

## Lemongrass (*Cymbopogon citratus*) Essential Oil: Extraction, Composition, Bioactivity and Uses for Food Preservation – a Review

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Lemongrass essential oil comes from the lemongrass plant (*Cymbopogon citratus*), which grows mainly in tropical and subtropical parts of the world. The prefix 'lemon' indicates its typical lemon-like odour, which is caused mainly by the presence of citral. Citral is a combination of two stereoisomeric monoterpene aldehydes; the *trans* isomer geranial is in predominance to the *cis* isomer neral. Lemongrass essential oil has been used since ancient times in folk medicine as a remedy to improve circulation, stabilise menstrual cycles, promote digestion or increase immunity. It is also used to produce perfumes, flavours, detergents, and pharmaceuticals. The method found to be the most suitable for the extraction of lemongrass essential oil is steam distillation, since it allows obtaining the oil without altering product quality. The chemical composition of the essential oil of *C. citratus* varies according to the geographical origin, farming practices, plant age, photoperiod, harvest period, genetic differences, and extraction methods. The chemical constituents of the essential oil which have constantly been detected and determine its biological activity are aldehydes, hydrocarbon terpenes, alcohols, ketones, and esters. The lemongrass essential oil shows a wide spectrum of biological activities. High antibacterial and remarkable antifungal activities make the lemongrass oil a potential food preservative. This paper reviews recent information on extraction methods of lemongrass essential oil, its chemical composition depending on the origin of the plant, bioactivity of the oil constituents as well as potential application as a food preservative.

### ABBREVIATIONS

ADI: acceptable daily intake; BHT: butylated hydroxytoluene; DPPH: 2,2-diphenyl-1-picrylhydrazyl; GAE: gallic acid equivalents; GC: gas chromatography; GC/MS: gas chromatography coupled with mass spectrometer; HD: hydrodistillation; MAHD: microwave-assisted hydrodistillation; MIC: minimum inhibitory concentration; and SFE: supercritical fluid extraction

### INTRODUCTION

In recent years, the quality and safety of food has gained a great concern among consumers, who increasingly search for healthier, nutritious, and safer food products. This tendency is reflected in research on advanced technologies for better preservation of food during production, storage and transport. For this reason, new alternatives from natural sources have been investigated such as the use of essential oils. The essential oil from *Cymbopogon citratus* leaves is one of the essential oils extensively studied in terms of its application as a food preservative.

*C. citratus* – commonly known as lemongrass – belongs to the *Poaceae* family which counts more than 635 gen-

era and 9000 species. This herb plant is widely distributed around the world. There are more than 140 cultivated species only for the *Cymbopogon*, 52 of them grow in Africa, 45 in India, 6 in Australia, 6 in South America, 4 in Europe (only in Montenegro), 2 in North America, and the others in South Asia. *Cymbopogon flexuosus* and *Cymbopogon citratus* represent the two major species vastly cultivated for their essential oils in different regions of the world. *C. citratus* is known by numerous international common names, such as West Indian lemon grass or lemon grass (English), citronelle or verveine des indes (French), hierba limon or zacate de limón (Spanish), xiang mao (Chinese), capim-cidrao or capim-santo (Portuguese), and locally there are identified more than 28 indigenous names from different countries of the world. The genus *Cymbopogon* has been reviewed comprehensively in several articles [Avoseh *et al.*, 2015; Haque *et al.*, 2018].

*C. citratus* is an aromatic, evergreen, clump-forming, perennial grass producing numerous stiff stems arising from a short rhizomatous rootstock, and growing around 1.5 m tall. It rarely produces flowers. The leaves are blue-green in colour, flat, erect, linear in shape and give off a characteristic lemon flavour when they are crushed. *C. citratus* is considered to have its origin in Malaysia, nowadays it is widely cultivated in the Central and South America and parts of Africa, Southeast Asia, and the Indian Ocean Islands, both on a commercial scale and in gardens – especially in the South-

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east Asia [Skaria *et al.*, 2012]. Lemongrass is used as a food flavouring, and can be dried and powdered, or used fresh. It is commonly used in teas, soups, and curries, it may also be served with poultry, fish, beef, and seafood. Many studies have confirmed that infusion of lemongrass leaves and other parts is highly effective in combatting various stomach infections, prevents ulcers, stimulates digestion and excretion, and is beneficial for treating nausea, stomach aches, and constipation [Carbajal *et al.*, 1989; Leite *et al.*, 1986]. Therefore, in many countries lemongrass is used as a medicinal herb [Avoseh *et al.*, 2015]. In Egypt, a hot water extract of the dried leaves is taken orally as a diuretic and renal antispasmodic. In Indonesia and Malaysia, a hot water extract of the whole plant is administered orally to stimulate blood flow in the pelvic area and uterus. The Brazilians prepare a tea from the leaves of lemongrass and use it for its antispasmodic, anti-inflammatory, and analgesic effects. In Thailand, a decoction of the dried entire plant is taken orally as a remedy for stomach ache and a hot extract of dried roots is recommended for diabetes. Health benefits of lemongrass plant were reviewed comprehensively by Tapsell *et al.* [2006]. The biological activity of lemongrass is due to the presence of the essential oil and phenolic compounds including phenolic acids, flavonoids, and tannins [Olorunisola *et al.*, 2014; Roriz *et al.*, 2014; Tavares *et al.*, 2015]. From the nutritional point of view, lemongrass is a rich source of essential vitamins, such as: vitamin A, vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B3 (niacin), vitamin B5 (pantothenic acid), vitamin B6 (pyridoxine), vitamin C and folate, along with being a host of important minerals like calcium, potassium, phosphorous, magnesium, copper, iron, and zinc [USDA National Nutrient Data Base, 2019].

Commercially, *C. citratus* is cultivated mostly for its essential oil which is biosynthesised mainly in leaves of the plant [d'Avila *et al.*, 2016]. Lemongrass essential oil is of a considerable commercial importance because it is used in the manufacture of fragrances, flavours, perfumery, cosmetics, detergents, and pharmaceuticals. According to the Food and Drug Administration [21 CFR § 182.20, 2018], lemongrass essential oil is generally recognized as safe (GRAS) and may be used as a food additive replacing the synthetic ones. As a culinary flavouring lemongrass essential oil is added to alcoholic and non-alcoholic beverages, frozen dairy desserts, candy baked foods, gelatins and puddings, meat and meat products as well as fats and oils. It improves the flavour of some fish, wines, and sauces. Biological research has shown that various chemical compounds of lemongrass essential oil exhibit antimicrobial [Bassolé *et al.*, 2011], antioxidant [Mansour *et al.*, 2015], antiparasitic [Kpoviesi *et al.*, 2014], insecticidal, and insect repellent activities [Brugger *et al.*, 2019]. Owing to its antimicrobial and antioxidant properties, it can be exploited in food preservation as an alternative to synthetic compounds which are recently less acceptable by consumers [Ekpenyong & Akpan, 2017].

This review article provides information on recent advances in the extraction methods of lemongrass essential oil, its composition, biological activity as well as its potential application for food preservation. The literature was carefully viewed in search for *C. citratus* essential oil data only.

## EXTRACTION OF LEMONGRASS ESSENTIAL OIL

Lemongrass essential oil may be extracted by many different methods like solvent extraction, steam distillation, hydrodistillation (HD), microwave-assisted hydrodistillation (MAHD), and supercritical fluid extraction (SFE) with CO<sub>2</sub>. A number of studies have proved that the quality of essential oils depends mainly on its constituents, which is significantly influenced by the extraction techniques [Desai & Parikh, 2015; Schaneberg & Khan, 2002; Wu *et al.*, 2019]. Moreover, methods involving heating may induce thermal degradation or hydrolysis of fragile constituents.

In solvent extraction, a hydrocarbon solvent (usually *n*-hexane) is added to the plant material in order to dissolve the essential oil. After filtering the solution and concentrating by distillation, a substance containing resin (resinoid) or a combination of wax and essential oil remains. The method is quite efficient for lemongrass essential oil extraction [Schaneberg & Khan, 2002] and relatively simple but generally requires high volumes of the solvent and sometimes yields unsatisfactory reproducibility. After the extraction operation, the sample is concentrated by evaporation, during which volatiles may be reduced. Moreover, contamination of the essential oil with solvent residues may occur. The Soxhlet apparatus is sometimes used to solvent extraction of lemongrass essential oil [Alhassan *et al.* 2018]. In Soxhlet extraction, plant material has a continuous contact with refluxing liquid phase, which results in increased extraction efficiency. When compared to the other conventional methods, the most significant drawback of Soxhlet extraction is long heating period at high temperature (usually close to the boiling point of the solvent) which may lead to thermal degradation of fragile compounds. Both solvent extraction by maceration and Soxhlet extraction require the correct choice of the solvent to obtain a good extraction yield as well as to prevent the loss of volatiles. In recent years, the lemongrass essential oil was successfully extracted from dry and fresh lemongrass leaves using solvent extraction by Suryawanshi *et al.* [2016] and Alhassan *et al.* [2018]. The oil yield obtained by Suryawanshi group was 1.85% and that achieved by Alhassan group was 4.5%. In both experiments, *n*-hexane was used as a solvent. In turn, Schaneberg & Khan [2002] reported that sonication-assisted *n*-hexane extraction allowed obtaining lemongrass essential oil with comparable contents of the main compounds to steam distillation.

Currently, the most popular method for the extraction of the lemongrass essential oil is steam distillation. It is mainly used for temperature-sensitive materials like oils, resins, hydrocarbons, *etc.* which are insoluble in water and may decompose at their boiling point. It is often used to extract other essential oils as well [Fernandes *et al.*, 2019]. In this method, steam passes through the dried or fresh plant material which softens the cells and enables the essential oil to escape in vapour form. The temperature of the steam should be high enough so that the oil could vapourize, but not so high that it damages the plant material or burns the essential oils. The released essential oil, together with steam molecules, is subsequently cooled in a condenser and collected. This process enables conducting extraction process below

the boiling point(s) of the individual component(s). Essential oils consist of chemical compounds which boiling points often exceed 200°C [Berk, 2013]. In the presence of steam, these substances may be extracted at a temperature close to 100°C, at atmospheric pressure. The basic advantage of steam distillation is simplicity, and low costs of the apparatus. The properties of the essential oil are not changed since its constituents never decompose. This technique can also be used under pressure. Lemongrass plant may be distilled fresh or after wilting. Wilting herbage before the distillation process decreases the moisture content and increases oil yield [Skaria *et al.*, 2012]. The yields of the essential oil obtained with this method reported in the literature differ substantially, ranging from 0.24% [Anggraeni *et al.*, 2018], 0.3% [Santin *et al.*, 2009], 0.6% [Boukhatem *et al.*, 2014a], to 0.71% [Kpoviessi *et al.*, 2014]. Steam distillation is still a leading preparative technique for the extraction of lemongrass oil. A newer methodology, such as subcritical carbon dioxide extraction, although promising but expensive, has not really threatened to surpass this simple type of distillation.

In the HD technique, the plant material is totally submerged in water, which is boiled by applying direct heat. Essential oil distills together with water molecules and then is separated after condensation. The method is relatively easy and does not involve high expenses associated with the setup. The process is very slow, which may result in the degradation of some compounds in hydrolysis or polymerisation reactions of sensitive constituents due to extended heat exposure. The yield depends on various parameters such as size and weight of raw material, the nature of the herb or volume of water. A typical HD of lemongrass is conducted in a Clevenger-type apparatus for 3 h, according to the method recommended by Guenther in 1950 [Guenther, 1950]. In recent reports, the yields of the essential oil obtained *via* HD range between 0.43% [Marongiu *et al.*, 2006] and 1.80% [Desai & Parikh, 2015]. Ajayi *et al.* [2016] proved that essential oil extraction from lemongrass leaves by HD, using not only neutral but weakly acidic and basic medium, significantly affected essential oil composition. The total yield of the volatile fractions was 0.73% for HD, 0.64% for MAHD, 0.7% for acid-distillation, and 0.45% for base-distillation. The main component in the obtained essential oil was citral with the content of 72.6% for HD, 44.7% for MAHD, 30.07% for acid-distillation, and 78.61% for base-distillation. Significant differences in contents of major components (geranial, neral, myrcene) were observed as well. The low concentration of citral in the essential oil distilled in acid conditions was a result of chemical transformations of this compound that may take place in an acidic solution [Ajayi *et al.*, 2016]. Citral contains an aldehyde moiety which can react with hydroxyl group of other terpenoids in the presence of acid molecules forming acetals. Other reactions such as polymerisation, disproportionation, cyclisation, are also likely. Basic medium provides the best environment for the extraction of lemongrass essential oil with a high citral content.

MAHD works basically the same as traditional HD, but the heating of the solvent is achieved by using microwaves. The flask containing the solvent (generally water) and the parts of the plant are placed inside a microwave oven

(usually operating at 2.45 GHz). The use of microwaves for the heating process accelerates the extraction of oil, which can be completed in a matter of minutes, which consequently shortens time needed to obtain similar quantities of extracts. This method is very attractive to use in laboratories as well as industry due to its effective heating, fast energy transfer, and being environmentally friendly. Its acceptance as a potential and powerful alternative to conventional extraction techniques of lemongrass oil has been verified [Desai & Parikh, 2015]. The chemical composition of the essential oils obtained with traditional HD and by MAHD does not differ substantially [Desai & Parikh, 2015]. Significant differences may, however, be observed in contents of major components (geranial, neral, myrcene) [Desai & Parikh, 2015]. The yields of MAHD and HD methods reported by Tran *et al.* [2019] were 0.35% and 0.2%, respectively, the MAHD method produced oil with 93.28% while HD 83.85% with citral content.

Over the last decades, the increasing demand for high quality natural products has contributed to the development of more environmentally friendly technique of essential oils isolation, namely supercritical fluid extraction (SFE). SFE can be regarded as an alternative to the solvent extraction of various compounds from natural solid matrices without any trace of the solvent [Haloui & Meniai, 2017]. The properties of the supercritical fluid can be modified by adjusting the critical temperature and pressure, which influences the density of the solvent allowing for selective extraction. This is particularly important for pharmaceutical and food systems. Carbon dioxide is used in most cases as the supercritical fluid due to its chemical and physical properties and to its relatively low critical temperature and pressure values (31–32°C and 7.38–7.39 MPa, respectively) [Carlson *et al.*, 2001]. As a natural constituent of many foods, it is a non-toxic, non-corrosive, non-flammable, and inexpensive gas. It has GRAS status [21 CFR § 184.1240, 2019]. Essential oils obtained by means of this technique are of a much better quality than those obtained using solvent extraction or steam distillation and HD [Al-Marzouqi *et al.*, 2007]. SFE with carbon dioxide can be performed at temperatures around 30°C, thereby preserving original oil composition and properties. However, the cost of the equipment is one of the main disadvantages of this method, which restrains its use for extremely sensitive industrial sectors where high quality and purity of the final products are of the outmost priority. When it comes to the extraction of lemongrass essential oil with supercritical carbon dioxide, only few reports can be found in literature. Usually, the experiments are aimed at the optimisation of temperature and pressure of the extraction process. Carlson *et al.* [2001] performed supercritical CO<sub>2</sub> extraction of fresh lemongrass leaves under different temperature and pressure conditions. They found that the composition of the essential oil significantly depended on changes in temperature and pressure parameters. The largest yields and extraction rates were determined under the conditions of 9 MPa and 23°C and 12 MPa and 40°C, *i.e.* 1.7% and 1.51%, respectively. The compounds recorded in larger quantities in the essential oil for all the pressure and temperature conditions applied were neral and geranial which contents ranged from 26.7% to 31.9% and from 44.6% to 53.0%, respectively. Marongiu *et al.*

[2006] also analysed the influence of pressure on the supercritical extraction of lemongrass oil. A series of experiments were carried out, for 360 min, at 50°C and at different pressures: 9, 10, 11 and 12 MPa. Extraction conditions were selected so as to maximise citral content in the extracted oil. The collected extracts composition was compared with that of the essential oil isolated with HD and steam distillation. 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 appearance of the extract was changing at higher solvent density, passing from a characteristic yellow oil to yellowish semi-solid products due to the extraction of high molecular mass compounds. Using the response surface methodology, Wu *et al.* [2019] predicted the optimum operational parameters of the supercritical CO<sub>2</sub> extraction of lemongrass (*C. citronella*) essential oil. Under these conditions (extraction time 120 min, pressure 25 MPa, temperature 35°C, CO<sub>2</sub> flow rate 18L/h), they conducted SFE extraction with the yield of 4.4% and compared their results with these obtained using HD. The main components of the essential oil extracted with SFE and HD were geranial (20.02% for SFE and 15.12% for HD), geraniol (10.22% for SFE and 25.45% for HD), and neral (15.11 for SFE and 11.15 for HD). Although, the experiment was carried out for different species of lemongrass, it was proved that the supercritical fluid did not alter the main effective components in lemongrass essential oil.

A greener approach to the extraction of lemongrass essential oil was proposed by Yen & Lin [2017] who utilised solar energy for the extraction process. The yield of the solar energy extraction (1.28%) was comparable with the yield of the essential oil obtained with HD (1.3 %) but the essential oil extracted by solar energy showed a higher antioxidant activity than that obtained with HD. This new technique may hold promise as a potent completely sustainable green extraction method in future.

#### COMPOSITION OF LEMONGRASS ESSENTIAL OIL

Lemongrass essential oil is mainly produced by leaves which contain about 1–2% of essential oil in a dry matter [Skaria *et al.*, 2012]. The essential oil is accumulated by plant in specific oil cells of the parenchyma tissues [Ganjewala & Luthra 2010]. The characteristic feature of lemongrass essential oil is a sherry colour, pungent taste, and lemon like odour. The chemical composition of the essential oil obtained from leaves of *C. citratus* has been extensively studied using GC and GC/MS methods. It varies according to the geographical origin, geobotanical conditions of the environment, farming practices, plant age, photoperiod, harvest period, genetic differences, and the extraction methods. Despite these differences, such compounds as hydrocarbon terpenes, alcohols, ketones, esters and mainly aldehydes have always been detected (Table 1).

The main component of lemongrass essential oil is citral. It is a mixture of two geometric isomers. The *E*-isomer is known as geranial or citral A and the *Z*-isomer is known as neral or citral B. Geranial (0.99–48.14%) dominates over neral (0–38.32%) as shown in Tables 1 and 2. The quality

of lemongrass essential oil is generally evaluated by its citral content. According to literature data, lemongrass oil should contain at least 75% of citral, in order for *C. citratus* essential oil to be considered as a product of high quality [Barbosa *et al.*, 2008]. Quality and quantity of lemongrass essential oil are highly dependent on the 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 [Verma *et al.*, 2015]. The harvesting methods usually have little effect on the essential oil yield. The increase in citral content of lemongrass may be influenced by fertilizer application or rhizosphere fungi present in the soil [Shaikh *et al.*, 2019]. The proportion of young leaves to older leaves during harvesting determines the high citral content and subsequently the quality of the essential oil [Tajidin *et al.*, 2012].

Another chemical compound which is often present in the lemongrass essential oil is myrcene. Its percentage content greatly varies and ranges from 0.8% in the essential oil obtained in Egypt [Mansour *et al.*, 2015] to 25% in oils obtained in Brazil [Farias *et al.*, 2019] and Nigeria [Kasali *et al.*, 2001]. Such great differences in myrcene content in the essential oil are strictly connected with the geographical region of the world (Table 2).

Besides citral and myrcene, geraniol, citronellal, and limonene are usually detected in amounts higher than 1% in some samples. The essential oil obtained with HD from Nigerian plants was found to be rich in limonene (7.90%), whereas the essential oil obtained with the same method from lemongrass from Kenya was lacking this terpene (Table 1). The amount of citronellal in the essential oil is very diverse: from 0.12% to 12.77% (Table 1). As for alcohols identified in the essential oils of *C. citratus*, geraniol was by far the most frequently found one (1.34% to 21.86%). Ester which was identified in significant amounts was geranyl acetate (0.24% to 3.42%). Terpenes which are most frequently detected, besides myrcene and limonene, are  $\alpha$ -pinene (0.01–2.12%),  $\beta$ -pinene (0.3–6.00%),  $\beta$ -caryophyllene (0.1–2.46%),  $\beta$ -ocimene (0.15–0.3%), and  $\alpha$ -copaene (1.13–1.29%). Other minor constituents found in the essential oil are:  $\beta$ -citronellol, globulol, linalool, hinesol, borneol, isopulegol, *trans*-verbenol, *cis*-verbenol, nerol, *trans*-farnesol, 3-methylcyclohexanol,  $\gamma$ -eucalyptol, carotol,  $\alpha$ -cardinol, cubenol, terpinen-4-ol, citronellyl acetate, citronellyl isobutyrate, piperitone, (+)-carvotanacetone, lauraldehyde, 2-undecanone,  $\alpha$ -cubebene,  $\alpha$ -muurolene,  $\gamma$ -muurolene, and  $\beta$ -guaiene. Table 1 summarises the components found in the essential oil of *C. citratus* obtained with various extraction methods in different regions of the world.

The chemical composition of *C. citratus* essential oil is strictly correlated with the geographical origin. Analysis of the essential oils from *C. citratus* species from Brazil, Asia, West and Eastern Africa showed high contents of neral and geranial chemotypes (Table 2). In turn, the essential oil from *C. citratus* of African origin was found to contain a high amount of myrcene, whereas the essential oil from the Ethiopian lemongrass contained geraniol (40%) as its main compound, followed by citral (13%) and  $\alpha$ -oxobisabolene (12%) [Ekpenyong *et al.*, 2014]. The major components identified in the Egyptian essential oil were geranial (20.90–40.72%),

neral (16.20–34.98%), geraniol (8.30%), and linalool (5.60%) [Hanaa *et al.*, 2012; Mansour *et al.*, 2015], whereas considerable amounts of geraniol (37.80%) and neral (33.60%) were found in Saudi Arabia sample [Mansour *et al.*, 2015]. The essential oil obtained from the lemongrass cultivated in Nigeria was poor in citral (0.99%), but rich in geraniol (21.86%), limonene (7.90%), and camphene (7.89%) [Moutassem *et al.*, 2019]. Geraniol and neral, limonene, citronellal, myrcene, and geraniol were identified as marker compounds in lemongrass essential oil [Schaneberg & Khan, 2002]. Marker compounds refer to chemical constituents within a medicinal plant that can be used to verify its potency or identity. As shown in Table 1, limonene, citronellal, and geraniol are not always found. Even geraniol and neral are not detected in essential oils obtained from *C. citratus* of different chemotypes [Moutassem *et al.*, 2019].

According to the research conducted by Hanaa *et al.* [2012], the method of drying has a significant effect on the essential oil content of *C. citratus*. The highest essential oil content (2.45%) was determined by these authors in the oil extracted from lemongrass leaves dried in an oven at 45°C. Whereas, lemongrass leaves dried in sunshine and in shade yielded the oil at percentages of 2.10% and 2.12%, respectively, without significant difference between them. Geraniol (31.53%, 37.24%, and 39.86%), neral (30.08%, 31.28%, and 34.52%), and myrcene (16.61%, 15.42%, and 14.49%) were the major components of the essential oils extracted from lemongrass leaves dried by sun, in an oven or in shade, respectively. Generally, drying methods of lemongrass leaves have no tangible effect on the composition of main essential oil components (neral and geraniol) [Kumar *et al.*, 2015].

The essential oil composition of lemongrass differs significantly at various harvesting stages [Tajidin *et al.*, 2012]. When lemongrass was harvested 5.5 months after planting, 44 compounds representing 98.64% of the essential oil were found. In the essential oil obtained from lemongrass harvested 6.5 month after planting, there were only 15 chemical compounds, representing 98.62% of the essential oil. However, at 7.5 months after planting, 50 chemical compounds were analysed accounting for 97.2% of the essential oil. Only 13 compounds were always present at each maturity stage, out of which only 7 compounds had concentrations greater than 1% (neral, geraniol, myrcene, 3-undecyne, nerol, geranyl acetate, and juniper camphor). Geraniol content in lemongrass oil increased when the lemongrass was harvested at 5.5 (37.58%) to 6.5 (45.95%) months after planting. When the plants were harvested at 7.5 months after planting its content decreased slightly to 42.95%.

#### BIOLOGICAL ACTIVITY OF LEMONGRASS ESSENTIAL OIL

Bioactivity of lemongrass has been extensively studied, including especially its antibacterial [Naik *et al.*, 2010; Falcao *et al.*, 2012], antioxidant [Anggraeni *et al.*, 2018], antifungal [Sharma *et al.*, 2017], insecticidal [Brugger *et al.*, 2019], larvicidal [Soonwera *et al.*, 2016], and insect repellent activities [Diabate *et al.*, 2019]. Biological activity of essential oils de-

pends on their chemical composition, which can vary dramatically, even within the same species, and also on interactions among their structural components. Even minor essential oil constituents are indispensable and participate in biological functions of the oil due to the synergistic interactions.

#### Antimicrobial activity

Antibacterial properties of lemongrass essential oil depend on the presence of three main components: geraniol, neral, and myrcene [Onawunmi *et al.*, 1984]. Geraniol and neral individually elicit antibacterial action on Gram-negative and Gram-positive organisms, while myrcene, does not show observable antibacterial activity on its own. However, myrcene was observed to generate enhanced bioactivity when it was mixed with either geraniol or neral or both. Naik *et al.* [2010] investigated the effectiveness of lemongrass essential oil against the selected pathogenic bacteria: *Staphylococcus aureus*, *Bacillus subtilis*, *Bacillus cereus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa* using agar diffusion method and broth dilution method. In general, Gram-positive bacteria were found to be more sensitive to the oil than the Gram-negative ones, which confirmed findings reported earlier by Onawunmi *et al.* [1984]. *P. aeruginosa* turned out to be resistant at all the concentrations of lemongrass oil including undiluted solution. *S. aureus* and *B. cereus* were more sensitive to lemongrass essential oil and were inhibited at 0.03% concentration. *B. subtilis* and *E. coli* were inhibited by the oil at a concentration of 0.06%, whereas *K. pneumoniae* at 0.25%. Moreover, the tested microorganisms, particularly the Gram-negative bacteria, turned out to be more susceptible to lemongrass oil than standard antibiotics. Similar results were reported by Premathilake *et al.* [2018] who investigated such pathogenic bacterial strains as *E. coli*, *B. cereus*, and *S. aureus*. Gram-positive bacterial strains were more sensitive to essential oil of *C. citratus* at all of its concentrations than the Gram-negative strain *E. coli*. Lemongrass essential oil was found to significantly inhibit the growth of such pathogenic foodborne bacteria as *Listeria monocytogenes* and *Salmonella* Typhimurium [Reis-Teixeira *et al.*, 2019; Mith *et al.*, 2014]. Food spoilage bacteria (*Brochothrix thermosphacta* and *Pseudomonas fluorescens*) were also sensitive to lemongrass essential oil [Mith *et al.*, 2014]. The antibacterial activity of lemongrass essential oil is due to an interaction between the main oil constituents and the bacterial cell membrane. The lipophilic terpenes can modify the fluidity and permeability of the cell membrane or change intracellular pH and ATP concentrations, which results in cell rupture [Shi *et al.*, 2016]. Nikaido [2003] suggested that the higher resistance of Gram-negative bacteria to essential oils is due to the structure of the outer membrane which protects the bacterial cell against extrinsic chemical agents. The outer membrane is one of the main factors contributing to the resistance of Gram-negative bacteria to hydrophobic antibiotics. However, several studies indicate that lemongrass essential oil can successfully inhibit the growth of numerous multidrug-resistant Gram-negative bacterial strains such as *P. aeruginosa*, *E. coli*, *Enterobacter cloacae*, *Morganella morganii*, *Proteus mirabilis* or *Burkholderia cepacia* [Bučková *et al.*, 2018; Vasireddy *et al.*, 2018].

TABLE 1. Composition (%) of selected *Cymbopogon citratus* essential oils obtained by different methods or commercially available in different regions of the world.

Compound	Commercial (South Africa) <sup>a</sup>	Hydrodistillation (China) <sup>b</sup>	SFE CO <sub>2</sub> (China) <sup>b</sup>	Hydrodistillation (Nigeria) <sup>c</sup>	Commercial (Greece) <sup>d</sup>	Hydrodistillation (Kenya) <sup>e</sup>
<b>Aldehydes and ketones</b>						
Camphor	nd	nd	nd	0.12	nd	nd
2-Carene-10-al	0.22	nd	nd	nd	nd	nd
(+)-Carvotanacetone	0.39	nd	nd	nd	nd	nd
<i>trans</i> -Chrysanthemal	0.14	nd	nd	nd	nd	nd
Citronellal	0.34	12.77	12.57	2.37	0.6	0.12
Geranial	48.14	15.12	20.02	0.99	38.5	39.53
Isogeranial	nd	nd	nd	nd	0.7	nd
Lauraldehyde	nd	0.30	0.13	nd	nd	nd
Neral	38.32	11.15	15.11	nd	28.7	33.31
Piperitone	0.99	nd	nd	nd	nd	nd
2-Undecanone	0.57	nd	nd	nd	nd	0.53
<b>Sum</b>	<b>89.11</b>	<b>39.34</b>	<b>47.83</b>	<b>3.48</b>	<b>68.5</b>	<b>73.49</b>
<b>Alcohols</b>						
Borneol	nd	nd	0.76	4.72	nd	nd
$\alpha$ -Cadinol	nd	0.25	1.47	0.37	nd	nd
Carotol	nd	0.37	nd	nd	nd	nd
$\beta$ -Citronellol	0.09	nd	nd	2.83	0.1	0.34
Cubenol	nd	0.55	3.41	nd	nd	nd
Elemol	nd	nd	nd	1.37	0.1	
$\alpha$ -Eudesmol	nd	nd	nd	0.34	nd	nd
$\beta$ -Eudesmol	nd	nd	nd	0.32	nd	nd
$\gamma$ -Eudesmol				0.24		
$\gamma$ -Eucalyptol	nd	nd	0.80	nd	0.6	nd
<i>trans</i> -Farnesol	nd	nd	1.34	nd	nd	nd
Geraniol	1.34	9.39	6.43	21.86	4.4	3.05
Globulol	nd	1.37	0.55	nd	nd	nd
Hinesol	nd	0.91	2.80	nd	nd	nd
Isoborneol	nd	nd	nd	nd	0.2	nd
Isopulegol	nd	0.35	0.18	nd	nd	nd
Linalool	0.98	nd	nd	0.70	1.6	1.29
3-Methylcyclohexanol	nd	0.71	2.01	nd	nd	nd
<i>E</i> -Methyleugenol	nd	nd	nd	0.19	nd	nd
Methylisoeugenol	nd	nd	nd	7.50	nd	nd
Nerol	nd	0.35	0.19	nd	0.1	0.34
Terpinen-4-ol	nd	nd	nd	2.21	0.1	nd
<i>cis</i> -Verbenol	nd	0.46	0.95	nd	nd	nd
<i>trans</i> -Verbenol	nd	nd	0.33	nd	nd	nd
<b>Sum</b>	<b>2.41</b>	<b>14.71</b>	<b>21.22</b>	<b>42.65</b>	<b>7.2</b>	<b>5.02</b>

Compound	Commercial (South Africa) <sup>a</sup>	Hydrodistillation (China) <sup>b</sup>	SFE CO <sub>2</sub> (China) <sup>b</sup>	Hydrodistillation (Nigeria) <sup>c</sup>	Commercial (Greece) <sup>d</sup>	Hydrodistillation (Kenya) <sup>e</sup>
<b>Esters</b>						
Bornyl acetate	nd	nd	nd	0.71	nd	nd
Citronellyl acetate	nd	nd	0.23	0.98	4.3	nd
Citronellyl isobutyrate	nd	0.61	1.27	nd	nd	nd
Geranyl acetate	0.82	2.24	0.65	3.42	nd	0.24
Geranyl butyrate	nd	nd	nd	nd	0.2	nd
Geranyl formate	0.17	nd	nd	nd	0.2	nd
Terpenyl acetate	nd	nd	nd	0.29	nd	nd
<b>Sum</b>	<b>0.99</b>	<b>2.85</b>	<b>2.15</b>	<b>5.40</b>	<b>4.7</b>	<b>0.24</b>
<b>Hydrocarbon terpenes</b>						
Bicyclgermacrene	nd	nd	nd	2.60	nd	nd
β-Bourbonene	nd	1.97	nd	nd	nd	nd
δ-Cadinene	nd	nd	nd	4.10	1.0	nd
Camphene	nd	nd	nd	7.89	1.0	nd
3-Carene	nd	0.46	nd	nd	nd	nd
β-Caryophyllene	0.17	2.46	0.10	1.86	1.4	0.15
α-Copaene	nd	1.29	1.13	nd	nd	nd
α-Cubebene	nd	0.94	0.46	nd	nd	nd
p-Cymene	nd	nd	nd	0.19	nd	nd
β-Elemene	nd	nd	nd	1.07	0.1	nd
Germacrene D	nd	nd	nd	0.97	0.1	nd
α-Guaiene	nd	0.25	0.45	nd	nd	nd
β-Guaiene	nd	0.14	nd	nd	nd	nd
α-Humulene	nd	nd	nd	0.30	nd	nd
D-Limonene	0.18	0.20	3.55	7.90	6.9	nd
8-Methyl-1-hendecene	nd	nd	0.18	nd	nd	nd
α-Murolene	nd	0.26	0.30	4.10	nd	nd
γ-Murolene	nd	1.67	0.20	0.17	nd	nd
Myrcene	nd	nd	nd	0.60	0.3	11.41
β-Ocimene	0.25	nd	0.15	nd	0.3	nd
Perillene	0.19	nd	nd	nd	nd	nd
β-Phellandrene	nd	nd	nd	0.32	nd	nd
α-Pinene	nd	0.71	0.67	2.12	0.6	0.01
β-Pinene	nd	4.31	6.00	nd	0.3	nd
Sabinene	nd	nd	nd	0.14	0.4	nd
Terpinolene	nd	nd	nd	0.50	0.1	nd
(6E, 10E)-2,6,12,15-Tetramethylhexadeca-2,6,10,14-tetraen-8-yne	0.44	nd	nd	nd	nd	nd
1-Undecyne	0.51	nd	nd	nd	nd	nd
<b>Sum</b>	<b>1.74</b>	<b>14.66</b>	<b>13.19</b>	<b>34.83</b>	<b>12.5</b>	<b>11.57</b>

nd – not detected; SFE CO<sub>2</sub> – supercritical fluid extraction with CO<sub>2</sub>; <sup>a</sup>Mbili *et al.* [2017]; <sup>b</sup>Wu *et al.* [2019]; <sup>c</sup>Moutassem *et al.* [2019]; <sup>d</sup>Hadjilouka *et al.* [2017]; <sup>e</sup>Matasyoh *et al.* [2011].

TABLE 2. Major component contents of *Cymbopogon citratus* essential oil (%) obtained from plants harvested in different regions of the world.

Country/ region	Compound			References
	Geranial	Neral	Myrcene	
Algeria	42.16	31.52	7.45	Boukhatem <i>et al.</i> [2014a]
Benin	39.5	35.5	nd	Kpoviessi <i>et al.</i> [2014]
Brazil	39.9	30.1	1.59	Andrade <i>et al.</i> [2009]
	31.89	24.62	25.37	Farias <i>et al.</i> [2019]
Burkina Faso	48.1	34.6	11.0	Bassolé <i>et al.</i> [2011]
Cameroon	37.7	21.2	2.5	Nguefack <i>et al.</i> [2012]
Egypt	40.72	34.98	15.69	Hanaa <i>et al.</i> [2012]
	20.9	16.2	0.8	Mansour <i>et al.</i> [2015]
Iran	39.16	30.95	3.57	Amini <i>et al.</i> [2016]
Ivory Coast	45.3	32.5	18.1	Sidibé <i>et al.</i> [2001]
Malaysia	37.58–45.95	29.44–31.13	3.18–7.68	Tajidin <i>et al.</i> [2012]
Mali	30.5	26.3	18.1	Sidibé <i>et al.</i> [2001]
Nigeria	33.7	26.5	25.3	Kasali <i>et al.</i> [2001]
Saudi Arabia	37.8	33.6	8.4	Mansour <i>et al.</i> [2015]
Sri Lanka	35.97	26.5	nd	Premathilake <i>et al.</i> [2018]
Zambia	39.0	29.4	18.0	Chisowa <i>et al.</i> [1998]

nd – not detected.

The antimicrobial activity of lemongrass essential oil is usually higher against fungi than bacteria. Premathilake *et al.* [2018] found that lemongrass essential oil exhibited fungitoxic activity against *Colletotrichum truncatum*, *Fusarium spp.*, *Penicillium spp.*, and *Cryosporium spp.* All four different concentrations of the essential oil used in this experiment elicited 100% inhibition of *Fusarium spp.*, *Penicillium spp.*, and *Cryosporium spp.* *C. truncatum* was also inhibited by the lemongrass essential oil but higher concentrations of the oil were necessary. The essential oil of *C. citratus* was also investigated towards *Candida albicans*, *Candida parapsilosis*, *Candida tropicalis*, *Candida glabrata*, and *Candida krusei* [da Silva *et al.*, 2008]. All those strains proved to be sensitive to *C. citratus* essential oil, which indicates new perspectives in the potential application of lemongrass oil in typical *Candida* infections. Tzortzakis & Economakis [2007] reported a broad antifungal activity of essential oil of *C. citratus* against such food pathogens as *Aspergillus niger*, *Colletotrichum coccodes*, *Botrytis cinerea*, *Cladosporium herbarum*, and *Rhizopus stolonifer*. Amini *et al.* [2016] demonstrated that lemongrass oil effectively controlled mycelium growth of three *Phytophthora* species: *P. capsici*, *P. drechsleri*, and *P. melonis*. The *Phytophthora* genus is a plant-damaging mold which causes enormous economic losses in crops as well as environmental destruction in natural ecosystems. Helal *et al.* [2006] investigated the antifungal activity of essential oil of *C. citratus* against *Aspergillus niger* ML2-strain. Lemongrass oil produces a fungi toxic effect against postharvest patho-

gens of the *Aspergillus* genus: *A. flavus*, *A. parasiticus*, and *A. clavatus* [Matasyoh *et al.*, 2011; Bozik *et al.*, 2017]. Five mycotoxigenic species isolated from maize samples, including *A. flavus*, *A. parasiticus*, *A. ochraceus*, *A. niger*, and *A. fumigatus*, were also found to be sensitive to lemongrass essential oil [Matasyoh *et al.*, 2011]. The highest activity of the oil was observed against *A. niger* with the minimum inhibitory concentration of 15 mg/mL and the highest resistance was observed from *A. flavus* with an MIC of 118 mg/mL. Sharma *et al.*, [2017] recorded an inhibitory effect of lemongrass essential oil against a pathogenic strain of *Fusarium oxysporum*. The genus *Fusarium* is infamous for infecting plants, leading to economic losses in agriculture and is known to produce mycotoxins in cereal crops. Lemongrass essential oil showed complete inhibition of spore germination at a concentration of 250 ppm, IC<sub>50</sub> value was found to be 0.98 ppm.

According to Boukhatem *et al.* [2014b], lemongrass oil showed a potent antimicrobial activity against Gram-positive bacteria and exhibited the strongest antifungal effect against *Candida albicans* and *C. parapsilosis*. MIC varied from 0.019 to 1.25 mg/mL for Gram-positive bacteria and yeasts, indicating *S. aureus*, *S. epidermidis*, and *C. albicans* as the most susceptible strains. Moreover, the diameter of inhibition zone (DIZ) increased with an increasing essential oil concentration. Considerably superior antimicrobial activity was observed in the vapour phase. The DIZ resulting from the exposure to essential oil vapour was significantly larger than that from the same volume in the liquid phase. The DIZ

varied from 22 to 90 mm for *Candida* strains. Essential oil in the vapour phase may be an effective antimicrobial system and has advantages over the oil in the liquid phase. These results [Boukhatem *et al.*, 2014b] imply that lemongrass oil could be useful for the development of novel types of natural preservatives for food control.

The high antifungal activity of lemongrass essential oil is attributed to the presence of two isomers of citral [Leite *et al.*, 2014]. According to Harris [2002], citral seems to interact mostly with the cell wall of fungi. Such interaction affects its construction, inhibiting its synthesis, which results in cell death. Earlier literature suggested that the fungitoxic activity of citral stems from its capability to form a charge transfer complex with fungal cell tryptophan, leading to fungi death [Kurita *et al.*, 1981]. In recent studies, the antifungal activity of citral was evaluated against *Geotrichum citri-aurantii* [Zhou *et al.*, 2014]. The experiment revealed that citral significantly inhibited mycelial growth. Antifungal properties of citral were attributed to cell membrane destruction and to the subsequent leakage of cellular constituents. The inhibiting activity of lemongrass essential oil may also stem from the synergistic effect of individual minor or major compounds [Nguefack *et al.*, 2012]. Further studies are needed to completely describe its effects especially if it is going to be used in the future as a component of new antifungals. The other major component of lemongrass essential oil – myrcene – is not known to exhibit any antifungal activity. Components with hydroxyl moiety have been known to be active but with differing specificity and levels of activity, which is related not only to the functional group present but also to hydrogen bonding parameters [Skaltsa *et al.*, 2003]. The mechanism of action of geraniol, one of the main alcohols found in lemongrass essential oil, probably does not involve complexation with ergosterol or inhibiting the fungal cell wall synthesis [Leite *et al.*, 2015]. Whereas, Pereira *et al.* [2015] suggested that the antifungal activity of geraniol and citronellol, *i.e.* two monoterpene alcohols, against *Trichophyton rubrum* involves ergosterol biosynthesis inhibition. In general, high lipophilic nature and low molecular weight of terpenes/terpenoids, that are irreplaceable constituents of lemongrass oil, determine its high antifungal activity which probably involves disrupting the cell membrane, causing cell death or inhibiting the sporulation and germination of fungi. Therefore, many *in vitro* tests have proved terpenes/terpenoids to show much lower antimicrobial activity when used as singular compounds compared to the whole essential oil [Lu *et al.*, 2013].

### Antioxidant activity

The antioxidant activity of *C. citratus* essential oil is due to the synergistic effect of all its constituents [Guimarães *et al.*, 2011]. However, recent reports indicate that the main terpenoid component of the essential oil – citral – shows antioxidant activity as well, which is a result of co-oxidation with the target substrate and cross-termination of the oxidative chain [Baschieri *et al.*, 2017]. The antioxidant properties of lemongrass essential oil have been studied by many researchers, though there are some discrepancies between the results, probably due to the different geographical origin of the plant, different extraction methods, and methodology

used to evaluate its antioxidant activity. The antioxidant activity assessment requires a combination of various methods because there are significant differences in sample preparation (solvent, temperature *etc.*), selection of end-points, and even the expression of results, hence the comparison between values reported by different scientists may be problematic. A single method will provide only a primary knowledge about antioxidant properties, whereas a combination of methods will produce more detailed information about the antioxidant properties of the sample.

Lawrence *et al.* [2015] thoroughly checked the antioxidant activity of lemongrass leaves oil from India using four different methods: free radical scavenging activity (DPPH method), reducing power assay, nitric oxide scavenging method, and  $\beta$ -carotene bleaching assay. Inhibition constant  $IC_{50}$  values recorded for DPPH and NO scavenging method were 0.5 mg/mL and 2.0 mg/mL, respectively. The reducing activity was also significant. The results proved that lemongrass essential oil is effective in scavenging free radical and has the potential to be a powerful antioxidant. Another study was done by Mansour *et al.* [2015] in which higher antioxidant activity was demonstrated for Egyptian lemongrass essential oil with  $IC_{50}$  1.0 mg/mL in comparison to the Saudi Arabian lemongrass volatile oil with  $IC_{50}$  6.9 mg/mL. The strong DPPH $\cdot$  scavenging ability of the Egyptian oil was attributed to its unsaturated alcohols and phenolic compounds such as linalool (5.6%), geraniol (8.3%), terpin-4-ol (2.1%), and eugenol (0.4%). On the other hand, Anggraeni *et al.* [2018] reported a low antioxidant activity of the Indonesian lemongrass essential oil when compared to ascorbic acid and commercial lemongrass oil used as a reference material. Similarly, Viuda-Martos *et al.* [2010] reported a low radical-scavenging capacity of lemongrass oil using a stable DPPH radical with  $IC_{50}$  199.63 mg/mL, whereas the ferric reducing antioxidant capacity (FRAC) of the essential oil was high. The same research group found lemongrass essential oil to be highly effective in chelating iron(II) ions, better than ascorbic acid and BHT. Viuda-Martos *et al.* [2010] also demonstrated that lemongrass EO might show a pro-oxidant activity, which was determined with the Rancimat method.

Various other scientists have also worked on the antioxidant activity of *C. citratus* essential oil. Guimarães *et al.* [2011] reported a low antioxidant activity of Brazilian lemongrass essential oil using the methodology that measures the scavenging of a stable DPPH radical; however, when analysed using the methodology that employs the  $\beta$ -carotene/linoleic acid emulsion system, the oil showed significant antioxidant activities. Using the Folin-Ciocalteu method, Mirghani *et al.* [2012] demonstrated the highest phenolics content in the essential oil extracted from lemongrass stalk, *i.e.* 2100.8 mg GAE/L. The high antioxidant activity of lemongrass stalk oil was also confirmed with the DPPH scavenging assay. The results obtained by Hartartie *et al.* [2019] indicate that the antioxidant activity of lemongrass essential oil depends on the method of distillation and on the part of the plant used. The antioxidant activity measured with DPPH free radical scavenging assay showed that steam-distilled lemongrass stalk oil had the highest antioxidant activity (72.724%), while water-distilled oil from the whole plant of lemongrass had

a lower antioxidant activity reaching up to 70.113%. The antioxidant activity of an essential oil made of leaves using the steam distillation method was higher (60.808%) than that obtained by water distillation (57.331%).

The antioxidant properties of lemongrass essential oils are attributed to the presence of terpenoid and phenolic compounds which may demonstrate their redox properties employing different possible mechanisms, like: hydrogen donation, free radical scavenging activity, transition metal chelating activity, and/or singlet oxygen quenching capacity [Viuda-Martos *et al.*, 2010]. In literature, the antioxidant properties of lemongrass essential oil are attributed to the mixture of different chemical compounds of the oil, because even minor constituents may influence and modulate the activity of the whole oil.

The antioxidant properties of *C. citratus* essential oil might be worth of consideration in terms of essential oil incorporation into formulations of nutraceuticals or/and functional food. Antioxidants can scavenge free radicals and retard lipid oxidation in food products, which is the main cause of food quality deterioration.

#### **Anti-inflammatory properties**

Traditionally, lemongrass is also known for analgesic and anti-inflammatory properties, however only few studies have been carried out to substantiate these effects of lemongrass oil. Only recently, a few research groups have undertaken studies to investigate anti-inflammatory properties of lemongrass essential oil and its major constituent – citral. Boukhatem *et al.* [2014a] used carrageenan-induced mouse paw oedema to determine the anti-inflammatory effect of Algerian lemongrass oil. The experiment has proved that lemongrass essential oil is able to considerably inhibit inflammation processes. The degree of oedema inhibition after 90 min of the oral intake turned out to be 82.75% for the dose of 10 mg/kg, while only a little higher degree of oedema inhibition (86.2%) was observed for a higher oil dose (100 mg/kg). The anti-inflammatory activity of the lemongrass oil was compared with the standard drug diclofenac which showed similar oedema inhibition (86.2%) to the lemongrass oil when used in a dose of 50 mg/kg. The detailed mechanism of the anti-inflammatory effect of the lemongrass essential oil remains unexplained. However, it has been indicated that several components of lemongrass oil may cause partial inhibition of the release of inflammation mediator molecules. The main plant constituents, particularly aldehyde monoterpenes (geranial and neral), have already been reported to be able to control inflammatory processes [Perez *et al.*, 2011].

#### **LEMONGRASS ESSENTIAL OIL USES FOR FOOD PRESERVATION**

Essential oils are considered as natural substituents of chemical preservatives, since their use in food is regarded as safe and natural. Food products containing essential oils are accepted by consumers and also meet the demands for “green” processing. However, the practical application of essential oils is limited due to their characteristic flavour, possible interactions with food components and structure,

which results in reduction of their efficacy [Amany *et al.*, 2010]. Among the various essential oils, the oil of *C. citratus* has been recognised most promising for uses as a food preservative since it exhibits a variety of fundamental and novel bioactivities. Owing to their GRAS status, essential oils are not harmful and are more widely accepted by consumers than the “synthetic” agents.

Currently, the focus of several research laboratories is to investigate the application of lemongrass oil especially in meat preservation. In the meat industry, a number of chemical additives have already been used, but the consumers’ growing concern about the safety of food products has contributed to the shift of the interests from synthetic compounds to natural ones. The antimicrobial and antioxidant activity of lemongrass oil can restrain foodborne pathogens and spoilage organisms against their development and subsequent deterioration of meat products. The advantages of such a treatment of meat are that lemongrass essential oil may be useful in extending shelf-life of meat products, preserving meat quality, preventing economic loss, and providing the consumer with meat products containing more acceptable natural additives.

Amany *et al.* [2010] studied the antioxidant and antimicrobial effectiveness of lemongrass oil at various concentrations on the quality of refrigerated fresh minced beef (4°C). The results were compared with the bioactivity of garlic oil and thyme oil, which are widely renowned for their antimicrobial properties against spoilage flora in meat products. Lemongrass oil at a concentration of 1.5% showed a significant effectiveness in decreasing aerobic plate count, coliform count, *Enteriobacteriaceae* count, and *Staphylococci* count. The antimicrobial activity of garlic and thyme oils was not as strong as that of the lemongrass oil. The decreased content of total volatile nitrogen, which determines the degree of meat deterioration during storage, indicated that all oils successfully inhibited the spoilage of minced meat at a comparable level. In the same experiment, lemongrass oil was found to be the most effective in preventing auto-oxidation of meat lipids and bacteriological and/or oxidative rancidity, which was estimated by the evaluation of decrease in thiobarbituric acid values. Different degradation reactions, involving lipid oxidation, influence the sensory profile of meat products. All tested oils proved to enhance the sensory properties of all the refrigerated beef samples to the similar extent. The greatest enhancement was observed for the samples containing 1.5% of lemongrass oil. In general, the best results in refrigerated minced beef preservation were demonstrated by lemongrass oil.

In a recent study, Zaki *et al.* [2018] evaluated the effect of using lemongrass essential oil in the formulation of camel burgers on changes in their physical, chemical, microbiological, and sensory properties during cold storage (4°C). Physical properties (percentage of cooking loss, percentage of reduction in diameter) were improved for camel burgers containing 1% of lemongrass oil. The total volatile nitrogen and thiobarbituric acid values significantly decreased for samples with lemongrass oil when compared to the control ones. The burgers formulated with addition of 1% of lemongrass oil were found to show the lowest total bacterial count, and were given the highest scores for taste, aroma, colour,

texture, and acceptability in the sensory analysis. Lemongrass essential oil antimicrobial properties may support storage stability of meat when combined with other essential oil. The combination of lemongrass and ginger essential oil successfully extended the shelf life of chicken meat [Hartanti et al., 2018].

The antimicrobial potential of lemongrass essential oil was also tested in reducing the microbial population of cream-filled baked goods [Vazirian et al., 2012]. Five main food-borne pathogens including: *Bacillus cereus*, *Candida albicans*, *Escherichia coli*, *Salmonella typhimurium*, and *Staphylococcus aureus*, were added manually to cream-filled cakes together with 1  $\mu\text{L}/\text{mL}$  of the lemongrass essential oil. After 72 h of storage, no observable microflora was detected in the baked cakes, except for *S. aureus* in the case of which lemongrass essential oil proved ineffective.

The antimicrobial effectiveness of lemongrass oil against *Salmonella enterica* serovar Newport on organic leafy vegetables such as romaine and iceberg lettuce as well as mature and baby spinach was investigated by Moore-Neibel et al. [2012]. Samples of leaves inoculated with *Salmonella* Newport were dipped in a lemongrass oil solution for 1 to 2 min and then stored for 1 to 3 days. Significant inhibition of *S. Newport* growth on fresh leafy greens was observed. The antibacterial activity of lemongrass oil depended on oil concentration and storage time. The highest reduction was observed (according to the activity order) on baby spinach, mature spinach, and romaine lettuce. The differences in the effectiveness of lemongrass oil among species of leafy green vegetables may be attributed to the surface morphology, chemical composition, and nutrient content of leaves. However, little differences were reported for the samples stored under refrigeration and abuse temperatures.

At present, research laboratories have focused on investigating the antimicrobial activity of lemongrass essential oil in the vapour phase. Such analyses were undertaken by, e.g., Mani-López et al. [2018] who evaluated the fungicidal properties of lemongrass oil vapours on the growth of *Penicillium expansum* inoculated on bread. The growth of *P. expansum* was inhibited for 21 days at 20°C with 750  $\mu\text{L}$  of oil/L air. The increasing concentration of the oil resulted in greater inhibition. No significant differences were observed in the sensory analysis for the samples exposed and not exposed to lemongrass oil vapours. Lemongrass essential oil vapours were also reported to control anthracnose disease development on papaya without affecting its natural ripening process [Ali et al., 2015]. A number of studies have demonstrated that the antifungal and antimicrobial activities of essential oils in the vapour phase are more effective than in the liquid phase. These have been extensively reviewed by Reyes-Jurado et al. [2019].

Lemongrass oil may also play a vital role in the inhibition of several fundamental postharvest pathogens like *Botrytis cinerea*, *Colletotrichum coccodes*, *Cladosporium herbarum*, and *Rhizopus stolonifer* that are important for food preservation [Mbili et al., 2017; Tzortzakis & Economaki, 2007]. Lemongrass essential oil as well as powdered plant have been recorded to prevent storage deterioration and aflatoxin contamination of melon seeds infected by *Aspergillus flavus*, *A. ni-*

*ger*, *A. tamarii*, and *Penicillium citrinum* [Bankole et al., 2005]. The chemical composition of melon seeds was not affected by lemongrass essential oil and the effects were nearly similar to a commercial fungicide iprodione.

The antifungal activity of essential oil of *C. citratus* grown in Iran was investigated for controlling three species of *Phytophthora*, including *P. capsici*, *P. drechsleri*, and *P. melonis*, on pepper, cucumber, and melon under *in vitro* and greenhouse conditions, respectively [Amini et al., 2016]. Essential oil of *C. citratus* inhibited *in vitro* the growth of *P. capsici* (91.9%), *P. drechsleri* (91.2%), and *P. melonis* (94.6%) and under greenhouse conditions the growth of *P. capsici* (60.5%), *P. drechsleri* (47.4%), and *P. melonis* (55.3%), which affords new perspectives for its application as an alternative to synthetic compounds for integrated control of diseases caused by *Phytophthora* species in crop, vegetable, and ornamental plants after suitable clinical trials.

It was also reported that lemongrass oil increases the shelf life of different fruits like guava [Murmur & Mishra, 2018], strawberries [Kahramanoglu, 2019], table grapes [Sonker et al., 2014], apples [Frankova et al., 2016; Jo et al., 2014] as well as fruit juice [Tyagi et al., 2014]. It was also found effective in preserving processed foods like cheese [Cui et al., 2016]. A recent report has indicated that lemongrass essential oil may influence lactic cultures in dairy products [Farias et al., 2019], which may curb its applicability in this sector of food industry. The application of *C. citratus* essential oil in food preservation was comprehensively reviewed by Ekpenyong & Akpan [2017].

Although numerous studies have indicated that lemongrass essential oil may serve as a potential food preservative, little is known about its toxic effects. Some reports suggest that its high levels in food products may have an adverse impact on the gustatory and olfactory systems [Smith et al., 2005]. On the other hand, lemongrass essential oil used in small concentrations is considered safe for human consumption [Sinha et al., 2014]. *In vitro* studies have shown that the antimicrobial activity of lemongrass essential oil is predominantly between 0.2 and 10  $\mu\text{L}/\text{mL}$ . In food products the concentration of the essential oil is much higher (25 – 100-fold) in order to achieve the comparable antimicrobial activity. The ADI value recommended by the European Union for geraniol is 0.5 mg/kg body weight/ day, hence food products contain excessive doses of the essential oil [Commission Implementing Regulation (EU) No 570/2013]. In many countries, the application of essential oils is not regulated whatsoever. Moreover, inappropriate and random uses of the lemongrass essential oil may result in health problems triggered by genetic damages, carcinogenic effects, and mutations [Sousa et al., 2010]. Thus, further studies on the toxicity of lemongrass essential oil and the comprehensive safety evaluation are needed.

## CONCLUSION

There is a growing interest in the application of the essential oil of *C. citratus* in the food system. The oil contains many phytoconstituents such as terpenes, terpenoids, esters, and phenolic compounds, which are responsible for different biological activities, primarily antibacterial and antifungal

ones. Many studies have confirmed that lemongrass essential oil may serve as a natural meat preservative offering protection against various microorganisms, increasing shelf-life of the product, and ensuring its quality. Before industrial application in the meat industry, further research is necessary to explore the efficiency of suitable concentrations of the oil. Additionally, the use of lemongrass oil opens new perspectives to the management of storage fungi, which not only deteriorate the quality of food but also may cause food-borne diseases. In general, lemongrass essential oil is a promising plant product for preserving stored foodstuffs replacing synthetic additives which are associated with various adverse human health effects. Its application in stored food products may be a good solution in remote rural areas which still have no possibility to use modern storage system.

### CONFLICT OF INTERESTS

The authors declare they do not have any conflicts of interest.

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