A brief review on the characteristics, extraction and potential industrial applications of citronella grass (Cymbopogon nardus) and lemongrass (Cymbopogon citratus) essential oils

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Abstract. Essential oils can be extracted from the leaves and stalk of aromatic grass plants, namely the citronella grass (Cymbopogon nardus) and lemongrass (Cymbopogon citratus), which grow primarily in the tropical and subtropical regions of the world. The word lemon denotes its unique lemon-like aroma, which is largely contributed by the existence of citral. This organic compound is an amalgamation of two stereoisomeric monoterpene aldehydes, in which the trans isomer geranial content is predominant over its cis isomer neral. The essential oil of lemongrass has been utilised since the old-times in traditional medicine as a natural remedy to improve circulation, control menstrual cycles, enhance digestion or improve immunity. It is also used to produce perfumes, flavours, detergents, and pharmaceuticals. Basically, citronella grass and lemongrass essential oil can be obtained by various extraction methods, such as conventional solvent extraction, ultrasound-assisted extraction (UAE), steam distillation, hydrodistillation (HD), microwave-assisted hydrodistillation (MAHD), and supercritical fluid extraction (SFE) with CO2. SFE is considered as the most selected consumer and environmentally friendly essential oil extraction method because its traceless solvent in the product. The quality of the essential oil from aromatic grass strongly depends on the extraction method and operating conditions. However, the chemical composition of the essential oil of C. nardus and C. citratus also varies with the geographical origin, cultivation practices, plant age, photoperiod, harvest period, cultivars, and extraction methods. The chemical markers which have consistently been identified in the essential oil of aromatic grass are aldehydes, hydrocarbon terpenes, alcohols, ketones, and esters. This article presents the recent information on extraction methods of aromatic grass essential oil, chemical composition and its potential in industrial applications.

1. Introduction

Essential oils are plant extracts of various botanical sources, and do not have only origin from flowers, but from herbs, trees and various other parts of plant. It is predicted that more than 300,000 plant species grow in the world and approximately 10% of them can be categorized as essential oil-bearing plants. Therefore, they could be used as a source for essential oil production [1]. Essential oils present in various parts of plant, which are commonly leaves, flowers, seeds, barks and roots. For the plant, essential oils are believed to be important for the life of the plants due to the existence of specific compounds that help them against herbivores, insects and infections caused by fungi, bacteria and parasites. The Asian
continent with its multitude of climates emerges to be the world’s most important producer of essential oils. In fact, China and India provide a primary role, which subsequently followed by Indonesia, Sri Lanka, and Vietnam [1].

There are approximately 140 species aromatic grasses species belong to the genus *Cymbopogon* [3, 4]. Citronella grass (*Cymbopogon nardus*) and lemongrass (*Cymbopogon Citratus*), are long-thin leaves contual medicinal plants mainly cultivated commercially in many parts of tropical and subtropical areas of Asia, America and Africa [2]. The important citronella grass species include the *C. nardus* and *C. winterianus*, popularly known as Java citronella and Ceylon citronella have been long used in the traditional medicine and spices market for centuries [3–7]. Being very popular plants in those regions, depending on the specific uses, these plants also go by many names, such as fever grass, silky heads, barbed wire grass, and Hierba Luisa.

As one of the grass traditional medicinal plants, *C. nardus* belongs to *Panicodiae* family of *Graminales* [1]. Physically, *C. nardus* plant has green and purplish red stems, green to bluish green leaves, flat elongated leaves resembling reeds with adventitious and clumpy roots. If the leaves are squeezed, they release a strong pungent aroma [3]. Although *C. nardus* can grow at an altitude of 200–1000 m above sea level (ASL), it grows best on sandy soil with neutral pH at 350-600 m ASL, 18-25°C, 1,800–2,500 mm/year precipitation and whole year direct sun light exposure by which highest essential oil yield and quality. As another aromatic plant, *C. citratus* (lemongrass) is also a tall grass with densely tufted fibrous root, which develops rhizomes. Different with *C. nardus*, this plant possesses short underground stems with ringed segments and coarse- slightly leathery green leaves in dense clusters.

The plant is a native medicinal plant of India and is now widely cultivated in other tropical and subtropical countries of Asia, Africa and America continents. Lemongrass contains essential oil in its specific oil-bearing cells of the parenchyma tissues, mainly exist in the leaves and stalk [4]. Therefore, generally Lemongrass essential oil is primarily extracted from the leaves, which contain about 12% (w/w) of essential oil [5]. Lemongrass essential oil exhibits a sherry aroma, pungent taste, and lemon-like odor.

Considering the huge potential cultivation of *C. nardus* and *C. citratus*, this review presents the insight of feasible extraction methods and industrial applications of their essential oil for the effort of strengthening the economic value of these aromatic grass plants.

2. Chemical composition of citronella grass and lemongrass essential oils

The essential oil composition of aromatic grasses varies significantly at various harvesting stages [2]. If lemongrass was harvested 5.5 months after planting, 44 compounds accounting 98.64% of the essential oil components were observed. As lemongrass was harvested 6.5 month after planting, there were only 15 chemical constituents, which represent 98.62% of the essential oil. However, the geraniol content in lemongrass oil increased from 37.58% to 45.95% as the plant leaves were harvested at 5.5 and 6.5 months after planting. Prolong harvest time to 7.5 months after planting slightly decreased the essential oil content to 42.95%. According to Hanaa et al., the method of drying has a significant effect on the essential oil content of *C. citratus*. The highest essential oil content (2.45%) of lemongrass leaves was achieved if the leaves were dried in an oven at 45°C [6]. They also found lower essential oil yields (2.10% and 2.12%) of lemongrass leaves if the leaves were dried under sunshine and in shade yielded. Fortunately, no significant compositional difference between them was observed. Commonly, drying methods of lemongrass leaves have no tangible effect on the composition of main essential oil components (neral and geranial) [7].

2.1. Primary chemical compounds

The biochemical compounds present in the essential oil extracted from *C. nardus* and *C. citratus* leaves has been widely investigated using gas chromatography (GC) and gas chromatography- mass spectrophotometry (GC-MS) methods. Literature surveys demonstrated that the biochemical compounds vary and depend on the genetic differences, geographical origin, environmental conditions...
of the cultivation area, plant age, photoperiod, farming practices, harvest period, and the extraction methods. However, such unique compounds as hydrocarbon terpenes, ketones, alcohols, esters and certain aldehydes have always been identified. The major constituents of the essential oil of aromatic grasses, commonly known as citronella oil, are α-cadinene, α-pinene, Δ3-cubebene, Δ3-cadinene, α-pinene, β-caryophyllene are the main components of citronella grass essential oil [8]. Whereas, trans-citral (geranial), cis-citral (neral), myrcene, α-pinene, γ-cadinene, δ-cadinene, citronellol, and α-copaene are the principal components of lemongrass essential oil. Chanthai et al. reported that geraniol, trans-citral (geranial), cis-citral (neral), α-copaene, citronellol, γ-cadinene, δ-cadinene, eugenol and β-caryophyllene are the major constituents of lemongrass essential oil [8]. Whereas, trans-citral (geranial), cis-citral (neral), myrcene, α-pinene, γ-cadinene, δ-cadinene, citronellol, and α-copaene are the principal components of lemongrass essential oil. Chanthai et al. reported that geraniol, trans-citral (geranial), cis-citral (neral), α-copaene, citronellol, γ-cadinene, δ-cadinene, eugenol and β-caryophyllene are the major constituents of lemongrass essential oil [8]. Whereas, trans-citral (geranial), cis-citral (neral), myrcene, α-pinene, γ-cadinene, δ-cadinene, citronellol, and α-copaene are the principal components of lemongrass essential oil. Chanthai et al. reported that geraniol, trans-citral (geranial), cis-citral (neral), α-copaene, citronellol, γ-cadinene, δ-cadinene, eugenol and β-caryophyllene are the major constituents of lemongrass essential oil [8]. Verma et al. explained that the quality and quantity of lemongrass essential oil are strongly dependent on the age and time of plant harvest, because the composition and the content of the essential oil are strictly connected with the developmental stage of the whole plant, plant organs, and cells [10]. The use of fertilizer and the presence of rhizosphere fungi in the cultivation soil usually enhance the citral content of lemongrass [11]. In addition, they also reported that the harvesting methods usually only give little influence on the essential oil yield. Tajdin et al. observed that the proportion of young leaves to older leaves during harvesting determines the high citral content and finally affects the quality of the essential oil [2].

2.2. Secondary chemical compounds

Other chemical compounds which are often present in the lemongrass essential oil in less than 1 %, include α-thujene, citronellol, and α-copaene. On the other hand, limonene oxide, citronellol, germacrene-D and δ-cadinol are the minor constituents of citronella grass essential oil with less than 1% content [8]. The α-pinene, humulene and α-cubebeene present at higher content, which is about 1 – 2%. Chanthai et al. did not observe the presence of myrcene, α-thujene and cis-β-oicinene in citronella grass essential oil. They also reported the absence of α-pinene, eugenol, α-cubebeene, Germacrene-D, δ-cadinol, γ-cadinene, δ-cadinene and β-caryophyllene in lemongrass essential oil [8].

3. Common methods for extraction of citronella grass and lemongrass essential oils

Lemongrass essential oil can be obtained from various extraction methods, such as solvent extraction, ultrasound-assisted extraction (USAE), steam distillation (SD), hydrodistillation (HD), microwave-assisted hydrodistillation (MAHD), and supercritical fluid extraction (SFE) employing carbon dioxide (CO2). Because the quality of lemongrass essential oil is largely depending on its biochemical constituents, the extraction techniques have been proven to significantly influence the yield and quality of lemongrass essential oil [12-13]. In addition, extraction methods involving heating may trigger the occurrence of remarkable thermal degradations or hydrolysis of thermally sensitive constituents.

3.1. Solvent extraction

In a solvent extraction (SE) system, a hydrocarbon solvent (usually n-hexane, petroleum spirit, alcohol or their mixture) is mixed with the selected plant material to leach the essential oil out at a given temperature or boiling point of the solvent. After separating the solution from the plant matrices and concentrating the solution by distillation or evaporation, and leaving substance containing resin (resinoid) or a combination of wax and essential oil remains. Although this method is simple and adequately efficient to extract essential oil from lemongrass [14], it usually needs large quantity of
solvent and results in low yield reproducibility. In addition, contamination of the essential oil by residual solvent is inevitable.

Figure 1. Solvent extraction with Soxhlet apparatus [15-16].

Figure 2. Ultrasound assisted solvent extraction with Soxhlet apparatus [16]

Solvent extraction of essential oil from lemongrass usually employs Soxhlet apparatus (Figure 1) [15]. This apparatus facilitates continuous contact between plant material and refluxing liquid solvent, which leads to increase extraction efficiency. Unfortunately, it requires a long heating period at high temperature (usually near to the boiling point of the solvent) which may trigger the thermal degradation of thermally sensitive constituents. Solvent extraction either by maceration and Soxhlet extraction needs an appropriate solvent to achieve a high extraction yield and to avoid the loss of volatiles. Lately, Alhassan et al. had successfully extracted essential oil from dry and fresh lemongrass leaves using n-hexane as solvent, which achieved 1.85% and 4.5% oil yield, respectively [15]. The physicochemical properties of the essential oil are not altered because no constituent’s decomposition take place. This solvent extraction method can also be performed at high pressure.

3.2. Ultrasound-assisted extraction

As a response to the increasing of awareness reduce greenhouse gas emissions and energy costs, food and plant-based chemical industries are driven to look for new technologies that require low energy consumption, investment and operating cost, meet legal environmental requirements, possess excellent product/process safety and control to achieve high quality products [16]. In the last few decades, these drawbacks have strengthened the use of advanced and efficient extraction methods compatible to automation such as ultrasound-assisted extraction (UAE) (Figure 2). Shorter extraction times and lower organic solvent consumption, energy and total costs, were the main issues to be achieved. Motivated by these objectives, advances in ultrasound-assisted extraction have achieved numerous innovations to the more established Soxhlet extraction, Clevenger hydrodistillation, continuous packed bed extraction system, and some hybrids of ultrasound with other extraction methods such as microwave, extrusive, and supercritical fluid extractions.

Sonochemical effects of ultrasound in a liquid are attributed to the acoustic cavitation phenomena [17]. In the ultrasound field, acoustic cavitation generally refers to bubble formation, growth and implosion occurring during the propagation of an ultrasound wave in a liquid media [18]. The propagation of an ultrasound wave through an elastic medium induces a succession of compression and rarefaction phases, which results in a longitudinal displacement of those constitutive molecules. At a
sufficient high intensity of a sound wave, during a rarefaction phase the attraction forces between them might be exceeded, forming a cavity in the liquid as cavitation bubbles [19]. The cavitation bubbles can grow due to coalescence, and/or rectified diffusion [20] as the vapor or gas dissolved in the medium will enter the bubble during rarefaction phase and will not fully be removed during the compression cycle. When acoustic cavitation bubbles collapse near and onto the surface of a solid material and produces high-speed jets of liquids into the surface and creates shockwave damages [17]. These effects lead to fragmentation of friable materials and localized erosion, which finally improve the reactivity of the media and enhance mass transfer of solid particles due to tremendous particle size reduction.

High power ultrasonic probes are usually selected for extraction processes. The probes system provides higher power than the ultrasonic bath as a result of intensive delivery of ultrasonic wave through a smaller surface of the probe tip end). They are commonly operated at around 20 kHz and employ transducer bonded to the probe, which is immersed into the extraction chamber resulting in a direct delivery of ultrasound in the extraction media with lower loss of ultrasonic energy. Kimbaris et al. have conducted that the application of ultrasound for essential oil extraction from garlic and found significant reduction of the degradation of thermal-sensitive molecules, compared to HD [21]. Schaneberg & Khan also noted that ultrasound-assisted n-hexane extraction resulted in lemongrass essential oil with comparable main compounds composition to steam distillation [14]. Ultrasound intensity (power and frequency), shape and size of ultrasonic chamber, solvent and temperature are the main influential parameters of the ultrasound-assisted extraction of essential oil [16].

3.3. Steam distillation

Steam distillation (SD) has been regarded as the most common method applied for the extraction of the lemongrass essential oil, because it is simple and low investment cost [22]. In a steam distillation system (Figure 3), steam continuously flows through the fresh or dried plant material, which softens the oil-bearing cells of the parenchyma tissues and eases the essential oil to drift in the form of vapor. The essential oil containing steam is then cooled in a condenser and the condensate is collected. Although the steam temperature should be high enough to enable the vaporization of the essential oil, too high steam temperature may lead to the destruction the plant material and/or remarkable decomposition of important constituents of the essential oil. The continuous flow of the steam enables this extraction process to be performed at a temperature close to 100°C under atmospheric condition, which is considerably below the boiling point(s) of the individual constituent(s) of the essential oil that mostly higher than 200°C [23].

Aromatic grass plant materials can be distilled either as fresh or wilted. Wilting herbaceous materials prior to distillation process reduces the moisture content and leads to enhance the oil yield [5]. The yields of the essential oil achieved from steam distillation of lemongrass were reported to vary from 0.24% [24], 0.3% [25], 0.6% [26], to 0.71% [27]. Steam distillation remains being the most preferred method for the extraction of essential oil from lemongrass compared with other methods. Even, the newer extraction method, such as the promising sub and supercritical carbon dioxide extractions will not impend this simple distillation technique due to their high investment cost.

3.4. Hydrodistillation

In the hydrodistillation (HD) technique, the plant material is perfectly submerged in the boiling water with continuous supply of direct heat (Figure 4). As a result, the essential oil jointly distills with water molecules and then is sequestered after condensation. Similar to steam distillation, this method is also easy to operate and requires low investment cost. However, the process is very slow, which may cause serious degradation of some important compounds following hydrolysis or polymerization reactions of sensitive components with regard to long exposure time to heat. In general, the oil yield largely depends on many parameters such as the size, weight and the nature of the raw material and volume of water used. Generally, the HD of lemongrass essential oil is performed in a boiling flask with total reflux or Clevenger-type apparatus for a few hours following to the method suggested by Guenther [28].
There has been variation of the yields of the essential oil obtained from HD of lemongrass leaves and stalks. The yields were reported to range between 0.43% [29] to 1.80% [13]. Ajayi et al. noticed that the pH of the water used for essential oil extraction from lemongrass leaves using HD remarkably affect the essential oil composition [30]. They observed that the total yield of the volatile fractions obtained from HD and microwave-assisted hydrodistillation (MAHD) using neutral water were 0.73% and 0.64%, respectively. On the other hand, the total yield of the volatile fractions obtained from HD employing weakly acid and weakly basic water were reported to be 0.7% and 0.45%. The contents of citral in the essential oil obtained from HD, MAHD, acid-distillation and base-distillation were identified to be 72.6%, 44.7%, 30.07%, and 78.61%, respectively. In addition, considerable differences of major components (geranial, neral, myrcene) contents were also noticed. The chemical transformations of citral that was possibly occur in an acidic solution could be the cause of its low concentration [30]. The presence of aldehyde moiety in citral, which can react with hydroxyl group of other terpenoids in the existence of acid molecules to form acetals. Furthermore, other reactions, such as polymerisation, disproportionation, cyclisation, are also likely to happen. As a conclusion, basic distillation medium facilitates best environment for the extraction of lemongrass essential oil with a high citral content.

3.5. Microwave-assisted hydrodistillation

The working principle of microwave-assisted hydrodistillation (MAHD) is notably equal to conventional HD. However, MAHD employs microwaves to heat up the solvent (Figure 5). The boiling flask containing the solvent (usually water) and the plant material are introduced to a controllable microwave oven (commonly operated at 2.45 GHz). The utilization of microwaves power speeds up the essential oil extraction, which can be accomplished in a few minutes and leads to shorten the time required to achieve the same amount of extracts.

This method is very interesting for both laboratory and industrial scale applications due to its efficient heating, rapid energy and mass transfer rate, and being environmentally benign. The essential oil yields obtained from MAHD and HD methods were reported respectively to be 0.35% and 0.2% [31]. Therefore, this method also receives wide acceptance as a potential and promising alternative to conventional essential oil extraction techniques due to close similarity of the chemical composition of
the essential oils obtained. The MAHD also exhibited its superiority over the conventional HD on the composition of major components (geranial, neral, myrcene) of the essential [12]. They reported that MAHD method resulted essential oil with citral content of 93.28%, while citral content of essential oil obtained from HD was 83.85%.

3.6. Supercritical fluid extraction

Over the last few decades, the augmenting requirement for premium quality natural products has supported to the establishment of more environmentally benign method of essential oils extraction, which is supercritical fluid extraction (SFE) [32]. The basic SFE unit comprises high-pressure pump, water bath heater or oven, extraction vessel, microfilter, ball valves, back pressure regulator, cold trap, volumetric gas quantifier, and vent (Figure 6). When cosolvent is required, another high-pressure pump and mixer should be added to the basic SFE unit. This method can be considered as a promising alternative to solvent extraction of valuable components for pharmaceutical and food applications from various botanical matrices without any harmful traces of solvent [33]. The solvation properties of supercritical fluid can be altered through the adjustment of temperature and pressure, which initially changes its density and subsequently allows selective extraction. Carbon dioxide is most common utilized supercritical fluid due to its excellent physicochemical properties, mainly related to its relatively low critical temperature and pressure (23 – 50°C and 8 – 12 MPa, respectively) [34]. Being a generally recognized as safe (GRAS) status by Food and Drug Administration of the United States, CO2 is a non-toxic, non-corrosive, non-flammable, and inexpensive gas. It has GRAS status [32].

![Supercritical fluid extraction apparatus.](image)

Al-Marzouqi et al observed that the essential oils extracted from herbaceous matrices using SFE are of a much better quality than those obtained using SE or SD and HD [35]. SFE with CO2 can be carried out at temperatures about 30°C, thereby taking care of the pristine composition and properties of the essential oil. Unfortunately, the high investment cost of the equipment is reported to be one of the main limitations of this method, which restricts its application for exceptionally special industries where high quality and purity of the end products are of the utmost priority. Hitherto, only few reports can be obtained in literature on extraction of lemongrass essential oil with supercritical CO2. Generally, the studies are targeted to optimize the extraction process through the adjustment of temperature and pressure, flow rate of the solvent, solvent mixture composition and raw material’s particle size. Carlson et al. performed supercritical CO2 extraction of fresh lemongrass leaves under different temperature and pressure conditions; and found that the composition of the essential oil significantly affected by temperature and pressure [34]. The highest yields and extraction rates were examined at 9 MPa & 23°C and 12 MPa & 40°C, which were 1.7% and 1.51%, respectively. The major components present in the essential oil obtained from all the studied conditions were neral and geranial, which ranged from 26.7% to 31.9% and from 44.6% to 53.0%, respectively. Marongiu et al. also investigated the influence of pressure (9, 10, 11 and 12 MPa) on the supercritical extraction of lemongrass at 50°C for 360 min to
maximize citral content in the extracted essential oil [29]. They determined the highest yield (0.65%) and the highest citral content in the essential oil (68%) at 9 MPa, while HD allowed achieving process yield of 0.43% and citral content of 73%. The visual appearance of the essential oil changed at higher solvent density; the color altered from yellow to yellowish semi-solid products due to the co-extraction of higher molecular mass components. Wu et al. predicted the optimum operational parameters of the supercritical CO2 extraction of lemongrass essential oil using response surface methodology [12]. They found that SCCO2 extraction at 25 MPa, 35°C, CO2 flow rate 18 (L/h) for 120 min resulted in 4.4% yield. The main components (geraniol and neral) of the essential oil obtained from the SFE were higher than those of HD. However, the geraniol content in the essential oil obtained from SFE was lower than that of HD. Although, the experiments were conducted for various species of lemongrass, it was proven that the SF did not alter the main components of the essential oil.

Most recently, Yen and Lin develop a greener technique for the extraction of essential oil from lemongrass using solar energy. Surprisingly, the yield of essential oil obtained from this technique (1.28%) was very close with that obtained from HD (1.3 %) [36]. In addition, the essential oil obtained from this method also exhibited a higher antioxidant activity than that extracted from HD. Therefore, this new technique offers high potential application as future’s sustainable green extraction method.

4. Industrial applications of citronella grass and lemongrass essential oils

As a result of back to nature concept in the recent decades, the use of plants extracts has gained steady increase of attention from customers leading to a promising commercial market, which comprises perfumery, pharmaceuticals, cosmetics, and food applications, mainly due to their beneficial active substances [1]. For millennium, lemongrass (C. citratus) essential oil has been used as traditional folk medicine in the treatment of nervous, gastrointestinal disturbances (common stomach ache, digestive problems and diarrhea), fevers and hypertension. In addition, lemongrass essential oil is also used an important folk remedy for cough, flu, consumption, gingivitis, headache, ophthalmia, leprosy, elephantiasis, malaria, pneumonia and other vascular disorders. Lemongrass essential oil has been regarded as carminative, powerful insect repellent herbicides and food preservative [37]. Studies the on extract from C. citratus leaves have demonstrated to be anti-inflammatory, vasorelaxing, diuretic and effective remedy in treating ringworm as local application [38]. The essential oil from C. citratus leaves may become highly attractive to the pharmaceutical industry, as most recent research has demonstrated that citral exhibits selective toxicity for specific cancer cells [39]. Therefore, quality of this essential oil is judged by the amount of citral present in the oil [40-41]. Essential oil, isolated from the leaves of lemongrass, possesses a wide range of biological activities like antimicrobial, antifungal, anticancer, and antioxidant properties [41].

Citronella grass (C. nardus) leaf and stalk are popularly used in domestic and professional cooking as well as for the preparation of functional tea for its unique flavor. Citronella grass essential oil is widely used in the food, drink, perfumery, soap, body and healthcare products and pharmaceutical products [42]. It is also applied in the treatment of orthopedics, muscular and skin problems [10]. Recent scientific studies have proven that citronella grass exhibited several biological activities, such as antiviral, antibacterial and insect repellent [43]. The Chinese also utilize the essential oil of citronella grass leaves more specifically for the treatment of rheumatism, fever, intestinal parasites, digestive and menstrual problems. The essential oil of citronella grass leaves has been effectively employed as a diaphoretic, stimulant, and promoter of internal detoxification by encouraging sweating [44]. In Thailand, the infusion of citronella grass essential oil has been functioned in folk medicine as a blood tonic and diuretic, and to cure flatulence, stomach ache, gastritis, intestinal cramps, irritable bowel, and indigestion [9]. However, only very few reports are available on the analgesic effect and African comparative study of chemical compounds of essential oil of this plant. Commercially, citronella oil is isolated to obtain three important constituents, namely citronellal, citronellol, and geraniol, which are popularly used for their antiseptic properties and perfumes and fragrances [45].
5. Conclusion
There is a steady increase of public interest in the application of the essential oil of aromatic grasses (*C. nardus* and *C. citratus*) in the food and pharmaceutical fields. The oil contains various phytochemicals such as terpenes, terpenoids, alcohol, esters, and phenolic compounds, which correspond to numerous biological activities, such as antibacterial, anticancer, antifungal, insecticide, etc. A lot of studies have performed to develop efficient methods for aromatic grass essential oil extraction and purification, and assuring its quality with reasonable price. Prior to commercial scale applications, techno-economic studies have to be accomplished to ensure the feasibility of the extraction methods and utilisations of the essential oil. In general, aromatic grass essential oil can be considered as a valuable botanical product that potentially attract the existing and future aromatic grass growers and users.

Acknowledgement
The authors greatly acknowledge the Faculty of Engineering - Universitas Diponegoro, Indonesia for its partial financial support through Annual Activity and Budget Plans (RKAT) 2020 under Strategic Research Grant 2020.

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