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Review Article

Pharmacognostic, phytochemical and pharmacological activities of *Ocimum kilimandscharicum* Guerke

Revti R. Shah*, Sunita Ogale, Aakash B. Makwana

Department of Pharmacology, Vishnu Waman Thakur Charitable Trust's VIVA Institute of Pharmacy, Virar, Maharashtra, India

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***Correspondence:**
Revti R. Shah,
Email: shahrevti2511@yahoo.com

ABSTRACT

The family *Lamiaceae* encompasses a diverse array of therapeutic plants, with the genus *Ocimum* being particularly esteemed. The plant known as Kapur Tulsi in India, *Ocimum kilimandscharicum* Guerke is a perennial woody shrub characterized by its essential oil, which predominantly contains camphor, along with linalool, limonene, eugenol, 1,8-cineole, and camphene. This review aims to provide current information on the taxonomy, botany, distribution, ethnomedicinal uses, phytochemistry, pharmacology, and toxicological profile of *O. kilimandscharicum*. The information presented was critically analyzed to understand the current research on this species and to explore potential future opportunities for this plant in pharmaceutical research. A comprehensive literature search was conducted and relevant information was collected through an extensive exploration of bibliographic databases, including Google Scholar, ScienceDirect, PubMed, Web of Science, Semantic Scholar, Europe PMC, and Scopus. The literature suggests that the plant contains a range of compounds that underpin its broad spectrum of pharmacological effects. These phytoconstituents have been widely employed in the treatment and management of numerous conditions. This review consolidates the latest information on its phytochemical and pharmacological activities, traditional applications, and scientific research. The review highlights the significant phytoconstituents of *Ocimum kilimandscharicum* Guerke and summarizes the evidence supporting its pharmacological potential. The findings suggest that the plant's diverse compounds contribute to its extensive use in traditional medicine and underscore its potential for therapeutic applications in various diseases.

Keywords: *Ocimum kilimandscharicum*, Phytoconstituents, Therapeutic plants, Pharmacological activities, *Ocimum* species

INTRODUCTION

Plants have proved as one of the major components in fulfilling the basic requirements in maintaining public health in the underdeveloped and developing nations. According to the world health organization, approximately 80% of people worldwide who live in underdeveloped nations exclusively depend on medicinal plants for their primary healthcare. The family *Lamiaceae* is home to a large variety of therapeutic plants. This family includes herbs, shrubs and trees from 236 genera and 7200 species distributed across the globe. It also has number of aromatic plant species whose enormous biological activity makes them extremely valuable in traditional medicine, the pharmaceutical, and food sectors. The most well-known and widely used plants in the *Lamiaceae* are Rosemary *(Salvia rosmarinus)*, thyme *(Thymus vulgaris)*, Oregano *(Origanum vulgare)*, and Sage *(Salvia officinalis)*. Another highly valued herb in the *Lamiaceae* is *Ocimum*. The plants from genus *Ocimum* are regarded as having

exceptional therapeutic potential, ranking highly among some of the astounding plants.

Belonging to the family *Lamiaceae*, the genus *Ocimum* get its name from the Greek word “Okimon” that means smell or to be fragrant. Commonly called as “Basil” or “Holy basil”, It consist of economic and widely distributed annual and perennial herbs and shrubs, which grows primarily in the seasonally dry tropical, sub-tropical and temperate areas of the world. It comprises of about 30 to 160 different aromatic and medicinally important different varieties of plant species of complex taxonomical properties caused due to inter- and intra-specific hybridization.[1]

They are geographically confined to tropical areas of southern Asia and India, as well as tropical regions of America and with greatest number of species found in tropical and subtropical regions of Africa.[2] Some of the best known Indian species from the genus include *O. adscendens, O. basilicum, O. canum, O. gratissimum, O. kilimandscharicum, and O. tenuiflorum* and other exotic species viz. *O. americanum L., O. minimum L.*, and *O. africanum Lour* which also serve as a rich source of flavouring, anti-oxidants and important essential oil components.[1,3] These plants are being used for several purposes in ethno medicine.

The plants have been widely used in the management and treatment of several conditions such as general cold and cough, abdominal pains, high fever, influenza, diarrhoea, constipation, warts, headache, mental illness, epilepsy, rheumatoid arthritis, paralysis, measles, gonorrhoea, kidney damage and are pharmacologically anti-microbial, anti-pyretic, anthelmintic, antiemetic, antimalarial agents.[2] This review aims to provide current information on the taxonomy, botany, distribution, ethnomedicinal uses, phytochemistry, pharmacology, and toxicological profile of *O. kilimandscharicum*.

A substantial amount of biological and phytochemical research has been done on this plant. A thorough literature survey was done on electronic versions of various bibliographic databases and relevant information was collected, including Google Scholar, ScienceDirect, PubMed, Web of Science, Semantic Scholar, Europe PMC, and Scopus. The search was conducted for studies that focused on, and using specific keyterms such as “*Ocimum kilimandscharicum*”, “African basil”, “distribution”, “phytoconstituents”, “chemical constituents”, “pharmacological activities”, “biological activities”, “traditional uses”. A total of 42 articles were obtained (published between years 2011 to 2023).

These articles focused mainly on phytochemical investigations, several *in-vivo and in-vitro* studies and pharmacological studies using different extracts of the plant. The review highlights the significant phytoconstituents of *Ocimum kilimandscharicum* Guerke and summarizes the evidence supporting its pharmacological potential.

PLANT PROFILE

Ocimum kilimandscharicum Guerke is a *Lamiaceae* plant that is indigenous to Zaire and Kenya. It is a perennial woody shrub at zone 10 but can be grown annual in colder climates and warmer summers which grows around 1-2 meter height. It is commonly known as Kapurr Tulsi in India, due to its strong and characteristic camphor smell. In Dioskurides' writings, basil is referred to by the Greek plant name Okimon, which is translated as "*Ocimum*" in Latin. It comes from the term "ozein," which means "smell" (see also ozone, "the smelling one," which is a direct translation of the Greek present participle ozon and the English word "odour").

According to the origin of the plant in the Kilimanjaro hills of Kenya, the species name *kilimandscharicum* is derived from the word scar, which refers to shattered cliffs on a mountainside or bare spots on a hill face.[4] Bright yellow in color, the essential oil has a potent camphor scent. The vast majority of the camphor derived from the leaf oil are utilized for religious purposes.[5] It is extensively utilized in flavouring, fragrances, medicines, and a variety of dental and oral preparations.

Figure 1: *Ocimum kilimandscharicum* Guerke plant.

Taxonomic classification

The taxonomic hierarchy of *O. kilimandscharicum* has been described in the Table 1.

Table 1: Taxonomy of *O. kilimandscharicum* Guerke.

Kingdom	Plantae-plants
Subkingdom	Tracheobionta – vascular plants
Super division	Spermatophyta – seed plants
Division	Magnoliophyta – flowering plants
Class	Magnoliopsida – dicotyledons
Subclass	Asteridae
Order	Lamiales
Family	Lamiaceae – mint family
Genus	Ocimum L. – basil
Species	Ocimum kilimandscharicum Guerke

ORIGIN AND DISTRIBUTION

Kilimandscharicum came from Kenya to India following the course of World War II, and during that time was domesticated in a wide range of settings for the massive manufacture of camphor.[6] Rwanda, Athens, Nigeria, Sudan, Ghana, and India are among the other places where it has been reported to occur, where in India it has been cultivated in the regions of Darjeeling, Kerala, Mysore, Maharashtra, U.P. and other regions such as Dehradun, Jammu and Kashmir, West Bengal.[7]

DESCRIPTION AND MORPHOLOGICAL CHARACTERISTICS OF THE PLANT

It is a perennial, multi-branched, aromatic undershrub that grows up to the height of 1 to 1.5 m (4 to 6 ft). The leaves are ovate to broadly elliptic, acute, dentate and pubescent to both the surfaces. They are roughly 6 cm long and have noticeable veining. (Figure 2A) shows the vegetative twig of the plant. The leaves release a strong camphor smell when they bruise. Flowers usually appears as four-flowered whorls that are pale purple or pinkish white in colour on lengthy vilose racemes at the end of branches (Figure 2B). Black to brown coloured ovoid and oblong nutlets. Generally, the leaves contain the maximum amount of oil, followed by the flower which contains camphor in the oil. The volatile oil obtained from the leaves is an important source of camphor and the seeds also yield about 12.5% oil.[5]

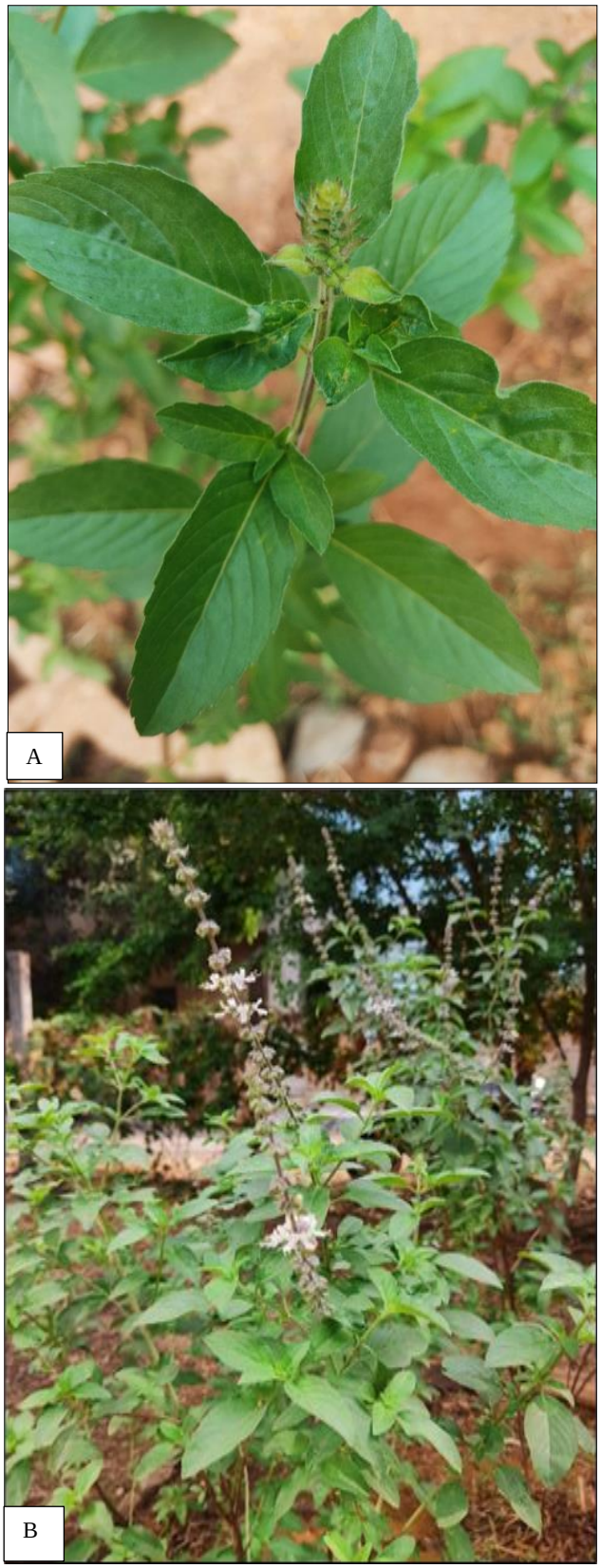

Figure 2 (A and B): Vegetative twig and aerial parts of *Ocimum kilimandscharicum* Guerke.

PHYTOCONSTITUENTS OF *OCIMUM KILIMANDSCHARICUM*

The major class of compounds found are the monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, oxygenated sesquiterpenes followed by phenylpropanoids.[8] The essential oil contains camphor as the predominant constituent of the oil along with other components like linalool, limonene, eugenol, 1,8-cineole, camphene, β-pinene, β-caryophyllene and α-terpineol.[5] Leaves are known to show presence of flavonoids, tannins, saponins, sterols, carbohydrates, proteins and triterpenoids whereas the aqueous extract of the leaves contains camphor, 1,8-cineole, limonene, trans caryophyllene, camphene, 4-terpeneol, myrtenol, α-terpineol, endo-borneol, linalool.[7]

Figure 3: Herbarium specimen of *O. kilimandscharicum* Guerke.

Table 2: Chemical composition of the essential oil of *O. kilimandscharicum*.[12,19,29-31]

Compound	Percentage composition					
Camphor	-	70.4	45.9	56.07	45.51	36.1
1,8-Cineole	-	7.2	14.6	0.85	0.6	0.80
Limonene	-	6.2	8.1	13.56	3.43	21.2
Camphene	-	5.1	5.5	7.32	13.57	5.65
Myrtenol	-	1.3	-	1.24	4.52	2.43
Endo-borneol	-	0.6	-	-	-	-
Isoborneol	-	-	0.2	-	-	-
Borneol	-	-	t	-	-	-
α-Thujene	9.82	-	0.2	-	-	-
Sabinene	11.69	-	0.1	-	-	-
cis-Sabinene hydrate	-	-	1.7	0.47	-	-
trans-Sabinene hydrate	-	-	0.6	0.49	-	-
β-Myrcene	12.43	-	1.7	1.58	-	-
α-terpinene	13.49	-	t	-	-	-
γ-terpinene	-	-	-	0.88	-	-
β-Pinene	-	-	1.9	-	-	-
α-Pinene	14.25	-	1	1.23	-	-
Ocimene	14.68	-	4.3	2	0.9	1.27
Terpinene	15.19	-	0.8	0.33	-	-
cis-β-Terpineol	15.66	-	-	-	-	-
Terpinolene	-	-	1.3	1.33	-	-
Linalool	16.9	0.5	-	1.7	4.92	2.00
Neo-allo-Ocimene	18.01	-	-	-	-	-
4-Terpeniol	20.03	1.4	0.8	3.5	4.62	4.82
L-α-Terpeniol	20.61	0.6	2.4	-	-	-
Eugenol	26.57	-	t	-	-	-
α –Copaene	27.22	-	-	-	-	-
(-)-β-Bourbonene	27.49	-	-	-	-	-
β-Elemene	27.68	-	0.1	-	-	-
Caryophyllene	28.71	2.8	1.9	0.33	0.23	0.24
β-Copaene	29.04	-	t	-	-	-
Humulene	29.89	-	-	-	-	-
Germacrene-D	30.75	-	-	0.43	-	-
Germacrene-B	31.2	-	-	-	-	-
Dihydro-β-agarofuran	31.83	-	-	-	-	-

Continued.

Compound	Percentage composition					
Delta-Cadinene	31.92	-	-	-	-	-
Germacrene D-4-ol	33.74	-	-	-	-	-
Diethyl phathalate	34	-	-	-	-	-
α-Cadinol	35.78	-	0.4	-	-	-
β-Cadinol	36.13	-	-	-	-	-
Tetratetracontane	55.4	-	-	-	-	-
Squalene	55.68	-	-	-	-	-
Tritetracontane	59.13	-	-	-	-	-
Tricyclene	-	-	0.2	-	-	-
α-Phellandrene	-	-	t	0.26	-	-
Isosylvestrene	-	-	0.3	-	-	-
p-Cymene	-	-	0.2	0.62	-	-
Spathulenol	-	-	0.1	-	-	-
Caryophyllene oxide	-	-	t	-	-	-
Globulol	-	-	t	-	-	-
Cubenol	-	-	0.1	-	-	-
α-Campholenal	-	-	0.2	-	-	-
β-Cubenene	-	-	t	-	-	-
α-Gurjunene	-	-	t	-	-	-
α-Humulene	-	-	0.2	-	-	-
γ-Muurolene	-	-	2.1	-	-	-
Cubebol	-	-	0.1	-	-	-
δ-Cadinene	-	-	0.1	-	-	-
Ethylamyl carbinol	-	-	-	0.88	-	-

t=trace (<0.01%)

PHARMACOLOGICAL ACTIVITY

Analgesic activity

The essential oil of *O. kilimandscharicum* was tested on mice using the carrageenan-induced paw edema model, with oral doses of 30, 100, and 300 mg/kg. Additionally, zymosan-induced articular inflammation was induced in mice, and the essential oil (100 mg/kg) along with camphor (30 mg/kg) was tested for their effects on knee edema, leukocyte infiltration, mechanical hyperalgesia, and nitric oxide production. The essential oil was also evaluated for its impact on leukocyte rolling and adhesion in mesenteric microcirculation, and it's *in vitro* activity against neutrophil chemotaxis induced by fMLP. This demonstrates that the essential oil of *O. kilimandscharicum* can significantly inhibit carrageenan-induced edema, mechanical and cold hyperalgesia, and reduced leukocyte migration and adhesion proving it's analgesic action.[9]

The methanolic extract of *O. kilimandscharicum* was intra-peritoneally injected at the dosage levels of 100, 200, 400 and 800 mg/kg body weight using Paracetamol 400 mg/kg as the standard drug treatment. After 1 hour of the drug treatment, evaluation was done using the Radiant tail-flick test and sensory motor testing method. The extract demonstrated considerable antinociceptive action at all tested dosage levels when compared to the control. The 800 mg/kg body weight dose level produced the greatest antinociceptive activity (11.8±0.5 vs. 4.1±0.2 sec) for the control group. Thus, these findings suggest that the plant possess strong antinociceptive activity.[10]

Free-radical scavenging activity

The study assessed the free radical-scavenging activity of the essential oil extracted from the leaves of *Ocimum kilimandscharicum* using the DPPH free radical method. The essential oil demonstrated significant antioxidant activity with an IC50 value of 8.21 µg/ml, which was notably potent, compared to the commercial antioxidant butylated hydroxytoluene (BHT), which had an IC50 value of 16.45 µg/ml. This remarkable free radical-scavenging ability was attributed to the high concentration of major monoterpenes present in the essential oil, specifically camphor, which exhibited an IC50 value of 12.56 µg/ml, and a mixture of limonene and 1,8 cineole with an IC50 value of 23.25 µg/ml. The data underscored the potent antioxidant potential of the plant's essential oil, surpassing even other essential oils from the *Ocimum* genus in effectiveness.[11]

Insecticidal activity

The repellent effects and fumigant toxicity of the essential oil obtained from the dried plant material of *O. kilimandscharicum* were evaluated against the tomato borer T. absoluta using 1 ml oil at different concentrations (0.031, 0.063, 0.125, 0.25, 0.5, and 1 µl ml^{-1}). The repellence tool used was a two-choice cuboidal plexi-glass

wind tunnel (25×25×200 cm), which showed an RI_{50} of 0.50%, F=92.62, df=5, and p<0.0001 repellence index at 50%. A fumigant toxicity assay by exposing adult T. absoluta to the aforementioned concentrations was also performed. It reflected lethal concentrations as LC_{50}=0.43 and LC_{90}=1.83 over a 24-hour exposure period. By GC analysis of the constituents, camphor and 1,8-cineole were identified as the major components, contributing most to these effects. This was demonstrated by the available constituents and the assessment of their relative contributions in subtraction assays. [12]

Pyrethrins were commonly used to control many pests. In a study, oil prepared from *O. kilimandscharicum* leaf extracts was utilized with slight modifications to the method described in WHO guidelines for larvicidal bioassay. The bioassay was conducted on 4th instar larvae and adult An. gambiae using various concentrations of crude extract oil. A comparative study between pyrethrins alone, pyrethrins combined with the crude extract oil (synergist), and with piperonyl butoxide (PBO), a conventional pyrethrum synergist, was performed at concentrations of 0.1, 0.01, and 0.001 mg/ml. The experiment demonstrated that *O. kilimandscharicum* was effective, and mortality rates increased with higher concentrations of the synergist. Monoterpene and phenylpropane were the major constituents among the 17 identified from GC-MS analysis and possibly acted as synergists for pyrethrins, enhancing their action. These studies indicated the potential insecticidal efficacy of the plant in pest management.[13]

Neuroprotective activity

The neuroprotective potential of *O. kilimandscharicum* leaf extract (OKLE) was evaluated using mice against ischemia reperfusion (I-R) brain injury by bilateral common carotid artery occlusion (BCCAO) method. A 15-minute period of ischemia was followed by a 24-hour period of reperfusion. Morris Water Maze and elevated plus Maze tests were employed from day 3 to day 7 in the present study to assess long and short-term memory, respectively, from day three to seven. OKLE at 200 and 400 mg/kg doses administered to mice for seven days prevented the impairments in motor function, sensory perception, and spatial memory caused by I-R. The size of the cerebral infarct decreased, lowered increased endogenous antioxidants such as GSH and SOD activity and brain oxidative stress (TBARS levels) by the extract treatment. Thus, from these findings it is clear that the plant *O. kilimandscharicum* mitigates oxidative damage and enhance neurological recovery post-stroke showing neuroprotective action. [14]

Thrombolytic activity

Thrombus i.e. a blot clot can result in deadly conditions by blocking blood vessels and limiting blood flow causing imbalance in the body's homeostasis. The study investigated the anti-thrombolytic efficacy of ethanolic extracts of *Ocimum kilimandscharicum* Linn using *in vitro* models. Researchers found that different concentrations of the extract exhibited significant anti-thrombolytic activity in a dose-dependent manner, comparable to a standard drug. The presence of flavonoids and polyphenols in the plant extract suggested its potential in treating thrombosis. The extract significantly enhanced clot lysis and demonstrated anti-platelet aggregation properties. The findings indicated a promising future for the clinical development of thrombolytic therapeutics derived from *Ocimum kilimandscharicum* Linn, contributing to the identification of potent anti-thrombolytic principles from natural resources. This study underscored the therapeutic value of medicinal plants and their bioactive compounds in modern medicine.[15]

Wound healing activity

The wound healing potential of the aqueous extract of *Ocimum kilimandscharicum* leaves was evaluated using albino Wistar rats across three wound models: excision, incision, and dead space. The study involved administering two doses (200 mg/kg and 400 mg/kg) of the extract and comparing the results to a control group.In the excision wound model, both doses significantly reduced the epithelization period (21.50±0.4282 days and 21.00±0.3651 days, respectively, p<0.0001) and decreased the mean scar area (31.00±0.5774 mm^2 and 27.83±0.6009 mm^2, respectively, p<0.0001) compared to the control (40.83±0.7923 mm^2). The incision wound model showed a significant increase in breaking strength with the extract at both doses (428.3±7.010 gm and 470.0±8.376 g, respectively, p<0.0001) compared to the control (299.3±6.987 gm). In the dead space wound model, the extract at both doses demonstrated a significant increase in the dry weight of granulation tissue (44.28±1.195 mg/100 gm and 50.92±1.046 mg/100g, respectively, p<0.0001) and breaking strength (262.4±7.776 g and 303.8±4.968 g, respectively, p<0.0001) compared to the control. Biochemical analyses revealed significant increases in L-hydroxyproline, hexoseamine, malondialdehyde, and ascorbic acid levels at both doses, indicating enhanced collagen deposition and antioxidant activity. Histopathological examinations confirmed the pro-healing effects, showing enhanced collagen deposition and fewer macrophages at the higher dose. The study concluded that the aqueous extract of *O. kilimandscharicum* leaves possesses strong wound healing properties, likely due to its antioxidant and free radical scavenging activities attributed to the presence of flavonoids.[16]

Anti-cancer activity

In a study, the anticancer activity of *Ocimum kilimandscharicum* essential oil was evaluated against ten human cancer cell lines. The essential oil was obtained through hydrodistillation and its chemical composition was determined using gas chromatography–mass spectrometry, revealing a predominance of monoterpenes, primarily camphor (51.81%), 1,8 cineole (20.13%), and

limonene (11.23%). The anticancer activity was assessed using the national cancer institute's sulforhodamine B (SRB) assay to measure the growth inhibition (GI50) across various cell lines including prostate (PC-3), ovarian (OVCAR-03 and NCI-ADR/RES), leukemia (K-562), colon (HT29), breast (MCF-7), glioma (CNS), and renal (786-0). The results demonstrated significant *in vitro* anticancer efficacy, particularly against the OVCAR-03 ovarian cancer cell line, which exhibited the highest sensitivity to ethanolic leaf extract. This study highlights the potential of *O. kilimandscharicum* essential oil as a promising candidate for further development in cancer therapeutics due to its potent anticancer properties.[11]

Anti-inflammatory activity

The study evaluated anti-inflammatory activity of essential oil from *Ocimum kilimandscharicum* using a carrageenan-induced pleurisy model in mice. Essential oil, primarily composed of camphor, 1,8-cineole, and limonene, was administered orally at doses of 30 and 100 mg/kg. Both pure camphor and a mixture of 1,8-cineole and limonene were also tested. The results indicated that essential significantly inhibited leukocyte migration, a key marker of inflammation. Specifically, the oil reduced leukocyte migration by 82% at 30 mg/kg and 95% at 100 mg/kg. Pure camphor and the cineole-limonene mixture inhibited leukocyte migration by 83% and 80%, respectively. These findings suggest that major compounds in the essential oil contribute to its potent anti-inflammatory effects. Study demonstrates that essential oil from *O. kilimandscharicum* has significant anti-inflammatory properties, likely due to actions of camphor and a combination of 1,8-cineole and limonene, providing a scientific basis for its traditional use in inflammatory conditions.[11]

Antioxidant activity

The study evaluated the antioxidant activity of extracts from *Ocimum kilimandscharicum*, Thymus serpyllum, and Spilanthes acmella, both individually and in combination. The research utilized the reducing power assay to measure the extracts' abilities to reduce the Fe3+/ferricyanide complex to its ferrous form, indicating antioxidant potential. Phytochemical screening revealed the presence of phenols and flavonoids, known for their potent antioxidant activities. The reducing power assay demonstrated that the combination of extracts exhibited superior antioxidant activity at both the lowest (0.0001 µg/ml) and highest (50 µg/ml) concentrations compared to individual extracts. Among the individual extracts, Thymus serpyllum extracts showed the highest absorbance at the lowest concentration, while *Ocimum kilimandscharicum* extract exhibited the highest absorbance at the highest concentration. The study concluded that the combined extract had enhanced antioxidant activity due to the synergistic effects of its constituents. This suggests that *Ocimum kilimandscharicum*, particularly in combination, could serve as effective antioxidant, offering a natural, economical, and safe alternative to synthetic antioxidants for managing oxidative stress-related diseases.[17]

Anti-diarrhoeal activity

The extract was tested using a castor oil-induced diarrhoea model, a castor oil-induced enteropooling assay in rats, and a charcoal meal/intestinal motility test in mice at three dose levels (100, 200, and 400 mg/kg PO), with Loperamide as the standard drug at a dose of 3 mg/kg p.o. The onset of defecation was delayed at 100 and 200 mg/kg doses of the plant aqueous extract, with an increase in cumulative faecal weight and a change in faecal consistency from loose watery to solid in the castor oil-induced diarrhoea model. In the castor oil-induced enteropooling assay, lower doses of the extract reduced intestinal fluid accumulation, but no significant change in the weight of intestinal contents was observed with the higher dose (400 mg/kg). In the charcoal meal test, doses of 140, 280, and 460 mg/kg in mice exhibited a decrease in the distance travelled by the charcoal in the extract-treated groups (20.337±0.88% at 280 mg/kg PO) compared to the control groups (45.67±6.93%), indicating reduced intestinal motility. Thus, the study demonstrated anti-motility and anti-secretory effects of the plant *O. kilimandscharicum*, supporting the claim that plant shows anti-diarrheal action.[18]

Anti-fungal activity

The silver nanoparticles of varied concentrations (20, 30, 40, and 50% v/v) of aqueous leaf extract of *Ocimum kilimandscharicum* and at different temperatures (40, 60, 80°C) were evaluated for their antifungal potential against plant pathogens; *Enterobacter cloacae*, *Bacillus* sp., *Fusarium oxysporum*, and *Colletotrichum gloeosporioides*. The antifungal assay involved growing the test fungal cultures, *F. oxysporum* and *C. gloeosporioides*, on potato dextrose agar (PDA) and incubating them at 25 °C for three days. Agar plugs with fungi of consistent size (8 mm in diameter) were placed in the center of each Petri dish along with silver nanoparticles for inoculation. The 30% concentration of plant extract showed the highest inhibition of 66.5% against *F. oxysporum*, while the 50% concentration showed the lowest inhibition of 28.3%. Complete inhibition of *F. oxysporum* was observed at a 75 ppm concentration of silver nanoparticles compared to 67.75±1.15 mm radial growth without silver nanoparticles after seven days of incubation. Inhibition of *C. gloeosporioides* varied from 18.4 to 48.7%, with 30% being the most effective concentration. *C. gloeosporioides* did not grow at 100 ppm silver nanoparticles but showed a 44.50±1.14 mm radial growth without them. The antibacterial assay against *Enterobacter cloacae* and *Bacillus* sp. was determined using the zone of inhibition around wells containing nanoparticle solution on soybean casein digest agar (SCDA) plates inoculated with pathogenic cultures. Biosynthesized silver nanoparticles were also found to have an inhibitory effect on bacterial infections, with the

largest inhibition zone of 14.5±1.11 mm observed against *E. cloacae* at 100 ppm.[19]

In another study, the hydro-distillated leaf extract oil of *Ocimum kilimandscharicum* was used in experiments to assess its effects on *Aspergillus flavus*. Fungal growth assays were conducted on potato dextrose agar (PDA) plates modified with varying concentrations of the oil. Fungal radial growth was significantly inhibited ($p<0.001$) at an oil concentration of 3.33 µl/ml. Concentrations exceeding 6.67 µg/ml completely inhibited fungal growth. At the highest dosage of 400 µl/ml, substantial broad zones of inhibition were observed ($p<0.001$).[20]

These findings indicated that *O. kilimandscharicum* plant effectively inhibits the fungal growth.

Anti-glycation activity

The principal metabolites of *O. kilimandscharicum* along with other plant species from *Ocimum* family *O. tenuiflorum* and *O. gratissimum*, were purified, described, and their anti-glycation action was assessed. The study suggested that eugenol fights diabetes through two different mechanisms: it inhibits α-glucosidase, which reduces blood sugar, and it binds to the ε-amine group on lysine, preventing AGE formation and potentially helping manage diabetes. Eugenol was discovered to have the greatest *in vitro* suppression of advanced glycation end products (AGEs). In order to comprehend the relationship between eugenol and albumin, preliminary biophysical analysis and blind docking tests revealed that eugenol has a considerable binding affinity for surface-exposed lysines. Eugenol's binding to bovine serum albumin (BSA) did not, however, significantly alter the protein's secondary structure. Studies using eugenol *in vivo* diabetic mice model demonstrated a 38% drop in blood glucose levels, most likely as a result of α-glucosidase inhibition, but insulin and glycated hemoglobin levels remained unaltered. Mice treated with eugenol had relatively less lesions upon histopathological testing. Eugenol therapy significantly reduced the number of AGE-modified peptides, both *in vivo* and *in vitro*, as shown by Western blotting with anti-AGE antibody and mass spectrometry.[21]

Anti-malarial activity

A formulation of *O. kilimandscharicum* oil was subsequently tested in field-simulated experiments using Bacillus thuringiensis subsp. israelensis (Bti) granules on *An. gambiae* larvae. After a 24-hour period, the LC50 of *O. kilimandscharicum* oil against An. gambiae third instar larvae was 0.74 ppm. In contrast, the LC50 of the emulsified *O. kilimandscharicum* oil formulation against *An. arabiensis* and *An. gambiae* third instar larvae was 0.07 and 0.31 ppm, respectively. Thus *O. kilimandscharicum* significant potential as a botanical larvicide for the control of disease vectors is suggested.[22]

Anti-melanogenic activity

The leaves and inflorescence extracts of *O. kilimandscharicum* were evaluated. Tyrosinase assays on crude 70% methanolic extracts *O. kilimandscharicum* leaves and inflorescences showed action in dose dependent manner. The inflorescence showed significantly higher tyrosinase inhibition activity than other plant species of *Ocimum* with an IC_{50} value of 1.73 mg/mL±0.435. The anti-melanogenic potential of the plant extracts were analyzed through *in vitro* assays and in silico docking studies. Thus, *O. kilimandscharicum* plant possess significant anti-melanogenic property.[23]

Anti-microbial activity

The antibacterial activity of the extracts and produced syrup was evaluated against *N. meningitis, B. cereus, P. aeruginosa,* and *E. coli*. The well diffusion method was used to assess the antimicrobial activity of *O. kilimandschricum* leaf extracts and syrup. Sterile borer wells measuring 3 mm in diameter and spaced roughly 2 cm apart were created on each plate after the 8-hour-old cultures were swabbed onto the nutritional agar plates. The wells were filled with about 100 µl of the plant extracts and produced syrup and incubated for 24 hours at 37 °C. The developing zone was observed and the diameter of the zone was measured. To ensure the reliability of the outcome, the experiment was conducted three times. Both the extract and the syrup were active against all the tested clinical pathogens. The extract showed maximum inhibition against *N. Meningitis* (5.2 mm) and lowest against *P. aeruginosa* (2.2 mm). The syrup showed maximum inhibition against *B. cereus* (5.5 mm) and lowest against *N. Meningitis* (3.7 mm). Through these results, it is discovered that there the plant *O. kilimandscharicum* possess exceptional antibacterial and antioxidant properties.[24]

Protective effects in reproductive dysfunction

Using a letrozole PCOS rat model, the study compared the therapeutic benefits of *Ocimum kilimandscharicum* with commercially available treatment metformin, which improves menstrual cycle and recovers the hormone profile to normal. PCOS rats were administered *O. kilimandscharicum* total extract and its ethyl acetate fraction at 100 mg/kg orally for 10 consecutive days. Phytochemical characterization using HPLC/PDA/ESI-MS identified various secondary metabolites in the bioactive fractions. Results demonstrated that both ok extract and the EA fraction significantly improved insulin sensitivity and normalized hormonal and lipid profiles. Additionally, these treatments restored the normal morphological structure of the reproductive system. Furthermore, *O. kilimandscharicum* total extract and Ethyl acetate fraction treatment elevated SOD levels and reduced VEGF levels more effectively than metformin. Thus *O. kilimandscharicum* could reverse letrozole-

induced reproductive dysfunctions, suggesting a novel therapeutic approach for managing PCOS.[25]

TRADITIONAL USES

The oil from the leaf extract is utilized as an insecticide and a repellent for mosquitoes, anti-bacterial and anti-fungal properties. The plant shows antimalarial, antimicrobial, anti-inflammatory, fungicide, antibacterial, insectifuge, insecticide, irritant, nematicide, antifeedant, herbicide, analgesic, antiviral, antiseptic, anti-oxidant, allergenic, anti tumor and spasmogenic. Additionally, it is advised for the treatment of a number of illnesses, such as bronchitis, measles, diarrhoea, colds, coughs, stomach aches, anorexia, and memory problems. The leaves are acrid, fragrant, thermogenic, insecticidal, and ophthalmic. To keep pests away from food, the plant leaves are used by farmers as pesticides. It is effective in CNS related conditions as anti-alzheimerian, sedative, neurotoxic, antineuralgic, and CNS stimulant properties.[26-28]

DISCUSSION

The review identified various bioactive compounds such as camphor, linalool, limonene, and eugenol, which are consistent with those found in previous studies. These compounds contribute to the plant's diverse pharmacological activities, including antioxidant, anti-inflammatory, and neuroprotective effects. One of the key findings of this review is the significant antioxidant potential of *O. kilimandscharicum's* essential oil, which exhibits stronger free radical-scavenging abilities compared to other *Ocimum* species. This is primarily attributed to its high camphor content, as well as the presence of monoterpenes such as 18-cineole and limonene. These results are consistent with the findings where camphor was identified as a major contributor to the plant's antioxidant properties.[11] This enhanced antioxidant capacity suggests that *O. kilimandscharicum* could be an effective natural alternative to synthetic antioxidants. In terms of anti-inflammatory activity, the essential oil demonstrated significant inhibition of leukocyte migration in animal models, similar to results found in previous studies. The camphor and 1,8-cineole were responsible for the potent anti-inflammatory effects observed in when tested in the carrageenan-induced paw edema model.[9] These findings validate the traditional use of *O. kilimandscharicum* in treating inflammatory conditions and highlight the importance of further clinical evaluation to establish its efficacy in human subjects.[9] The study also underscores the plant's insecticidal properties, particularly against pests such as *Tuta absoluta* and *Anopheles gambiae* that clearly demonstrated the efficacy of *O. kilimandscharicum* as a pyrethrum synergist in pest management. The high camphor content, once again, plays a central role in this bioactivity, emphasizing the plant's potential for developing eco-friendly insecticides.[13] A notable finding in this review is the neuroprotective effect of *O. kilimandscharicum* extracts, which has been shown to mitigate ischemia-reperfusion-induced brain injury in animal models. However, there are limitations to the existing studies, including a reliance on *in vitro* assays and animal models. These methods, while useful, do not fully capture the complexities of human physiology.[15,21,23] Moreover, variations in chemical composition due to environmental factors and geographic differences present challenges in replicating results across different studies.[12,29-31] To address these issues, future research should prioritize clinical trials to rigorously assess the therapeutic potential of *O. kilimandscharicum* in human populations. Additionally, standardizing extraction methods and phytochemical analyses will be essential to improve comparability between studies.[24]

CONCLUSION

Ocimum kilimandscharicum exhibits remarkable therapeutic potential due to its rich phytochemical profile, including key compounds such as camphor, linalool, and limonene. These bioactive constituents underpin the plant's diverse pharmacological activities, including antioxidant, analgesic, anti-inflammatory, insecticidal, and neuroprotective properties. While numerous *in vitro* and *in vivo* studies support its efficacy, further clinical trials are essential to substantiate these findings in human subjects. Standardizing extraction methods and exploring synergistic effects between its phytoconstituents could unlock novel therapeutic applications, especially in oxidative stress-related diseases and inflammatory conditions. In conclusion, *O. kilimandscharicum* demonstrates considerable promise as a therapeutic agent, further scientific investigation is required to comprehensively understand its therapeutic potential and address existing research gaps. This review emphasizes the need for comprehensive future research to optimize the plant's use in modern medicine.

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