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REVIEW ARTICLE

Comparative study of the performance of Supercritical Fluid Extraction, Microwave assisted Hydro-distillation and Hydro-distillation of Lemongrass (*Cymbopogon Citratus*): A Review

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ABSTRACT

This review study deals with the collocation of the performance of three different separation techniques for the extraction of essential oil of Lemongrass (*Cymbopogon Citratus*) accordant with yield produced, time utilized for extraction, and overall cost of production. The system of Supercritical CO2 extraction (SFC), Microwave-assisted Hydro-distillation (MAHD), and conventional hydro-distillation (HD) method were juxtaposed from the yield and time point of view. SFE is a modern extraction technology that uses a Supercritical phase of CO2for the isolation of essential oil from lemongrass (*Cymbopogon Citratus*) and is a green process because of the use of natural and climate-friendly solventCO2. MAHD is a microwave-powered extraction procedure that provides efficient and effective heating to the plant material and uses deionized water as a solvent. A lab-scale apparatus of conventional hydro-distillation was used. SFE and MAHD were found to be superior green technology when compared with HD producing high quality of oil, in a short period with negligible environmental degradation.

Key words: Supercritical fluid extraction; essential oil; Microwave-assisted Hydro distillation; Lemongrass

1) INTRODUCTION

Essential oils are highly concentrated, volatile liquids educed from rinds of fragrant greens; they have the characteristic odor of the plants they are extracted from. The oil glands or sacs are present in the entire body (roots, flowers, stem, bark, and seed) of the plant which secrete these oils when processed with suitable extraction mechanisms. These complex volatile mixtures are present in low concentrations in different parts of the plant and are naturally occurring products of plants with high-grade biological properties. Animals such as the black civet, blue whale also produce such odorous oils [1]. From the early ages till now they have great importance in the different sectors of society and are used as raw material and served the food, beverage, fragrance, and pharmaceutical industries equally. Flora itself has several applications of self-produced oils like prevention from infections, regeneration of cells, safeguarding themselves from fungal and viral attacks, and also serves in pollination.

About 120 classes of lemongrass have been inspected to date, one of which is the *Cymbopogon Citratus* [2]. Lemongrass (*Cymbopogon Citratus*) can be described as a tall bushy perennial grass, with long striped leaves and irregular edges, generally found in the subtropical and tropical regions like Africa, Asia, and America, this plant of the grass or Poaceae family is known for its sweet, herbaceous, smoky and lemon-like fragrance [3]. This species of Lemongrass belongs to the Cymbopogon genus of fragrant grasses and comprises volatile oils with a fine fragrance and flavor of lemon. Being a source of natural citral it is exceedingly popular as a raw material in the therapeutic, fragrance, flavor, and cosmetic manufacturing industries. The monoterpenes like 1,8 cineole, citronellal, linalool, citronellol, geraniol and the quantity in which they are present in the Cymbopogon volatile oils is one of the aspects that differentiate different classes of these crops from each other, chemical configuration of lemongrass scented oil differs in diverse species is due to the variety in habitat and genetics [2]. Essential oils are chemically characterized by the use of different analytical techniques like GC-MS and GLC [4]. The leaves of *Cymbopogon Citratus* are utilized in and as for tea because of their pain-relieving, antipyretic, sedative, and anti-inflammatory properties [5]. Citral present in the lemongrass essential oil is used as a flavoring agent in soft drinks, also ionone is produced from citral which is a major constituent in manufacturing perfumes.

Very first traces of techniques for the isolation of plant extracts were of distillation, in the 9th century A.D from Arab, later in the 13th century for the development of remedy oils by the pharmacies [3]. Arnold-de-Villanova, a

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Catalonia-based physician is credited to deliver an authentic explanation for the distillation of essential oils [6]. The process of fermentation is used for extraction in the early stages [7]. Numerous methods are now available in the mainstream for the extraction and development of essential oils from the matrix of the plant. Development and processing of abundant customer goods involve the use of essential oils for instance cleaners, food products, lavatory products, beverages (alcoholic and non-alcoholic), cosmetics, insect repellent and incenses [5]. The qualitative, quantitative, and sensory assets of the essential oils depend majorly on the isolation procedure. The choice of extraction method depends on several factors like the type of raw material (flower, seed, root, stem, leaves, peel, wood, rhizome), usage of the solvent, type of solvent (organic solvents or Supercritical CO_2) and, time of extraction [4]. Every technique is vital and has a place in the production or formation of a top-grade potentially aromatic essential oil. Diverse extraction approaches have different impacts on the quality value and yield of volatile/non-volatile essential oils. The cost of processing and the time of extraction also may vary for different extraction practices.

Distillation of volatile oils at raised temperatures results in the alteration of thermolabile compounds. Heat-sensitive plant materials are generally extracted from the solvent-extraction procedure, non-volatile components with fixative properties are also obtained from solvent-extraction [4]. Some commonly used processes in the extraction of essential oils are the circulatory distillation devices based on the Clevenger, which later implemented several modifications. One such unit defined by Middleton and Cocking in 1935 comprises a round-bottom flask were finely chopped raw material with water as a solvent is placed and heated at a specified temperature and the flask is connected to a condenser [6]. The type of plant material used decides the span of distillation which generally varies from 3 to 4 hours. Further advances in the extraction apparatus were described by Likens and Nickerson in 1964 which was solvent distillation also known as hydro-distillation [6].

The production and consumption of essential oils in the world are increasing at a very high rate. Brazil, China, Egypt, India, Mexico, and Indonesia are a few of the major essential oil-producing countries of the world whereas developed countries like the United States of America (USA), Japan, and some of the Western European countries are chief consumers of essential oils [1]. Hence, the development in the production technology of essential oils is an essential element to improve the overall yield and decrease the cost of production to match the requirements of the world for essential oils.

Hydro-distillation has been involved in the extraction of Essential oil for a very long time. Hydro-distillation can be performed in three ways which are, water distillation, direct steam distillation, and water-steam distillation [8]. Hydro diffusion, hydrolysis, and decomposition of heat are three physicochemical phenomena involved in the process of hydro-distillation. Steam and hot water are used as extracting and transporting media to release bioactive constituents from the plant resources and carry them along as a mixture. The apparatus comprises a condenser that offers indirect cooling of the mixture for the separation of water from oil. The process is conducted at elevated temperature (above the boiling point of water) causing excessive heating which may dry out the material in the still due to which some of the volatile and heat-sensitive constituents of the oil can be lost during the process, causing burn leading to the production of poor-quality oil. The hydro-distillation method is applicable for the extraction of only those essential oils that are thermo-stable, and to access the thermostability raw materials that are hard like clove, cinnamon, and black pepper, whereas the oil extracted from flowers like rose, jasmine is usually thermo-labile and hence cannot be isolated from hydro-distillation as it may alter the composition of the essential oil produced or even produce a foul odor in it [8].

The idea of sustainable development promoted the use and development of technology that are climate-friendly or "green technologies" which are the amalgamation of efficient work processing without triggering the well-being of the environment [9]. Microwave-powered technologies have provided us a way to sustainable development in the extraction sector. The past 2 decades has proven that the usage of Microwave as a non-contact heating source promotes effective and efficient heat generation inside the plant matrix resulting in higher extraction rates, fast energy transfer, reduced thermal gradient, less induction time, higher yield, and low extraction time as compared to conventional processes. Verity of microwave motorized extraction technologies has been developed to date such as microwave-assisted hydro-distillation (MAHD), microwave steam distillation (MSD) [10], vacuum microwave hydro-distillation (VMHD) [11], microwave-accelerated steam distillation (MASD) [12], solvent-free microwave extraction (SFME) [13], and microwave hydro diffusion and gravity (MHG) [14]. All these techniques promote effective heating, shorter extraction time, low solvent consumption and contribute towards ecological development [13] [14].

Essential oil extraction using supercritical solvents is referred to as a pressurized extraction procedure, which operates using environment-friendly solvents, such as CO_2 in the supercritical phase or mobile phase. Fluids with temperature and pressure above the critical point are said to be supercritical fluids. CO_2 shows supercritical behavior at a temperature and pressure of 31.3^{o}C and 73.8 bar respectively [15]. SC phase is a liquid-gas intermediate phase, which has properties of both liquid and gas, liquid-like density (up to 1000 times higher than gases), gas-like diffusivity (10-3 to 10-4 cm2 per second), low or no surface tension, and non-viscous (10-100 times less than liquids) nature promotes high diffusion or penetration rate and excellent solvation power encouraging faster extraction and quality yield [16]. Over 100 years ago in 1879 studies concluded about how SCF's possess solvent properties. Since the 1990s SCF has been used in several industrial processes, being an advanced separation technique designed to replace traditional, multi-step, time-consuming extraction techniques which use a large quantity of organic solvents [17]. Previous studies prove that biologically active compounds such as essential oils, flavonoids, protein, and polysaccharides are isolated using supercritical fluid extraction [18]. The SFE uses elevated pressures and low-

temperature conditions. The use of an environment-friendly solvent such as CO_2 in the SFE process positions it into the category of green extraction technologies, despite being a greenhouse gas, CO_2 is climate-friendly and cheap as compared to other solvents [17].
An efficient extraction process selectively dissolves one or more of the mixture components in an appropriate solvent. The solution of these dissolved compounds is often referred to as extract. The extraction process depends upon the mass transfer phenomena, the factor controlling the rate of extraction is normally the rate of diffusion of the solute through the liquid boundary layer at the interphase. Ideally, an extraction method should be rapid, inexpensive, and simple in its structure and mechanism. It should give a qualitative recovery of analyte without any loss or degradation, also the waste generated during the process should be minimal and recyclable.

2) PROCEDURE

a) Hydro-distillation of Lemongrass using Clevenger apparatus:

In 1928, Joseph Franklin Clevenger described the Clevenger device [19]. The hydro-distillation procedure uses a Clevenger apparatus for the extraction of essential oils. Before the Clevenger apparatus is put into use pre-treatment of the lemongrass (*Cymbopogon Citratus*) is done where fresh lemongrass leaves are harvested and dried over sunlight for a specified time. The heating mantel, round bottom flask, Clevenger apparatus, and the condenser are arranged together [20]. Variable size round bottom flask can be used containing the heating media (deionized water) which is boiled along with chopped lemongrass [21]. Temperature above the boiling point of water is maintained, the diffusion of hot water swells up the lemongrass raw material which makes extraction from the oil sacs easy. After the boiling point of water is maintained, the mixture of water vapor and oil rises to the condenser assembly, where the vapor mixture condenses to the liquid form and is collected. There are two types of Clevenger apparatus used based on the density of oil extracted, if the oil which needs to be extracted is heavier than water then an "H" shaped Clevenger apparatus is used (clove oil), whereas the "N" type of Clevenger is used for oils that will float on water. Lemongrass oil is lighter than water and hence, due to the difference in densities and water being heavier will settle down and is gradually returned to the heated flask through the return tube or diagonal duct preventing dryness in the flask, working on the principle of cohobating [4]. This process may take 3 to 5 hours for completion, which may lead to excessive heating, dryness and foul smell in the extract produced. Prolonged heating may also cause isomerization of heat-liable constituents and large electricity consumption which may lead to high production costs [13].

b) Microwave assisted hydro-distillation of Lemongrass

MAHD is a combination of conventional hydro-distillation and microwave. Microwave-assisted hydro-distillation works on the principle that microwave radiation influences the solvent polarity, which is based on the phenomena of ionic conduction and dipole rotation occurring simultaneously [14]. A typical Microwave-assisted hydro-distillation apparatus consists of a microwave unit operating at 2.45 GHz with a variable power control system that provides controlled and efficient heating to the whole volume of the mixture in the flask placed inside the oven cavity [9]. The mixture present is a combination of chopped lemongrass raw material and water, inflexible ratios. The efficiency of this process is entirely based on the absorption energy of the solvent used, water being a decent absorber of microwave radiation promotes effective heat transfer to the plant material. The time of extraction, temperature, and power of operation can be varied and controlled manually based on the type of material used and matrix to solvent ratio. Internal heating of water with lemongrass swells up the plant matrix and rapturing the oil secretors. Oil from the lemongrass leaves is released which rises with the water vapor as a mixture and gets condensed through a vertical condenser mounted on the top of the flask outside the oven cavity [22].
Operating microwave power, solvent to matrix ratio, and extraction time are the key factors that influence the quality, quantity, and cost of lemongrass oil produced [23]. Previous studies concluded that microwave power is directly related to the yield of the oil. When operated at higher microwave powers quantity of lemongrass oil increases and vice versa [24]. Although the use of microwave as a heating source lessens the time of extraction compared to the traditional extraction procedures, the yield obtained hinges on how long the processing unit is at work, with the increase in time the yield upsurges [24].

c) Supercritical fluid extraction of Lemongrass

The supercritical method is considered a modern method of extraction, because of the use of a supercritical form of CO_2 which is environment friendly, cheap, odourless [25], non-toxic, non-flammable, easy to remove from the product, and easily available. CO_2 is recognized as safe by the food and drug administration (FDA) [26]. CO_2 in the mobile phase allows extraction of thermally-liable/easily oxidizing compounds even at low temperatures and under a non-oxidant medium. SC (CO_2) possesses physiochemical properties that are intermediate between those of liquids and gases, these fluids can diffuse through solid raw material like a gas and dissolve biochemical extracts present inside the plant matrix like a liquid [27]. Small changes in pressure and temperature close to the critical point result in greater changes in density allowing many properties of supercritical fluids to be finely tuned, thus SCF can preferably substitute organic solvents for extraction purposes [28]. The driving force for any extraction process is the solubility of the target compound in the selected solvent, which depends on the interactions between the solvent and solute. Supercritical fluid extraction (SFE) has emerged as a superior alternative technique for the extraction of bioactive species from natural produces. SFE is based on the solvating properties of supercritical fluid (SF), which can be obtained by employing pressure and temperature above the critical point of a compound, mixture, or element. The SFE setup comprises an extraction vessel, accumulator, and separator [29]. The system is charged with liquid CO_2 mixed with lemongrass (*Cymbopogon Citratus*) material and is injected into the extraction vessel through a syringe pump having a pressure rating of at least 400 ATM. The liquid is pumped to the heating zone where it is heated to supercritical conditions at elevated pressure. The fluid then is passed through the extraction vessel where it rapidly diffuses through the solid lemongrass matrix and dissolves the material to be extracted. The dissolved material is swept from the extraction cell into the separator at a lower pressure so that there is high relative volatility between lemongrass oil and CO_2 which will turn CO_2 into vapor making a vapor-liquid equilibrium. The extracted material settles out and the SC CO_2 can then be cooled, discharged into the atmosphere, or recirculated through the closed-loop system [30].

3) COMPARISON ON THE BASIS OF YIELD AND TIME

a) Hydro-distillation

Production of lemongrass essential oil from hydro-distillation has been performed earlier by several researchers. The quantitative analysis of the lemongrass oil majorly depends on the amount of solvent used and the time taken for the extraction to take place. Data obtained based on previous studies show that hydro-distillation produced a fairly good amount of essential oil from the lemongrass matrix, the main components of the oil were geraniol, neral (citral-a), geranial (citral-b), Myrcene, E, E-cosine, Citronella, Linalool, Atrimesol, nerol, Geranyl acetate, Cis-carveol, Cis-verbal, etc [31].

$$\text{Yield Obtained} = \frac{\text{Amount of essential oil obtained}}{\text{Amount of raw material used}} \quad (1)$$

- The HD process was carried out using the Clevenger apparatus, 100 grams of lemongrass (*Cymbopogon Citratus*) was added to a 1000 ml RBF along with 400 ml of deionized water. The matrix to solvent ratio was 1:4 and the process was carried out for 6 hours which produced 0.15% of yield. GC-MS analysis was conducted which showed the % of citral content (83.85%) in the oil along with other major isolates Neral = 35.13%, Myrcene = 3.61%, and, Geranial = 48.72% [22].
- A mixture of 50 grams of *Cymbopogon Citratus* and 400 ml deionized water was placed into a 1 litre RBF, the yield obtained was analyzed after every 30 minutes till 2 hours. The results show that the maximum yield attained was 0.98% in 90 minutes and there was no significant increase in the yield after that. The induction time noted was 30 minutes [32].
- 29 ml of lemongrass oil was obtained when the temperature was maintained at 130°C, the run time was 180 minutes and 0.5 cm of chopped lemongrass was used. After 300 minutes of run time, 31 ml of lemongrass volatile oil was obtained. The GC-MS analysis of the oil was, citral-a = 41.82%, myrcene =12.75%, geranyl acetate = 3.00%, citral-b = 0.18%, geraniol = 1.85% [33].
- An experiment conducted with 50 grams of lemongrass matrix mixed with 500 ml of deionized water, yielded 1.04 percent EO [34].

The yield produced by conventional HD technique produced a fairly good amount of yield, but was found to be time-consuming, also prolonged heating may cause decomposition of the plant material and a smaller number of constituents were found to be present in the oil.

Hydro-distillation is a very simple process, it has a simple mechanism and a non-complex processing unit. The process is very popular on the industrial scale as the cost of operation is low and the solvent used (water) is easily available and inexpensive.

Despite all these positives, Hydro-distillation does not produce rich quality oil because of thermal degradation and uneven heating of the matrix and solvent mixture which may burn the mixture and previous studies prove that some isolates are lost during hydro-distillation due to prolonged heating, deteriorating the purity of the extract.

Table 1: Yield obtained by Hydro-distillation v/s Time

Yield	Citral Content	Matrix to solvent ratio	Time	References
0.15 %	83.85 %	1:4	6 hours	[22]
0.98 %	85.15 %	1:8	90 minutes	[32]
29 ml	42 %	-	180 minutes	[33]
1.04 %	69.86 %	1:10	1.5 hours	[34]
0.946 %	82%	1:3	-	[25]
57 ml	90 %	1:2	300 minutes	[4]
1.38 %	**83.50 %**	**1:8**	**3 hours**	**[32]**

b) Microwave assisted hydro-distillation

The yield produced by Microwave-assisted hydro-distillation utterly depends on the heating source used in the process, its operating power, and the material to solvent ratio. A hydro-distillation apparatus with a microwave is used at variable microwave power and different material to solvent ratios affecting the yield of the essential oil [35]. Time is also an important factor that determines the quantity of oil obtained. The microwave offers rapid heating of the material and water mixture, the boiling water will break the oil glands present, and then water will dissolve the extract with itself, if the material to solvent ratio is not appropriate, diffusion of oil into the solvent may not happen effectively leading to reduced oil yield. Localized heating provided by microwave power is a motive force to eradicate the plant matrix so that oil can be released from the glands. Increasing the microwave power not always increases the yield of the extract, it may also degrade the oil eliminating the thermally sensitive compounds. A general increase in microwave power increases the yield of the oil [28].

Table 2: Yield obtained by Microwave assisted distillation v/s Time

Yield	Citral content	Microwave power (W)	Matrix to solvent ratio	Time	References
1.72 %	-	640	1:5	90 minutes	[24]
0.35 %	93.28 %	750	1:3	90 minutes	[22]
1.46 %	86.98 %	250	1:8	90 minutes	[32]
0.57 %	**-**	**288**	**1:5**	**120 minutes**	**[24]**

c) Supercritical fluid extraction

The use of solvents or heating media has always been a key factor that determines the efficiency of an extraction process. A large variety of organic solvents are available and are used in several extraction procedures for a very long time, but the use of such solvents has resulted in the degradation of the environment and is considered hazardous for nature. The use of solvents in their supercritical form is one way to reduce this degradation and move towards a green future, as they are non-toxic, easily recyclable. The liquid-like solvation power of supercritical solvents increases the interaction probability of the solute and the solvent leading to an immense increase in solubility of the extract in the solvent, producing a higher yield.
Supercritical carbon dioxide technology utilizes pressure in combination with carbon dioxide to destroy microorganisms without affecting the nutritional content, organoleptic attributes, being a promising alternative for pasteurization of bioactive compounds in food and medicine in which compounds would be destroyed by conventional thermal processes.

4) MERITS AND DEMERITS

Every process which deals with the processing and manufacturing of a product is considered worthy for mass scale start-up only if it stands out on two major attributes which are Efficiency and Economic feasibility. Hydro-distillation extraction is adopted worldwide because of its simple working process, easy mechanism, and cheap operating cost. This industrial-scale process deals with the processing of biological extracts from plant material using water as a solvent or we can call it the heating media. The simple and economical setup comprises the heating mantel for maintaining the transfer of heat to the material, a vertical condenser for phase transformation, market-friendly Clevenger glassware along the water (solvent) which is abundantly available and is inexpensive. But the fact that this process takes around 4 to 5 hours for the extraction to complete cannot be ignored. Prolonged heating required for this process leads to the consumption of a lot of electrical energy which eventually alters the cost efficiency of the process [38]. The consumption of electrical energy can be calculated through,

$$\text{Electricity Consumption} = \frac{\text{Power Consumption} \times \text{Time}}{3600000} \quad (2)$$

Here, Electricity consumption has the unit of kWh and Power in W [24] [22].
For different extraction procedures the relative electricity consumption can be calculated by,

$$\text{Relative Electricity Consumption} = \frac{\text{Electricity Consumed}}{\text{Mass of oil obtained}} \quad (3)$$

Which has unit of kWh g^{-1} [22] [24].
As mentioned before excessive heating of the plant material decreases the yield and deteriorates the quality of the oil obtained. GC-MS analysis conducted by researchers proves that the extract obtained from the hydro-distillation process discovers fewer number botanical isolates compared to other modern processes [39].

Table 3: Yield obtained by Supercritical fluid extraction v/s Time

Yield	Purity of CO_2	Temperature (°C)	Pressure (bar)	Citral Content	Time (min)	References
-	99.95 %	40	120	84.7 %	20	[36]
2.97 %	99.5 %	40	200	85%	20	[30]
27.55 g EO/Kg CO_2	99 %	35	200	72.3 %	-	[29]
2.04 %	99 %	50	120	50.3 %	-	[26]
0.65 %	99 %	50	90	68%	-	[26]
1.51 %	99.5 %	40	120	77.1 %	60	[37]
2.11	99.5 %	40	110.1	94.4 %	-	[15]
0.7 %	99 %	50	117.2	47.8 %	80	[17]
0.94 %	99 %	75	81.06	68%	90	[16]

Microwave-operated extraction processes on the other hand are less time-consuming, have negligible waste generation, and produce exceptional quality of extract. MAHD is a climate-friendly technology because of the use of microwave as a heating source, using less or no solvent, and the extraction time is relatively low as compared to the traditional hydro-distillation process [40]. MAHD process is an unspoiled and simple extraction process, which does not require large volumes of solvent and heavy extraction equipment [9]. Among some modern extraction processes, MAHD also offers eco-friendly advantages over traditional HD based on energy. The emission of such harmful gases is assessed in terms of CO_2 units [9]. According to the previous studies, 800 grams of carbon-di-oxide will be emitted to the atmosphere to gain 1 kWh energy from fuel or coal during combustion [41].

The use of microwave radiations as a heating source increases the rapidity of extraction and provide surround heating to the material, but at the same time, the addition of a microwave unit in the setup of the MAHD triggers the overall operating cost of the process as microwave heating source is expensive equipment and is not easily affordable, the electricity consumption by the microwave should also be kept in mind. MAHD still has not been accepted on an industrial scale because of the complex equipment setup but is popular on the lab-scale because of speedy heat transfer. The accelerated rate of extraction and high yield by the MAHD process is a consequence of the synergistic grouping of heat transfer and mass transfer phenomena employed in identical directions [12]. The direction of mass transfer of extract from the matrix of lemongrass occurs from inside of the plant material to the outside, similarly, heat transfer operation also takes place in the same direction which accelerates the rate of extraction, as heat dissipates volumetrically around the mixture of material and solvent in the flask.

The foremost advantage of Supercritical fluid extraction is selectivity, with the alteration in pressure and temperature, the properties of the supercritical fluid can be altered, thus improving the selectivity [8].

One factor that SFE surpasses every other extraction process is its rapid extraction rate. As compared to liquids, supercritical fluids have negligible surface tension and are non-viscous in nature which allows SC CO_2 to penetrate into the solid plant matrix and extract out the constituents present inside the oil glands of the lemongrass. Processing at elevated temperatures or heating of the solvent and plant matrix is not employed in this process which makes it a perfect choice for extracting thermally sensitive materials. After the action of diffusion and solvation by the supercritical fluid, it can be easily removed from the analyte by simply releasing the pressure leaving almost no traces. SC (CO_2) is cheap, inert, and non-toxic in nature, it can be released into the atmosphere and no waste is generated during the process. All these advantages make Supercritical fluid extraction as a green technology, causing negligible or no adverse effect to the environment. The only demerits accounted about the supercritical extraction process is that CO_2 being a non-polar solvent in nature the use of modifiers like ethanol and methanol becomes necessary to extract polar phytoconstituents [17] [42]. For utilizing a supercritical solvent like CO_2, the process has to be carried out under very high pressure, which leads to an increase in the operational cost of the process.

5) CONCLUSION

This review was based on the comparative study of the performance of three uniquely driven processes for the isolation of Lemongrass (*Cymbopogon Citratus*) essential oil. Lemongrass oil obtained using the conventional hydro-distillation method casting deionized water as the solvent in the process produced high yields but lacked in maintaining the quality of the oil, also the process was lengthy and time-consuming which led to the deterioration of oil isolates when analyzed through GC-MS. Incessant heating to the plant matrix for about 4 to 5 hours above the boiling point of water reduced the efficiency of the process. The reported research work presented by scholars and scientists from around the world concluded that Microwave-assisted hydro-distillation and Supercritical fluid extraction are alternatives to the conventional hydro-distillation extraction process for the extraction of quality essential oil in a shorter period. The use of microwave radiations which is a no-contact heating source provides rapid and effective heating with faster energy transfer, high rate of mass, and heat transfer in a co-current direction. The induction time of SFE was the least followed by MAHD and Hydro-distillation process had a 30-minute-long induction time. This estimated that 60% of the oil will be recovered through MAHD, while HD will finish with heating of the material and solvent mixture. SFE has an induction time of seconds and yield is recovered in about 30 to 40 minutes. SFE also offers greater solubility, smaller and simpler extraction units, a high production rate, and recovery of thermally sensitive isolates from lemongrass oil. Moreover, SFME promotes green features like no waste generation, no organic solvent or water used and reduced atmospheric degradation. SFE was found to be a superior technique among the three-extraction technology.

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