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Review article

## A Review of Ethnopharmacology, Phytochemistry and Pharmacology of *Cymbopogon* Species

Soodeh Karami<sup>1</sup> , Alireza Yargholi<sup>2</sup> , Seyede Nargess Sadati Lamardi<sup>1</sup> , Samaneh Soleymani<sup>1</sup> , Laila Shirbeigi<sup>2</sup> , Roja Rahimi<sup>1,3\*</sup> 

<sup>1</sup>Department of Traditional Pharmacy, School of Persian Medicine, Tehran University of Medical Sciences, Tehran, Iran.

<sup>2</sup>Department of Persian Medicine, School of Persian Medicine, Tehran University of Medical Sciences, Tehran, Iran.

<sup>3</sup>Evidence-Based Medicine Group, Pharmaceutical Sciences Research Center, Tehran University of Medical Sciences, Tehran, Iran.

### Abstract

The genus *Cymbopogon* belongs to Poaceae family and contain about 54 species, commonly known as "lemongrass". *Cymbopogon* is a medicinal plant native to tropical and subtropical areas which is applied traditionally for its numerous properties including antirheumatic, antispasmodic, analgesic, antiseptic, hypotensive, antitussive and anticonvulsant activities, and as a treatment for gastrointestinal and nervous disorders and fever. The aims of this study were to discuss about current state of phytochemistry, pharmacology, and pharmacological effects of different species of *Cymbopogon*. Electronic databases including PubMed, Scopus, Cochrane library and Google Scholar were searched with the scientific name and the common name of the plant until November 2019. In spite of the small number of clinical investigations, *Cymbopogon* genus is widely evaluated for its phytochemistry, ethnopharmacology and biological activities. Monoterpenes specially geraniol, citronellol and citral are the chief components of the essential oil. Biological activities including antioxidant, antibacterial, antiviral, insecticidal, anticancer, hepatoprotective activities as well as its effect on skin, urogenital, gastrointestinal, neuropsychological and cardiovascular systems are proved in cell lines and animal models. Extensive studies have been done on various biological activities of lemongrass; nevertheless, safety and efficacy of *Cymbopogon* species are not fully evaluated in human and further well-designed clinical trials are required to confirm preclinical findings.

**Keywords:** citral; diabetes mellitus; hyperlipidemia; inflammation; lemongrass

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### Introduction

Herbal medicine has been used worldwide for a long time. Medicinal plants are the most important part in traditional medicines of many countries [1]. The genus *Cymbopogon* from Poaceae family, known with the common name of lemongrass, contains about 54 species. Most of them grow in Africa and some of them grow in Australia; other species are distributed in south Asia [2].

*Cymbopogon* plants are tall perennial plants with narrow and long leaves that are mostly characterized by the presence of silica thorns aligned one the leaf edges. They are native to warm temperate and tropical regions of the old world and Oceania [2]. Most of the species such as *C. citratus* (DC.) Stapf, *C. martini* Roxb., *C. flexuosus* DC. Stapf, and *C. winterianus* Jowitt

\*Corresponding author: rahimi\_r@tums.ac.ir

produce aromatic essential oil (EO). Their EOs are rich in monoterpenes which have great commercial role in pharmaceutical industries, cosmetics, perfumery, and flavors [3]. The morphological properties and EO constituents of most of the species have been investigated but because of different varieties and races, identification of *Cymbopogon* species and varieties is hard in some cases since identifiable factors are impressed by environmental parameters. DNA based markers are useful methods to identify species and varieties [4]. The purpose of this study was a detailed review on phytochemistry, ethnopharmacology and pharmacologic effect of the most popular species of *Cymbopogon* species.

### Ethnopharmacology

The consumption of *Cymbopogon* genus has been popular in many countries. People have used this plant for various reasons, for instance, medicinal plant, insect repellent and insecticide. Table 1 shows various species of this genus, ethnopharmacological uses, part used and the region.

*Cymbopogon citratus* is one of the most mentioned species with various medical applications in Brazil. This plant is known for its calmative, anti-depressant, blood depurative, sedative, analgesic, antifungal, antimicrobial, anti-inflammatory, and diuretic effects. The second popular species of *Cymbopogon* in Brazil is *C. nardus* and regional people use it to control fever. *Cymbopogon citratus* is one of the most-cited anxiolytic plant in Ghana also it is used as sedative, anticonvulsant, and analgesic agent. It is commonly used as a repellent against housefly, *Musca domestica* L. in Uganda. *Cymbopogon citratus* has been mentioned as one of the mostly used herbs in Wayanad District of Kerala, India for digestive problems, toothache, and rheumatism. Also, *C. flexuosus* is used in this region to alleviate fever, rheumatism and as an anti-cancer agent [5]. In Singapore, *C. citratus* is among 200 popular plant species that people use to treat paronychia, cold and flu symptoms, insect bites, sore and itchy throat, flatulence, indigestion, and to prevent cancer [6]. *Cymbopogon citratus* is

one of the frequently mentioned plants as insect repellent. In Western Hararghe zone, Ethiopia, people commonly burn or smolder it to produce smoke to repel insects. They also cover the floor of houses with *C. citratus* leaves to ward off Mosquito, house flies and fleas. In the town of Newcastle, South Africa, *C. citratus* is sold to control diabetes as infusion. People use infusion of the whole plant in water [7].

In Nicaragua, *C. citraus* is one of the species that Rama midwives use it topically to treat backache [8]. It is also used to eliminate abdominal pain after childbirth and improve lactation [9]. In Lao PDR, *C. citratus* is used for postpartum recovery by treating anemia, dizziness, headache, puerperal fever; and as a galactagogue. The people of Lao PDR put fresh leaves on the bed and the mother lies on them covered by a blanket. Essential oil of the leaves is evaporated by heat of the fire, and it can surround the mother. The mother inhales EO and her skin exposes to the vapor. [10] *Cymbopogon citratus* is also prevalent among women in Mauritius for treating postpartum pain and bleeding [11].

Aerial part and root of *C. distans* is used in Lakki Marwat District of Pakistan as carminative and for prevention of heart disease [12].

In Saravan region, Baluchistan province, Iran, people use infusions of *C. jwarancusa* aerial parts to treat respiratory tract infections [13]. People in Dera Ismail Khan region, Pakistan, use decoction of *C. jwarancusa* root with sugar for dyspepsia in children and for alleviation of typhoid and fever [14].

### Phytochemistry

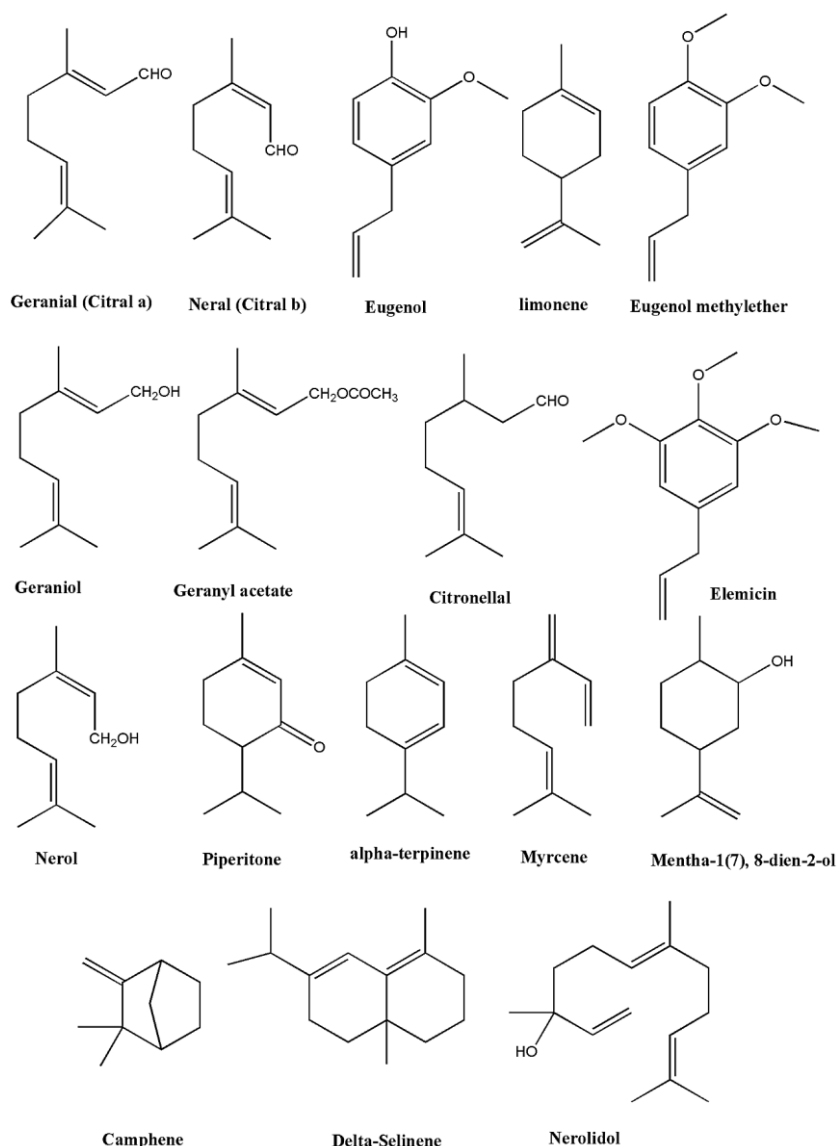
Due to medical benefits of the essential oil (EO) of *Cymbopogon* species, more phytochemical studies on these species have been concentrated on the EO. The EO is mainly composed of monoterpenes and monoterpenoids, sesquiterpenes and sesquiterpenoids, and some fatty alcohols. The structure of chemical compounds isolated from essential oil of *Cymbopogon* species has been shown in Figure 1. The phytochemical constituents of *Cymbopogon* species have been demonstrated in Table 2.

**Table 1.** Ethnomedicinal use of *Cymbopogon* species in different geographical regions

Plant	Region	Plant part (s) used	Traditional uses and ethnobotanical reports	Reference
<i>Cymbopogon citratus</i> (DC.) Stapf	Bangladesh	Leaves	Rheumatism, skin disease, pharyngitis, tonsillitis	[15]
		-	Tension	[16]
		-	Flu, stress, inflammation, fever, high cholesterol, high blood pressure, indigestion	[17]
		Leaves	Fever, headache, liver disease	[18,19]
		Roots	Lactation, postpartum abdominal pain	[9]
		Whole plant, leaves	Malaria, high blood pressure, anxiety, stress, fever, vomiting	[20]
	Brazil	Aerial parts	Tension, depression, stress, hypertension, insomnia, local pain, digestive problems, bronchitis, flu, infection in throat, pneumonia	[21]
		Essential oil	Leishmaniosis	[22]
		-	Anemia, emesis, stroke, stress, high cholesterol, colic, congestion, depression, diabetes, dyspnea, pain, headache, diarrhea, weight loss, migraine, inappetence, fever, flatulence, influenza, insomnia, indigestion, nervousness, irregular blood pressure, digestive problems, hepatic problems, renal problems, cold, dizziness, cough	[23]
	Ghana	Leaves, essential oil	Anxiety, tension, convulsion, pain	[24]
	Guadeloupe, French West Indies	Leaves	Flu syndrome	[25]
	Lao PDR	Whole plant	Postpartum problems: anemia (dizziness, headache), puerperal fever, lactation	[10]
	Kenya	Leaves	Headache, HIV/AIDS	[26]
	Mauritius	Stems and leaves.	Influenza	[27]
		Leaves	Postpartum pain, postpartum bleeding	[11]
	Paraguayan migrants living in Misiones, Argentina	Leaves	Heart problems, nervous tension, hypertension, digestion problems	[28]
	Thailand	Whole plant	Hypertension	[29]
		Stems	Menstrual disorders, leucorrhea	[30]
	Northern Thailand	Leaves and stems	Bone and joint pain, postpartum problems	[31]
		Leaves and stems	Repellents against housefly, <i>Musca domestica</i>	[32]
	Uganda	Leaves and twigs	Bad breath, toothache	[33]
		Aerial parts, leaf, roots	HIV/AIDS	[34]
	Southwestern Nigeria	Leaves	Cancer	[35]
		Leaves	Malaria	[36]
	Nigeria	Leaves	Malaria, fever	[37-40]
		-	Flatulence and digestive problems, toothache, insect bite, itchy throat, uterine cancer, fever, dysentery, headache, rheumatism	[5]
	India	Leaves and Essential oil	Insect repellent such as whitefly, cough and nasal congestion	[41]
		Leaves	Pain	[42]
		Whole plant	Snakebites	[43]
	Rio de Janeiro	Leaves	Skin problems	[44]
	Leaves	Anxiety-depression like disorders	[45]	
Mexico	Aerial parts	Kidney problems, grippe	[46]	
Rodrigues Island	Leaves	Cough	[47]	
Singapore	Leaves, Stems	Paronychia, cold & flu symptoms, insect bites, sore and itchy throat, stomach belatedness, swollen gums, uterine cancer, indigestion, cancer	[6]	
Togo	Leaves	Liver diseases, malaria	[48,49]	
Trinidad	Leaves and roots	Fever, common cold & cough	[50]	

Table 1. Continued

Plant	Region	Plant part (s) used	Traditional uses and ethnobotanical reports	Reference
	Amazonian Ecuador	Leaves	Common cold, fever	[51]
	Chana and Nathawee district, Songkhla	Whole plant	Diabetes mellitus	[52]
	Newcastle region	whole plant	Diabetes mellitus	[7]
	Western Har arghe zone, Ethiopia	Leaves	Repellents against mosquito, house fly and fleas	[53]
<i>Cymbopogon densiflorus</i> (Steud.) Stapf	Kinshasa	Leaves	Drepanocytosis	[54]
<i>Cymbopogon distans</i> (Nees ex Steud.) W. Watson	Pakistan	Aerial parts, roots	Flatulence, heart diseases	[12]
<i>Cymbopogon flexuosus</i> (Nees ex Steud.) W. Watson	India	-	Cancer, fever, rheumatism, pain	[5]
		Leaves	Cold and cough	[55]
<i>Cymbopogon giganteus</i> Chiov.	Ghana	Leaves	Tuberculosis	[56]
	Nigeria	EO of leaves	Insecticidal	[57]
<i>Cymbopogon jwarancusa</i> (Jones) Schult.	Pakistan	Whole plant	Urine complaint	[58]
		Roots	Dyspepsia, typhoid, fever	[14]
		Whole plant	Fever, catarrh, joint pain and inflammation	[59]
	Iran	Aerial parts	Respiratory tract infection	[13]
<i>Cymbopogon martini</i> (Roxb.) W. Watson	India	Essential oil	Malaria	[60]
		Essential oil	Hair loss	[61]
<i>Cymbopogon nervatus</i> (Hochst.) Chiov.	Sudan	Leaves	Indigestion, flatulence	[62]
	Tassili N' Ajjjer, another distinct region of the Southern Algerian Sahara	Whole plant	Aching bones and joints, rheumatism, fever, digestive diseases, postpartum problems, bad breath, urinary incontinence	[63]
<i>Cymbopogon nardus</i> (L.) Rendle	Uganda	Aerial parts, leaf, roots	HIV/AIDS	[34]
	Brazil	Aerial parts	Fever	[21]
	Mauritius	Stem and leaves	Cough and fever	[27]
	Thailand	Aerial parts	Muscle pain, muscle and joint swelling, runny nose and asthma, skin disease, post-partum problems	[30]



**Figure 1.** Chemical structure of the main constituents in *Cymbopogon* species essential oil

**Table 2.** Chemical compounds isolated from *Cymbopogon* specie

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
<i>Cymbopogon ambiguus</i> (Hack.) A. Camus	Elemicin	Phenylpropene	Whole plant / dichloromethane extract	[64]
	Eugenol	Phenylpropanoid	Whole plant / dichloromethane extract	[64]
	Eugenol methylether	Phenylpropanoid	Whole plant / dichloromethane extract	[64]
	Trans iso-elemicin	phenylpropene	Whole plant / dichloromethane extract	[64]
<i>Cymbopogon citratus</i>	6-methylhept-5-en-2-one	Ketone	Commercial essential oil	[65]
	Camphene	Monoterpene	Commercial essential oil	[65]
	Limonene	Monoterpene	Commercial essential oil	[65]
	Nonan-4-ol	Fatty alcohol	Commercial essential oil	[65]
	Citronellal	Monoterpene	Commercial essential oil	[65]
	Citronellol	Monoterpene	Commercial essential oil	[65]
	Neral	Monoterpene	Commercial essential oil	[65]
	Geraniol	Monoterpene	Commercial essential oil	[65]
	Citral	Terpenoid	Commercial essential oil	[65]
	Geranyl acetate	Monoterpene	Commercial essential oil	[65]
	$\beta$ -Caryophyllene	Sesquiterpene	Commercial essential oil	[65]
	$\gamma$ -Muurolene	Sesquiterpene	Commercial essential oil	[65]
	Caryophyllene oxide	Sesquiterpene	Commercial essential oil	[65]
<i>Cymbopogon distans</i>	$\alpha$ -Thujene	Monoterpene	Aerial parts/essential oil	[66]

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
<i>Cymbopogon flexuosus</i> (Nees ex Steud.) W. Watson	$\alpha$ -Pinene	Monoterpene	Aerial parts/essential oil	[66]
	Camphene	Monoterpene	Aerial parts/essential oil	[66]
	6-Methyl-5hepten-2-one	Ketone	Aerial parts/essential oil	[66]
	Myrcene	Monoterpene	Aerial parts/essential oil	[66]
	Limonene	Monoterpene	Aerial parts/essential oil	[66]
	Linalool	Monoterpene	Aerial parts/essential oil	[66]
	Citronellal	Monoterpene	Aerial parts/essential oil	[66]
	Borneol	Terpene	Aerial parts/essential oil	[66]
	Terpinen-4-ol	Monoterpene alcohol	Aerial parts/essential oil	[66]
	$\alpha$ -Terpineol	Monoterpene alcohol	Aerial parts/essential oil	[66]
	Citronellol	Monoterpene	Aerial parts/essential oil	[66]
	Nerol	Monoterpene	Aerial parts/essential oil	[66]
	Neral	Monoterpene	Aerial parts/essential oil	[66]
	Geraniol	Monoterpene	Aerial parts/essential oil	[66]
	Geranial	Monoterpene	Aerial parts/essential oil	[66]
	Neryl formate	Monoterpene	Aerial parts/essential oil	[66]
	Geranyl formate	Ester	Aerial parts/essential oil	[66]
	Citronellyl acetate	Monoterpene	Aerial parts/essential oil	[66]
	Geranyl acetate	Monoterpene	Aerial parts/essential oil	[66]
	Neryl acetate	Monoterpene	Aerial parts/essential oil	[66]
	6-Methyl -hept-5-en-2-on	Methylated ketone	Whole plant/ essential oil	[67]
	Myrcene	Monoterpene	Whole plant/ essential oil	[67]
	Limonene	Monoterpene	Whole plant/ essential oil	[67]
	Ocimene	Monoterpene	Whole plant/ essential oil	[67]
	Bergamal	Bergamal	Whole plant/ essential oil	[67]
	Terpinolene	Monoterpene	Whole plant/ essential oil	[67]
	Linalool	Monoterpene	Whole plant/ essential oil	[67]
	Rose oxide	Monoterpenoid	Whole plant/ essential oil	[67]
	Photocitral	Terpenoid	Whole plant/ essential oil	[67]
	Pulegol	Monoterpene	Whole plant/ essential oil	[67]
	Citronellal	Monoterpene	Whole plant/ essential oil	[67]
	Rosefuran epoxide	3-methyl-2-prenylfuran	Whole plant/ essential oil	[67]
	Isocitral	Terpenoid	Whole plant/ essential oil	[67]
	Decanal	Aldehyde	Whole plant/ essential oil	[67]
	Nerol	Monoterpene	Whole plant/ essential oil	[67]
Citronellol	Monoterpene	Whole plant/ essential oil	[67]	
Neral	Monoterpene	Whole plant/ essential oil	[67]	
Geraniol	Monoterpene	Whole plant/ essential oil	[67]	
Geranial	Monoterpene	Whole plant/ essential oil	[67]	
Citronellyl acetate	Monoterpene	Whole plant/ essential oil	[67]	
Geranyl acetate	Monoterpene	Whole plant/ essential oil	[67]	
Bourbonene	Sesquiterpenoid	Whole plant/ essential oil	[67]	
Elemene	Sesquiterpenes	Whole plant/ essential oil	[67]	
Caryophyllene	Sesquiterpene	Whole plant/ essential oil	[67]	
$\alpha$ -Humulene	Monocyclic sesquiterpene	Whole plant/ essential oil	[67]	
Germacrene -D	Sesquiterpenes	Whole plant/ essential oil	[67]	
$\gamma$ - Cadinene	Bicyclic sesquiterpene	Whole plant/ essential oil	[67]	
$\Delta$ - cadinene	Bicyclic sesquiterpene	Whole plant/ essential oil	[67]	
$\gamma$ - bisabolene	Sesquiterpenes	Whole plant/ essential oil	[67]	
Elemol	Sesquiterpenoid	Whole plant/ essential oil	[67]	
Germacrene - D- 4- ol	Sesquiterpenoid	Whole plant/ essential oil	[67]	
Caryophyllene oxide	Sesquiterpene	Whole plant/ essential oil	[67]	
<i>Cymbopogon giganteus</i> Chiov.	$\alpha$ -Pinene	Monoterpene	Leaves /essential oil	[68]
	Camphene	Monoterpene	Leaves /essential oil	[68]
	Myrcene	Monoterpene	Leaves /essential oil	[68]
	Menthatriene-1,3,8-para	Monoterpenoide	Leaves /essential oil	[68]
	p-Cymene	Monoterpene	Leaves essential oil	[68]
	Limonene	Monoterpene	Leaves /essential oil	[68]
	Eucalyptol	Monoterpenoid	Leaves /essential oil	[68]
	p-Cymenene	Monoterpene	Leaves /essential oil	[68]
	Linalool	Monoterpene	Leaves /essential oil	[68]
	Mentha-2,8-diene-1-ol transpara	Monoterpene	Leaves /essential oil	[68]
	Cis-imonene oxide	Monoterpene	Leaves /essential oil	[68]

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
<i>Cymbopogon goeringii</i> (Steud.) A.Camus	Mentha-2,8-diene-1-ol cis-para	Monoterpene	Leaves /essential oil	[68]
	Camphor	Monoterpene ketone	Leaves /essential oil	[68]
	Trans-limonene oxide	Monoterpene	Leaves /essential oil	[68]
	Cis-mentha-1(7),8-dien-2-ol	Monoterpene	Leaves /essential oil	[68]
	Cis-dihydrocarvone	Monoterpenoid	Leaves /essential oil	[68]
	Trans-dihydrocarvone	Monoterpenoid	Leaves /essential oil	[68]
	Cis-4-caranone	Monoterpene ketone	Leaves /essential oil	[68]
	Mentha-1(7),8-dien-2-ol trans	Monoterpene	Leaves /essential oil	[68]
	Carvone	Monoterpene	Leaves /essential oil	[68]
	Bornyl acetate	Monoterpene	Leaves /essential oil	[68]
	b-Caryophyllene	Sesquiterpene	Leaves /essential oil	[68]
	Trans a-bergamotene	Sesquiterpene	Leaves /essential oil	[68]
	$\alpha$ -Cubebene	Sesquiterpene	Leaves /essential oil	[68]
	Aromadendrene	Sesquiterpene	Leaves /essential oil	[68]
	$\alpha$ -Farnesene	Sesquiterpene	Leaves /essential oil	[68]
	Viridiflorene	Sesquiterpene	Leaves /essential oil	[68]
	Bicyclogermacrene	Sesquiterpene	Leaves /essential oil	[68]
	Spathulenol	Tricyclic sesquiterpene	Leaves /essential oil	[68]
	Caryophyllene oxide	Sesquiterpene	Leaves /essential oil	[68]
	epi globulol	Oxygenated diterpene	Leaves /essential oil	[68]
	$\beta$ -Myrcene	Monoterpene	Leaves /essential oil	[69]
	Linalool	Monoterpene	Leaves /essential oil	[69]
	Citronellal	Monoterpene	Leaves /essential oil	[69]
	Isopulegol	Monoterpene	Leaves /essential oil	[69]
	Citronellol	Monoterpene	Leaves /essential oil	[69]
	Neral	Monoterpene	Leaves /essential oil	[69]
	Geraniol	Monoterpene	Leaves /essential oil	[69]
	Geranial	Monoterpene	Leaves /essential oil	[69]
	Bornyl acetate	Monoterpene	Leaves /essential oil	[69]
	Citronellyl acetate	Monoterpene	Leaves /essential oil	[69]
	$\beta$ -Elemene	Sesquiterpene	Leaves /essential oil	[69]
	Geranyl acetate	Monoterpene	Leaves /essential oil	[69]
	Germacrene D	Sesquiterpene	Leaves /essential oil	[69]
	$\alpha$ -Murolene	Sesquiterpene	Leaves /essential oil	[69]
	$\delta$ -Cadinene	Bicyclic sesquiterpene	Leaves /essential oil	[69]
Elemol	Sesquiterpenoid	Leaves /essential oil	[69]	
$\alpha$ -Cadinol	Sesquiterpenoid alcohol	Leaves /essential oil	[69]	
<i>Cymbopogon jwarancusa</i>	Tricyclene	Monoterpene	Fruit/essential oil	[70]
	$\alpha$ -Pinene	Monoterpene	Fruit and root / essential oil	[70]
	Camphene	Monoterpene	Fruit and root/ essential oil	[70]
	$\beta$ -Pinene	Monoterpene	Fruit/ essential oil	[70]
	$\Delta$ -2-Carene	Bicyclic monoterpene	Root/ essential oil	[70]
	$\alpha$ -Terpinene	Monoterpene	Fruit/ essential oil	[70]
	p-Cymene	Monoterpene	Fruit/ essential oil	[70]
	Limonene	Monoterpene	Fruit and root/ essential oil	[70]
	Z- $\beta$ -Ocimene	Monoterpene	Root/ essential oil	[70]
	1-Phenyl-propanol	Phenylpropane	Fruit/ essential oil	[70]
	Cis-p-menth-2en-1-ol	Monoterpene	Root/ essential oil	[70]
	1-Terpineol	Monoterpene alcohol	Fruit/ essential oil	[70]
	Trans-p-menth-2en-1-ol	Monoterpene	Root/ essential oil	[70]
	Camphene hydrate	Monoterpene	Root/ essential oil	[70]
	Borneol	Terpene	Fruit and root/ essential oil	[70]
	$\alpha$ -Terpineol	Monoterpene alcohol	Fruit and root/ essential oil	[70]
	Neral	Monoterpene	Fruit/ essential oil	[70]
	Piperitone	Monoterpene ketone	Fruit and root/ essential oil	[70]
	1-Phenyl-propanol	Phenylpropanes	Fruit/ essential oil	[70]
	$\alpha$ -Copaene	Sesquiterpene	Root/ essential oil	[70]
	$\beta$ -Bourbonene	Sesquiterpenoid	Fruit/ essential oil	[70]
	$\beta$ -Elemene	Sesquiterpene	Fruit and root/ essential oil	[70]
	E-Caryophyllene	Sesquiterpene	Root/ essential oil	[70]
	Calarene	Sesquiterpene	Fruit/ essential oil	[70]
	$\alpha$ -Guaiene	Sesquiterpene	Root/ essential oil	[70]
	$\alpha$ -Himachalene	Sesquiterpene	Root/ essential oil	[70]
	$\alpha$ -Humulene	Sesquiterpene	Root/ essential oil	[70]
	$\gamma$ -Murolene	Sesquiterpene	Root/ essential oil	[70]

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
<i>Cymbopogon khasianus</i> (Hack.) Stapf ex Bor	Germacrene D	Sesquiterpene	Root/ essential oil	[70]
	cis- $\beta$ -Guaiene	Sesquiterpene	Root/ essential oil	[70]
	Valencene	Sesquiterpene	Root/ essential oil	[70]
	Murolene	Sesquiterpene	Root/ essential oil	[70]
	$\beta$ -Bisabolene	Sesquiterpene	Root/ essential oil	[70]
	$\gamma$ -Cadinene	Bicyclic Sesquiterpene	Root/ essential oil	[70]
	Cubebol	Sesquiterpene alcohol	Root/ essential oil	[70]
	$\delta$ -Cadinene	Bicyclic Sesquiterpene	Fruit and root / essential oil	[70]
	E- $\gamma$ -Bisabolene	Sesquiterpene	Root/ essential oil	[70]
	$\alpha$ -Cadinene	bicyclic Sesquiterpene	Root/ essential oil	[70]
	Elemol	sesquiterpenoid	Fruit and root/ essential oil	[70]
	Spathulenol	Tricyclic sesquiterpene	Fruit/ essential oil	[70]
	Caryophyllene oxide	Sesquiterpene	Fruit/ essential oil	[70]
	Widdrol	Sesquiterpene	Root/ essential oil	[70]
	5-epi-7-epi- $\alpha$ -Eudesmol	Sesquiterpenoid alcohols	Root/ essential oil	[70]
	Selina-6-en-4-ol	Sesquiterpene	Root/ essential oil	[70]
	$\gamma$ -Selinene	Sesquiterpene	Fruit/ essential oil	[70]
	$\gamma$ -Eudesmol	Sesquiterpene	Fruit and root/ essential oil	[70]
	Hinesol	Oxygenated Sesquiterpene	Fruit and root/ essential oil	[70]
	$\alpha$ -Murolol	Sesquiterpene	Root/ essential oil	[70]
	Agarospirol	Sesquiterpene	Root/ essential oil	[70]
	$\beta$ -Eudesmol	Sesquiterpene	Fruit and root/ essential oil	[70]
	Himachalo	Sesquiterpene	Fruit/ essential oil	[70]
	Intermedeol	Sesquiterpene	Root/ essential oil	[70]
	$\alpha$ -Bisabolol	Sesquiterpene	Root/ essential oil	[70]
	Cis-dihydro agarofuran	Sesquiterpene	Root/ essential oil	[70]
	Elemicin	Phenylpropene	Leaves /essential oil	[71]
	Cis-Asarone	Phenylpropanoid	Leaves /essential oil	[71]
	$\beta$ - ocimene	Monoterpene	Leaves /essential oil	[71]
	Methyl eugenol	Phenylpropanoid	Leaves /essential oil	[71]
	Limonene	Monoterpene	Leaves /essential oil	[71]
	Germacrene-D	Sesquiterpene	Leaves /essential oil	[71]
	Neral acetate	Monoterpene	Leaves /essential oil	[71]
	Camphene	Monoterpene	Leaves /essential oil	[71]
	$\alpha$ - pinene	Monoterpene	Leaves /essential oil	[71]
	Geranyl acetate	Monoterpene	Leaves /essential oil	[71]
	Caryophyllene	Sesquiterpene	Leaves /essential oil	[71]
	Trans- $\beta$ - farnesene	Sesquiterpene	Leaves /essential oil	[71]
	Isopentyl acetate	Ester	Whole plant/essential oil	[72]
	$\alpha$ -Pinene	Monoterpene	Whole plant/essential oil	[72]
	Camphene	Monoterpene	Whole plant/essential oil	[72]
1,8-Dehydro cineole	Monoterpenoid	Whole plant/essential oil	[72]	
$\delta$ -2-Carene	Bicyclic monoterpene	Whole plant/essential oil	[72]	
$\alpha$ -Phellandrene	Monoterpene	Whole plant/essential oil	[72]	
$\alpha$ -Terpinene	Monoterpene	Whole plant/essential oil	[72]	
p-Cymene	Monoterpene	Whole plant/essential oil	[72]	
imonene	Monoterpene	Whole plant/essential oil	[72]	
(Z)- $\beta$ -oCimene	Monoterpene	Whole plant/essential oil	[72]	
$\gamma$ -Terpinene	Monoterpene	Whole plant/essential oil	[72]	
m-Cymenene	Monoterpene	Whole plant/essential oil	[72]	
p-Mentha-2,4(8)-diene	Monoterpene	Whole plant/essential oil	[72]	
Linalool	Monoterpene	Whole plant/essential oil	[72]	
Trans-p-mentha-2,8-dien1-ol	Monoterpene	Whole plant/essential oil	[72]	
Cis-limonene oxide	Monoterpene	Whole plant/essential oil	[72]	
Allo-ocimene	Monoterpene	Whole plant/essential oil	[72]	
Camphor	Monoterpene ketone	Whole plant/essential oil	[72]	
Sabina ketone	ketone	Whole plant/essential oil	[72]	
Trans- $\beta$ -terpineol	Monoterpene alcohol	Whole plant/essential oil	[72]	
Terpinen-4-ol	Monoterpene alcohol	Whole plant/essential oil	[72]	
p-Methyl acetophenone	Phenolic compound	Whole plant/essential oil	[72]	
Trans-p-mentha-1(7),8dien-2-ol	Monoterpene	Whole plant/essential oil	[72]	
Dihydro carveol	Monoterpene	Whole plant/essential oil	[72]	
Cis-dihydro carveone	Monoterpene	Whole plant/essential oil	[72]	



Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference	
<i>Cymbopogon microstachys</i> (Hook.f.) Soenarko	Isopiperitenol†	Monoterpene	Whole plant/essential oil	[72]	
	Trans-Dihydro carvone	Monoterpene	Whole plant/essential oil	[72]	
	p-Menth-1-en-9-al	Monoterpene	Whole plant/essential oil	[72]	
	Verbenone	Terpene	Whole plant/essential oil	[72]	
	Trans-carveol	Monoterpenoid alcohol	Whole plant/essential oil	[72]	
	(Z)-Ocimenone	Monoterpene	Whole plant/essential oil	[72]	
	Cis-p-mentha-1(7),8-dien2-ol	Monoterpene	Whole plant/essential oil	[72]	
	Trans-chrysanthenyl acetate	Monoterpene	Whole plant/essential oil	[72]	
	Carvone	Monoterpene	Whole plant/essential oil	[72]	
	Isoamyl hexanoate	Ester	Whole plant/essential oil	[72]	
	Cis-carvone oxide	Monoterpene	Whole plant/essential oil	[72]	
	Perilla aldehyde	Monoterpenoid	Whole plant/essential oil	[72]	
	α-Terpinen-7-al		Whole plant/essential oil	[72]	
	Bornyl acetate	Monoterpene	Whole plant/essential oil	[72]	
	Trans-Pinocarvyl acetate	Ester	Whole plant/essential oil	[72]	
	Cis-Pinocarvyl acetate	Ester	Whole plant/essential oil	[72]	
	Myrtenyl acetate	Monoterpenoid	Whole plant/essential oil	[72]	
	Trans-carvyl acetate	Ester	Whole plant / essential oil	[72]	
	(E)-aryophyllene	Sesquiterpene	Whole plant/essential oil	[72]	
	Caryophyllene oxide	Sesquiterpene	Whole plant/essential oil	[72]	
	(E)-Methyl isoeugenol	Phenylpropanoid	Aerial part/essential oil	[73]	
	Myrcene	Monoterpene	Aerial part /essential oil	[73]	
	(Z)- and (E)-β-ocimene	Monoterpene	Aerial part /essential oil	[73]	
	Cis-α-bergamotene	Sesquiterpene	Aerial part /essential oil	[73]	
	Trans-α-bergamotene	Sesquiterpene	Aerial part /essential oil	[73]	
	Germacrene D	Sesquiterpene	Aerial part /essential oil	[73]	
	(Z,E)-α-Farnesene	Sesquiterpene	Aerial part /essential oil	[73]	
	<i>Cymbopogon pendulus</i> (Nees ex Steud.) W. Watson	3-Hexen-1-ol	Alcohol	Leaves /essential oil	[74]
		6-Methyl-5-hepten-2-one	Ketone	Leaves /essential oil	[74]
		Decanal	Aldehyde	Leaves /essential oil	[74]
		Undecanone	Ketone	Leaves /essential oil	[74]
		2-Tridecanone	Ketone	Leaves /essential oil	[74]
		Myrcene	Monoterpene	Leaves /essential oil	[74]
		Limonene	Monoterpene	Leaves /essential oil	[74]
Cis-ocimene		Monoterpene	Leaves /essential oil	[74]	
Trans-ocimene		Monoterpene	Leaves /essential oil	[74]	
Cis-linalool oxide		Monoterpenoid	Leaves /essential oil	[74]	
Trans-linalool oxide		Monoterpenoid	Leaves /essential oil	[74]	
Linalool		Monoterpene	Leaves /essential oil	[74]	
Exo-isocitral		Terpenoid	Leaves /essential oil	[74]	
(E)-Chrysanthenol		Monoterpene	Leaves /essential oil	[74]	
Citronellal		Monoterpene	Leaves /essential oil	[74]	
Chrysanthenone		Terpene	Leaves /essential oil	[74]	
α-Terpineol		Monoterpene alcohol	Leaves /essential oil	[74]	
Citronellol		Monoterpene	Leaves /essential oil	[74]	
Neral		Monoterpene	Leaves /essential oil	[74]	
Geraniol		Monoterpene	Leaves /essential oil	[74]	
Geranial		Monoterpene	Leaves /essential oil	[74]	
Citronellol acetate		Monoterpene	Leaves /essential oil	[74]	
Geranic acid		Monoterpene	Leaves /essential oil	[74]	
Geranyl acetate		Monoterpene	Leaves /essential oil	[74]	
Geranyl propanoate		Fatty esters	Leaves /essential oil	[74]	
Geranyl butanoate		Monoterpene	Leaves /essential oil	[74]	
Eugenol		Phenylpropanoid	Leaves /essential oil	[74]	
(E)- Isoeugenol		Phenylpropanoid	Leaves /essential oil	[74]	
β-Elemene		Sesquiterpene	Leaves /essential oil	[74]	
β-Caryophyllene		Sesquiterpene	Leaves /essential oil	[74]	
(E)-α-Bergamotene		Sesquiterpene	Leaves /essential oil	[74]	
(E)-β-Farnesene		Sesquiterpene	Leaves /essential oil	[74]	
α-Humulene		Monocyclic sesquiterpene	Leaves /essential oil	[74]	
(Z)-β-Farnesene		Sesquiterpene	Leaves /essential oil	[74]	
Germacrene-D	Sesquiterpene	Leaves /essential oil	[74]		
α-Murolene	Sesquiterpene	Leaves /essential oil	[74]		
γ-Cadinene	Bicyclic Sesquiterpene	Leaves /essential oil	[74]		
δ-Cadinene	Bicyclic Sesquiterpene	Leaves /essential oil	[74]		

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
<i>Cymbopogon pospischilii</i> (K. Schum.) C.E. Hubb.	Hedycaryol	Oxygenated sesquiterpene	Leaves /essential oil	[74]
	Germacrene D-4-ol	Sesquiterpenoid	Leaves /essential oil	[74]
	Caryophyllene oxide	Sesquiterpene	Leaves /essential oil	[74]
	Humulene epoxide II	Sesquiterpene	Leaves /essential oil	[74]
	$\beta$ -Eudesmol	Sesquiterpene	Leaves /essential oil	[74]
	$\tau$ -Muurolol	Sesquiterpene	Leaves /essential oil	[74]
	$\alpha$ -Eudesmol	Sesquiterpene	Leaves /essential oil	[74]
	$\alpha$ -Cadinol	Sesquiterpenoid alcohol	Leaves /essential oil	[74]
	Z,Z-Farnesal	Sesquiterpenoid	Leaves /essential oil	[74]
	E,Z-Farnesal	Sesquiterpenoid	Leaves /essential oil	[74]
	2-Hexenal	Aldehyde	Leaves /essential oil	[75]
	Heptanal	Aldehyde	Leaves /essential oil	[75]
	3-Carene	Bicyclic monoterpene	Leaves /essential oil	[75]
	$\alpha$ -Pinene	Monoterpene	Leaves /essential oil	[75]
	Camphene	Monoterpene	Leaves /essential oil	[75]
	Benzaldehyde	Aldehyde	Leaves /essential oil	[75]
	$\beta$ -Phellandrene	Monoterpene	Leaves /essential oil	[75]
	$\beta$ -Myrcene	Monoterpene	Leaves /essential oil	[75]
	2-Carene	Bicyclic monoterpene	Leaves /essential oil	[75]
	(+)-4-Carene	Bicyclic monoterpene	Leaves /essential oil	[75]
	D-Limonene	Monoterpene	Leaves /essential oil	[75]
	$\beta$ -Ocimene	Monoterpene	Leaves /essential oil	[75]
	1-Octanol	Fatty alcohol	Leaves /essential oil	[75]
	4-Nonanol	Fatty alcohol	Leaves /essential oil	[75]
	6-Undecanol	Alcohol	Leaves /essential oil	[75]
	Linalyl acetate	Ester	Leaves /essential oil	[75]
	Carveol	Monoterpenoid alcohol	Leaves /essential oil	[75]
	2-Cyclohexen-1-ol	Oxygenated monoterpenes	Leaves /essential oil	[75]
	3-Tetradecyn-1-ol	Hydrocarbone alcohol	Leaves /essential oil	[75]
	Camphor	Monoterpene ketone	Leaves /essential oil	[75]
	Geraniol	Monoterpene	Leaves /essential oil	[75]
	1,3,5-Cycloheptadiene	Hydrocarbone	Leaves /essential oil	[75]
	endo-Borneol	Terpene	Leaves /essential oil	[75]
	Benzenamine,3-ethoxy	Amine	Leaves /essential oil	[75]
	$\alpha$ -Terpineol	Monoterpene alcohol	Leaves /essential oil	[75]
	N-(2-Methyl-propenyl) pyrrolidin-2-one	Pyrrolidin	Leaves /essential oil	[75]
	Photocitral B	Terpenoid	Leaves /essential oil	[75]
	3-Cyclohexen-1-ol	Oxygenated monoterpenes	Leaves /essential oil	[75]
	Bornyl acetate	Monoterpene	Leaves /essential oil	[75]
	Hexanoic acid	Carboxylic acid	Leaves /essential oil	[75]
	Furan	Heterocyclic organic compound	Leaves /essential oil	[75]
	9-Hexadecenoic acid	Trans fatty acid	Leaves /essential oil	[75]
	$\alpha$ -Ionone	Ketone	Leaves /essential oil	[75]
	3-Nonen-1-ol	Hydrocarbone alcohol	Leaves /essential oil	[75]
	Geranyl acetate	Monoterpene	Leaves /essential oil	[75]
	Epizonarene	Sesquiterpene	Leaves /essential oil	[75]
	Cycloheptane, 4methylene-1- methyl-2(2-methyl-1-propen- 1vinyl	Sesquiterpene	Leaves /essential oil	[75]
	Nephtalene	Aromatic hydrocarbon	Leaves /essential oil	[75]
	Caryophyllene	Sesquiterpene	Leaves /essential oil	[75]
	$\alpha$ -Guaiene	Sesquiterpene	Leaves /essential oil	[75]
	Isoledene	Sesquiterpene	Leaves /essential oil	[75]
	2,3-Octanedione	Ketone	Leaves /essential oil	[75]
Humulene	Monocyclic sesquiterpene	Leaves /essential oil	[75]	
$\beta$ -Coopaene	Sesquiterpene	Leaves /essential oil	[75]	
Alloaromadendrene	Sesquiterpene	Leaves /essential oil	[75]	
4-Epi-cubedol	Sesquiterpene	Leaves /essential oil	[75]	
Cycloprop (e) azulene	Sesquiterpene	Leaves /essential oil	[75]	
Nerolidol 2	Sesquiterpene	Leaves /essential oil	[75]	
Trifluoroacetyl-afenchol	Monoterpene	Leaves /essential oil	[75]	

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
	Caryophyllene oxide	Sesquiterpene	Leaves /essential oil	[75]
	Ethanopentalen-4-ol	Hydrocarbone	Leaves /essential oil	[75]
	Tau-Cadinol	Sesquiterpenoid alcohol	Leaves /essential oil	[75]
	Tau-Muurolol	Sesquiterpene	Leaves /essential oil	[75]
	Delta - Selinene	Sesquiterpene	Leaves /essential oil	[75]
	Trans- $\alpha$ -Bergamotene	Sesquiterpene	Leaves /essential oil	[75]
	Pyrazole	Heterocycle organic compound	Leaves /essential oil	[75]
	$\beta$ -Pinene	Monoterpene	Leaves /essential oil	[75]
	$\beta$ -Santalol	Sesquiterpene	Leaves /essential oil	[75]
	Isoaromadendrene epoxide	Sesquiterpene	Leaves /essential oil	[75]
	Phytol acetate	Diterpenes	Leaves /essential oil	[75]
	Epiglobulol	Oxygenated diterpenes	Leaves /essential oil	[75]
	Diethyl ether	Ether	Leaves /essential oil	[75]
	Shizukanolide	Sesquiterpene	Leaves /essential oil	[75]
	2-Ethylacridine	Alkaloid	Leaves /essential oil	[75]
	Heptasiloxane	Organosiloxane	Leaves /essential oil	[75]
	Octasiloxane	Organosiloxane	Leaves /essential oil	[75]
	Cyclotrisiloxane	Organosiloxane	Leaves /essential oil	[75]
	1,3,5-Hexatriene	Hydrocarbone	Leaves /essential oil	[75]
	Citronella	Monoterpene	Leaves/ essential oil	[76]
	$\delta$ -Cadinene	Bicyclic Sesquiterpene	Leaves/ essential oil	[76]
	Methyl Isoeugenol	Phenylpropanoids	Leaves/ essential oil	[76]
	Caryophyllene	Sesquiterpene	Leaves/ essential oil	[76]
	Geranyl butyrate	Ester	Leaves/ essential oil	[76]
	Geranyl acetate	Monoterpene	Leaves/ essential oil	[76]
	Citronellyl propionate	Monoterpene	Leaves/ essential oil	[76]
	Germacrene-D	Sesquiterpene	Leaves/ essential oil	[76]
	$\alpha$ -Bergamotene	Sesquiterpene	Leaves/ essential oil	[76]
	Eugenol	Phenylpropanoids	Leaves/ essential oil	[76]
	$\beta$ -Elemene	Sesquiterpene	Leaves/ essential oil	[76]
	$\delta$ -Guaiene	Guaiene	Leaves/ essential oil	[76]
	(-)-Isolongifolof	Sesquiterpene	Leaves/ essential oil	[76]
	Farnesol Isomer B	Sesquiterpene	Leaves/ essential oil	[76]
	Linalool	Monoterpene	Leaves/ essential oil	[76]
	$\delta$ -Limonene	Monoterpene	Leaves/ essential oil	[76]
	1,2,4-Metheno-1H-indene, octahydro-1,7a-dimethyl-5-(1-methylethyl)	Sesquiterpene	Leaves/ essential oil	[76]
	Geranyl hexanoate	Monoterpene ester	Leaves/ essential oil	[76]
	$\alpha$ -Humulene	Monocyclic sesquiterpene	Leaves/ essential oil	[76]
	Citral	Terpenoid	Leaves/ essential oil	[76]
	$\gamma$ -Cadinene	Bicyclic Sesquiterpene	Leaves/ essential oil	[76]
<i>Cymbopogon nardus</i>	Epi-Bicyclosesquiphellandrene	Sesquiterpene	Leaves/ essential oil	[76]
	$\alpha$ -Guaiene	Sesquiterpene	Leaves/ essential oil	[76]
	Trans- $\beta$ -farnesene	Sesquiterpene	Leaves/ essential oil	[76]
	3a(1H)-Azulenol, 2,3,4,5,8,8a-hexahydro-6,8a-dimethyl-3-(1-methyl ethyl)	Sesquiterpene	Leaves/ essential oil	[76]
	Z-Citral	Terpenoid	Leaves/ essential oil	[76]
	Naphthalene	Aromatic hydrocarbon	Leaves/ essential oil	[76]
	Seychellene	Sesquiterpene	Leaves/ essential oil	[76]
	Cis-ocimene	Monoterpene	Leaves/ essential oil	[76]
	$\beta$ -Ocimene	Monoterpene	Leaves/ essential oil	[76]
	1,2,4-Metheno-1H-indene, octahydro-1,7a-dimethyl-5-(1-methyl ethyl)	Sesquiterpene	Leaves/ essential oil	[76]
	2-N-Butyldecalin	Hydrocarbone	Leaves/ essential oil	[76]
	$\beta$ -Myrcene	Monoterpene	Leaves/ essential oil	[76]
	$\alpha$ -Patchoulene	Sesquiterpene	Leaves/ essential oil	[76]
	n-Decanal	Aldehyde	Leaves/ essential oil	[76]
	Neryl acetate	Monoterpene	Leaves/ essential oil	[76]
	$\beta$ -Sesquiphellandrene	Sesquiterpene	Leaves/ essential oil	[76]
	$\beta$ -Patchoulene	Sesquiterpene	Leaves/ essential oil	[76]
	Naphthalene, 1,2,3,4,4a,7-hexahydro-1,6-dimethyl-4-(1-methyl ethyl)	Hydrocarbone	Leaves/ essential oil	[76]

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
<i>Cymbopogon schoenanthus</i> (L.) Spreng.	Thiogeraniol	Monoterpene	Leaves/ essential oil	[76]
	(-)-Caryophyllene oxide	Sesquiterpene	Leaves/ essential oil	[76]
	$\alpha$ -Cubebene	Sesquiterpene	Leaves/ essential oil	[76]
	Germacrene B	Sesquiterpene	Leaves/ essential oil	[76]
	Citronellyl butyrate	Ester	Leaves/ essential oil	[76]
	B-Bourbonene	Sesquiterpenoid	Leaves/ essential oil	[76]
	Neophytadiene	Diterpene	Leaves/ essential oil	[76]
	Isomenthone	Monoterpenoid	Leaves/ essential oil	[76]
	$\beta$ -Selinene	Sesquiterpene	Leaves/ essential oil	[76]
	Geraniol formate	Ester	Leaves/ essential oil	[76]
	Geranyl Isovalerate	Monoterpene hydrocarbone	Leaves/ essential oil	[76]
	n-Dodecanal	Aldehyde	Leaves/ essential oil	[76]
	$\delta$ -Elemene	Sesquiterpene	Leaves/ essential oil	[76]
	Verbenene	Terpene	Leaves /essential oil	[77]
	Cis-meta-mentha-2,8-diene	Monoterpene	Leaves /essential oil	[77]
	Dehydro-1,8-Cineole	Monoterpenoid	Leaves /essential oil	[77]
	$\delta$ -2- Carene	Bicyclic monoterpene	Leaves /essential oil	[77]
	$\delta$ -3-Carene	Bicyclic monoterpene	Leaves /essential oil	[77]
	$\alpha$ -Terpinene	Monoterpene	Leaves /essential oil	[77]
	p-Cymene	Monoterpene	Leaves /essential oil	[77]
	Sylvestrene	Monoterpene hydrocarbon	Leaves /essential oil	[77]
	Z- $\beta$ -Ocimene	Monoterpene	Leaves /essential oil	[77]
	$\gamma$ -Terpinene	Monoterpene	Leaves /essential oil	[77]
	Terpinolene	Monoterpene	Leaves /essential oil	[77]
	p-Cymenene	Monoterpene	Leaves /essential oil	[77]
	Exo-Fenchol	Monoterpene	Leaves /essential oil	[77]
	Allo-ocimene	Monoterpene	Leaves /essential oil	[77]
	Cis-Verbenol	Monoterpene	Leaves /essential oil	[77]
	Isopulegol	Monoterpene	Leaves /essential oil	[77]
	p-Mentha-1,5-dien-8-ol	Monoterpene	Leaves /essential oil	[77]
	Terpinen-4-ol	Monoterpene alcohol	Leaves /essential oil	[77]
	Cryptone	Monoterpene	Leaves /essential oil	[77]
	Cis - Piperitol	Monoterpene	Leaves /essential oil	[77]
	p-Cymen-9-ol	Monoterpene	Leaves /essential oil	[77]
	Trans- Piperitol	Monoterpene	Leaves /essential oil	[77]
	Trans-Carveol	Monoterpenoid alcohol	Leaves /essential oil	[77]
	Neo iso-dihydro carveol	Monoterpene	Leaves /essential oil	[77]
	Cumin aldehyde	Monoterpene	Leaves /essential oil	[77]
	Car-3-en-2-one	Monoterpene	Leaves /essential oil	[77]
	Piperitone	Monoterpene ketone	Leaves /essential oil	[77]
	p-Menth-1-en-7-al	Monoterpene	Leaves /essential oil	[77]
	3'-methoxy-Acetophenone	Phenolic compound	Leaves /essential oil	[77]
	p-Menth-1-en-9-ol	Monoterpene	Leaves /essential oil	[77]
	$\delta$ -Elemene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Cubebene	Sesquiterpene	Leaves /essential oil	[77]
	Neo iso dihydro carveol acetate	Monoterpene	Leaves /essential oil	[77]
	$\alpha$ -Ylangene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Copaene	Sesquiterpene	Leaves /essential oil	[77]
	Modheph-2-ene	Sesquiterpene	Leaves /essential oil	[77]
	$\beta$ -Bourborene	Sesquiterpenoid	Leaves /essential oil	[77]
	$\beta$ - Elemene	Sesquiterpene	Leaves /essential oil	[77]
	$\beta$ -Longipinene	Sesquiterpene	Leaves /essential oil	[77]
	$\beta$ -Cedrene	Sesquiterpene	Leaves /essential oil	[77]
	$\beta$ -Duprezianene	Sesquiterpene	Leaves /essential oil	[77]
	Cis-Thujopsene	Sesquiterpene	Leaves /essential oil	[77]
	$\beta$ -Gurjunene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Guaiene	Sesquiterpene	Leaves /essential oil	[77]
	6,9-Guaiadiene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Himachalene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -neo-Clovene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Humulene	Monocyclic sesquiterpene	Leaves /essential oil	[77]
	Allo-Aromadendrene	Sesquiterpene	Leaves /essential oil	[77]
	Cis-Muurola-4(14),5-diene	Sesquiterpene	Leaves /essential oil	[77]

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
	Cis-Thujopsadiene	Sesquiterpene	Leaves /essential oil	[77]
	$\gamma$ -Muurolene	Sesquiterpene	Leaves /essential oil	[77]
	Germacrene D	Sesquiterpene	Leaves /essential oil	[77]
	Aristolochene	Sesquiterpene	Leaves /essential oil	[77]
	Epi-Cubebol	Sesquiterpene alcohol	Leaves /essential oil	[77]
	$\alpha$ -Muurolene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Bulnesene	Sesquiterpene	Leaves /essential oil	[77]
	Modhephene-8- $\beta$ -ol	Sesquiterpene	Leaves /essential oil	[77]
	Nootkatene	Sesquiterpene	Leaves /essential oil	[77]
	7-epi- $\alpha$ -Selinene	Sesquiterpene	Leaves /essential oil	[77]
	$\delta$ -Cadinene	Bicyclic Sesquiterpene	Leaves /essential oil	[77]
	(E)-Iso- $\gamma$ -bisabolene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Cadinene	Bicyclic Sesquiterpene	Leaves /essential oil	[77]
	Selina-3,7(11)-diene	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Calacorene	Sesquiterpene	Leaves /essential oil	[77]
	Trans- dauca-4(11),7-diene	Sesquiterpene	Leaves /essential oil	[77]
	$\beta$ -Calacorene	Sesquiterpene	Leaves /essential oil	[77]
	1 $\alpha$ ,10 $\alpha$ -epoxy-Amorph-4-ene	Sesquiterpene	Leaves /essential oil	[77]
	Germacrene D-4-ol	Sesquiterpene	Leaves /essential oil	[77]
	Caryophyllene oxide	Sesquiterpene	Leaves /essential oil	[77]
	Cis-dihydro-Mayurone	Sesquiterpene	Leaves /essential oil	[77]
	Guaiol	Sesquiterpene	Leaves /essential oil	[77]
	5-Epi-7-epi- $\alpha$ -eudesmol	Sesquiterpene	Leaves /essential oil	[77]
	1,10-Di-epi-Cubenol	Sesquiterpene	Leaves /essential oil	[77]
	1-epi-cubenol	Sesquiterpene	Leaves /essential oil	[77]
	$\gamma$ -Eudesmol	Sesquiterpene	Leaves /essential oil	[77]
	Hinesol	Oxygenated Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Muurolol	Sesquiterpene	Leaves /essential oil	[77]
	Cubenol	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Cadinol	Sesquiterpenoid alcohol	Leaves /essential oil	[77]
	$\alpha$ -Eudesmol	Sesquiterpene	Leaves /essential oil	[77]
	7-epi- $\alpha$ -Eudesmol	Sesquiterpene	Leaves /essential oil	[77]
	Longiborneol acetate	Sesquiterpene	Leaves /essential oil	[77]
	Cadalene	Sesquiterpene	Leaves /essential oil	[77]
	Eudesma-4(15),7-dien-1 $\beta$ -ol	Sesquiterpenoid alcohol	Leaves /essential oil	[77]
	Acorenone	Sesquiterpene	Leaves /essential oil	[77]
	Amorpha-4,9-diene-2-ol	Sesquiterpene	Leaves /essential oil	[77]
	Eudesm-7(11)-en-4-ol	Sesquiterpenoid alcohols	Leaves /essential oil	[77]
	10-nor-Calamenen-10-one	Sesquiterpene	Leaves /essential oil	[77]
	Mayurone	Sesquiterpenoid ketone	Leaves /essential oil	[77]
	iso-Longifolol	Sesquiterpene	Leaves /essential oil	[77]
	Curcumenol	Sesquiterpenoid	Leaves /essential oil	[77]
	7, 14-Anhydro-amorpha-4,9-diene	Sesquiterpene	Leaves /essential oil	[77]
	Cyclocolorenone	Sesquiterpenoid	Leaves /essential oil	[77]
	Aristolone	Sesquiterpene	Leaves /essential oil	[77]
	14-hydroxy- $\alpha$ -Muurolene	Sesquiterpene	Leaves /essential oil	[77]
	(E)-Isovalencenol	Sesquiterpene	Leaves /essential oil	[77]
	14-Hydroxy- $\delta$ -cadinene	Sesquiterpene	Leaves /essential oil	[77]
	iso-Longifololacetate	Sesquiterpene	Leaves /essential oil	[77]
	Cryptomeridiol	Sesquiterpene	Leaves /essential oil	[77]
	$\beta$ -Vetivone	Sesquiterpene	Leaves /essential oil	[77]
	Eudesm-7(11)-en-4-ol, acetate	Sesquiterpenoid alcohol	Leaves /essential oil	[77]
	(2E,6E)-Farnesyl acetate	Sesquiterpene	Leaves /essential oil	[77]
	$\alpha$ -Chenopodiol	Sesquiterpene	Leaves /essential oil	[77]
	Cubitene	Diterpene	Leaves /essential oil	[77]
	Totarene	Diterpene	Leaves /essential oil	[77]
	Carissone	Sesquiterpene	Leaves /essential oil	[77]
	Z,E-Geranyl linalool	Diterpene	Leaves /essential oil	[77]
	Heptanal	Aldehyde	Leaves /essential oil	[78]
	Camphene	Monoterpene	Leaves /essential oil	[78]
<i>Cymbopogon tortilis</i> (J. Presl) A. Camus	6-Methylhept-5-en-2-one	Ketone	Leaves /essential oil	[78]
	Octanal	Aldehyde	Leaves /essential oil	[78]
	p-Cymene	Monoterpene	Leaves /essential oil	[78]
	Limonene	Monoterpene	Leaves /essential oil	[78]

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
	Cis-linalool oxide THF	Monoterpenoid	Leaves /essential oil	[78]
	Trans-linalool oxide THF	Monoterpenoid	Leaves /essential oil	[78]
	Linalol	Monoterpene	Leaves /essential oil	[78]
	Citronellal	Monoterpene	Leaves /essential oil	[78]
	Borneol	Terpene	Leaves /essential oil	[78]
	Pinocampheol	Monoterpene	Leaves /essential oil	[78]
	a-Terpineol	Monoterpene alcohol	Leaves /essential oil	[78]
	Decanal	Aldehyde	Leaves /essential oil	[78]
	2,3-Epoxyneral	Monoterpene	Leaves /essential oil	[78]
	2,3-Epoxygeranial	Monoterpene	Leaves /essential oil	[78]
	Nerol	Monoterpene	Leaves /essential oil	[78]
	Neral	Monoterpene	Leaves /essential oil	[78]
	Piperitone	Monoterpene ketone	Leaves /essential oil	[78]
	Geraniol	Monoterpene	Leaves /essential oil	[78]
	Geranial	Monoterpene	Leaves /essential oil	[78]
	Trans-7-hydroxy-3,7-dimethyl-3,6-oxyoctanal	Aldehyde	Leaves /essential oil	[78]
	Cis-7-hydroxy-3,7-dimethyl-3,6-oxyoctanal	Aldehyde	Leaves /essential oil	[78]
	Neryl formate	Monoterpene	Leaves /essential oil	[78]
	Lavandulyl acetate	Monoterpene	Leaves /essential oil	[78]
	Isoascaridole	Monoterpene	Leaves /essential oil	[78]
	6,7-Epoxyneral	Monoterpene	Leaves /essential oil	[78]
	Methyl geraniate	Monoterpene	Leaves /essential oil	[78]
	6,7-Epoxygeranial	Monoterpene	Leaves /essential oil	[78]
	Neryl acetate	Monoterpene	Leaves /essential oil	[78]
	Eugenol	Phenylpropanoid	Leaves /essential oil	[78]
	Geranic acid	Monoterpene	Leaves /essential oil	[78]
	Geranyl acetate	Monoterpene	Leaves /essential oil	[78]
	b-Elemene	Sesquiterpene	Leaves /essential oil	[78]
	Trans-a-bergamotene	Sesquiterpene	Leaves /essential oil	[78]
	1,5-Diepi-aristolochene	Sesquiterpene	Leaves /essential oil	[78]
	Tridecan-2-one	Ketone	Leaves /essential oil	[78]
	(Z,E)-a-Farnesene	Sesquiterpene	Leaves /essential oil	[78]
	c-Cadinene	Bicyclic Sesquiterpene	Leaves /essential oil	[78]
	d-Cadinene	Bicyclic Sesquiterpene	Leaves /essential oil	[78]
	Cuparene	Sesquiterpene	Leaves /essential oil	[78]
	b-Elemol	Sesquiterpenoid	Leaves /essential oil	[78]
	Caryophyllene oxide	Sesquiterpene	Leaves /essential oil	[78]
	Humulene epoxide	Sesquiterpene	Leaves /essential oil	[78]
	a-Cadinol	Sesquiterpenoid alcohol	Leaves /essential oil	[78]
	(2E,6E)-Farnesol	Sesquiterpene	Leaves /essential oil	[78]
	$\beta$ -Elemene	Sesquiterpene	Leaves / essential oil	[79]
	$\alpha$ -Muurolene	Sesquiterpene	Leaves / essential oil	[79]
	Germacrene D	Sesquiterpene	Leaves / essential oil	[79]
	$\beta$ -Copaene	Sesquiterpene	Leaves / essential oil	[79]
	$\gamma$ -Cadinene	Bicyclic Sesquiterpene	Leaves / essential oil	[79]
	Squalene	Triterpene	Leaves / essential oil	[79]
	Linalool	Monoterpene	Leaves / essential oil	[79]
	Melonol	Monoterpene	Leaves / essential oil	[79]
	Citronellal	Monoterpene	Leaves / essential oil	[79]
	Dihydrocarveol	Monoterpene	Leaves / essential oil	[79]
	Citronellol	Monoterpene	Leaves / essential oil	[79]
	$\alpha$ -Citral	Terpenoid	Leaves / essential oil	[79]
	Neryl formate	Monoterpene	Leaves / essential oil	[79]
	Citronellol acetate	Monoterpene	Leaves / essential oil	[79]
	Isopulegol hydrate	Monoterpene	Leaves / essential oil	[79]
	Eugenol	Phenylpropanoid	Leaves / essential oil	[79]
	Geranyl acetate	Monoterpene	Leaves / essential oil	[79]
	Cadinol acetate	Sesquiterpene	Leaves / essential oil	[79]
	Trans-cubebol	Sesquiterpene alcohol	Leaves / essential oil	[79]
	$\alpha$ -Acorenol	Sesquiterpene	Leaves / essential oil	[79]
	Elemol	Sesquiterpenoid	Leaves / essential oil	[79]
	Germacrene d-4-ol	Diterpene	Leaves / essential oil	[79]
	Geranyl geraniol acetate	Sesquiterpene	Leaves / essential oil	[79]
	Guaiol	Sesquiterpene	Leaves / essential oil	[79]

*Cymbopogon winterianus* Jowitt ex Bor

Table 2. Continued

Plant	Phytochemical name	Phytochemical category	Part/extract	Reference
	t-Farnesol	Sesquiterpene	Leaves / essential oil	[79]
	$\beta$ -Eudesmol	Sesquiterpene	Leaves / essential oil	[79]
	Caryophyllene oxide	Sesquiterpene	Leaves / essential oil	[79]
	Epicubanol	Sesquiterpene	Leaves / essential oil	[79]
	$\gamma$ -Eudesmol	Sesquiterpene	Leaves / essential oil	[79]
	Muurolol	Sesquiterpene	Leaves / essential oil	[79]
	$\alpha$ -Cadinol	Sesquiterpenoid alcohol	Leaves / essential oil	[79]
	5-Cyclodecen-1-ol	Monoterpene	Leaves / essential oil	[79]
	Eudesmol-4,11-diene-2-ol	Sesquiterpene	Leaves / essential oil	[79]
	Iso-spathulenol	Tricyclic sesquiterpene	Leaves / essential oil	[79]
	Oplopanone	Sesquiterpene	Leaves / essential oil	[79]
	Viridiflorol	Sesquiterpene	Leaves / essential oil	[79]
	2-Naphthalenemethanol	Hydrocarbone	Leaves / essential oil	[79]

### Monoterpenes

According to Bayala et al. (2018), predominant constituents of *C. citratus* EO are geranial or citral A (48.18%) followed by neral or citral B (34.37%) and myrcene (5.37%) which shows monoterpene aldehydes (83.75%) are the most prevailing in the EO of *C. citratus*. Similar results have been reported by Brugger et al. and Jain et al. [80,65]. Bayala et al. reported monoterpene alcohols (46.59%) and hydrocarbons (21.31%) are the main terpenes of *C. giganteus* EO. The major compounds in *C. giganteus* EO were limonene (19.33%), mentha-1(7), 8-dien-2-ol cis (17.34%), mentha-1(7), 8-dien-2-ol trans (13.95%), and trans-para-mentha-2,8-diene-1-ol (13.91%) [68]. Chauhan et al. reported seven monoterpenes as the main constituents of *C. distans* EO: geranial (20.3–25.9%), neral (13.2–17.5%), geraniol (15.3–18.6%), geranyl acetate (17.2–23.0%), limonene (3.1–4.4%), nerol (0.8–1.5%), and camphene (1.4–2.4%). According to this article, type of post-harvest storage can affect the percentage of these monoterpenes but not the quality of the EO [81].

According to Balti et al., geranial and neral are the frequent monoterpenes identified in the EO of the *C. flexuosus* leaves. The temperature of drying process and ultrasonic pretreatment affected the EOs extraction yield and citral percentage. The greatest number of compounds (23 compounds) was found with high ultrasonic power with lowest temperature [82].

Huang et al. introduced citronellal as the most frequent compound in the EO of *C. goeringii* leaves [69].

Asgarpanah et al. reported that there are differences between the EO compounds of the fruit and roots of *C. jwarancusa* growing in south of Iran. The main constituents of fruit EO were piperitone (44.1%) and  $\alpha$ -terpinene (13.7%);

while the major compounds of roots were piperitone (20.6%),  $\alpha$ -muurolol (9.5%), and  $\beta$ -eudesmol (8.5%). [70]

### Sesquiterpenes

According to Omoruyi et al., whole amount of sesquiterpene hydrocarbons of *C. pospischilii* was 14.26%. Delta-selinene (8.50%) was detected as the highest amount while total amount of oxygenated sesquiterpenes was 11.6% and nerolidol 2 (13.6%) was found as the highest level. Bellik et al. reported that oxygenated sesquiterpenes (30.28–50.37%) followed by sesquiterpenes hydrocarbons (23.49–29.63%) were dominant in leaves EO of *C. schoenanthus* L. Spreng. In addition, EO extraction method has remarkable influenced EO compositions. As reported, oxygenated sesquiterpenes were available in major quantity with hydrodistillation method (50.37%) in comparison with microwave techniques (microwave assisted hydrodistillation (MAHD) and microwave assisted steam distillation (MASD) [77].

It is interesting to know the main compounds of *C. citratus* roots were totally different from the shoots. According to Li. et al., the predominant compounds of *C. citratus* roots were longifolene-(V4) (56.67% of the total) and selina-6-en-4-ol (20.03%) and other components were less than 10 percent whereas all the terpenes in the EO from roots were sesquiterpenes [83].

### Phenylpropanoids

Grice et al. reported four phenylpropanoids in dichloromethane extract of *C. ambiguous* called eugenol, elemicin, eugenol methylether and trans-isoelemicin [64].

Rana et al. also reported three phenylpropanoids in *C. flexuosus*, called eugenol(Z)- isoeugenol (E)-

Isoeugenol; however, they exist in lesser amount (0.0– 1.8%) in comparison with monoterpenes [74].

### Miscellaneous compounds

In addition to the compounds described in the previous sections, other compounds have been detected in the EO of these species such as ketones, fatty alcohols, aldehydes, etc.

### Pharmacological activities of *Cymbopogon* species

#### Antimicrobial, antiparasitic and insecticidal effects

Methanolic extract of *C. citratus* revealed antibacterial activity against some bacterial species. The most potent antibacterial activity was recorded against *Bacillus* species and *Escherichia coli* (*E. coli*) [84]. However, its EO was extremely active against *Staphylococcus aureus* and *E. coli* and showed no significant activity on *Bacillus* species [85]. The essential oil showed inhibitory activity against oral pathogens [33]. EO and some fractions of methanolic extract from *C. citratus* inhibited the growth of *Mycobacterium tuberculosis* [86]. The antibacterial effects of other *Cymbopogon* species have been demonstrated in supplementary table.

No anti-candidiasis activity was recorded for *C. citratus* extract [87]. However, EO of *C. citratus* leaves demonstrated strong antifungal activity against *C. albicans* and dermatophytes [80,88]. Aw shampoo made from EO of *C. citratus* exhibited anti-malassezia activity and was suggested as a candidate for treatment of dandruff [89]. Essential oil of *C. martinii* showed antifungal activity against some species especially *Trichophyton mentagrophytes* [90]; EO of *C. nardus* eradicated *C. albicans* colonization on diabetic wounds [91] while EO of *C. flexuosus* demonstrated antifungal activity against *Trichosporon ovoides* [92]. The essential oil of *C. winterianus* exhibited antifungal activity against some fungal species [93,94].

Aqueous extract of *C. citratus* leaves demonstrated giardicidal activity in mice infected by *Giardia lamblia* which was comparable to metronidazole [95]. *Cymbopogon citratus* exhibited higher antimalarial activity against both *Plasmodium chabaudi* and *Plasmodium berghei* than chloroquine [96]. Isolated compounds from

EO of *C. schoenanthus* demonstrated antiparasitic activity against *Trypanosoma brucei brucei* [97]. Essential oil of *C. jwarancusa* showed interesting activity against larvae of *Anopheles stephensi* [98] And EO of *C. schoenanthus* demonstrated insecticidal activity against *Anopheles gambiae* [99]. The piperitone-rich EO of *C. schoenanthus* showed to be effective against *Callosobrochus maculatus* [100]. The insecticidal activity of other *Cymbopogon* species is demonstrated in supplementary table.

#### Antiviral activity

Methanolic extract of *C. citratus* showed in vitro antiviral activity against Dengue virus and the EO inhibited human immunodeficiency virus (HIV-1) transcription [101]; moreover, EO showed strong antiviral activity against HSV-1 and HSV-2 [102].

#### Effect on cardiovascular system

Dichloromethane extract of *C. ambiguous* demonstrated in vitro antiplatelet activity which was mostly attributed to its eugenol content [64]. Also, EO from *C. citratus* exhibited antiplatelet effects [103]. Methanolic extract of *C. citratus* and its active component, citral, revealed a dose-dependent relaxant activity on endothelial vasoconstriction via nitric oxide (NO) pathway and involvement of prostacyclin [104]. Methanolic extract of *C. schoenanthus* subsp. *proximus* and EO of *C. winterianus* caused dose-dependent hypotension [105]. Citronellol, one of the main compounds of EO, induced hypotension associated with tachycardia in rats. Its hypotensive activity seemed to be mediated via blocking the calcium channel [106]. Ethanol extract of *C. citratus* demonstrated cardioprotective activity against isoproterenol-induced cardiotoxicity through reduction of cardiac markers in serum and heart tissue [107].

#### Anticancer and antimutagenic effects

Essential oil from *C. citratus* leaf exhibited anti-proliferative effect against tumor prostate cell lines and glioblastoma cell lines [68]. Furthermore, it reduced early development of proliferative/preneoplastic lesions in mammary gland, colon, and urinary bladder of mice via apoptotic activity [108]. Essential oil of *C. jwarancusa* exhibited cytotoxicity against some human cell lines. The most potent activity was



against THP-1 (leukemia) and A-549 (lung) [109]. EO of *C. schoenanthus* revealed great anti-proliferative activity against colorectal cancer (HCT116) cell line [110]. Ethanolic extract of *C. flexuosus* inhibited the growth of human hepatocellular carcinoma cell line (HepG-2) and A-549 cells via induction of apoptosis [111].

Extract from *C. citratus* stems reduced tumor growth in lymphoma model in mice. Moreover, it reduced viability various Hodgkin and non-Hodgkin's lymphoma cell lines in a dose-dependent manner via inducing apoptosis, mitochondrial depolarization, and reduction of oxygen consumption in lymphoma cells, as well as inducing production of reactive oxygen species (ROS) [112].

Polysaccharides isolated from *C. citratus* suppressed the growth of the transplanted sarcoma 180 (S180) tumors in mice via immunoenhancement activity rather than direct cytotoxicity. Decoction of *C. citratus* bulbs and leaves inhibited clastogenic activity of tetracycline in rats [113]. Essential oil of *C. martini* showed antigenotoxic activity on human lymphocyte cells [114].

#### **Antioxidant, anti-inflammatory and immunological activities**

Essential oil from *C. citratus* and *C. densiflorus* exhibited strong antioxidant activity in DPPH assay [86,115,116]. Flavonoid-rich extract of *C. citratus* leaves increased reduced glutathione (GSH) level, catalase (CAT) and superoxide dismutase (SOD) activities and decreased serum total protein (TP), tumor necrosis factor- $\alpha$  (TNF- $\alpha$ ), C-reactive protein (CRP), and malondialdehyde (MDA) levels in rats [59]. Essential oil of *C. goeringii* revealed significant in vitro antioxidant activity [69].

Infusion of *C. citratus* leaves exhibited anti-inflammatory and analgesic activity in rats [118,119]. Methanolic extract of *C. citratus* leaves strongly inhibited the release of IL-1 $\beta$  (interleukine) from peripheral blood mononuclear cells [120]. Hexane extract of *C. citratus* reduced the levels of immunoglobulins against *Blomia tropicalis* in the serum of mice sensitized with this mite. It also reduced the numbers of inflammatory cells and cytokines in bronchoalveolar lavage and the mucus secretion in the respiratory tract [121]. Citral and geraniol produced significant anti-allergic and anti-inflammatory effects in mice [122]. Essential oil of *C. giganteus* inhibited

lipoxygenase-1 but it had no effect on cyclooxygenase [123]. Essential oil of *C. nardus* reduced levels of the inflammatory cytokines and accelerated wound healing in diabetic wound [91]. It exhibited remarkable decrease in IL-1 $\beta$ -induced IL-6 by human gingival fibroblasts [33]. Essential oil of *C. flexuosus* inhibited production of inflammatory and immunological biomarkers in pre-inflamed human dermal fibroblasts [124].

#### **Effects on glucose and lipid profiles**

Aqueous extract of *C. citratus* leaves demonstrated alpha-amylase inhibitory activity in vitro [102]. Treatment of diabetic rats with EO of *C. citratus* improved glycemic indices, lipid metabolism, histopathological features of pancreas as well as HbA1c level [125]. Aqueous extract of *C. citratus* reduced total cholesterol and LDL-cholesterol in hypercholesterolemic rats via expression of genes and protein of sterol regulatory element binding protein-1c (SREBP1c) and HMG-CoA reductase activity as well as increasing serum antioxidant capacity [126]. Citronellol isolated from *C. citratus* demonstrated significant inhibition of aldose reductase activity similar to epalrestat and so may be a suitable candidate for diabetic neuropathy and retinopathy [127]. Ethanolic extract of *C. jwarancusa* improved lipid and glucose profiles and reduced atherogenic index in rats fed with high-fat high-sugar diet [128]. Chloroform fraction of aqueous extract from *C. martini* showed alpha-glucosidase inhibitory effect in streptozotocin-induced diabetic rats [129]. *Cymbopogon schoenanthus* exhibited alpha-glucosidase and pancreatic lipase inhibitory activities [130]. Moreover, its aqueous extract restored the elevated blood glucose level to the normal level in diabetic rats [131]. Essential oil of *C. nardus* reduced feed consumption, percentage of weight gain and the blood cholesterol level in rats that received high fat diet [132].

#### **Gastrointestinal and hepatoprotective effects**

Essential oil from *C. citratus* and its active constituent, geraniol, reduced ulcer area and accelerated wound healing process in mice model of gastric ulcer via inhibition of H<sup>+</sup>/K<sup>+</sup>-ATPase activity [133]. Moreover, administration of EO-free infusion of *C. citratus* leaves in ethanol-induced rat model of gastric ulcer as a preventive intervention before ethanol, reduced both number and severity of gastric lesions. When administered

after ethanol, it also caused a remarkable reduction in the ulcer index [134].

Methanolic extract of *C. citratus* and one of its main components, citral, exhibited spasmolytic activity on isolated rabbit ileum [135]. Extract of *C. citratus* reduced the levels of liver enzymes Alanine transaminase and Aspartate transaminase (AST and ALT) and revealed antioxidant activity in rat model of hepatotoxicity [136]. Aqueous extract of *C. citratus* leaves attenuated hydrogen peroxide-liver damage represented by reduction in liver enzymes and oxidative markers as well as improvement of liver histopathological changes [120]. Inhalation of EO of *C. martinii* and its active compound, geraniol, exhibited moderate hepatoprotective effect via antioxidant activity [137]. Hydroalcoholic extract of *C. schoenanthus* caused a significant decrease in bilirubin and liver enzymes activities in mice [138]. Essential oil of *C. flexuosus* and its active constituent, citral, changed the activities of drug-metabolizing enzymes and reduced oxidative stress in the liver [139].

### Neuropsychological effects

*Cymbopogon citratus* polysaccharides inhibited neuroinflammation in glioblastoma cells via down-regulation of lipopolysaccharide-induced reactive oxygen species (ROS) overproduction and inhibition of nitric oxide (NO) production [140]. Essential oil of *C. citratus* increased cell viability in cerebellar granule neurons before, during and after exposure to glutamate via its antiapoptotic activity [141]. Moreover, it increased latency to the first convulsion and latency to death. It also potentiated the barbiturate-induced sleeping time. The GABAergic neurotransmission seems to be a crucial role in its anticonvulsant activity [142]. Aqueous extract of *C. citratus* leaves increased memory performance and attenuated amnesia in mice through antioxidant and acetyl-cholinesterase inhibitory activity [143]. Aqueous extract of *C. citratus* demonstrated antidepressant activity via involvement of noradrenergic and serotonergic pathways [144]. Ethanolic extract of *C. martinii* inhibited monoamine oxidase activity with competitive mode of inhibition [145]. Essential oil from *C. citratus* exhibited anxiolytic activity in mice mediated by GABA-A receptor

benzodiazepine complex [146]. Pretreatment of human neuroblastoma cells with ethanolic extract of *C. schoenanthus* inversed neurotoxicity. Moreover, oral administration of this extract resulted in reduction of stress in mice by regulation of blood serum corticosterone and cerebral cortex levels of catecholamine (dopamine, adrenaline, and noradrenaline) [147]. Essential oil of *C. martinii* protected brain from ischemic damage in rats [148]. Essential oil of *C. winterianus* significantly reduced seizures and increased the latencies of clonic seizures in mice [149].

### Effects on urogenital system

Aqueous extract of *C. citratus* leaves increased the weight of reproductive organs and reduced oxidative stress in male rats [150]. Essential oil of *C. martinii* revealed remarkable estrogenic activity, stimulating ER+ cell growth and ERE-luciferase reporter activity to levels seen with premenopausal estradiol concentrations. It demonstrated promising efficacy in urogenital atrophy but should be used with precaution in breast cancer survivors [151]. Ethanolic extract of *C. citratus* protected alteration in renal function parameters and histological changes of rabbits induced by gemcitabine [152]. Administration of *C. citratus* infusion to healthy volunteers for 30 days reduced creatinine clearance and glomerular filtration rate. Serum and urinary creatinine and serum urea levels significantly increased. It had no effect on serum electrolytes; however, urinary levels of electrolytes increased [153]. Aqueous extract of *C. schoenanthus* showed renal protective activity by improvement of morphological appearance and inhibited necrosis of renal epithelial cells. Its antioxidant and anti-inflammatory activity may play an important role in this effect [154]. Its ethanolic extract reduced the level of urea and creatinine to near normal values in potassium dichromate -induced nephrotoxicity in rats due to the potent antioxidant activity [155]. Treatment of pregnant rats with *C. schoenanthus* caused growth retardation, external anomalies, embryonic resorption, and skeletal malformation [156].

### Effects on hematological parameters

Administration of *C. citratus* leaves infusion to healthy volunteers for 30 days markedly increased

packed cell volume (PCV), hemoglobin (Hb), and red blood cell (RBC). However, it had no significant effect on Mean corpuscular hemoglobin (MCH), Mean corpuscular volume (MCV), and mean corpuscular hemoglobin concentration (MCHC). All types of white blood cell (WBC) significantly decreased but neutrophils and lymphocytes remarkably increased in some or all groups [157]. Hydroalcoholic extract of *C. schoenanthus* increased Hb, RBC and hematocrit and caused a significant decrease in the number of WBCs of mice [138].

### Effects on respiratory tract

Methanolic extract of *C. martini* showed relaxant effect on isolated rabbit tracheal muscles through antimuscarinic and/or Ca<sup>2+</sup> channel blocking activity [158]. Essential oil of *C. schoenanthus* exhibited bronchodilator activity through inhibition of histamine and serotonin receptors [159].

### Dermatological effects

Essential oil of *C. flexuosus* showed anti-dandruff activity in a randomized clinical trial [160]. Ethanolic extract of *C. schoenanthus* increased the melanin content of melanocytes by upregulating the expression of tyrosinase, tyrosinase-related protein 1 (TRP1), and dopachrome tautomerase at the protein and mRNA levels [161]. Administration of topical formulations from EO of *C. citratus* to patients with Pityriasis versicolor led to cure in 60% of volunteers compared to 80% in ketoconazole group [162]. Hydrogel formulation from EO of *C. citratus* was nonirritant and demonstrated topical antifungal activity in cyclophosphamide- induced immunosuppressed rat [88]. Oral administration of *C. citratus* infusion to HIV patients with oral thrush for 11 days showed more efficacy and lower number of adverse events than gentian violet. [163]

### Safety and toxicity

Fandohan et al. investigated acute and subacute toxicity of *C. citratus* EO on gastric tolerance in rat. In acute toxicity test, no abnormalities were observed in first day in rats that were given EO at dose of 5-1500 mg/kg body weight and the median lethal dose of EO was 3250 mg/kg body weight. In subacute toxicity evaluation, no significant abnormalities were observed after 14 days of administration of 5-1500 mg/kg body weight

[164]. Investigation of acute and subacute toxicity of *C. citratus* EO in mice and rabbit demonstrated that the median lethal dose of EO following oral administration was higher than 2000 mg/kg. Oral administration of EO at the dose of 2000 mg/kg for 21 days caused no toxicity and death. Moreover, no skin irritation, edema, and erythema were reported during the study with 10% ointment of *C. citratus* EO in rabbits [165]. Another study on the oral toxicity of *C. citratus* essential oil in mice reported Median lethal dose (LD<sub>50</sub>)

greater than 3500mg/kg and no abnormalities were observed in body weight, histology, and biochemical parameters in subacute toxicity test during 21 days of oral consumption of EO. Furthermore, comet test in peripheral blood cells showed no genotoxic effects from EO of *C. citratus* [166]. A clinical trial has evaluated *C. citratus* herbal tea administration for two weeks in healthy volunteers. No adverse effect was reported but some of the volunteers showed slight increase in direct bilirubin and amylase without any clinical manifestation [167].

A dose of 200 µL/plate of *C. giganteus* essential oil was not mutagenic on *Salmonella typhimurium* strains. LD<sub>50</sub> was greater than 2000 mg/kg in oral acute toxicity test. Subacute oral toxicity test at 50 and 500 mg/kg of EO showed no significant abnormalities compared to the control group. Also, inhalation toxicity test showed that 0.125% or 0.5% v/v of *C. giganteus* EO did not cause mortality and lung inflammation [168].

### Discussion

Investigating about ethnopharmacology and phytochemistry as well as biological and pharmacological activities of medicinal plants give us worthwhile information about the current research and help us for better planning about future studies [1,169,170]. *Cymbopogon* species are valuable medicinal plant with several biological activities, which have been known since ancient times. They widely grow in tropical and subtropical areas of the North America, South America, Africa, Australia, Indian subcontinent, and Europe. These plants are used as flavoring material and for their fragrance. They are used in folk medicine as antirheumatic, antispasmodic, analgesic, antiseptic, hypotensive, antitussive, antiemetic, and anticonvulsant agents, and as treatment for gastrointestinal and nervous disorders and fevers. Also, these species are known to be antioxidant and antibacterial, and

have hepatoprotective, gastrointestinal, neuropsychological, anticancer, and dermatological effects.

The most significant therapeutically relevant constituent obtained from *Cymbopogon* species leaves is the EO, containing citral, geranial and citronellol as the chief compounds, that plays a crucial role in different biological activities of the plant including antimicrobial, antioxidant, hepatoprotective, spasmolytic and gastrointestinal effects. A range of factors such as geographical location, climatic conditions, time of harvest, field storage, age of the plant, and the distillation method can affect chemical composition of EOs [171]. For example, EO from West Indian *C. flexuosus* showed high citral content and little or no myrcene whereas the East Indian type contained low citral and high amounts of myrcene. Despite many in vitro and animal studies conducted on biological activities of *Cymbopogon* species, the number of human studies on this genus is small and limited to antifungal properties of topical preparations and erythropoietic and diuretic activity following oral administration. Due to various pharmacological activities reported from *Cymbopogon* species in preclinical studies, it is worthy to design clinical trials for investigating these activities including neuropsychological, gastrointestinal, and cardiovascular effects as well as the effects on biochemical blood parameters such as glucose and lipid profile [172-174].

The EO of lemongrass was remarkably active against several important bacterial species and fungi. It has been that reported it was effective in preserving processed foods such as cake, bread, and bakery products [175], cheese, and other dairy products [175-177]. It was also found that lemongrass increases the shelf life of several fruit juices, fruits like cucumber and guava [178]. Thus, lemongrass has potential properties to be used as a natural flavoring and preservative agent for food storage. Of course, it should be noted that it may cause toxicity, especially at high concentration of exposure to olfactory or digestive systems [179]. The biological activities of lemongrass components are not limited to food and drug usage. They are also useful for cosmetics applications. The antimicrobial effect of *Cymbopogon* species make it a suitable candidate to be applied in antibacterial detergents [180]. Activity of lemongrass EO on bacteria like

*Propionibacterium acne*, *Staphylococcus epidermidis*, *Staphylococcus aureus*, and *Streptococcus pneumonia* as well as its antioxidant activity suggest its application for management of dermatological disorders like acne and aging [181].

There are many similarities between chemical constituents of EOs as well as pharmacological activities of lemon grass and *Aloysia citriodora*. *Aloysia citriodora* commonly known as lemon verbena has neral and geranial as major compounds of essential oil and has comparable biological effects including antimicrobial, insecticidal, gastrointestinal, and neuropsychological activities. So, it seems that these two components are responsible for many of pharmacological activities that reported from *Cymbopogon* and *Aloysia* species.[182]

Toxicologic studies demonstrated safety of *Cymbopogon* EO in acute and subacute exposure. However, because of lack of human data, it is required to conduct clinical trials for obtaining more precise information about the safety and toxicology of *Cymbopogon* species and the plant should be used with caution in patients with hepatic or renal failure as well as elderlies, children, pregnant and nursing women.

## Conclusion

Extensive research has been already done on various biological activities of *Cymbopogon* species which are mostly preclinical and a few numbers of them are devoted to clinical studies. Therefore, to achieve more conclusive results about the efficacy of lemongrass, well-designed clinical trials are recommended.

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## Author contributions

Roja Rahimi Designed the study; Soodeh Karami, Alireza Yargholi, and Samaneh Soleymani drafted the manuscript; Roja rahimi, Seyede Nargess Sadati Lamardi and Laila Shirbeigi revised the manuscript for important intellectual content.

## Declaration of interest

The authors declare that there is no conflict of interest. The authors alone are responsible for the accuracy and integrity of the paper content.

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### Abbreviations

ALP: alkaline phosphatase; ALT: Alanine transaminase; AST: Aspartate transaminase; CAT: catalase; CK: creatine kinase; CKMB: Creatine kinase-MB; CRP: C reactive protein; E. coli : Escherichia coli; EO: essential oil ; GABA: gamma-Aminobutyric acid; GSH: glutathione; Hb: hemoglobine; HbA1c: Hemoglobin A1c; HIV: human immunodeficiency virus; HMG-coA: 3-hydroxy-3-methylglutaryl-CoA; HSV: Herpes simplex virus; IL: interleukine; LD50: Median lethal dose; MAHD: microwave assisted hydrodistillation; MASHD: microwave assisted steam distillation; MCH: Mean corpuscular hemoglobin; MCHC: Mean corpuscular hemoglobin concentration; MCV: Mean corpuscular volume; MDA: malondialdehyde; MNU: methyl-N-nitrosourea; NO pathway: nitricoxide pathway; PCA: passive cutaneous anaphylactic; PCV: packed cell volume; RBC: red blood cell; ROS: reactive oxygen species; SOD: superoxide dismutase; SREBP1C: sterol regulatory element binding protein-1c; TNF: tumor necrosis factor; TP: tota protein; TRP: tyrosinase-related protein; WBC: white blood cell