Lemongrass

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Abstract

Secondary metabolites (SMs) are known to have a wide range of therapeutic values. Large numbers of drugs are derived from these SMs. These naturally occurring SMs known to act as a potent source of antimicrobial, antiviral, anti-inflammatory, anticancer, and insecticidal agents. Aromatic plants are the prime source of variety of easily available SMs. Numerous classes of these SMs also act as powerful natural antioxidants. Antioxidants are the compounds that inhibit or slow down the oxidation of other molecules and help to cure the oxidative stress condition. Oxidative stress is the condition where the amount of free radicals in the body of organism exceeds the homeostatic balance of free radicals and indigenous antioxidant. This excess of free redials leads to various types of chain reactions that damage cells. These free radicals are the cause of more than hundred kinds of diseases in living beings. *Cymbopogon* is a genus of about 180 species of monocots grasses in a family of Poaceae (Gramineae). The species of genus *Cymbopogon* are rich source of naturally occurring antioxidants (such as phenolic acids, flavonoids, tannins, hydroquinone, terpenoids and fatty alcohols, etc.), and lemongrass (*Cymbopogon citrates*) is one of them. Further, the pharmacological applications of lemongrass are also

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well explored. Hence in the present chapter, we intend to discuss the botanical description, traditional uses, phytochemistry, antioxidant potential, health benefits, and potential economic importance of lemongrass.

Keywords

Lemongrass · Cymbopogon · Phytochemistry · Secondary metabolites · Antioxidants

4.1 Introduction

Aromatic medicinal plants are extensively used owing to their potent medicinal and nutritional properties (Sharma and Cannoo 2013; Joshi 2014). Medicinal aromatic plants are source of variety of biologically active secondary metabolites (SMs). These SMs can be categorized into various classes, namely, phenolic acids, tannins, flavonoids, alkaloids, terpenoids, saponins, steroids, glycosides, etc. (Sharma et al. 2018, 2019). All the classes of SMs are known to show a particular biological potential, just like alkaloids cure HIV infection, saponins have antifungal activity, tannins have antimicrobial activity, flavonoids have physically powerful anticancer activity, etc. (DellaGreca et al. 2009). Further, aromatic medicinal plants have diverse kind of volatile SMs, which are isolated from different parts of plants like roots, rhizome, stems, and flowers. The essential oils isolated from these aromatic plants mostly use for perfumery, food flavoring industries, aroma therapy, and various health benefits (Sharma and Cannoo 2013).

The World Health Organization (WHO) report revealed that the more than two-third of the world's population is largely dependent on the use of traditional medicine for their primary health care needs because of its relatively safe therapeutic results (Gopal et al. 2014; Sharma et al. 2018). Different parts of aromatic medicinal plants (flowers, roots, rhizomes, stems, leaves) as such or in the modified forms are used as nutraceuticals, food supplements, folk medicines, drugs, food additives, flavoring agents, herbicides, fungicides, etc. (Suhaib et al. 2011; Rahman et al. 2011). Hence, there is always a constant growth in their demand. On account of this, the aromatic medicinal plants play an important role in the life of the people particularly living in the tribes and remote areas by giving them both food and medicine (Chhetri et al. 2015). The plant families such as cupessaceae, apiaceae, asteraceae, lauraceae, piperaceae, lamiaceae, rutaceae, myrtacea, zingiberaceae, etc. are well known for their important and valuable bioactive SMs, and poaceae is one of them.

Cymbopogon is a multiregional genus belonging to significant essential oil–yielding family Poaceae (Gramineae) of monocots grass. The genus comprises of about 180 species, including varieties, sub-varieties, and subspecies. The Cymbopogon is a Greek name, composed of "kymbe" (boat) and "pogon" (beard), which refer to the flower spike arrangement of the species (Shah et al. 2011). It is widely distributed in tropical and temperate regions all around the world (Asia, Africa, Europe, and America) (Bertea and Maffei 2010). Many species of this genus are known to be a rich source of volatile essential oils and have been largely used in traditional medicine pharmaceuticals, perfumery, and cosmetics industries (Shah et al. 2011; Avoseh et al. 2015). The genus is native to tropical Asia and India. There are different species of genus Cymbopogon viz., *C. winterianus, C. flexuosus, C. schoenanthus, C. ambiguous, C. bombycinus, C. refractus, C. obtectus, C. nardus*, *C. citratus,* etc. that are growing in the different countries of world like China, India, Japan, Nepal, Malaysia, Sri Lanka, Thailand, Mali, Benin, Cameroon, Egypt, Ghana, Kenya, Nigeria, Zambia, Zimbabwe, Italy, the United Kingdom, Canada, Cuba, Mexico, the USA, Argentina, Brazil, Peru, Venezuela, Australia, Papua New Guinea, etc. Out of these species *C. citrates* (lemongrass) is most studied species of this genus, owing to its numerous ethnopharmacological applications (Shah et al. 2011; Avoseh et al. 2015).

Traditionally lemongrass is used to cure coughs, flu, headache, elephantiasis, leprosy, gingivitis, ophthalmic, pneumonia, arthritis, malaria, and vascular disorders (Manvitha and Bidya 2014). Lemongrass is also used to detoxify the liver, kidney, bladder, pancreas, and the digestive tract due to its good cleansing properties. It also helps to reduce the cholesterol, excess fats, uric acid, and various toxins in the body. It stimulates the digestion, lactation, blood circulation, and alleviates gastroenteritis and indigestion (Shah et al. 2011; Manvitha and Bidya 2014). Lemongrass has also known to show various pharmacological activities such as insecticidal (Kumar 2013), antidiabetic (Kumar 2013), anti-amoebic (Blasi et al. 1990), acetylcholinesterase inhibitory (Khadri et al. 2008), cytotoxicity, anti-trypanosomal, anti-plasmodial (Kpoviessi et al. 2014), anti-inflammatory (Francisco et al. 2011), antioxidant (Khadri et al. 2008), anti-HIV (Wright et al. 2009), larvicidal (Barreira et al. 2004), antiprotozoal (Pedroso et al. 2006), antinociceptive (Viana et al. 2000), dermatotoxicity (Carmo et al. 2013), anticancer (Thangam et al. 2014), antibacterial, antifungal, antifilarial, antimutagenicity, antidiarrheal, antimalarial, antimutagenicity, antihypoglycemic, etc. (Shah et al. 2011; Avoseh et al. 2015).

The previous studies have shown that the chemical diversity of various extracts and essential oils obtained from different parts of *C. citratus* varied in accordance with its geographical origin (Negrelle and Gomes 2007). The biological potential of different essential oils and extracts obtained from *C. citratus* may be attributed to the composition of different classes of SMs present in these essential oils and extracts. The various key classes SMs present in different essential oils and extracts of *C. citratus* are phenols (elemicin, catechol, hydroquinone etc.), phenolic acids (chlorogenic, caffeic, p-coumaric acid, etc.), flavonoids (luteolin, quercetin, kaempferol, apigenin, and their glycosides), steroids (β-sitosterol and fucosterol), fatty alcohols (hexacosanol and triacontanol), terpenoids (volatile: monoterpenes – neral, geranial, myrcene, limonene etc. and sesquiterpenes – caryophyllene, humulene, beta-eudesmol; non-volatile: triterpenoid – cymbopogonol and cymbopogone), tannins (hydrolysable tannins – proanthocyanidins) (Ansari et al. 1996; Negrelle and Gomes 2007; Shah et al. 2011; Avoseh et al. 2015).

The occurrence of medicinally important SMs in *C. citratus* and tremendous therapeutic potential of these SMs in food, cosmetics, aroma, pharmaceutical, and agrochemical industries allow us to write the present chapter in order to provide significant knowledge concerning this plant to scientific society.

4.1.1 Traditional Uses

C. citratus was widely used in different ancient medicinal systems to cure various kinds of illness. Some of the key traditional uses of lemongrass are summarized below (Shah et al. 2011; Avoseh et al. 2015):

- In Cuba, the hot water extract obtained from dried leaves is taken orally which act as a hypotensive for rheumatism and catarrh (Carbajal et al. 1989).
- In Argentina, the decoction prepared from leaves is taken orally with mate tea to cure empacho, sore throat, and as an emetic (Filipoy 1994).
- In Egypt, the hot water extract obtained from dried stems and leaves is taken orally as a diuretic and renal antispasmodic (Locksley et al. 1982).
- In Brazil, the tea prepared from leaves is usually used as analgesic, antipyretic, diuretic, sedative, antispasmodic, and anti-inflammatory (Leite et al. 1986; Souza-Formigoni et al. 1986).
- In USA, the hot water extract obtained from whole plant is used externally for healing bone fractures and wounds by Laotian Hmong peoples in Minnesota (Spring 1989).
- In Indonesia and Malaysia, the hot water extract prepared from whole plant is taken orally which act as emmenagogue (Quisumbing 1951).
- In Thailand, the fresh whole plant is eaten as a condiment and inhaled as a fragrance (Praditvarn and Sambhandharaksa 1950). The hot water extract prepared from whole dried plant is taken orally which act as stomachic, while the hot water extract obtained from dried root is taken orally to treat diabetes (Ngamwathana and Kanchanapee 1971).
- In India, the fresh whole plant is used to repel snakes. A few drops of essential oil mixed in hot water are taken orally to treat gastric troubles, while a few drops of essential oil mixed with lemon juice are taken orally to treat cholera. In cases of severe fever and headache, the hot water extract obtained from dried leaves is usually used during bathing. Further, a lemongrass tea is used as a sedative (Rao and Jamir 1982; John 1984).

4.1.2 Botanical Description and Taxonomical Classification

C. citratus is a fast-growing perennial grass having lemon-scented bluish-green leaves arising from sparingly branched rhizomes. It can grow up to 1 m height and 5–10 mm width. The species does not produce seeds. It has large number of bulbous stems. The leaves are glabrous, linear, long, tapering upward, and along the margins. It has nodding inflorescences with paired racemes of spirelets (Ross 1999; Jayasinha 1999). The taxonomical classification of lemongrass is as follow (Shah et al. 2011):

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Poales
Family: Poaceae
Genus: Cymbopogon
Species: citratus

Common Names Hindi – Sera, Verveine; Chinese – xiang mao, Thailand – Ta-khrai; English – Lemongrass, Citronella, Squinant; USA – Citronella; Egypt – Lemongrass; Brazil – Capim-cidrao, Capim-santo; Ethiopia – Tej-sar; Indonesian – Sereh; Italian – Cimbopogone; Malaysia – Sakumau; Mexico – Zacate limon; Swedish – Citrongrass; Turkish – Limon out; Spanish – hierba limon or zacate de limón; French – citronelle or verveine des indes; Colombia – Limonaria; Argentina – Limonaria; Nigeria – Lemongrass; Cuba – Cana Santa; Costa Rica – Grass tea (Ross 1999; Jayasinha 1999; Shah et al. 2011; Avoseh et al. 2015)

Synonym(S) *Andropogon ceriferus* Hack, *Andropogon roxburghii* Nees ex Steud., *Andropogon citratus* DC. ex Nees, *Cymbopogon nardus* (DC. ex Nees) Roberty and *Andropogon nardus* subsp. ceriferus L. Hack (Ross 1999; Jayasinha 1999).

Parts Used Rhizome, stem, leaves, and whole plant (Avoseh et al. 2015).

4.1.3 Production: India and Worldwide

In world trade, the oil of lemongrass is generally known as Cochin oil, as about 90% of it is transported from Cochin port. The lemongrass is cultivated in various states of India, but the Indian state of Kerala has the monopoly in its production and export. The annual production of lemongrass in the world is around 1000 tons, with 16,000 ha area of cultivation (Skaria et al. 2006). The leading exporters of lemongrass are Guatemala with trading of about 250,000 kg/year and Russia with trading of about 70,000 kg/year (Anonymous 2012). In India, the annual production of lemongrass is around 250 tons with cultivated area about 4000 ha (Skaria et al. 2006).

In India, generally three species have been identified viz. *C. flexuosus* var. flexuosus also known as Malabar, Cochin, or East Indian grass; *C. pendulus* (Nees ex Steud) Wats, also known as Jammu lemongrass; and *C. citratus* (DC) Stapf., also known as American or West Indian lemongrass. It grows wild in all areas ranging from sea level to 4200 m of altitude. It is mainly cultivated in Kerala, Maharashtra, Madhya Pradesh, Uttar Pradesh, Uttarakhand, Bengal, Assam, Sikkim, and Jammu and Kashmir. The large-scale cultivation of lemongrass is done at Chinnar Wildlife Sanctuary situated in Western Ghats of India (Nair and Jayakumar 1999; Handa and Kaul 1997). The key cultivated varieties of lemongrass in India, which evolved by clonal selection are Sugandhi, Praman, Pragati, Kavery, Krishna, CKP-25, RRL16, GRL-1, RRL-39, SD-68 and SB-9 (Patra et al. 1999; Farooqi and Sreeramu 2001).

4.2 Antioxidant Potential

Free radicals are competent, independent existing molecular species with unpaired electrons. Oxygen- and nitrogen-containing reactive free radical species are known as reactive oxygen species (ROS) and reactive nitrogen species (RNS), respectively. In human body, free radicals and other ROS/RNS are produced during vital metabolic processes by xanthine oxidase, peroxisomes, inflammation, phagocytosis, arachidonate pathways, and ischemia/reperfusion injury (Ebadi 2001). Many exogenous sources are also responsible for the production of these reactive species in human body such as various kinds of radiations, ozone, cigarette smoke, air pollutants, industrial chemicals, certain drugs, and pesticides etc. (Bagchi and Puri 1998; Bhardwaj et al. 2019). Excessive ROS/RNS and free radicals can attack nitrogenous bases in nucleic acids, amino acid side chains in proteins, and double bonds in unsaturated fatty acids, resulting in oxidative stress which eventually lead to serious health problems and diseases (Rao et al. 2006). Therefore, maintenance of critical balance between the production and scavenging of free radicals is very important for proper functioning and well-being of human body (Rock et al. 1996).

Antioxidants are chemical substances which assist in combating and limiting damage caused by free radicals/ROS/RNS and oxidative stress. Antioxidants are broadly of two types: endogenous and exogenous. Endogenous antioxidants are produced inside the human body and include intracellular antioxidant enzymes, viz. superoxide dismutase (SOD), glutathione peroxidase (GPX), catalase (CAT) and nonenzymic substances, including ascorbic acid (vitamin C), α-tocopherol (vitamin E), β-carotene (provitamin A), and glutathione (GSH), while exogenous antioxidants are taken from outside and may be naturally occurring (polyphenolic acids, flavonoids, tannins, etc.) or synthetic ones (Mates et al. 1999; Glatthaar et al. 1986; Sokol 1988; van Poppel and Goldbohm 1995). Although cells can generate their own antioxidants, still there is always need to consume antioxidants as a part of healthy diet in order to tackle with oxidative stress conditions (Harasym and Oledzki 2014). Exogenous antioxidants from fruits, vegetables, and other medicinal plants promote endogenous antioxidant activity and hence contribute to the strengthening of defense mechanisms (Stahl and Sies 2005). Fruits, vegetables, and medicinal plants are a rich source of vitamins, minerals, and natural antioxidant phytochemicals like carotenoids, phenolic acids, polyphenols, flavonoids, and tannins. Owing to this, fruits, vegetables, and medicinal plants have held indispensable place in daily human diet. Moreover, the essential oils and various extracts of aromatic plants have been of great interest for their potent antioxidant potential (Miguel 2010).

Lemongrass is a commonly used plant in traditional medicinal system due to its promising pharmacological activities and has promising antioxidant potential (Leite et al. 1986; Shah et al. 2011; Avoseh et al. 2015).

4.2.1 Antioxidant Potential of Lemongrass

Studies conducted by different research groups throughout the world for determination of antioxidant potential of lemongrass gave varying results depending upon the growing region, condition of plant, sample preparation, part used, extraction procedure, and technique of analysis. Hydroalcoholic extract (60 μg/ml) of lemongrass was able to inhibit different radicals, namely, 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), hydroxyl, superoxide, nitric oxide up to different percent inhibition values of 85, 77, 70, 76, and 78%, respectively (Rao et al. 2009). Mansour et al. (2015) reported that the lemongrass collected from Egyptian region was found better for inhibition of linoleic acid oxidation (55.1%, IC_{50} 1.0 mg/ml) as compared to that collected from Madina (36.3%, IC_{50} 6.9 mg/ml). Cheel et al. (2005) observed a promising free radical scavenging activity (76%) resulting from the flavonoids content extracted from the aerial parts of *C. citratus* from Chile. It was concluded by Orrego et al. (2009) that the infusions are better than decoctions for extraction of antioxidant phytochemicals from lemongrass. Out of methanol and ethanol, latter is considered better as its extract was found more effective in DPPH and NO radical scavenging (Soares et al. 2013). Halabi and Sheikh (2014) found that 50% ethanolic extract of *C. citratus* had better DPPH radical scavenging potential (48.3%) compared to aqueous extract (45%). Acetone extract of lemongrass possessed 38.49 μg/ml IC_{50} value in DPPH radical scavenging assay, 709.73 ± 6.21 mmol Fe(II)/g FRAP content, 37.32 ± 1.07 mg/EDTA/g chelating ability, 238.84 ± 3.57 μg/ml IC_{50} value in superoxide radical scavenging assay, 535.16 ± 50.26 mg AAE/g of extract phosphomolybdenum value (Geetha and Geetha 2016). IC_{50} values of different solvent extracts, viz. aqueous, 40% ethanol, 50% ethanol, 70% ethanol, 80% ethanol, and chloroform have been reported to be equal to 278 μg/ml, 191.97 μg/ml, 258.9 μg/ml, 79.44 μg/ml, 1140 μg/ml, and 1998.10 μg/ml, respectively (Halabi and Sheikh 2014; Falah et al. 2015; Sah et al. 2012; Lu et al. 2014). Varying antioxidant potential of different solvent extracts may be attributed to the presence of varying amount of phytochemicals (polyphenolics) in them. In a study conducted by Patel and Mehta (2006), dry lemongrass exhibited better antioxidant properties with high flavonoids and phenolic content as compared to fresh one.

Free radicals and oxidative stress are involved in an important pathophysiological mechanism of depression (Davies 1995). *C. citratus* (10 mg/kg) was found more effective antidepressant when compared with standard Imipramine in albino mice (Dudhgaonkar et al. 2014). Antioxidant effects of *C. citratus* were observed in terms of increased liver glutathione content in paracetamol-treated animals (Saenthaweesuk et al. 2017). Aqueous extract of lemongrass decreased serum lipid peroxidation in rats, contributing toward its antioxidant capacity (Somparn et al. 2018). *C. citratus* aqueous extracts (5% and 10%) also alleviated cis-platin-mediated oxidative damage (decrease in superoxide dismutase, catalase, and glutathione peroxidase activity) in rats (Arhoghro et al. 2014). Cardioprotective effects of lemongrass in doxorubicin-treated animals were observed by Ahmed and Ibrahim (2018). They reported that the pretreatment with lemongrass caused a significant decrease in ROS, malondialdehyde levels, and consequently increased total proteins as well as antioxidant capacity. The ethanolic extract of lemongrass helped in suppressing oxidative stress in Wistar rats screened for diabetic conditions (Ademuyiwa and Grace 2015). Various studies carried out by Jamuna et al. (2017), Sanadhya et al. (2014), Adesegun et al. (2013), Balakrishnan et al. (2014), Ojo et al. (2006), Dang et al. (2001), Lean and Mohammad (1999) and Baratta et al. (1998) also confirmed the antioxidant potential of lemongrass.

4.2.2 Lemongrass as Antioxidant in Food

Oxidation and free radical formation reactions are not limited to human body only. Many biological systems, living organisms, and even food products are accessible to oxidative damage. Food products particularly with high fat content are susceptible to atmospheric oxidation, resulting in rancidity and spoilage. Antioxidants are added to food stuffs to protect it from lipid peroxidation, to keep its texture and taste, and to assure consumption safety properties (Carocho et al. 2018). A variety of plant materials having high phenolic, flavonoid, carotenoid, and terpene content have been proved effective antioxidants as well as preservatives in food (Arabshahi et al. 2007; Martin et al. 2002).

4.2.2.1 Lemongrass Essential Oil

The antioxidant effect of lemongrass oil (1.5%) in terms of total volatile nitrogen (TVN) and thiobarbituric acid (TBA) values in refrigerated minced beef (4 °C) during a storage period of 6 days has been confirmed by Salem et al. (2010). Similar use of lemongrass oil in 12 days cold storage (4 °C) of camel burger has been reported by Zaki et al. (2018). TBA and total volatile base nitrogen (TVBN) values were significantly increased with increase in time of storage and camel burger formulated with different concentrations of lemongrass oil (0.5, 0.75 and 1.0%) exhibited lowest values than untreated control. Alrefaie and Bostan (2017) also recommended the use of lemongrass essential oil (600 ppm) to increase the shelf life of cakes at room temperature. They reported that the peroxide value (PV) and TBA values of cake sample treated with lemongrass essential oil was significantly lower ($p > 0.05$) at the end of the storage (1 month) in comparison to control. Also, in the fatty acid profile obtained by Gas Chromatography (GC), sample containing lemongrass (600 ppm) exhibited lower percentage of palmitic acid (26%) when compared with control (33.6%). Petchsoongsakul and Pechyen (2012) characterized eugenol extracted from lemongrass essential oil as a substitute to butylated hydroxytoluene (BHT) for packaging of raw materials.

4.2.2.2 Lemongrass Leaf Powder

The antioxidant potential of lemongrass leaf powder on refrigerated raw and cooked pork patties has been evaluated by Olorunsanya et al. (2010). Treatment of 200 g raw pork patties with different concentrations lemongrass leaf powder (0.5, 1.0 and 1.5%) decreased the thiobarbituric acid reactive substance (TBARS) in comparison to untreated reference as well as standard tocopherol (200 mg). Also, the preservative antioxidant effects of lemongrass were observed more in raw pork patties as compared to their cooked counterparts. Effectiveness of lemongrass leaves powder (2%) in reducing lipid peroxidation and increasing total phenolic content (TPC) of fresh and cooked chicken burgers during a storage (4 °C) period of 12 days was stated by Eldeeb and Mosilhey (2018). Lemongrass (0.5%, 1.0%, 1.5%, and 2.0%) containing uncooked chicken burger samples possessed less TBARS values (1.49, 0.81, 0.77, and 0.53) when compared with control (1.92). Chicken burger treated with 2% lemongrass exhibited higher level of TPC (112.23 ± 0.301 mg/100 g) than untreated control (44.32 mg/100 g). Also, the antioxidant activity of lemongrass leaves powder was found higher than that of α-tocopherol (Eldeeb and Mosilhey 2018).

4.2.2.3 Lemongrass Leaves Extract

Hydroalcoholic (70%) leaves extracts obtained from *C. citratus* (using conventional and ultrasonic method) were found to possess high antioxidant activity in stored chicken sausages (Boeira et al. 2018). In another study, Kanatt et al. (2014) reported that the aqueous extract of lemongrass leaves (0.1%) showed antioxidant preservative effects on radiation-processed minced chicken meat during 10 days of chilled storage. The antioxidant potential was monitored in terms of TBARS values as γ radiation, which was given at a dose rate of 2.5 k Gy/h accelerated lipid peroxidation (Ahn et al. 2000). Aqueous lemongrass extract (0.1%) containing irradiated chicken meat sample had significantly lower TBARS value proposing that it successfully retarded the lipid peroxidation during storage. The extract was also able to protect DNA from radiation (500 Gy)-induced damage by protecting the supercoiled form of DNA in comparison to control. Further, the IC_{50} value of lemongrass extract was recorded as 90.3 mg/ml in comparison to standard BHT (25.2 mg/ml) in DPPH radical scavenging assay. Falah et al. (2015) studied the application of lemongrass leaves extract for prevention of soybean oil oxidation. The oxidative stability of dry air (110 °C) exposed soybean oil, when treated with ethanol (70%) extract of lemongrass, was found to be 1.19 in comparison to sample having soybean oil with BHT (1.53). The addition of aqueous and methanolic lemongrass leaves extract to refrigerated chicken patties (4 °C) caused reduction of lipid peroxidation, monitored in terms of TBARS values on 9th day of storage (0.39 mg malondialdehyde/kg sample) in contrast to control (0.44 mg malondialdehyde/kg sample) (Ibrahim and Abu Salem 2013). Methanol extract possessed higher antioxidant potential than aqueous extract with antioxidant value of 11.45 ± 0.020 mgGA/g) and 33.56 ± 0.025 mg BHT/g. Abd-El Fattah et al. (2010) used lemongrass as a conventional chemical preservative for storage of refrigerated yoghurt at 5 °C. Owing to the effectiveness of lemongrass as a significant natural antioxidant preservative, it can conveniently replace synthetic antioxidants in food industry.

4.2.2.4 Formulations Having Lemongrass

Herbal infusions and teas are beneficial to human health because of their high phenolic, flavonoid content and hence have high antioxidant potential (Moraes-de-

Souza et al. 2008). Hot percolations of lemongrass tea from five different locations in southern Ghana possessed phenolics (2.6–7.3 mgGAE/g) and flavonoids (6.9–12.9 μg/g QE). Owing to this lemongrass tea had high total antioxidant capacity (65.4–81.3%) (Godwin et al. 2014). Temperature has pronounced effects on extraction of phytochemicals as indicated by low phenolic (1.3–4.7 mgGAE/g) and flavonoid (6.9–11.3 μg/g QE) content of cold percolations. Dzah (2015) developed a tea formulation by taking herbs "Srenunum" (*Lippia multiflora*) and lemongrass (*C. citratus*) with a medicinal mushroom "Reishi" (*Ganoderma lucidum*) in ratio 5:3:2. This tea formulation exhibited significantly higher antioxidant power than a known control Lipton yellow label. Lemongrass aqueous extract also increased the TPC and antioxidant potential of a mixed beverage having lemon juice and soymilk powder (Kieling and Prudencio 2019). A beverage with 50 ml/L of lemongrass aqueous extract, 1.25 g/L of lemongrass essential oil mixed in 16 g/L of soymilk powder exhibited higher DPPH scavenging activity (109.37 μgTE/ml), ABTS scavenging activity (381.89 μgTE/ml), and phenolic content (22.11 μg GAE/ml) as compared to beverage without lemongrass extract and lemongrass essential oil. *Nefang* is a polyherbal formulation of mango (*Mangifera indica*), guava (*Psidium guava*), papaya (*Carica papaya*), lemongrass (*C. citratus*), sweet orange (*Citrus sinensis*), and clove basil (*Ocimum gratissimum*) used for the treatment of malaria. Rats treated with *Nefang* showed increased levels of triglycerides, superoxide dismutase, and catalase confirming the antioxidant potential of this polyherbal product (Tarkang et al. 2013). A herbal mixture having 12.5% lemongrass, 12.5% curry leaves (*Murraya koenigii*), 12.5% turmeric (*Curcuma longa*), and 62.5% ginger (*Zingiber officinale*) was found to have a synergistic action on antioxidant activity with DPPH radical scavenging activity value of 88.38% (Poh et al. 2018). A herbal ice cream containing 10%, 15%, and 20% lemongrass was prepared by Chanmchan et al. (2017) exhibited high antioxidant activities as compared to control formula. Meena Anand et al. (2011) suggested the use of lemongrass oil as mouth wash for antioxidant effects. The superoxide dismutase levels of saliva and gingival crevicular fluid were increased after administration of lemongrass oil in all treatments. Efficacy of gel prepared from lemongrass essential oil as an adjunct to scaling and root planning for the treatment of chronic periodontitis was evaluated by Warad et al. (2013). Antioxidant activity of lemongrass gel resulted in increased tissue healing response, which further prevented the tissue destruction. Gargling with 2% and 4% lemongrass essential oil solutions increased the glutathione (GSH), nonenzymatic antioxidant found in cells, levels of saliva in gingivitis patients (Susanto et al. 2010). Dany et al. (2015) also concluded similar results in a study conducted to determine the efficacy of 0.25% lemongrass oil mouth wash.

4.2.2.5 Products/Materials from Lemongrass

Silver nanoparticles prepared by using lemongrass showed ABTS radical scavenging activity of 70.12% at a concentration of 500 μg/ml with and IC_{50} value of 30.60 μg/ml. Microencapsulated lemongrass extract (25%) in β-cyclodextrin at 120 °C exhibited high phenol content value (34.64 mg/100 g) and hence high antioxidant activity. This powder form of microencapsulated lemongrass extract was able to retain its stability over high oxygen contact and high temperature (Naufalin et al. 2019). Mishra et al. (2018) fabricated lemongrass essential oil–loaded composites of cellulose nanofibers–polyethylene glycol and suggested that these composite systems retain the properties of pure essential oil. Total phenolic and total antioxidant content of composite system ranged between 104–670 μg GAE/mg and 3.5–63.1 μg AAE/mg of lemongrass composite, respectively. These studies propose that fabricated essential oil composites may find applications in food storage and indoor air quality improvement.

4.2.3 Antioxidant Potential of Some *Cymbopogon* Varieties Other Than *C. citratus*

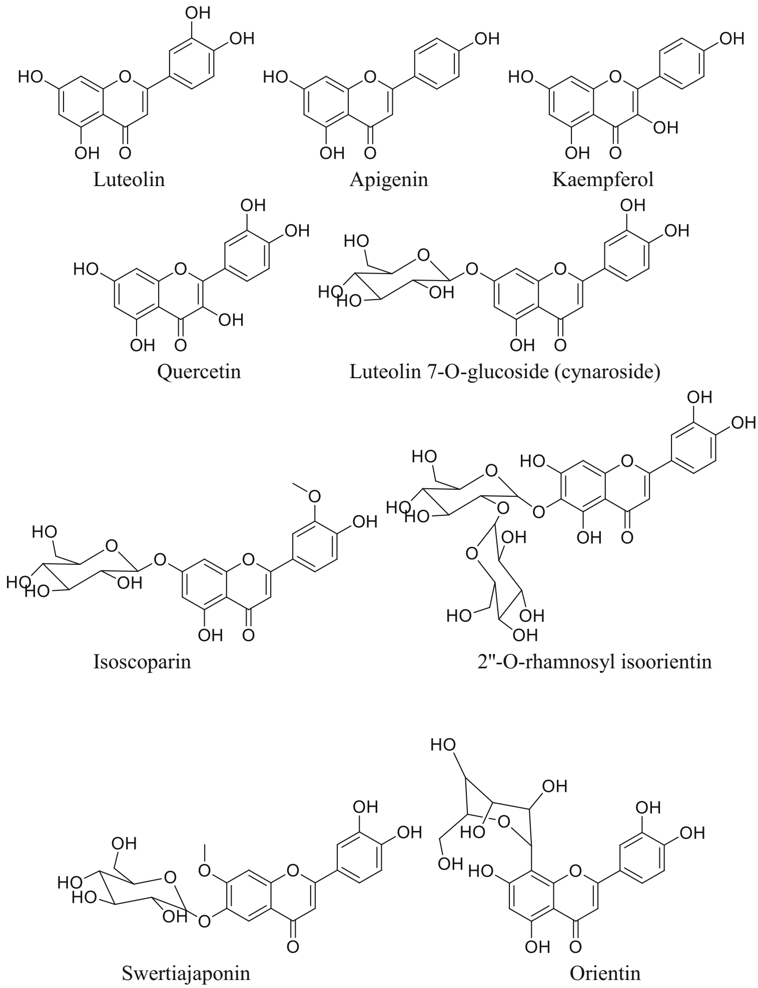
Khadri et al. (2010) measured the antioxidant capacity of *C. schoenanthus* shoots collected from three different locations of South Tunisia. Proanthocyanidin-rich extract of plant variety obtained particularly from desert region possessed highest antioxidant potential with IC_{50} value of 50.52 mg/ml in β-carotene/linoleic acid bleaching test. *C. schoenanthus* essential oil (5%) obtained by hydrodistillation of plant collected from Egypt exhibited promising DPPH radical scavenging activity (32.28 mmol AAE, IC_{50}: 401.67 μg/ml) (El-Shennawy and Abozid 2017). Lower IC_{50} value of methanolic extract (48.66 μg/ml) of C. *proximus* obtained from Egypt as compared to its essential oil (998.47 μg/ml) suggested the better DPPH radical scavenging action of the former (Selim 2011). In another study conduct by Wibowo et al. (2018), the essential oil of *C. nardus* collected from Lembang, West Java, was found to be very strong antioxidant with DPPH radical IC_{50} value of 2.405 μg/ml.

4.3 Phytochemical Composition of *C. citratus*

Lemongrass has been well known for its volatile and nonvolatile SMs. The composition of these SMs varies depending upon their geographical origin. Terpenoids (volatile and nonvolatile), steroids, polyphenolics, flavonoids, tannins, and fatty alcohols are the key classes of SMs present obtained from lemongrass. These classes of SMs are mainly responsible for various ethno-pharmacological applications of lemongrass (Ansari et al. 1996; Negrelle and Gomes 2007; Shah et al. 2011; Avoseh et al. 2015). Figure 4.1 presents the structures of prime SMs isolated from lemongrass.

Flavonoids Various researcher isolated different flavonoids from *C. citratus*, luteolin, luteolin 7-O-glucoside (cynaroside), apigenin, quercetin, kaempferol, 2″-O-rhamnoside isoorientin, isoscoparin, swertiajaponin, and orientin were the major flavonoids isolated from lemongrass (Matouschek and Stahl 1991; Miean and Mohamed 2001; Cheel et al. 2005; Avoseh et al. 2015).

Flavanoids



Phenols

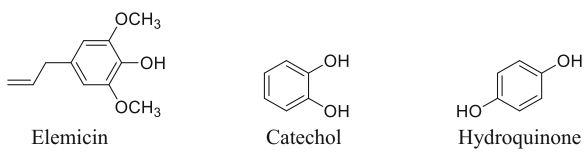
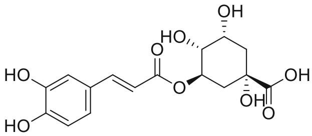
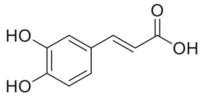


Fig. 4.1 Structures of prime SMs isolated from lemongrass

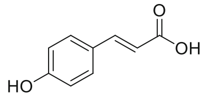
Phenolic acids



Chlorogenic acid

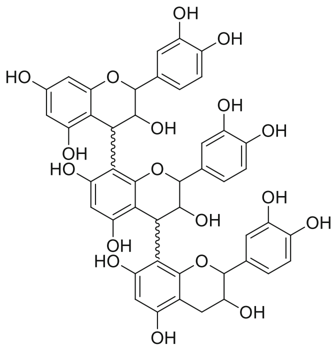


Caffeic acid



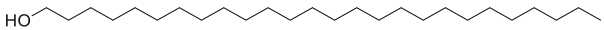
p-Coumaric

Tannins (hydrolysable tannins)

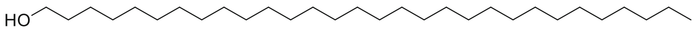


Proanthocyanidin

Fatty alcohols

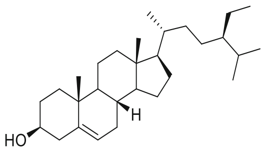


Hexacosanol

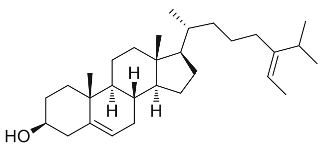


Triacontanol

Steroids



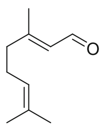
β-Sitosterol



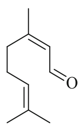
Fucosterol

Terpenoids

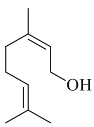
A) Voletile teprenoids - a) Monoterpens



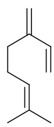
Geranial (Citral a)



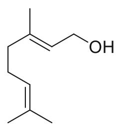
Neral (Citral b)



nerol

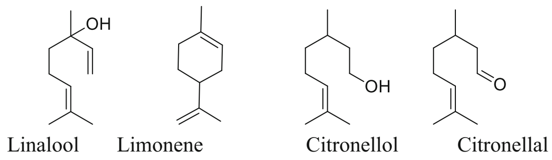


Myrcene

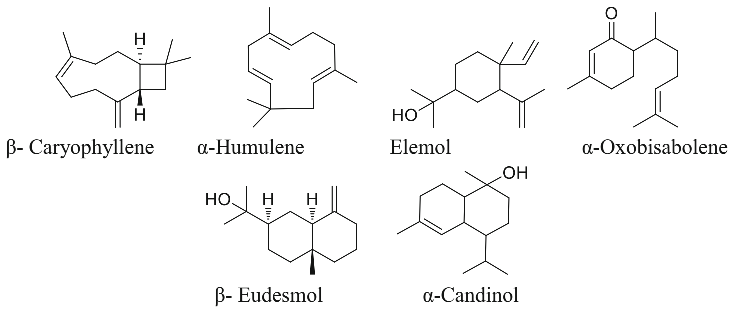


Geraniol

Fig. 4.1 (continued)



b) Sesquiterpens



B) Non-voletile terpenoids – Triterpenoids

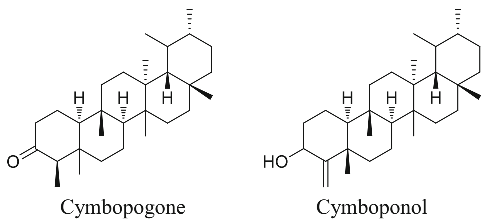


Fig. 4.1 (continued)

Polyphenolics The key polyphenolics isolated from lemongrass comprises of phenols such as elemicin, catechol, hydroquinone, and phenolic acids like caffeic, chlorogenic, and *p*-coumaric acids (Faruq 1994; Matouschek and Stahl 1991).

Tannins Many reports in literature revealed the presence of tannins (by qualitative test) in the lemongrass (Edeoga et al. 2005; Aftab et al. 2011; Avoseh et al. 2015). Figueirinha et al. (2008) reported the presence of 10 mg DW (dry weight) of hydrolysable tannins (proanthocyanidins) in lemongrass.

Fatty Alcohol and Steroids Hexacosanol and triacontanol were the prime fatty alcohols, while β-sitosterol and fucosterol were the leading steroids reported in lemongrass (Olaniyi et al. 1975).

Terpenoids The literature revealed that the composition of volatile terpenoids phytochemicals of lemongrass essential oils varies depends on the method of extraction, genetic differences, part of the plant used, age/stage of maturity, season of harvest, and geographical origin (Idrees et al. 2012; Ewansiha et al. 2012). Regardless of these variations monoterpenes such as myrcene, neral (citral b), nerol, geranial, geraniol (citral a), linalool, limonene, citronellol, citronellal, and diterpenes like β-caryophyllene, α-humulene, elemol, α-oxobisabolene, β-eudesmol and α-candinol were the major terpenoids present in the essential oils isolated from lemongrass (Shah et al. 2011; Piarua et al. 2012; Farhang et al. 2013; Ranitha et al. 2014; Pinto et al. 2015; Avoseh et al. 2015). Further, nonvolatile triterpenoids isolated from lemongrass extract were cymbopogone and cymbopogonol (Ansari et al. 1996).

Minerals Joy (2003) reported that the lemon or spent grass contained N (0.74%), K (2.12%), P (0.07%), S (0.19%), Mg (0.15%), Ca (0.36%), Zn (35.51 ppm) Mn (155.82 ppm), Fe (126.73 ppm) and Cu (56.64 ppm).

4.4 Phytochemicals Responsible for Antioxidant Properties and the Pathways Involved in the Biological Activities

Antioxidants are classified into two types: primary and secondary. Primary antioxidants donate hydrogen atom to a radical, resulting in a more stable radical. On the other hand, secondary antioxidants decrease the rate of free radical formation via inhibition of radical reactions initiating enzymes (NADPH oxidase, peroxidase, xanthine oxidase), deactivation of singlet oxygen, and absorption of UV radiation (Singh and Singh 2008). In order to determine the antioxidant activity of plant-based materials, direct and indirect methods are being used. Direct methods include the effect of antioxidant on oxidative degradation of lipids, oils, blood plasma, DNA, proteins, and low-density lipoproteins of testing system. Whereas, indirect methods (DPPH assay, ABTS assay, TE antioxidant capacity (TEAC), ferric reducing/antioxidant power (FRAP) assay, reducing power, chelating ability, hydroxyl radical scavenging, superoxide anion scavenging, etc.) determine the potential of antioxidant to scavenge some free radicals, which are not related to actual oxidative degradation (Roginsky and Lissi 2005).

Oxidation of lipids by free radicals generate hydroperoxides as intermediates, which further decompose to give secondary products like alcohols, aldehydes, ketones, alkoxy radicals, and formic acid (Miguel 2010). Antioxidant potential is determined by measuring the substrate (oils, fats or linoleic acid, methyl esters of fatty acids) and oxidant consumption, or by estimating the intermediates and final products formed using five methods, namely, peroxidation evaluation by ferric thiocyanate, β-carotene bleaching test, TBARS assay, aldehyde/carboxylic acid assay, and formic acid measurement (Miguel 2010). Chemical processes involved in free radical scavenging reactions are based either on hydrogen atom or single electron transfer (Miguel 2010).

Fruits, vegetables, and aromatics plants produce chemicals required for their growth as well as for defense against predators and pathogens. These biologically active chemical species, namely, polyphenols (flavonoids, phenolic acids), terpenoids (carotenoids and noncarotenoids), thiols (glucosinolates, allylic sulfides, indoles) etc. are called phytochemicals (Vasanthi et al. 2009). Owing to the presence of phytochemicals, fruits, vegetables, and herbs exhibit protective action against free radicals and ROS/RNS. These free radicals and ROS/RNS are responsible for various kinds of diseases in human beings (Ames et al. 1993; Toniolo et al. 2001; Sharma and Cannoo 2016, 2017). Researches carried out by various authors (Sies 1997; Fukumoto and Mazza 2000; Valko et al. 2007; Prakash and Gupta 2009; Sharma and Cannoo 2017) have revealed that antioxidant potential of plants may be attributed to the presence of phytochemicals such as polyphenols, flavonoids, tannins alkaloids, carotenoids, lignins, terpenoids, vitamins, etc. These plant-based chemicals inhibit lipid oxidation, reduce rancidity, and help in maintaining the nutritional value and shelf life of food samples (Promila and Madan 2018). Antioxidant potential of plant extracts is due to the synergistic action of above-mentioned phytochemicals (Kanatt et al. 2014). These natural antioxidants mainly perform following functions (Karadag et al. 2009):

- Prevent free radical and ROS/RNS generation
- Prevent free radical and ROS/RNS access to cell membranes
- Act as chemical traps to absorb electrons and quench free radicals
- Enhance action of catalytic enzymes, viz. SOD and CAT
- Bind to metal ions to prevent generation of free radical and ROS/RNS
- Scavenge and destroy free radical and ROS/RNS by chain breaking

Polyphenolic compounds interrupt the oxidation of lipids by inhibiting free radical chain reaction, consequently preventing production of hydroxyl free radical as well as other secondary products such as aldehydes, ketones, alcohols, malondialdehyde, etc. (Johnston et al. 2005; Ozen et al. 2011). Polyphenolic compounds being better donors of electrons and hydrogen atoms help in stabilization of radical via delocalization (Djenane et al. 2012). Also, due to the presence of hydrophobic benzenoid ring and hydrogen-bonding ability (through hydroxyl groups), polyphenolic compounds interact strongly with proteins. By virtue of these interactions, polyphenolics are capable of inhibiting radical generating enzymes, namely, xanthine oxidase, lipoxygenase, cytochrome P_{450} isoforms, etc. (Cos et al. 1988; Parr and Bolwell 2000). Further, redox properties of polyphenolics and flavonoids help in absorption, neutralization, and quenching of peroxides and owing to this polyphenolics and flavonoids are mainly responsible for strong antioxidant potential of lemongrass extracts and essential oils (Jamuna et al. 2017). Geetha and Geetha (2016) have confirmed the fact that radical scavenging activity of lemongrass depends upon the extent of conjugation and degree of hydroxylation of phenolic compounds. Further, number of hydroxyl groups and phenolic structure play an important role in radical scavenging and metal chelation of antioxidants (Pazos et al. 2005; Kanatt et al. 2014; Jamuna et al. 2017). Shan et al. (2005), Khadri et al. (2010), and Thorat et al. (2017) have also concluded that antioxidant potential of lemongrass is due to the presence of polyphenolic compounds in it.

Tapia et al. (2007) described that *C. citratus* shoots flavonoid contribute less (28.6%) as compared to total phenolics (49.7%) toward radical scavenging activity. Contrary to this result, Cheel et al. (2005) have reported 76% contribution of flavonoids to antioxidant activity of lemongrass collected from Chile. Figueirinha et al. (2008) have confirmed that flavonoid and tannin fractions of lemongrass extract were more effective radical scavengers as compared to phenolic acid fractions. Due to low redox potential and high electron-donating capacity, flavonoids possess efficient radical scavenging properties (Pannala et al. 2001; Rice-Evans et al. 1997; Kieling and Prudencio 2019). Flavonoids are also known to react with myeloperoxidase (MPO), in the presence of hydrogen peroxide, consequently preventing the reaction of NO_2 with low density lipoproteins and hence retard the lipid peroxidation (Nambiar and Matela 2012). Some authors have reported antioxidant action of flavonoids via suppression of plasma cholesterol concentrations (Almoosawi et al. 2010; Anila and Vijayalakshmi 2000). The configuration and substitution of hydroxyl groups has a significant impact on radical scavenging activity of flavonoids (Kelly et al. 2002; Pandey et al. 2012). Chelation of metal ions with at specific hydroxyl groups (Fig. 4.2) of different rings of basic flavonoid structure is an important mechanism of free radical inhibition (Van Acker et al. 1996; Kumar and Pandey 2013; Mishra et al. 2018). Halabi and Sheikh (2014), Geetha and Geetha (2016), Eldeeb and Mosilhey (2018), and Sari et al. (2017) have stated the antioxidant activity of lemongrass through chelation/deactivation of transition metal ions, consequently inhibiting the decomposition of hydroperoxides as well as Fenton reaction.

Among three C-glycosyl flavonoids, viz. isoorientin, swertiajaponin, and isoorientin 2″-O-rhamnoside isolated from lemongrass leaves, isoorientin has been found to possess considerable antioxidant action through inhibition of low-density lipoprotein oxidation (Orrego et al. 2009). Campos et al. (2014) have also confirmed the compounds, namely, chlorogenic acids (VIII), isoorientin, and swertiajaponin in lemongrass to be responsible for antioxidant activity via alleviation of Cu^{+2}-induced low-density lipoprotein oxidation. Other minor derivatives of luteolin and apigenin

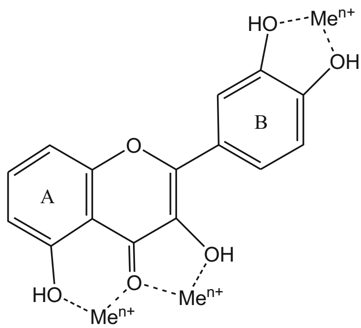


Fig. 4.2 Chelation of metal ions with specific hydroxyl groups of basic flavonoid structure

were also speculated for contribution in antioxidant potential of lemongrass (Campos et al. 2014).

Antioxidant potential of lemongrass essential oil is related with the presence with monoterpene hydrocarbons, oxygenated monoterpene, and sesquiterpenes which help in breaking free radical chain reactions (El-Shennawy and Abozid 2017; Tepe et al. 2007; Yanishlieva et al. 1999; Foti and Ingold 2003). Synergistic action between terpenes and other antioxidants such as rutin and α-tocopherol is also an interesting feature of antioxidant mechanism (Grabmann 2005). Vyshali et al. (2016), Ruberto and Baratta (2000) attributed the antioxidant activity of *C. citratus* essential oil to synergistic action of terpenoids namely neral, geranial, and myrcene. Warad et al. (2013) have concluded that monoterpene such as citral and citronellal contribute to antioxidant activity of lemongrass. Essential oils having high content of phenolic compounds (like thymol, carvacrol, eugenol, etc.) possess high antioxidant properties (Lambert et al. 2001; Bagamboula et al. 2004). These components increase the oxygen absorbance and hydroxyl radical scavenging activity of plant tissue (Wang et al. 2008).

4.5 Health Benefits

Lemongrass, a nervine, is considered as a tonic for maintaining well-being of nervous system. It activates the mind and assists in countering neuronal disorders such as nervousness, convulsions, and vertigo. It is used in therapeutic baths with a purpose of calming the nerves and reducing the signs of fatigue and anxiety caused by stress (Goes et al. 2015; Costa et al. 2011a, b). It is also considered as a useful herb for relaxing muscles, nerves for inducing sleep and curing insomnia. Blanco et al. (2009) has explored the sedative and hypnotic effects of lemongrass for increasing sleep duration. The antioxidant properties of lemongrass aid in protection of body cells from free radicals/ROS/RNS and facilitate regeneration of cells (Patnaik et al. 1997). It is also effective in prevention of cancer cell growth without any harmful effects on healthy cells. Dudai et al. (2005) have studied and justified the inhibiting effect of citral, a constituent of lemongrass, on growth of hepatic cancer cells during initial stages. Citral has also shown antiproliferative effect in delaying the growth and induction of apoptosis of cancer cells responsible for breast cancer (Ghosh 2013; Philion et al. 2017).

Lemongrass has been found to possess anti-hypercholesterolemic and anti-hyperlipidemic properties (Kumar et al. 2011; Lee et al. 2018). It assists in reduction of blood cholesterol and supports maintaining healthy cholesterol levels (Costa et al. 2011a, b). Regular consumption of lemongrass prevents lipid accumulation and promotes unhindered blood flow in blood vessels, thereby reducing the risk of various heart diseases (Kumar et al. 2011). Citral, main constituent of lemongrass, reduces buildup of abdominal fat, encourages the utilization of stored energy resulting in prevention of diet-produced weight gain (Modak and Mukhopadhaya 2011). Olorunnisola et al. (2014) has revealed that lemongrass increases the body metabolism and therefore can be used effectively for control of obesity. In addition to this, lemongrass has been found to possess diuretic properties and aid in flushing and cleansing of harmful toxins from body (Nakamura et al. 2003). Diuretic property of herbs helps in sustaining digestive health by increasing the frequency and quantity of urination (Wile 2012). Use of lemongrass is also beneficial in alleviating gastro-intestinal disorders and inflammation thereby relieving from constipation, ulcerative colitis, ulcers, nausea, diarrhea and stomach aches (Fernandes et al. 2012). Due to its antimicrobial activity, lemongrass essential oil is capable of fighting stomach infections caused by pathogens *Helicobacter pylori* and *Escherichia coli* (Ohno et al. 2003). Adukwu et al. (2012) have confirmed the antibiofilm capacity and usefulness of its essential oil against infections caused by *Staphylococcus aureus*. The antimicrobial properties of lemongrass make it an effective herb for treatment of infections like scabies, ringworm, and urinary tract infections (Silva et al. 2008). Abe et al. (2003) have also proposed the healing effects of lemongrass on various dermatological yeast infections and oral and vaginal candidiasis via inhibition of growth of pathogens.

The analgesic properties lemongrass provides relief from headache, migraine, and rheumatism (Meenapriya and Priya 2017). When applied topically, it improves blood circulation (Kamkaen et al. 2015) and can be useful for treating spasms, sprains, backaches, muscle cramps, bruises, internal injuries, dislocations, etc. Another heath benefit of lemongrass is seen in its cleansing effect on lymphatic congestion which soothe the swelling and provides relief from edema (Boukhatem et al. 2014). Owing to its effectiveness in lowering fever, it also referred to as “fever grass” (Toungos 2019). In Ayurvedic medicinal system, antipyretic and diaphoretic properties of lemongrass are extensively explored for curing fevers through sweating (Gbenou et al. 2013; Toungos 2019). Modak and Mukhopadhaya (2011) have studied type-2 diabetes managing properties of lemongrass. Its constituent citral helps in maintaining optimal insulin levels and develops the glucose tolerance in body by enhancing energy dissipation and insulin sensitivity.

Antiseptic and astringent properties of lemongrass makes it an effective cleansing agent and skin care tonic for oily and acne prone skin through strengthening, sterilizing, and toning of skin tissues (Narayan and Maheshwari 2017). It is also used for tightening and uplifting of loose skin. Lemongrass improves blood circulation and is used in making deodorants (Mathew et al. 2017) and perfumes (Mane et al. 2015). Studies conducted by various authors (Oyedele et al. 2002; Baldacchino et al. 2013) have also confirmed the mosquito repellent, antiprotozoal, and antimalarial properties of lemongrass essential oil. Various pet-grooming products like shampoos having lemongrass are commercially available due to its repellent effects on ticks and lice. Doran et al. (2009) have suggested the use of its oil for air disinfection. It is also having protective hydrophobic properties for preservation of palm leaf manuscripts from bacterial damage by preventing humidity loss and providing the required moisture (Toungos 2019).

4.6 Conclusion

Till date, numerous bioactive SMs has been isolated and characterized so far, still the Mother Nature must have many new in her basket. So, a meticulous and organized study has been needed in order to recognizing and documenting the plants that have been biologically significant and presented array of SMs of therapeutic importance. *C. citratus* (lemongrass) has been envoy species of genus *Cymbopogon* that belongs to family Poaceae. Lemongrass has been well known for its numerous conventional usages and used to cure coughs, headache, elephantiasis, gingivitis, leprosy, flu, arthritis, malaria, ophthalmic, vascular disorders, and pneumonia, etc.

The phytochemical diversity of lemongrass has chiefly been represented by flavonoids, phenolic acids, tannins, fatty alcohols, steroids, and terpenoids (mainly mono-, sesqui-, and triterpenoids) classes of SMs. These classes of SMs have been largely responsible for its numerous pharmacological activities especially its antioxidant potential. Apart from this lemongrass also have large number of health benefits as discussed above. These facts related to pharmacological and health benefits of the plants have been sufficient to support the fact that the lemongrass can be used as natural remedy for various kinds of ailments. In spite of this, still there has been need of more pharmacological justifications to explain its potential as natural remedy. The current data would be encouraging in the development of today's research in the investigation of new pharmacologically potent SMs (especially natural antioxidants) from plants belongs to genus *Cymbopogon*. Therefore, it is very crucial, to conserve our diverse natural flora and to support their protection to maintain inexhaustible sources of potent leads SMs, which may have numerous applications in various fields.

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