



Review

Phytochemical Composition and Pharmacological Potential of Lemongrass (*Cymbopogon*) and Impact on Gut Microbiota

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Abstract: Phytochemicals are versatile plant secondary metabolites with therapeutic properties. In this review, we explore lemongrass's phytochemistry and pharmacological potential (*Cymbopogon*) as well as its impact on gut microbiota. Lemongrass is well-known for its antioxidant, anti-microbial, anti-inflammatory, anti-hypertensive, anti-diabetic, anti-mutagenicity, anxiolytic properties, and for its hypoglycemic and hypolipidemic activities. Therefore, it is widely used in pharmaceuticals, food, feed, and the cosmetics industry. Lemongrass contains phenolic metabolites (including phenolic acids, flavonoids, stilbenes, and lignans), terpenoids, and alkaloids, which are potent bioactive ingredients. Lemongrass is a precious medicinal plant. Furthermore, lemongrass phytochemicals are considered potential agents to improve health by establishing a balanced gut ecosystem. Lemongrass is considered a quintessential food and feed additive at the industrial level, since there are no issues with residue or toxins. Lemongrass powder and essential oils are used to modulate the gut ecosystem by generating anti-microbial, anti-inflammatory, and antioxidant responses, increasing the optimum nutrient absorption in the gut system. This review will further explore lemongrass's phytochemical, pharmacological, and therapeutic potential.

Keywords: phytochemistry; volatile compounds; polyphenols; microbiota; health



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1. Introduction

Phytonutrients are considered unique substances which are present naturally in plants, and have been found to carry disease-preventing possibilities which are not only specific, but also powerful. Both kinds of essential and nonessential phytonutrients impart some specific physiological function. They are described as bioactive food mechanisms, with descriptions of their metabolic and physical processes, related goals, and biomarkers [1]. However, the future need for nutraceuticals will rely on consumer awareness and the association between diet and disorder. Although a useful functional diet and nutraceuticals have a noteworthy role in the improvement and care of human health, in order to stop biotechnologists, regulatory toxicologists, diseases, health professionals, nutritionists, and nutraceutical industrialists should deliberately work in an organized way to create suitable rules to deliver therapeutic methods which can improve the health and welfare of human beings with efficacy, purity, and safety.

Innovative dietary methodologies have improved the developing theory of nutraceutical and designer foods by merging various functional ingredients in order to attain health assistance. Dietary enrichment through nutrification provides significant health benefits due to many plant-based non-nutritive components, i.e., phytoconstituents. Plant-based therapies have, so far, appeared to be an effective strategy to address metabolic and immune dysfunction [2]. They have been used as therapeutic agents since the earliest times, in both systematized (Unani and Ayurveda) and disorganized (native, folk, tribal) forms.

Plants have been well-known to be strong therapeutic agents due to the presence of some nutritional minerals and vitamins, as well as the presence of non-nutritional components, including fibers and active phytochemicals, such as the terpenoids, flavonoids, lignans, sulfides, plant sterols, polyphenolics, coumarins, carotenoids, and saponins [3–5]. Plant foods are a vital source of two kinds of mixtures: polyphenolic and phenolic [6]. These phytochemicals, namely flavonoids and polyphenols, are present in the seeds of fruits and skin, but leaves frequently supply an abundant source of phenolics. Lemongrass is considered to be a potentially beneficial antioxidant source when it is processed under optimal conditions. Additionally, these leaves are a rich source of several bioactive substances, including alkaloids, flavonoids, terpenoids, saponins, phenols, and tannins, which provide lemongrass leaves with their distinctive flavour [7]. Previously, it has been reported that leaves exhibit better antioxidant activity against hepatitis virus expression. Although the concept of antioxidants is mostly used to explain the therapeutic potential of phenolic and polyphenolic components, the application of phenolic compounds improves antioxidant potential, which may act as reducing agents due to their usefulness in scavenging chelating pro-oxidants, free radicals, and metal ions [8–10]. Lemongrass is a scented grass that is typical of tropical areas, and contains plenty of vitamins and minerals. Lemongrass has antiparasitic effects, and its essential oil is an excellent side treatment for those who suffer from ulcers secondary to *Helicobacter pylori* infections. Additionally, lemongrass tea is an excellent way to relieve stomach cramps, and is recommended in cases of constipation and diarrhea. It has a mild anti-bacterial effect, capable of sweeping off pathogenic bacteria from the colon and improving gut health.

2. Phytochemical Constituents of Lemongrass

The herb *Cymbopogon*, a member of the Poaceae family, is also referred to as lemongrass [11]. A perennial grass, lemongrass can reach a height of one meter, and has multiple stiff, green stalks that emerge from short and rhizomatous roots [12]. A perennial aromatic grass known as *Cymbopogon citratus* is widely grown in the Philippines and Indonesia. It is also cultivated in America and Asia, and, more specifically, in their tropical regions [13]. The plant is mostly an indigenous herb to India, but it is also grown in several tropical and subtropical nations, including in Pakistan [14]. Several species of lemongrass have been found worldwide: *Cymbopogon citratus* (*C. citratus*), *C. bombycinus*, *C. refractus*, *C. nardus*, and *C. ambiguus*. The lemongrass plant, lemongrass oil, and lemongrass stalks are shown in Figure 1.



Figure 1. Lemongrass plant (A), lemongrass oil (B), and lemongrass stalks (C).

2.1. Volatile Constituents of Lemongrass

Due to its commercially valuable essential oils, lemongrass is frequently used in food technology, pharmaceuticals, and traditional treatments. The terpenes, alcohols, ketones, and esters present, as well as the essential oil of lemongrass, differ according to its

topographical origin, which affects its chemical makeup. The essential oil that is extracted from lemongrass is mostly found in the leaves of the plant, which are also a great source of it [1]. Up to 5% dry weight of essential oils, primary citral with a distinctive lemonade scent, are present in the leaves [15]. Due to the presence of citral, a cyclic monoterpene, the word “lemon” in its name refers to its distinctive lemon-like aroma [16]. Numerous consumer products contain fragrances made using the oil of lemongrass, such as linalool (1.3%), geranial (39.0%), neral (29.4%), geraniol (1.7%), and myrcene (18.0%) [17]. Myrcene is an anti-bacterial and analgesic compound found in lemongrass, and citronellal, citronellol, and geraniol are its active ingredients. Citral, a volatile oil with a robust lemon aroma, is present in the essential oil. Citral is a mixture of two aldehydes and a stereoisomeric monoterpene; it is used to make perfumes and colored soaps, and synthesizes vitamin A. The geranial with trans isomer nature (40–62%) prevails over the neral with cis isomer nature (25–38%) in citral [1]. Lemongrass has a long history of use in food and beverage recipes, folk medicine, and cosmetics. Due to its alluring scent, Lemongrass is utilized as a flavoring component in many non-food products, such as soaps, perfumes, candles, and insect repellents.

The essential oil of this plant is considered one of the chief volatile oils. Essential oils, perfumes, and volatile plant byproducts have a significant advantage in both the perfume and folk medicine businesses. Many essential oils and the substances that make them up have pharmacological capabilities that act as anti-inflammatory, antioxidant, and anti-cancer agents [18]. Lemongrass essential oil carries great importance, with citral as the main element. The citral content fluctuates from 44.3–91.4% to 79–91.5% in the essential oil [1]. Other important volatile constituents are β -myrcene (11%) and geraniol (1.9%) [19]. The structures of the main volatile constituents are given in Figure 2.

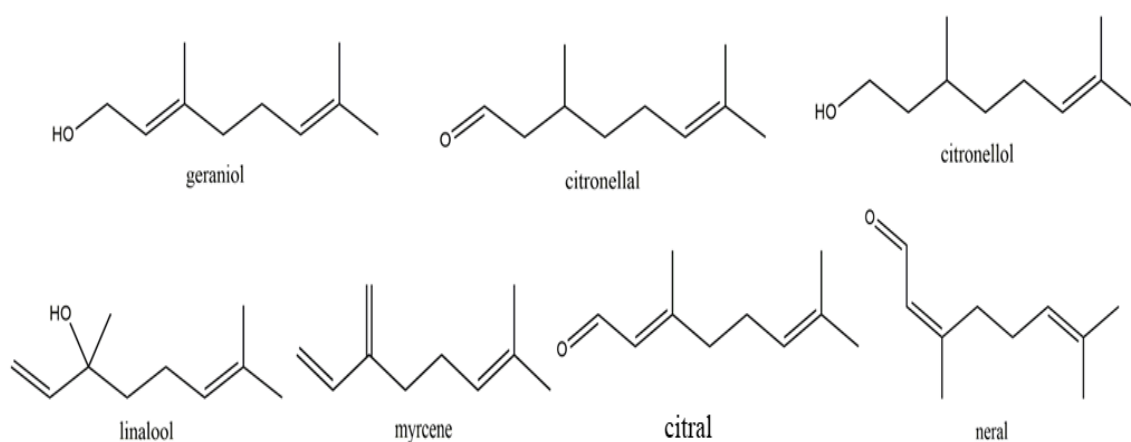


Figure 2. Structures of abundant volatile constituents of Lemongrass.

2.2. Phenolic Constituents of Lemongrass

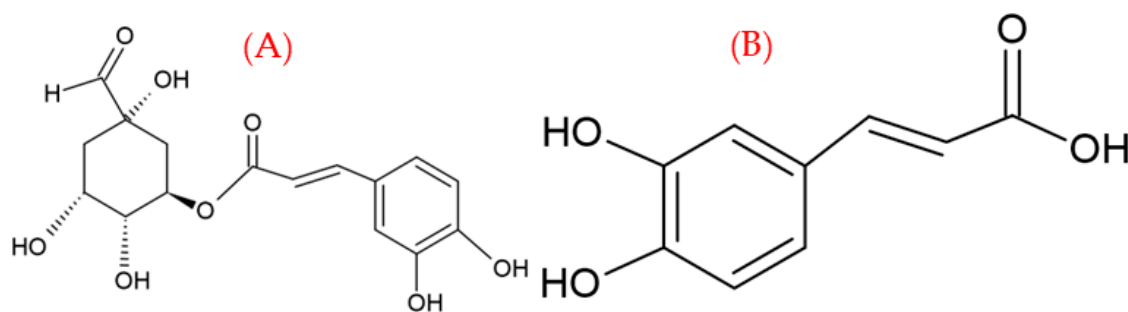
Phenolic compounds are a diverse class of plant secondary metabolites, including phenolic acids, flavonoids, stilbenes, lignans, coumarins, curcuminoids, and other polyphenols. Flavonoids are the most abundant phenolic constituents, containing more than ten thousand compounds [5]. The highest concentration of caffeic acid ($445.21 \pm 32.77 \mu\text{g/g}$), *p*-coumaric acid ($393.32 \pm 39.56 \mu\text{g/g}$), chlorogenic acid ($377.65 \pm 4.26 \mu\text{g/g}$), quinic acid ($161.52 \pm 17.62 \mu\text{g/g}$), and quercetin-3-glucoside ($151.35 \pm 11.34 \mu\text{g/g}$) were reported by Ali et al. [20], and these results are given in Table 1. Moreover, catechin, tricetin, pyrogallol, diosmin, procyanidin B2, ferulic acid, protocatechuic acid, and *p*-hydroxybenzoic acid have also been reported in Australian lemongrass (Table 1). Lutein, apigenin, and their 6,8-glucosides were also reported by Shah et al. [1].

Table 1. Phytochemical constituents of lemongrass.

Name of Compound	Formula	Concentration	References
Citral α	$C_{10}H_{16}O$	40.8%	[1]
Geraniol	$C_{10}H_{18}O$	1.9–3.04%	[1,19]
Citral β	$C_{10}H_{16}O$	32%	[1]
Geranyl acetate	$C_{12}H_{20}O_2$	0.83%	[1]
Terpinol	$C_{10}H_{18}O$	0.45%	[1]
Nerol	$C_{10}H_{18}O$	4.18%	[1]
β -Pinene	$C_{10}H_{16}$	0.4%	[1]
Citronellal	$C_{10}H_{18}O$	2.10%	[1]
β -Myrcene	$C_{10}H_{16}O$	11%	[19]
Methylheptenone	$C_{10}H_{16}O$	0.2%	[1]
α -Pinene	$C_{10}H_{16}$	0.7%	[1]
Limonene	$C_{10}H_{16}$	NR	[1]
Linalool	$C_{10}H_{18}O$	NR	[1]
β -caryophyllene	$C_{15}H_{24}$	NR	[1]
α -Bisabolol	$C_{15}H_{26}O$	NR	[21]
Eugenol	$C_{10}H_{12}O_2$	NR	[21]
Citronellol	$C_{10}H_{20}O$	NR	[21]
Elemicin	$C_{12}H_{16}O_3$	NR	[21]
α -Thujene	$C_{10}H_{16}$	NR	[21]
Neral	$C_{10}H_{16}O$	NR	[21]
Camphene	$C_{10}H_{16}$	NR	[21]
β -Selinene	$C_{15}H_{24}$	NR	[21]
Diosmin	$C_{28}H_{32}O_{15}$	$19.32 \pm 5.47 \mu\text{g/g}$	[20]
Catechin	$C_{15}H_{14}O_6$	$19.23 \pm 2.37 \mu\text{g/g}$	[20]
Procyanidin B2	$C_{30}H_{26}O_{12}$	$46.75 \pm 6.56 \mu\text{g/g}$	[20]
Quercetin-3-glucoside	$C_{21}H_{20}O_{12}$	$151.35 \pm 11.34 \mu\text{g/g}$	[20]
Tricin	$C_{17}H_{14}O_7$	$12.34 \pm 2.31 \mu\text{g/g}$	[20]
Kaempferol-3-glucoside	$C_{21}H_{20}O_{11}$	$21.45 \pm 4.12 \mu\text{g/g}$	[20]
Caffeic acid	$C_9H_8O_4$	$445.21 \pm 32.77 \mu\text{g/g}$	[20]
Chlorogenic acid	$C_{16}H_{18}O_9$	$377.65 \pm 4.26 \mu\text{g/g}$	[20]
Cinnamic acid	$C_9H_8O_2$	$61.30 \pm 17.31 \mu\text{g/g}$	[20]
Quinic acid	$C_7H_{12}O_6$	$161.52 \pm 17.62 \mu\text{g/g}$	[20]
Ferulic acid	$C_{10}H_{10}O_4$	$12.17 \pm 3.11 \mu\text{g/g}$	[20]
<i>p</i> -Coumaric acid	$C_9H_8O_3$	$393.32 \pm 39.56 \mu\text{g/g}$	[20]
<i>p</i> -Hydroxybenzoic acid	$C_7H_6O_3$	$94.01 \pm 2.24 \mu\text{g/g}$	[20]
Protocatechuic acid	$C_7H_6O_4$	$54.16 \pm 3.65 \mu\text{g/g}$	[20]
Pyrogallol	$C_6H_6O_3$	$27.54 \pm 5.76 \mu\text{g/g}$	[20]

Not reported (NR).

The structures of the main phenolic constituents are given in Figure 3, while the main phenolic constituents of lemongrass are given in Table 1.

**Figure 3.** Cont.

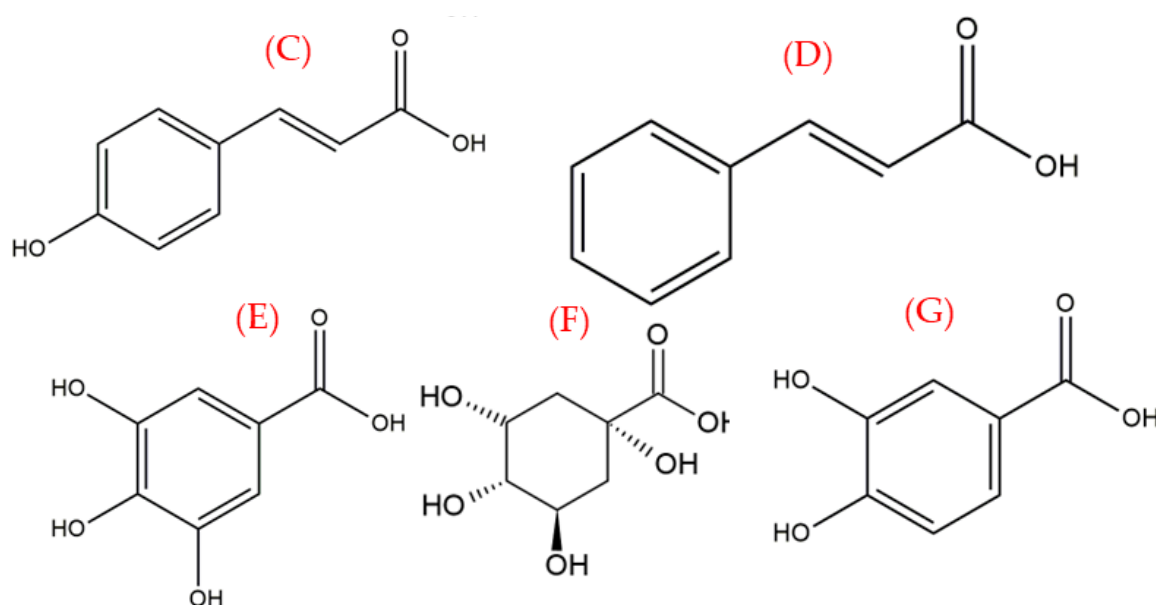


Figure 3. Structures of chlorogenic acid (A), caffeic acid (B), *p*-coumaric acid (C), cinnamic acid (D), gallic acid (E), quinic acid (F), and protocatechuic acid (G).

3. Therapeutic Potential of Lemongrass

Lemongrass is a well-known medicinal plant in traditional medicines, and contains an abundance of monoterpenes, sesquiterpenoids, tannins, and phenolic metabolites. The therapeutic potential of lemongrass is given in Table 2.

Table 2. Therapeutic utilization of lemongrass.

No.	Therapeutic Utilization of Lemongrass	Plant Part Used	References
1	Fever, headache, liver disease	Leaves	[22,23]
2	Stress, fever, inflammation	Leaves	[24–26]
3	High blood pressure, vomiting, stress, malaria	Leaves	[27,28]
4	Hypertension, flu, digestive problems	Aerial parts	[29]
5	Influenza	Leaves	[30]
6	Heart problems, nervous tension, digestion problems	Whole plant	[31,32]
7	Menstrual disorders, leucorrhea	Stems	[33]
8	Hypertension	Whole plant	[34]
9	HIV/AIDS	Leaves	[35,36]
10	Kidney problems	Aerial parts	[37]
11	Fever, common cold, malaria	Leaves	[30,38–40]
12	Cancer	Leaves	[31,41]
13	Diabetes	Whole plant	[42,43]
14	Muscle pain, runny nose and asthma, joint swelling	Aerial parts	[21]
15	Hair loss	Essential oil	[44]
16	Malaria	Essential oil	[28]
17	Insecticidal	Essential oil	[45]

Human Immunodeficiency Virus (HIV), Acquired Immune Deficiency Syndrome (AIDS).

3.1. Disease Modulatory Role of Lemongrass

Since ancient times, people have used herbal medicine and various plant-based therapeutic/preventative remedies to cure illnesses. Phytomedicine and herbal medicine are widely acknowledged and used across the globe. Various herbs ingested by people have been the topics of research which uses cutting-edge techniques to support their alleged phytochemical and pharmacological profiles. The current research emphasizes a regularly used

herb, lemongrass, and its phytochemistry and pharmacological profile. According to earlier research, lemongrass has a wide range of medicinal uses, including anti-inflammatory, anti-filarial, anti-diarrheal, anti-mycobacterial, anti-bacterial, and anti-fungal qualities [13]. It has been linked to health benefits such as treating coughs, constipation, headaches, leprosy, malaria, pneumonia, vascular problems, and diarrhea. It is a highly esteemed folk remedy in Brazil. It has been asserted that lemongrass functions has nervous, anti-inflammatory, diuretic, and therapeutic effects on vasorelaxant, gastrointestinal, feverish, ringworm infestation-related, and hypertensive conditions. Lemongrass also has many antioxidant metabolites [46].

3.2. Utilization of Lemongrass in Folk Medicine

Several illnesses have been treated using lemongrass in medicine produced in traditional ways. According to Nambiar and Matela [46], lemongrass is used worldwide to treat gastrointestinal problems, fevers, menstrual irregularities, malaria, and pneumonia. The aerial portions of lemongrass are frequently employed in traditional medicine through infusions or stews. According to scientific research, this plant is recommended for treating fever, mental disorders, inflammation, digestive disorders, and other human health issues. According to Heinerman's Encyclopedia of Healing, drinking one cup of lemongrass tea every four hours can help decrease fever, along with herbs and spices. Similarly, lemongrass has some components that may be tumor chemo-protective, as demonstrated by Puatanachokchai et al. [47]. As a result, the extract has demonstrated several qualities that can reduce the risk of rat colon cancer in animal models. Lemongrass tea is also considered to have diuretic properties, and can be helpful for urination issues. It also plays a role in water balance in the body.

The phytochemical components of the leaves, which are essential oils containing terpinolene, geranyl acetate, myrcene, and terpinol methylhistamine, were recently analyzed [48]. The analysis demonstrated the presence of phytochemicals, such as flavonoids and phenols, in lemongrass. Each of these phytochemicals is famous for various protective and advantageous properties. Additionally, pentylenetetrazol-induced colonic seizures brought on by maximal electroshock were delayed by required oil and congested tonic allowances. These were examples of the spread of seizures being halted or promoted. One of the essential components of lemongrass extracts is an essential oil, which acts as a co-ingredient in perfumes and cosmetics. Due to its high citral content, it is crucial for several chemical syntheses [49]. Accordingly, previous studies on different lemongrass extracts depicted further significant therapeutic potentials, including anti-cancer and anti-mutagenicity properties. Anxiolytic, anti-diabetic, antioxidant, non-toxic, and anti-fungal characteristics are additional benefits [1]. The aerial parts of lemongrass have been infused and used in traditional medicines worldwide. Similarly, the lemongrass plant is recommended in numerous parts of India to cure digestive issues, inflammation, neurological disorders, fever, and other health disorders. The biological properties of lemongrass leaves include anti-hypolipidemic, anti-atherosclerotic, antioxidant, immune-stimulating, anti-hypertensive, and anti-tumor properties.

Lemongrass has also been used to cure various diseases and problems, including rheumatism, menstrual disorders, infections, and other multiparty issues. It has been determined that lemongrass extraction with alcohol at a concentration of 60 µg/mL has significant results, including DPPH foraging ability (85%), superoxide (76%), hydroxyl (70%), nitric oxide (78%), and ABTS assay (77%) of free radicals via in vitro analysis, and it also has a reasonable anti-lipid peroxidative effect (57%), as depicted by Nambiar and Matela [46].

In a competitive market, therapeutic plant parts are used often. Their uses include pharmaceuticals, food, cosmetics, and perfumery markets. In pharmaceuticals, extracts of plant parts are particularly valid due to their usage of active ingredients for the development of medicine, and also as sources of raw material [50]. For the manufacture of vitamin A in perfumery and flavorful grass, it is used as a raw material, and it has a valuable effect when

used as a medicinal tea. In different countries of the world, leaves are used in teas as well as in cooking and treating coughs. The stalks are hard and are not easily edible, but they can be either crushed or chopped and added to fish or fowl sauces for flavor. Lemongrass can be used as a stomach smoother, as it lowers cholesterol levels when used medicinally. Each day, lemongrass tea or powder can be consumed in quantities of 1–4 cups; this helps with vomiting, bladder issues, congestion, headaches, coughing, fever, stomachaches, digestive issues, and diarrhea, and increases respiration, acting as a potential hypocholesterolemic agent. Prior to this, Lonkar, et al. [51] researched the processed lemongrass powder sold in stores as “Sereh powder”. There are several recipes for lemongrass-based items, including lemongrass meat, sweet lemongrass blend, and lemongrass rice. It also has many uses in the food, medicine, and flavoring industries. It cannot be kept as fresh for a long time in ambient conditions, because its quality and, therefore, its taste will deteriorate. Therefore, it can only be stored in powdered form. The potential health benefits of lemongrass are given in Figure 4.

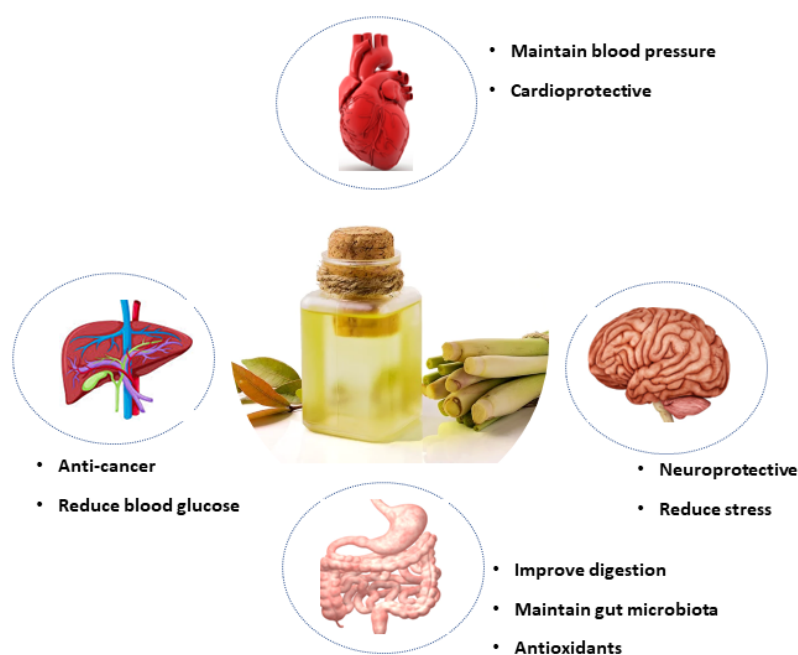


Figure 4. Potential applications of lemongrass.

3.3. Antioxidant Potential

In nature, the well-recognized polyphenols are small molecules, and flavonoids are the most abundant class of phenolic compounds [5]. They reveal the antioxidant chemistry, and are accountable for their coloring and organoleptic profile in nutraceutical foods [5,52–54]. The considerable interaction with flavor and taste is the outcome of their innocuous reaction with glycoproteins in saliva. They are highly prone to oxidation, owing to their reactions with atmospheric oxygen. The most copious polyphenols are flavonoids, phenolic acids, and tannins, as well as lignans and stilbenes. Amongst flavonoids, catechins (flavanol) in green tea, quercetin (flavonols) in onions and apples, and genistein and daidzein (isoflavones) in soybeans are of more importance. Phenolic acids are classified into two types of derivatives: the first is the derivative of benzoic acid, which is gallic acid, and the second comprises the derivatives of cinnamic acid, including caffeic acid (mostly in coffee), coumaric acid, tannins [55], and ferulic acid (found in cereals). Tannins are hydrolyzable and condensed. Several significant bioactive chemicals found in lemongrass help with the treatment of various medical conditions.

Limonene, granite, citral, graminon, myrcene, and linalool are active chemicals typically found in leaves. People chew on the lemongrass root in many cultures worldwide to clean their mouths. Lemongrass extracts carry a crucial component, essential oil, which is

utilized as a co-ingredient in cosmetics and perfumes. Because of its higher citral content, it is crucial for several chemical syntheses [49]. Research on lemongrass extracts, which have a varied nature, may have revealed other significant medicinal potentials, including anti-mutagenicity, anti-cancer, and anti-hypertensive.

Phytochemicals are organic substances present in plants. They are not only essential nutrients for life, but also carry potential health benefits. Up-to-date data [56] examined the therapeutic worth of plant-based products. They discovered that their effectiveness as a medicine mostly depends on the phytochemical components' capacity to exert potent physiological and pathological effects on the human body. The nutritional, therapeutic, and cosmetic properties of lemongrass have led to its widespread consumption worldwide. The existence of alkaloids, tannins, phenols, deoxy sugars, flavonoids, saponins, anthraquinones, and different essential oil constituents in lemongrass has been demonstrated in several previous investigations on phytoconstituents.

In the explorations, alcohols, ketones, esters, terpenes, and aldehydes were found to be the primary components of lemongrass, according to Shah et al. [1]. Essential oils (which include the flavonoids nerol, geraniol, citral, geranyl acetate, citronellal, myrcene, citral, terpinolene, and terpinol methylheptenone) and phenolic compounds, which include kaempferol, isoorientin 2'-O-rhamnoside, luteolin, quercetin, and apigenin, are the main phytoconstituents. The body's various biochemical processes form free radicals, which have a role in the development of ischemic heart disease, tumors, inflammation, immunosuppression, diabetes, atherosclerosis, aging, hair loss, and neurological diseases, including Parkinson's and Alzheimer's disease [56]. The human body has built-in defenses against free radicals, including the enzymes glutathione peroxidase, catalase, and superoxide dismutase [57].

Recent observations have shown that the destruction of cells caused by free radicals is one of the main reasons for the aging process and disease development. The primary line of resistance uses antioxidants that are contrary to free radical damage, and that is supposed to be critical for maintaining excellent health. Lemongrass is a significant source of antioxidants and phytochemicals. Likewise, Godwin et al. [17] found that total phenolic activity in both cold and hot filtrations of lemongrass ranged from 1.3 to 4.7 mg and from 2.6 to 7.3 mg of gallic acid equivalents (GAE)/g DW, respectively; total antioxidant activity in both cold and hot filtrations ranged from 65.4 to 81.3% and from 65.4 to 81.3%, which was exactly the same, while the total flavonoid concentration ranged from 6.9 to 11.3 µg/g and from 6.9 to 12.9 µg/g QE on a dry weight basis for cold and hot filtrations, respectively.

Since other explorations have shown that there has been an increased demand for the extraction of oil from natural plants due to their bioactive compounds and therapeutic effects. For this purpose, the quality of the oil depends upon its constituents and the extraction method [58]. Conventional methods that are the most frequently used for oil extraction from various plants, including lemongrass, are hydro-distillation, steam distillation, maceration, and empyreumatic distillation [59]. Previously, Karakaya et al. [60] proved that the quality of the oil primarily determines the extraction procedure and constituents. They also reported that these conventional methods have drawbacks, such as the water solubilization of some scents, hydrolysis, and heat degradation. The monoterpene molecule underwent susceptible chemical modifications during steam distillation. Additionally, residues from the oil obtained via solvent-aided extraction may have chances to contaminate the food scents into which they are inserted and, thus, cause losses of compounds that are volatile during the solvent removal process. A more recent technique (microwave-assisted hydro-distillation) has been used to overcome these drawbacks. It is preferred due to its benefits in the laboratory and on an industrial scale, as it provides more control over energy transfer [61].

In human tissue cells and systems, oxidation is a necessary process that produces reactive oxygen species (ROSs), for instance, superoxide anion (O_2^-), hydrogen peroxide (H_2O_2), as well as free radicals [62]. ROSs may cause harm to biological elements such as proteins, cell membranes, DNA, and cellular lipids due to their reactivity. Additionally,

ROSs can perform a dominant role in the development of several medical conditions, including atherosclerosis, rheumatoid arthritis, and muscular atrophy. Others include cancer, neurological conditions, cataracts, and aging. In order to provide a defense mechanism against the harmful consequences of the oxidation process brought on by free radicals, antioxidants must be present in the body. Researchers have shown that lemongrass extracts have antioxidant properties, and have verified their powers to reduce ROS. This process involved DPPH (2,2-diphenyl-1-picrylhydrazyl) decolorization and lipoperoxidation suppression [63]. Lemongrass infusions, as well as decoctions, have been shown to have antioxidant properties, including superoxide anion scavenging, preventing lipoperoxidation, and discoloring DPPH. Infusions have more of these qualities than decoctions do [64]. If we compare lemongrass infusion with other extracts (aqueous ethanol, methanolic, 80%, and decoction), it can be seen that the lemongrass infusion presented better antioxidant effects.

Further research revealed that, when compared to tannins, phenolic acids, and flavonoid fractions of oil-free infusion extract were considered to be the most effective anti-oxidative agents [14]. The production of reactive oxygen species and lipid peroxidation were reported to be reduced by aqueous ethanol extract, while glutathione synthesis and superoxide dismutase activity were increased [65]. Recently, the DPPH scavenging assay was used to demonstrate the antioxidant properties of lemongrass essential oils. Some up-to-date findings have demonstrated that both stalk and leaf extracts have a dose-dependent capacity to scavenge free radicals [63]. After that, the pressurized liquid extraction (PLE) approach was used by Ain et al. [66] to maximize the extraction of lemongrass oleoresin. Using GC/MS, bioactive substances such as neral, geranial, and geraniol, which made up 72% of the oleoresin, were tracked during this optimization study. According to a study by Nambiar and Matela [46], lemongrass has a higher antioxidant capacity than coriander (leaf and stem), ginger, tomato, and garlic. It also has a higher total phenolic content than these other herbs, spices, and vegetables. The order of the results regarding the total antioxidant capacity of herbs analyzed in the study was as follows: turmeric > cumin, dried > curry powder > lemongrass > coriander (leaves and stem) > ginger > tomato > garlic ($1126.12 \pm 94.2 > 302.26 \pm 0.9 > 236.55 \pm 7.9 > 120.57 \pm 5.46 > 92.18 \pm 62.9 > 62.24 \pm 0.19 > 22.97 \pm 4.8 > 8.77 \pm 1.93$ mg TE/100 g, respectively).

3.4. Anti-Hypertensive and Anti-Obesity Activity

The potential of lemongrass extract as a source of hypolipidemic and hypoglycemic components, which can reduce the risks of hypertension and obesity, has been the subject of numerous studies. According to the available data, feeding rats 500 mg/kg/day of citratus aqueous extracts may cause a significant reduction in the hypoglycemia index, despite counter-regulatory substances such as cortisol, catecholamine, and glucagon. A hypolipidemic impact was observed, with a discernible decrease in low-density lipid levels present in the bloodstream. Although the exact mechanism by which tea produces these effects is still unknown, some researchers have linked it to either hyperinsulinemia or enhanced peripheral glucose consumption. Since lemongrass aqueous extract contains essential oil and other extractants, the presence of anti-hypertensive compounds such as alkaloids and flavonoids has been shown to promote the hypoglycemic effects of this extract.

Obesity is closely related to an imbalance between two things: energy intake and energy expenditure. Nevertheless, lemongrass tea acts as a vehicle to boost energy expenditure, reducing weight gain and liver fats. It also motivates the thermogenesis process to decrease plasma cholesterol and LDL, and to facilitate the fecal excretion of cholesterol [67]. There was a study which was conducted to observe the (*Cymbopogon citratus*) anti-lipidemic effect of lemongrass by using its aqueous roots and flower extracts. *Cymbopogon citratus* aqueous extracts were tested for anti-lipidemic efficacy in rats. Under minimal ether anesthesia, an intracardiac puncture was used to draw blood from treated mice, and measurements of total serum cholesterol, HDL, and LDL levels were taken from mice. The result showed that it was quite effective, as it was observed that root and flower extracts of

lemongrass had significantly lowered the cholesterol levels in mice with higher levels of HDL and lower levels of LDL [68,69].

Another study observed in detail how normal rats' cholesterol levels, lipid profiles, and hormonal profiles were affected by *Cymbopogon citrates*' extracts. For approximately 30 days, oral treatment of *C. citrates* ethanolic and aqueous extract, at doses of 200 mg/kg of body weight, resulted in a considerable drop in blood sugar levels. TSH, T3, and T4 effects were also assessed, and it was discovered that they were all considerably greater in all administered groups compared to the control [70].

3.5. Anti-Inflammatory Potential

A fundamental health issue is the global inflammation of tissues. Its low incidence has been attributed to the more affluent lifestyles brought on by technological advancement. Inflammation contributes to greater incidences of human mortality, and has been significantly linked to conditions such as diabetes, rheumatoid arthritis, cardiovascular disease, and cancer [71]. Animal tissue typically becomes inflamed in response to physical stress or when chemical inducers (such as lipopolysaccharide) are present. When lipopolysaccharide (LPS) is incubated with macrophages, inflammation will develop systemically and result in the release of nitric oxide (NO) and prostaglandin E2 (PGE2), which are proven to be pro-inflammatory mediators. Reactive oxygen species (ROS); cytokines, such as interleukins; tumor necrosis factor (TNF); and up-regulation of nuclear factor kappa-B cellular proteins (NF- κ B) are additional inductive agents.

Many researchers presented data showing that the main components of lemongrass have anti-inflammatory properties; these include polyphenol-rich extractants, solvent extracts, and citral isolate. The anti-inflammatory effects of lemongrass leaves' polyphenol fractions (phenolic acids, flavonoids, and tannins) and aqueous extracts free of fat and essential oil were also studied. In LPS-induced RAW 264.7 macrophage cell lines, along with skin-derived dendritic cell line (FSDC), it is being depicted that the aqueous lemongrass extract may suppress NO, PGE2, and iNOS expression, but not COX-2 [14,72]. Additionally, it was noted that the same extract prevented phosphorylation (which is LPS-induced) of p38MAPK and JNK 1/2. However, it was observed that it had no significant impact on the activation of ERK 1/2. The aqueous extract inhibited the degradation of IB caused by LPS stimulation by preventing NF- κ B activation. We can observe further, in skin-derived dendritic along with RAW 264.7 cell lines that had been activated with LPS, that the extracts with polyphenolic fractions can decrease both NO release and expression of iNOS. However, because luteolin glycosides were present, flavonoid and tannin fractions showed superior anti-inflammatory efficacy. On the other hand, phenolic acids effectively reduced PGE2 synthesis in LPS-induced RAW 264.7 macrophages. There were no polyphenolic fractions from lemongrass that reduced COX-2 expression [14,72].

It has been suggested that the essential oil, which contains citral, be removed due to such inactivity. Similarly, ethanolic lemongrass extract (50%) possesses anti-inflammatory properties against LPS-induced inflammation in mouse alveolar macrophages. The action method prevents the release of NO and the pro-inflammatory cytokine known as tumor necrosis factor TNF- α [65].

3.6. Anxiolytic Properties

Researchers have observed the anxiolytic qualities of lemongrass tea to determine whether it is effective in treating disorders associated with anxiety [73]. In earlier studies, it was discovered that the anxiolytic effects of the decoctions made from lemon tea had adverse effects. However, prior research showed that when lemongrass decoctions and infusions (lemongrass tea) are specially presented to animals, they have the potential to have calming effects [72]. Positive results from the light or somewhat dark box test made this apparent. A biphasic dosage response (U-shaped) curve that resembled those extensively examined by [74] was observed in this test.

As proven anxiolytic medicines signal the GABAergic system, the extract's calming effects appeared to do the same. Therefore, these results supported the traditional medicine practice of using lemongrass extracts to treat disorders of the central nervous system (CNS). Researchers agree that lemongrass tea is proven to be safe for home and other applications, contrary to what folk medicine practitioners believe. In the past, lemongrass tea was widely used for its anti-bacterial, anti-fever, anti-dyspeptic, carminative, and anti-inflammatory properties, making it popular in South American, Asian, and West African nations. Other uses include stomachic agents, analgesics, spasmolytics, antipyretics, diuretics, and febrifuges [49]. One of the critical elements of lemongrass extracts is an essential oil, which is used as a co-ingredient in perfumes and cosmetic products.

3.7. Hypoglycemic and Hypolipidemic Effects

Diabetes is a chronic metabolic syndrome with two types: insulin-dependent diabetes mellitus (type I diabetes) and diabetes mellitus, which is non-insulin-dependent (type II diabetes). The protective mechanism of lemongrass tea catechins is a reduction in amylase activity during chewing and later, in intestinal digestion. Plant extracts are safe moieties, compared to pharmaceuticals, to regulate hyperglycemia and hypercholesterolemia. Fresh leaf aqueous extract of Lemongrass was observed, in normal rats, to decrease abstaining triglycerides, plasma glucose, low-density lipoproteins, and total cholesterol. A very low-density lipoprotein dose was observed, while an increased level of plasma high-density lipoprotein was achieved in the same dose-related manner that seems not to affect plasma triglyceride levels [75]. Hypercholesterolemia is considered a significant risk factor for atherosclerosis and coronary events. Healthful dietary interventions are considered to be the prerequisite requirement to overcome this disease. A healthy lifestyle demands the inclusion of phytochemicals and flavonoids from different sources, such as fruits, vegetables, grains, etc., in a balanced way. Lemongrass tea phytochemicals form cardioprotective diets, owing to their reductant potential on LDL cholesterol. It has also been observed that five cups of tea/day reduced LDL cholesterol by 11.1%, and total cholesterol by 6.5% [76]. Hypercholesterolemia is one of the root causes of atherosclerosis. However, the induction of 1% of heat-treated catechins resulted in increased fecal excretion of steroids from cholesterol and lower cholesterol absorption by the intestine.

3.8. Anti-Cancer Activity

Researchers have also investigated *Cymbopogon citratus*' anti-cancer abilities. Its unique oil might offer a strong barrier against certain malignancies. When directly injected, Cymbopogon citrate oil inhibits cancer tumors in a dosage-dependent manner, meaning the higher the oil dose, the better the outcome, according to animal studies. The trial's findings suggest that the oil has a potentially practical anti-cancer effect, reducing the viability of tumor cells by inducing the apoptotic process. This was recognized by microscopy. According to much research, lemongrass can stop the spread of cervical cancer cells and other types of cancer cells, and can induce cancer cell apoptosis, also known as programmed cell death. According to the authors' analysis of all the data, lemongrass oil and citral emulsion are strong candidates for use as anti-cancer agents [27].

3.9. Cytotoxicity and Anti-Mutagenicity

In order to verify the safety of lemongrass tea, numerous studies, both in vivo and in vitro, have been carried out to examine the cytotoxicity and mutagenicity effects of lemongrass extract. Even at high concentrations, none of the phenolic chemicals identified from lemongrass methanolic extracts were harmful to fibroblasts belonging to the human lung [64]. In another study, adult rats who drank lemongrass tea orally for two months had no harmful effects, either on themselves or their progeny. Unlike the analgesic medication morphine, rats that were fed lemongrass myrcene regularly did not develop a tolerance to it [77]. Studies may be impacted if they consider the aspects mentioned above because 5% ethanol extract was reported to reestablish the safety of mitochondrial membrane

integrity in alveolar macrophages, which are stressed murine. Nano-emulsion improves the lemongrass essential oil's bioavailability by incorporating it into the dietary matrix [78].

In a test for the *Salmonella* mutation, extracts of lemongrass made with 80% ethanol did not exhibit any mutagenic characteristics. Even *Salmonella typhimurium* strains TA98 and TA100 showed resistance to a chemical mutation in the presence of the extract [73]. Lemongrass also prevented the damage inflicted specifically on chromosomes, which is caused by mitomycin C in human cells [79]. Recently, N-methyl-N-nitrosourea (MNU)-induced leukocyte DNA in female Balb/C mice was the subject of an investigation by [80] into the protective effects of lemongrass essential oil. It has been claimed that MNU-induced DNA damage is protected from lemongrass essential oil. The toxic effect of a lemongrass infusion on humans was examined. After drinking lemongrass tea for 6 and 14 days, no significant differences were observed in the urine analysis, biochemical blood tests, or physical examination; therefore, the toxicological effect was reported to be negative. While some of the participants' bilirubin and amylase levels slightly increased, these changes had no apparent medical significance. Furthermore, lemongrass tea had no hypnotic or anxiolytic effects [73].

Three essential oils, including lemongrass, were examined for stomach tolerance and toxicity in adult rats. When administered at doses of 5–1500 mg/kg of body weight, lemongrass essential oil did not only exhibit acute (1 day), but also subacute (14 days) toxicity; however, abnormalities were noted at higher doses of approximately 2000 to 3000 mg/kg of body weight. The morphological structure of the rat stomach and liver did not change with a low oil dose. However, a high oil dosage caused hepatocyte necrosis and leukocyte infestation of the liver parenchyma, in addition to changing the stomach's structure. As a result, when utilized at a specific concentration, lemongrass essential oil is considered safe for human consumption [80]. Several other studies have also been conducted to evaluate the toxicity of lemongrass and to confirm the safety of lemongrass essential oil or lemongrass tea. It has been reported that the phenolic compound methanolic extract, at concentrations of 1 mM, were non-toxic to human lung fibroblasts [64]. Furthermore, lemongrass tea was fed to rats for two months, and no toxicity was reported in rats or their offspring [81]. Lemongrass oil and its components, including citral and geranyl acetate, were toxic to *Sitophilus granarius* at $LC_{50} = 4.03 \mu\text{g}$ per insect, $LC_{50} = 6.92 \mu\text{g}$ per insect, and $LC_{50} = 3.93 \mu\text{g}$ per insect, respectively, as reported by [82].

4. Lemongrass and Gut Microbiota

It is likely that the desired optimal health and performance of human and animal health can be achieved by modulating the intestinal microbiota and their functions with suitable dietary strategies [83]. Thus, phytochemicals are potential agents for improving health by establishing a balanced gut ecosystem. Phytochemicals are considered quintessential food and feed additives at the industrial level, since there are no residue or toxin issues. Among the phytochemicals, phytobiotics are used to modulate the gut ecosystem by generating anti-microbial, anti-inflammatory, and antioxidant responses, thus increasing the optimum nutrient absorption in the gut system [84]. In the intestinal ecosystem, the digestion and absorption of many nutrients occur in the small intestine. At the same time, the cecum is the site that is densely populated with a range of bacteria that are primarily responsible for the fermentation of nutrients not absorbed in the ileum.

Plant extracts and oils have been used for food preservation, pharmaceuticals, alternative medicine, and natural therapies for many years [85]. The inclusion of dietary lemongrass bioactive compounds contributes to the production and maintenance of gut microflora and digestive functions. Dietary lemongrass promoted the growth of beneficial bacteria while reducing the pathogenic bacterial load, compared to the control groups [86,87]. They also found that dietary lemongrass increased the growth of *Lactobacillus* spp. while inhibiting *Campylobacter* spp. and *E. coli* in the ileum and cecum. Pinene, a component of lemongrass, possesses a broad spectrum of anti-bacterial activities [88]. The effects of lemongrass on gut microbiota are given in Table 3.

Table 3. Effect of lemongrass on gut microbiota.

Concentration in Diet	Gut Microbiota	Animal or Gut Part or Type of Study	Ref.
300 mg/kg	<i>Coliform</i> , <i>E. coli</i> , and <i>Salmonella</i> ; ↓ total bacterial count and <i>Lactobacillus</i> ↑	caecal	[86]
400 mg/kg	Total bacteria, <i>Coliforms</i> , <i>Escherichia coli</i> , and <i>Aeromonas</i> spp. counts ↓	fish	[87]
1 mg/mL	<i>Lactobacillus acidophilus</i> , <i>Morganella morganii</i> , most of the <i>Bacillus</i> spp. strains (84.3%), <i>aeromonads</i> (78%), <i>Edwardsiella</i> spp. (73.9%), 53.6% <i>pseudomonads</i> , 53.1% <i>streptococci</i> , and 50% of <i>Budvicia aquatica</i> and <i>Leminorella ghirmontii</i> were found to be sensitive to Lemongrass	in-vitro	[89]
0.2–0.8 g/kg	<i>Escherichia coli</i> , <i>Salmonella</i> spp., ↓ <i>Lactobacillus</i> spp. ↑	caecal	[90]
0.5–1.5%	<i>Salmonella</i> Heidelberg ↓	in-vitro	[91]
* MIC—0.65%	<i>Acinetobacter baumannii</i> strains ↓	in-vitro	[92]

* = Minimum inhibitory concentration (MIC). Increase (↑) and decrease (↓).

5. Industrial Applications of Lemongrass

It has been claimed that the oil can enhance the flavor of some fish, as well as to flavor wines, sauces, confections, spices, and tea leaves. Lemongrass is a popular culinary herb, used extensively in Southeast Asian nations such as Indonesia, Vietnam, Malaysia, Thailand, Pakistan, and the Philippines. It can be used fresh, powdered, or dried due to its aromatic, lemon-scented qualities. Although the lemongrass pseudostem is challenging to consume, it can be crumbled and added to dishes or grilling rubs. The oil glands which carry aromatic oils in the pseudostem are released if it is bruised or added whole. The lemongrass leaves and stalks have a light lemon flavor, according to Majewska et al. [93]. Lemongrass is a widely used primary component in Thai and other Asian cuisines, such as Indonesian and Malaysian, due to its mild citrus flavor. This fragrant herb is widely used in Latin American and African nations for curries, poultry, seafood, soups, and teas [94]. Other nations, such as Thailand, have recently expressed interest in lemongrass. Dried lemongrass leaves are widely used as a lemon-flavored component in herbal teas. In contrast to regular tea, lemongrass is a diuretic and does not alter the body's biochemistry. According to Nambiar and Matela [46], Lemongrass is frequently used as the foundation for a well-liked beverage called "Takrai" in Thailand. Additionally, lemongrass is frequently used to prepare marinades, curries, and seafood soups.

Commercial applications for the essential oil of the *Cymbopogon* genus include its use as an aroma for soap and an ingredient in perfume and palm arosa oil. In the cosmetic industry, several lemongrass products with proprietary formulae combine glycerol, lemongrass, and lemon balm oil. It has been demonstrated that lemongrass essential oil deters insects, making it possible to use it as an insect-repellent lotion [95]. The cosmetic industry benefits significantly from this oil's antioxidant properties, as it can be utilized to prevent several skin ailments caused by oxidative stress. Additionally, this substance can be utilized as an anti-aging cream, as oxidative stress is linked to degenerative disorders of chronic nature that accelerate the process of aging (Sara et al. 2006). In the past year, a thorough analysis of the bioactivities of lemongrass that are relevant to its possible aesthetic benefits has also been conducted [20].

6. Conclusions

Conclusively, we have deduced that Lemongrass possesses high therapeutic potential due to phytochemicals, such as plant sterols, flavonoids, lignans, carotenoids, terpenoids, saponins, sulfides, and fiber, which play a preventive role in oxidative damage and various human diseases. The essential oil extracted from lemongrass has applications in perfumes, cosmetics, the soap industry, and insect repellent. Lemongrass has a major bioactive com-

ponent with many types of therapeutic potential, including anti-cancer, anti-hypertensive, and anti-mutagenicity. Furthermore, it should not be consumed as a tea only for its typical flavor, instead of for its proper purpose of utilization. In the case of the development of lemongrass-based therapeutic foods and functional beverages, it is considered to have the potential to be used in diet-based therapies. There is a need for further research on the potential interaction of lemongrass with other drugs to evaluate its effect on their pharmacokinetics and bioavailability, since the herb is most often consumed with other biologically active substances. Lemongrass has been extensively consumed worldwide for its cosmetic, medicinal, and nutritional benefits. Lemongrass has therapeutic applications which can be used to prevent various physiological threats. Therefore, it is mostly consumed as tea due to its typical aroma and its biological applications, such as immune-boosting, anti-inflammatory, and anti-malarial effects, as well as its potential to treat digestive disorders. In this regard, owing to its polyphenol-enriched profile and therapeutic potential, lemongrass has the potential to be used in numerous kinds of functional food products to benefit humanity.

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