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Comprehensive analysis and therapeutic potential of ginger essential oil

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Abstract
Zingiber officinale Rosc., popularly known as ginger, is widely utilized in traditional medical systems such as Chinese, Indian, and Tibb-Unani medicine, both as a spice and medicinal herb. The chemical makeup and biological properties of the essential oil that was isolated from the rhizomes of ginger are the main topics of this review. Geography, extraction techniques, and the freshness of the rhizomes influence the oil content. Studies have demonstrated ginger essential oil's antimicrobial, antifungal, analgesic, anti-inflammatory, anti-ulcer, immunomodulatory, and calming effects. It is considered safe and can potentially treat respiratory and gastrointestinal disorders. Ginger oil's principal ingredients are Zingiberene, curcumene, citral, β-bisabolene, geranial, and camphene. Its antibacterial effect is attributed to highly oxygenated molecules, as revealed by analysis utilizing methods such as GC and GC-MS. Ginger oil is made from dried and fresh rhizomes for commercial purposes; different cultivars have distinct commercial and medicinal uses. The vast therapeutic qualities and unique chemical makeup of ginger essential oil are still being discovered via ongoing studies, adding intrigue and engagement to this review. This review briefly summarizes what is currently known about its composition and possible uses as a medicine.

Keywords: Ginger, essential oil, therapeutic uses, chemical analysis

Introduction
Essential oils from aromatic plants have long been valued for their various benefits to humanity. Given their extensive properties, systematic research into the natural compounds, characterization, and activities of these herbs is crucial. One such vital essential oil is extracted from *Zingiber officinale*, commonly used in therapeutic and flavoring industries worldwide.
Ginger (*Zingiber officinale* Rosc.) is a rhizome-bearing plant from the Zingiberaceae family. Its precise origin is unclear, though it is believed to have originated in Southeast Asia and later spread to regions like China, Japan, Jamaica, Latin America, and Africa. Historically, ginger has been utilized in Indian and Chinese medicine and as a spice. It gained recognition in France and Germany by the ninth century and in England by the tenth century for its therapeutic benefits. In India, significant ginger cultivation occurs in states like Assam, Meghalaya, Arunachal Pradesh, Orissa, Karnataka, and Gujarat, collectively contributing to about 65% of the nation's total production. The northeastern region of India is noted for its diverse ginger varieties. The first detailed description of ginger was made by Van Rheede in 1692 in his work "Hortus Indicus Malabaricus," documenting the plants of India's Malabar coast [61, 62].

Methods of Production
Seed rhizomes are segments of ginger rhizomes that are used for propagation. It thrives in warm, humid climates with sandy lateritic loam, well-drained clay, and red soil. Ginger is typically planted between March and May when showers are before the monsoon. Early establishment in February-Walk can prompt diminished illness frequency and better returns. The optimal ginger rhizomes are characterized by low fiber content, high volatile oil content, and a high level of spice, influenced by the rhizome's maturity at harvest [9]. Ginger reaches full maturity 210-240 days after planting. Due to its high nutrient demand, ginger should not be grown consecutively in the same soil. Various agricultural universities and the National Research Centre for Species collect and preserve cultivated and wild ginger germplasm in India. The CSIR-NEIST plant reproducing group has amassed north of 324 germplasm tests, kept up with at their trial ranch, and extends its assortment from different Indian districts. The development of high-yielding ginger varieties with improved essential oil and dry rhizome recovery is aided by this effort [10].

Analysis by GC-MS and Extraction

The plant's origin, variety, cultivation methods, harvesting conditions, extraction procedure, and age all affect the quality of ginger essential oil. The cultivation's location impacts the oil's color, flavor, and aroma. Fresh ginger essential oil costs between USD 75 and USD 130 per kilogram on the market as of 2024, while it costs between Rs 6000 and 7000 per kilogram in India [1, 3, 4]. Hydro-distillation, steam distillation, and the most recent microwave extraction method can all be used to extract essential oils from ground fresh or dried ginger rhizomes. Every strategy yields different oil quality and extraction times [12]. Steam refining stays the business standard for medicinal oil extraction [16, 46]. Conventional techniques, including bubbling plant material with water or solvents, can corrupt oil quality because of delayed extraction times, leaving poisonous buildups. Because it produces oil without solvent residues, microwave technology has gained scientific attention for its high yield and efficiency [11]. Chromatographic tests identify the essential oil's constituents following extraction. Anhydrous sodium sulfate is used to remove moisture, and gas chromatography (GC) or gas chromatography-mass spectrometry (GC-MS) is used to analyze the oil [29, 30]. Dry ginger typically has a higher oil yield than fresh ginger. Nitrogen is the carrier gas in GC analysis, requiring specific temperature protocols. GC-MS frameworks with cutting-edge locators and trial conditions are likewise utilized, contrasting the outcomes and reference spectra in the Public Establishment of Norms and Innovation (NIST) library and writing (Table 1) [17, 46].

Table 1: Chemical composition of Ginger essential oil from different geographical regions (Mahboubi 2019) [46]

Yield	Rhizomes	Components	Location
1.02 1.84%	Fresh Dried	β-zingiberene (12.2%), geraniol (15.0%), neral (8.9%), β-bisabolene(5.6%) and β-sesquiphellandrene (6.4%) β-zingiberene (28.1%), geraniol (9.0%), neral (5.3%), β-bisabolene (8.4%) and β-sesquiphellandrene (10.6%)	Nigeria
-	Fresh	Zingiberene + zingiberol (38.9%), ar-curcumene (17.7%), β-sesquiphellandrene+β-bisabolene (11%), β-phellandrene (4.9%), linalool+α-terpiniol (3.8%)	Bangalore Market
1.2%	Dried	Zingiberene (32%), β-sesquiphellandrene (15.6%), β-bisabolene (9.3%), ar-curcumene (15.9%)	market Iran
-	fresh	α-zingiberene (23.9%), citral (21.7%)	Brazil
-	-	Zingiberene (20-28%), ar-Curcumene (6-10%), β-Sesquiphellandrene (7-11%), β-Bisabolene (5-9%)	Australia
-	-	α-zingiberene (29-40%), β-Sesquiphellandrene (10-14%), ar-Curcumene (5-11%), camphene (4.5-10%), β-bisabolene(2.5-9%), α-zingiberene (35-40%), β-sesquiphellandrene (11.5-13.5%), ar-curcumene (6.5-9%), camphene (5-8%), β-bisabolene (2.5-5.5%) α-zingiberene (23-45%), β-sesquiphellandrene (8-17%), ar-curcumene (3-11%), camphene (0.2-12%), β-bisabolene (3-7%)	China India west Africa
2.22%-4.17%.	unpeeled rhizomes cultivars	Camphene (8.49%), neral (4.95%), geranial (12.36%), zingiberene (20.98%), and β-sesquiphellandrene (7.96%)	North-East India
	-	Zingiberene (10.5-16.6%), ar-Curcumene (2.9-9.8%), β-Sesquiphellandrene (5.8-7.2%), e-citral (7.4-10.5%), z-citral (5.3-7%), o-cymene (0.9-6.5%), camphene (0.9-7.6%), limonene (1.3-6.4%)	India
2.4% w/w	-	Zingiberene (29.5%), sesquiphellandrene (18.4%), farnesene (6.46%), germacrene D (3.58%), neral (2.5%), geranial (3.46%),	Nigeria
2.1%	-	ar-cucumene (11.7-12.6%), β-bisabolene (4.1-8.1%) α-zingiberene (10.3 %), β-sesquiphellandrene (7.4 %)	Vietnam
-	-	citral (30.8%), zingiberene (17.1%), β-bisabolene, geranyl acetate (6.7%), β-Sesquiphellandrene (5.9%), 1, 8-cineol (6.1%) and geraniol (6.1%)	Alegria

Active Constituents

Ginger essential oil is highly valued in therapeutic, aromatherapy, and flavoring applications. Past chemical investigations have shown that GC-MS analysis primarily reveals high sesquiterpene hydrocarbons and relatively low monoterpene hydrocarbons in ginger oil. However, a study of ginger oil from Nahan, Himachal Pradesh, India, found a higher concentration of monoterpenes, likely due to climatic effects. Comparisons between fresh and dried ginger oils indicate that fresh ginger oil has more oxygenated compounds (29.2%) than dry ginger oil (14.4%) [53, 54, 55, 46]. Drying reduces the presence of sesquiterpenes and monoterpenes, except for myrcene. Ginger essential oil's composition also varies with altitude and region. For instance, ginger oil from higher altitudes in Uttarakhand is rich in oxygenated monoterpene geraniol, while oil from lower altitudes has more monoterpene hydrocarbon β-phellandrene [60, 46]. In India, ginger oil from the southern regions is rich in sesquiterpenes, whereas northern regions have more oxygenated monoterpenes. The main bioactive compounds are depicted in Figure 1 [1, 3].

Biological and Pharmacological Activities

Ginger essential oil exhibits significant antimicrobial properties. Dry ginger oil is effective against *Pseudomonas aeruginosa*, *Penicillium* spp., and *Candida albicans*. In contrast, fresh ginger oil works against *Aspergillus niger* and *Candida albicans*, offering an eco-friendly alternative to synthetic chemicals. It can alter bacterial cell morphology, enhancing its antibacterial efficacy [2, 4, 5].

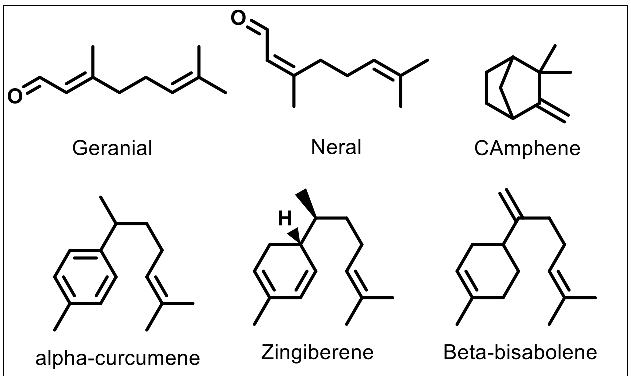

Fig 1: Major chemical compounds in ginger essential oil

In vitro studies have shown ginger oil's virucidal activity against herpes simplex virus type 2 (HSV-2), suggesting its potential as a treatment by interacting with the viral envelope before adsorption [63, 64]. GC-MS analysis identified compounds like β-sesquiphellandrene, caryophyllene, and zingiberene in ginger oil, which possess notable antimicrobial activity against various bacterial and fungal strains [31, 46, 33] Ginger oil also demonstrates anti-inflammatory and analgesic effects. A higher dose (500 mg/kg) reduces serum cholesterol and mitigates pain responses induced by thermal stimuli [14]. It modulates leukocyte migration and reduces acute and chronic inflammation in experimental models. Ginger essential oil inhibits lipoxygenase activity and shows significant analgesic activity, offering a low-cost treatment for pain [32, 35].

As an antioxidant, ginger oil protects against H_2O_2-induced DNA damage and is a radical scavenger. It has been shown to lower oleic acid oxidation temperatures, demonstrating its antioxidant capacity [15, 46].

Ginger oil's cytotoxicity has been assessed through MTT assays, showing potential against cancer cell lines and suggesting its anticancer properties.[25] It also reduces rat myometrial contractility and protects against gastric ulcers induced by aspirin and pylorus ligation. Histopathological studies confirm its ability to mitigate ethanol-induced gastric lesions [24].

In experimental models, Ginger essential oil protects against steatohepatitis and non-alcoholic fatty liver disease. It also reverses the bronchodilatory effects of propranolol and enhances the humoral immune response in immunosuppressed mice [36, 37, 46]. Inhalation of ginger oil significantly reduces nausea and vomiting in clinical trials, and its monoterpenes exhibit antitumor activities, serving as potential cancer chemopreventive agents [26, 27, 46].

Antibacterial Properties: Brazilian Ginger: Essential oil from Brazilian ginger, rich in compounds like α-zingiberene, β-sesquiphellandrene, ar-curcumene, α-farnesene, and β-bisabolene, has shown significant antibacterial activity [28, 46, 43]. It exhibits higher inhibition against Staphylococcus aureus and Listeria monocytogenes, with lesser effects on *Pseudomonas aeruginosa*. However, Salmonella typhimurium, Shigella flexneri, and Escherichia coli resist this oil [39, 40]. Studies have consistently noted that S. aureus is more sensitive to ginger essential oil than *E. coli* [8]. The oil's minimum inhibitory concentration (MIC) values are as follows: S. aureus (8.69 mg/ml), Bacillus subtilis (86.92 mg/ml), *E. coli* (173.84 mg/ml), and Penicillium spp. (869.2 mg/ml) [66, 67, 46]. Essential oil also shows moderate effectiveness against multidrug-resistant strains of Acinetobacter baumannii with inhibition zone diameters and MIC values comparable to those of tea tree oil, a known antimicrobial agent [7].

Antifungal Properties: Vietnamese Ginger: The essential oil from Vietnamese ginger, containing ar-cucumene, β-bisabolene, α-zingiberene, and β-sesquiphellandrene, exhibits antifungal activity against pathogens such as *Botrytis cinerea*, *Penicillium* sp., and *Aspergillus niger* [23, 46]. Ginger essential oil has also shown antifungal activity against organisms like Trichophyton rubrum and Microsporum gypseum, demonstrating its potential as an anti-dermatophyte agent. Ginger essential oil tends to have more potent antibacterial activity against Gram-positive bacteria than Gram-negative bacteria, likely due to differences in cell wall structures.[18,46] This broad-spectrum antimicrobial activity makes it a candidate for use in pharmaceuticals, food preservation, and cosmetics. The antimicrobial properties are closely related to the chemical composition of the oil, which can vary significantly depending on the source and preparation method [8, 41, 42].

Antioxidant Activity: Chinese Ginger: Studies on Chinese ginger essential oil have demonstrated its potent antioxidant capabilities, with EC50 values for reducing power, DPPH scavenging, and H2O2 scavenging assays being competitive with those of known antioxidants like ascorbic acid and quercetin. Ginger essential oil also shows significant radical scavenging activity in ABTS assays, highlighting its potential to protect cells from oxidative stress by enhancing serum and liver antioxidant enzymes [68, 69]. Oral administration of ginger essential oil in animal models has been shown to boost levels of antioxidant enzymes such as catalase, superoxide dismutase, and glutathione peroxidase, indicating its role in mitigating oxidative damage and supporting cellular health [5, 6].

Bronchodilator Effects: Airway Relaxation: Ginger essential oil, containing citral, eucalyptol, and camphor, has been shown to relax airway muscles and counteract contractions induced by agents like carbachol in rats [22, 46]. This effect is mediated through β-adrenergic receptors, suggesting potential therapeutic use for respiratory conditions like asthma. These modern findings support the traditional use of ginger syrup for treating respiratory ailments and coughs, confirming its efficacy in modern medicinal applications [13].

Anti-inflammatory and Analgesic Effects: Rheumatoid Arthritis Model: In models of rheumatoid arthritis, ginger essential oil reduces chronic joint inflammation and acts as a phytoestrogen without significant side effects on estrogen target organs. Ginger essential oil effectively reduces inflammation and edema in various experimental models, such as carrageenan-induced paw edema and formalin-induced chronic inflammation, indicating its potential for treating inflammatory conditions. Ginger essential oil has demonstrated significant analgesic effects in models of acetic acid-induced writhing and hot plate tests in mice, comparable to standard pain relievers like aspirin and indomethacin.[44,45,46] The analgesic effects primarily inhibit arachidonic acid metabolites and suppress inflammatory mediators, highlighting its potential for pain management in various conditions [47, 46, 19, 50].

Massage Therapy: In clinical trials, massage with ginger essential oil has been shown to reduce pain and disability in patients with chronic low back pain and knee osteoarthritis, supporting its use as a complementary therapy for musculoskeletal pain [46].

Anticancer Effects: Ginger essential oil, particularly its component α-zingiberene, exhibits cytotoxic effects against cancer cell lines, including HeLa, SiHa, MCF-7, and HL-60. It induces apoptosis and inhibits cell proliferation, making it a promising candidate for cancer treatment. The oils help in DNA fragmentation, chromatin condensation, and cell death in cancer cells, further supporting its potential as an anticancer agent. Ginger essential oil enhances the activity of hepatic carcinogen metabolizing enzymes, such as cytochrome P450 and glutathione-S-transferase, in animal models, suggesting its role in detoxification and cancer prevention [21, 22].

Anti-ulcer Effects: In rat models, ginger essential oil reduces ulcer indices and increases gastric wall mucus thickness, showing protective effects against aspirin-induced gastric ulcers [74]. The oil also demonstrates efficacy in reducing symptoms of ulcerative colitis, comparable to standard treatments like prednisolone, indicating its potential for treating inflammatory bowel diseases [71, 72, 73]. T Lymphocyte Inhibition: Ginger essential oil significantly inhibits T lymphocyte proliferation and modulates immune responses by affecting T cell ratios and reducing inflammatory cytokine production [19, 46].

Inflammatory Response: The oil's ability to reduce leukocyte migration and decrease thymus and spleen index in animal models further supports its role as an immunomodulatory agent [50, 51].

Anti-nausea: Ginger essential oil effectively reduces the incidence of nausea and vomiting in patients undergoing surgery, supporting its use as a safe anti-emetic treatment. Its efficacy in reducing nausea during pregnancy and chemotherapy treatments has also been well-documented [46].

Conclusion

This review highlights ginger essential oil's extraction processes, chemical analysis, and therapeutic applications. Extracted primarily from the rhizomes of ginger, mostly grown in Southern Asia and India, the oil is obtained through various methods, with steam distillation being the most common. Ginger oil contains numerous active compounds, such as zingiberene, ar-curcumene, citral, β-bisabolene, geranial, and camphene, contributing to its value and utility. The monoterpene content decreases in dried ginger oil compared to fresh, with most sesquiterpene alcohols also reducing upon drying.

Therapeutically, ginger essential oil exhibits a broad spectrum of medicinal properties, including anti-inflammatory, anticancer, analgesic, anti-arthritic, antitussive, and antimicrobial activities. Its antimicrobial properties make it a potential food preservative and a topical treatment for fungal and bacterial infections. This review underscores the pharmacological advances in understanding the active constituents of ginger essential oil. Northeast India is recognized for its organic ginger cultivation and accounting.

Ethics Declaration

Data availability statement

The data supporting this study's findings are available in Google Scholar at https://scholar.google.com/.

Because this work is a review, the data supporting the findings of this study are available online on various websites. All references (Doi) are reported in the references section. The dataset that supports the findings of this review is included in the article.

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Availability of data and materials

The data was collected from various websites and search engines, such as Science Direct, Taylor and Francis, Google Scholar, etc.

Author’s Contribution

Parul Sharma: Drafting and revising the manuscript, giving final approval of the version to be published.

Ramandeep Kaur: Revising the manuscript and finishing the version to be published.

All authors have read and approved the definitive version of the manuscript submitted for publication and are responsible for the final content.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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