrasound Extraction (Sonication)

According to Sukhdev *et al.* (2008), ultrasound extraction procedure involves the use of ultrasound with frequency range of 20 kHz - 2000 kHz. This method is function of frequency. Ultrasound-assisted extraction is recommended to accomplished vital valuable compounds. This technique was developed in 1950 (Vinatoru, 2001). In ultrasound extraction as shown in Figure 6, the plants raw materials are immersed in solvent like water, methanol or ethanol and then subjected to ultrasound. This technique has also been featured as worthful technique in food and plants processing (Bhaskaracharya *et al.*, 2009).

4.9. Simultaneous-distillation-extraction technique (SDE)

In this method, the combination of either hydro-distillation and or steam distillation with solvent extraction is utilized. This technique is mostly used for isolation of volatile constituents from oils bearing plants. Solvent of choice must be indissoluble in water as well possess high purity. Simultaneous distillation process has been modified into several variants with the consideration of efficiency, scale and quality of end-products. The technique uses less solvent; eliminate excessive thermal degradation and dilution of extract with water. The only disadvantage is that, it introduces artifact into the extract as well loss of compounds that have strong affinity for water.

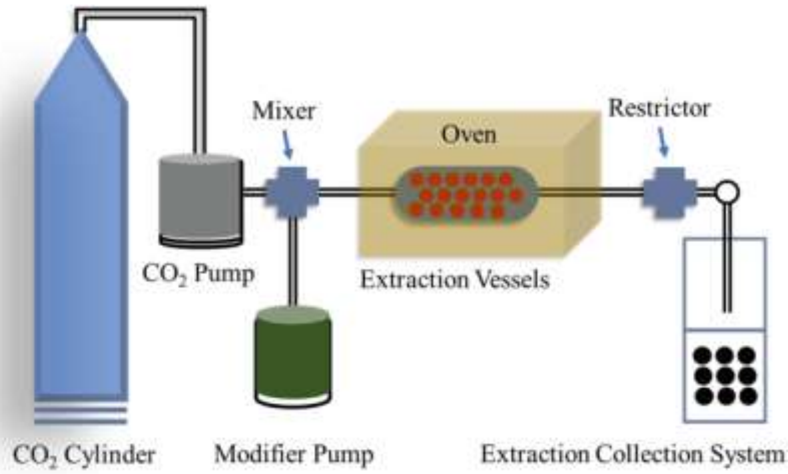

Figure 5. Supercritical fluid extraction (SFE) process (El Hamd, et al., 2022)

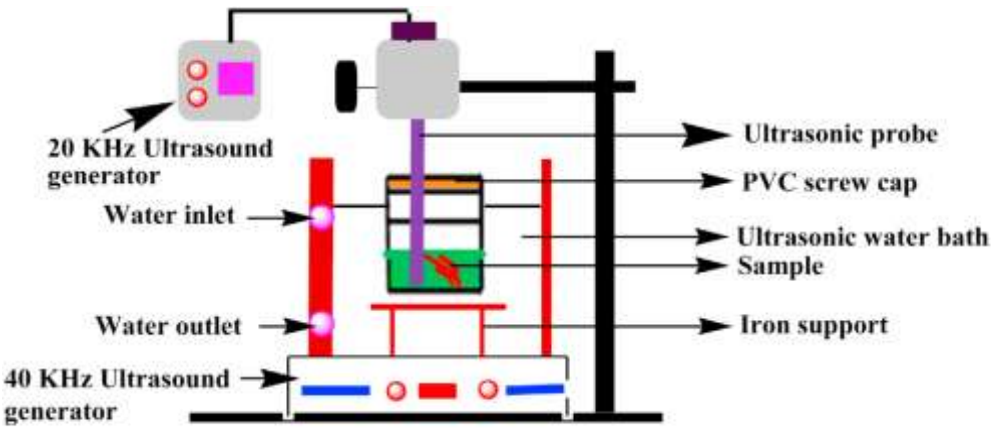

Figure 6. Sonication assisted extraction (Kaur, 2016)

4.10 Microwave-assisted hydro-distillation technique (MAHD)

The MAHD's technique is an advanced hydro-distillation techniques which utilized microwave oven. Golmakani and Rezaei (2008) have reported the use of MAHD in removal or recovery of bioactive compound (components) from plants raw material. The performance efficiency of MAHD strongly depends on the insulation of water and plant material to be extracted (Brachet, *et al.*, 2002). MAHD is represented in Figure 7. MAHD is a new technology presently used to separate biological materials from its carcass. It is being considered as an important alternative in extraction techniques because of its merits in reduction of extraction time, solvents and selectivity. The heating process is easily monitor and controllable.

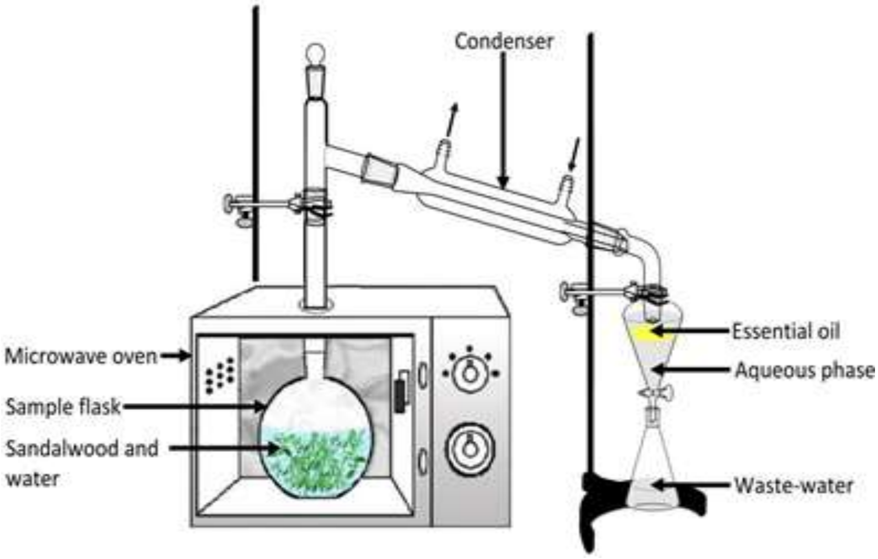

Figure 7 Microwave-assisted hydro-distillation (Kusuma and Mahfud, 2016)

4.11. Solvent-Free -Microwave-Extraction Technique (SFME)

SFME show in Figure 8 does not required solvents for its operation of bringing out oil from plant materials (Lucchesi *et al.*, 2007). In operation, the solid plant materials are moistened by soaking in a certain considerable quantity of water for about 1 to 2 hours. Thereafter, surplus H_2O is discharged off from the mixture. After this, the moistened plant materials are made to stay in the microwave oven cavity of which the condenser that will receive the extracted essential oils will be preset to predetermine condition. The separated essential oil is kept dry over and stored at 4^oC in the dark. The control panel attached to equipment front is used to manipulate irradiation power, temperature and extraction time.

5.0. OIL YIELD METHODS REPORTED BY DIFFERENT INVESTIGATORS ON LEMONGRASS OIL EXTRACTION

5.1. Steam Distillation

This is still being considered as one of the preferred lemongrass essential oil extraction method among others. Suryawanshi et al., (2016) in their work, "methodology to extract essential oils from lemongrass leaves: solvent extraction approach", solvent

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extraction and steam distillation method were used to extract essential oil from lemongrass. The oil yield using steam distillation method by different researchers is presented in Table 5.

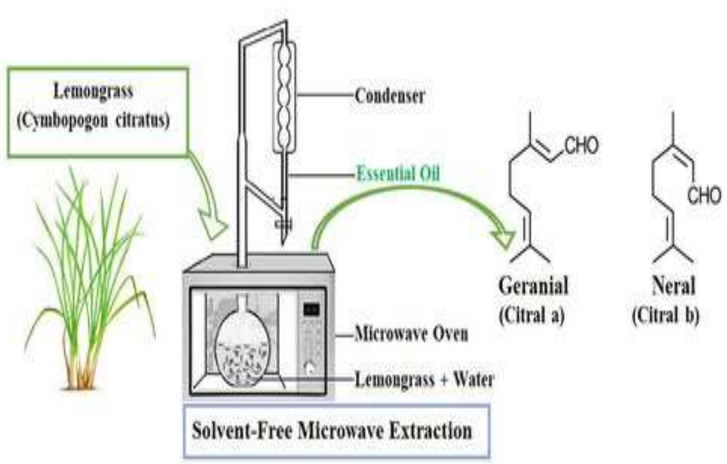

Figure 8 Solvent-Free Microwave Extraction (Boukhatem *et al.,* 2022)

Table 5. lemongrass essential oil yield using steam distillation method by various researchers

Oil yield (%)	Quantity lemongrass used (g)	Ref.
0.85	150	Suryawanshi et al. (2016)
0.24	1272	Anggraeni et al. (2018)
0.3	-	Santin et al. (2009)
0.6	200	Boukhatem et al. (2014)
0.46 (dry plant)	45	Sargenti and Lancas (1997)
0.03 (fresh plant)	45	Sargenti and Lancas (1997)

Also in the work of Akhihiero et al. (2013), there is progressive increase of the essential oil yield from 0.51 to 0.84 as the particle size increases from 4 mm to 20 mm and the distillation time increases from 30 minutes to 120 minutes. Similarly, oil yield increases as temperature increases from 10 to 50^{o}C for all the different sizes of the leaves.

5.2. Microwave-Assisted Hydrodistillation (MAHD) and Hydrodistillation(HD) method

In the research conducted by Ranitha et al.,(2014), “comparative study of lemongrass(*Cymbopogon Citratus*) essential oil extracted by microwave–assisted hydrodistillation and conventional hydrodistillation method, the result of their work after 90 minutes of extraction shows that the oil yield of 1.46% and 0.98% respectively for MAHD and HD. According to Ranitha et al., (2014), oil yield of 1.46% obtained for lemongrass at optimum operating parameters of; water to plant material ratio of 8:1, microwave power of 250W and 90 minutes of extraction. Similarly results of research work conducted using microwave-assisted hydrodistillation (MAHD) and hydrodistillation (HD) method are presented in Table 6.

Table 6. Results of MAHD and HD method on extraction of lemongrass

Oil yield (%)	**Amount of lemongrass used(g)**	**Time (minutes)**	**Method**	**Ref.**
1.46	50	90	MAHD	Ranitha et al. (2014)
0.98	50	90	HD	Ranitha et al. (2014)
0.35	100	90	MAHD	Tran et al. (2019)
0.15	100	90	HD	Tran et al. (2019)
2.6	250	180	HD	Olayemi (2017)

5.3. Solvent extraction and Soxhlet extraction method

In their research, “extraction and formulation of perfume from locally available lemon grass leaves”, Alhassan et al., (2018) reported oil yield of 4.5% and 3.8% for solvent extraction and soxhlet extraction methods respectively. In cases, 300g of lemongrass sample were used in their experiment. Solvent extraction method produced an oil yield of 4.5% which is 0.7% more than 3.8% obtained for Soxhlet extraction. The results of other researchers who have used these methods of extraction of lemongrass EO are presented in Table 7.

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5.4. Supercritical Fluid Extraction Method (SFE)

Sargenti and Lancas (1997) explained the SFE Method for EO lemongrass is more efficient and effective with respect to time than steam extraction but less than by Soxhlet extraction. In their report, SFE of cymbopogon citratus (DC), they reported oil yield of lemongrass with varied modification of organic solvent. The result of their findings is presented in Table 8. It was found that SFE using CO_2-10% hexane provides extract yields very similar to those obtained by steam distillation but yields additional compounds. The modification of the organic solvents influenced the oil yield as seen in table 8. Similarly, Marongia et al., (2006), also reported oil yield of 0.65% and 0.43% respectively for SFE and HD method that was employed in the extraction Lemongrass EO.

Table 7. Oil yield for Solvent extraction and Soxhlet extraction method

Oil yield (%)	Amount of lemongrass used (g)	Solvent	Method	Ref.
4.5	300	n-hexane	Solvent extration	Alhassan et al. (2018)
3.8	300	n-hexane	Soxhlet extraction	Alhassan et al. (2018)
1.30	150	n-hexane	Solvent extration	Suryawanshi et al. (2016)
6.27	300	n-hexane	Solvent extration	Abera (2020)
7.8	82	n-hexane	Soxhlet extraction	Ojewumi et al. (2017)
2.9	82	ethanol	Soxhlet extraction	Ojewumi et al. (2017)

Table 8. Extraction yield and time of SFE of lemongrass (Sargenti and Lancas, 1997)

Extraction	Yields (%)	Extraction time (h)	Amount extracted with time (% h^{-1})	Total amount extracted per hour (% h^{-1})
For Dry plant				
Steam distillation	0.46	4	0.11	0.11
Soxhlet, Hexane	2.83	4	0.71	
Soxhlet, Acetone	1.22	4	0.31	1.02
Cold extraction, Hexane	2.96	72	0.04	
Cold extraction, Acetone	1.76	72	0.03	0.07
SFE-CO_2-10% Hexane	0.05	1.5	0.03	
SFE-CO_2-30% Hexane	0.94	1.5	0.63	
SFE-CO_2-10% Acetone	0.02	1.5	0.01	0.84
SFE-CO_2-20% Acetone	0.01	1.5	0.00	
SFE-CO_2-10% Methanol	0.26	1.5	0.17	
For Fresh Plant				
Steam distillation	0.03	4	0.01	0.01
SFE-CO_2-10% Hexane	0.25	4	0.06	
SFE-CO_2-10% Acetone	0.05	4	0.01	0.07

6.0. USES AND APPLICATIONS OF LEMONGRASS OIL

Lemongrass and its bioactive components has been comprehensively used in traditional medicines from long past around the world in many nations due to presence of many therapeutic properties like antifungal, antimicrobial, anti-inflammatory and analgesic which it possesses (Yousef, 2013). Shah *et al.*, (2011) has stated that, stalks and leaves of lemongrass are also used as an anticonvulsant, antispasmodic, antiemetic, hypotensive, antibacterial, analgesic, antitussive, antirheumatic, and in the treatment of nervous and gastrointestinal problems traditionally around the world. Furthermore, essential oil of lemongrass are used for food and beverages, cosmetic, perfumery, pharmaceuticals, nutraceuticals, sanitary, agronomy and drinks flavoring industries (Swamy et al., 2016). Generally, lemongrass oil had found great application in aromatherapy, cosmetics, perfumery, foods and drinks flavouring industries.

6.1. Cosmetics

Lemongrass oil is an ingredient in soaps, detergents, and cosmetics formulations. It is also used to aid systematic recirculation of blood and muscle toning. Lemongrass non-irritating, inexpensive, eco-friendly deodorant that is long-lasting without side-effects in proper dilution (NDA, 2018).

6.2. Pharmaceutical and Therapeutic

The oil from lemongrass is administered to treat diarrhea, stomach-ache, headaches, fevers, muscle pains/pull and flu. Apart from the aforementioned medicinal uses of the lemongrass oil, studies have also shows that lemongrass oil have antimicrobial and antifungal effect on some phartogenic organisms which make it to be useful in pharmaceutical industries (Boukhatem *et al.*, 2014; Sridhar *et al.*, 2003). Nambiar *et al.*, (2012) has reported possible Role of Lemongrass oil (*Cymbopogon citratus*) in treatment of coughs, constipation, elephantiasis flu, gingivitis, headache leprosy, malaria, ophthalmia, pneumonia, vascular disease. The anti-inflammatory and antioxidant properties have been well documented in numerous literatures. Promila and Madan (2018 have revealed that lemongrass essential oil has anti-inflammatory, anti-viral, anti-cancer, anti-hyperglycemic, anti-oxidant, anti-malaria, anti-mutation and antibacterial properties. These properties and chemicals in lemongrass make it a very important medicinal plant for the curing and prevention of various ailments.

6.3. Food and Drinks

Joy et al. (2006) has reported the used of lemongrass oil in culinary flavoring. Lemongrass oil have been used in food flavoring alcoholic products such as spices, tea leaves, candy baked foods, confectionery , meat/meat products. Mishra and Dubey (1994) confirmed that lemongrass oil is effective to fight against postharvest fungitoxicant for the protection of foodstuffs against storage fungi. Moreover, quite a lot of studies have been carried out to determine the efficacy of lemongrass essential oil in preserving different types of finished food products and the possibility of using them as substitutes for synthetic preservers in food productions. Abd-El Fattah et al. (2010) has reported that lemongrass EO has been used for the decontamination of mycotoxigenic fungi and prevention of mycotoxin formation in dairy products. The antifungal and antibacterial activities of lemongrass essential oil against different activities of microbial species have been well documented in literatures (de Silveira et al., 2012; Abd-El Fattah et al., (2010); Tzortzakis and Economakis, 2007; Mishra and Dubey, 1994). The antifungal activities of lemongrass EO against fungi known to cause the spoilage of bakery products have also been demonstrated (Guynot et al., 2003; Suhr and Nielson, 2003). For the reason that lemongrass has antimicrobial properties, its EO is applied in the cheese-making industry as a natural preservative (Khorshidian et al., 2018), preserve meat products against spoilage and pathogenic microbes (Pateiro et al., 2021).

6.4. Industrial Uses

Due to its attractive fragrance, lemongrass oil is used as an additive ingredient in several products which include deodorant, mosquito and insect repellents cream, candles, polish, waxes, pesticides, anti-fungal cream and perfumes (Toungos, 2019; Sharma et al., 2020).

6.5. Agriculture Uses

In spite of numerous uses of lemongrass oil in various industries, it has been widely used also in agricultural sector. The oils of certain species of lemongrass have been found application in germicide and bactericide production. Moreover, insecticidal, nematicidal and fungicidal activities of lemongrass oil have also been reported (Saksena and Tripathi, 1985). Moustafa et al.,(2021) reported that lemongrass essential oil has potential anti-insecticidal activity against the second-instar larvae of *A. ipsilon* and other insect pest, black cutworm, *Agrotis ipsilon* (Lepidoptera: Noctuidae) that attacks the seedling stage of many field crops in several countries around the world.

7.0. CONCLUSIONS

Essential oils of lemongrass consist of many volatile molecules that find applications in pharmaceutical, cosmetic, agricultural, food and aromatherapy etc. Extraction of lemongrass essential oils could be carried out by various methods. However Innovative methods devoid of shortcomings techniques to reduced chemical risk, extraction time and high energy input and obtain yield quality of essential oils are being sort for in the recent time. Therefore, for extraction of lemongrass oil, green technology such SFE, SDE, SFME that are consumer and environmental friendly recommended as the products are solvent free, saving time and energy consumption. Moreover, the chemical composition of the essential oil of Lemongrass also varies with the geographical origin, cultivation practices, plant age, photoperiod, harvest period, cultivars, and extraction methods. Findings from this present review indicates that lemongrass essential oil has significant potential for the advancement of drugs for the treatment of various types of infectious diseases and other ailments affecting humans and as well find countless applications industries.

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