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Significance of essential oils from *Eucalyptus camaldulensis* on human health: A literature review

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Abstract

Eucalyptus camaldulensis is an evergreen plant with remarkable industrial importance and biological properties. Its effectiveness against numerous diseases has been reported throughout human history. Recent research reports on this plant have also confirmed its medicinal properties. This review compiled different biological activities and medicinal properties of essential oil extracted from *Eucalyptus camaldulensis*. It has been concluded that this marvelous natural product exhibits a wide range of biological activities e.g., antibacterial, antifungal, antidiabetic, antiviral, antioxidant, antiprotozoal, larvicidal, acaricidal, and cytotoxic activities, etc. Its active component Eucalyptol has the potential to combine with drugs to take them inside the cell. This review can be beneficial for researchers working in the field of medicinal plants, natural products from *Eucalyptus camaldulensis*, and their medicinal applications to explore new research horizons.

Introduction

Eucalyptus camaldulensis belongs to the family Myrtaceae and the genus *Eucalyptus* [1]. There are 140 genera and around 3800 species in this family that are distributed around the globe in tropical and subtropical regions [2-4]. Eucalyptus has almost 700-800 species [5, 6]. It is substantially used in plywood, pulp and solid wood while its essential oils have applications in cosmetic, perfumes, food and medicine industries [7]**.** In the present review, the scope of *Eucalyptus camaldulensis* in treating human diseases is discussed. Specifically, medicinal properties and various traditional and current biological applications of *Eucalyptus camaldulensis* with more focus on the role of its essential oil and active component of oil in imparting these properties are described.

Importance of medicinal plants

Plants make up a large proportion of medicines worldwide. Out of 374,000 species of plants, vascular plants are about 308,312, of which 295,383 are flowering plants/angiosperms (monocots 74,273 & dicots 210,008). While smaller plants consist of algae 44,000, ferns 10,560, hornworts 225, gymnosperms 1,079, mosses 12,700, liverworts 9,000 and lycopods 1,290. Out of approximately 4 million plant species one-quarter of species are exploited due to their medicinal properties (**Fig. 1**) [8].

Traditional and indigenous medicines widely use natural products and half of the medicines consumed globally today are provided by the derivatives of these natural products [9-12]. Vascular plants are a large source of phytochemicals that have the potential to fight off several fatal illnesses worldwide [8].

Plants having medicinal properties are termed medicinal plants. Chemical constituents present in different parts of the plant have the potential to be used in drug synthesis. These constituents may be present in leaf, root, fruit, seeds, flowers, bark, or the whole plant and are called active substances. The compounds having a physiological impact on living organisms are active substances. They can be used as a medicinal drugs because they have a therapeutic effect (directly or indirectly) against certain illnesses [13-16] (**Fig. 2**).

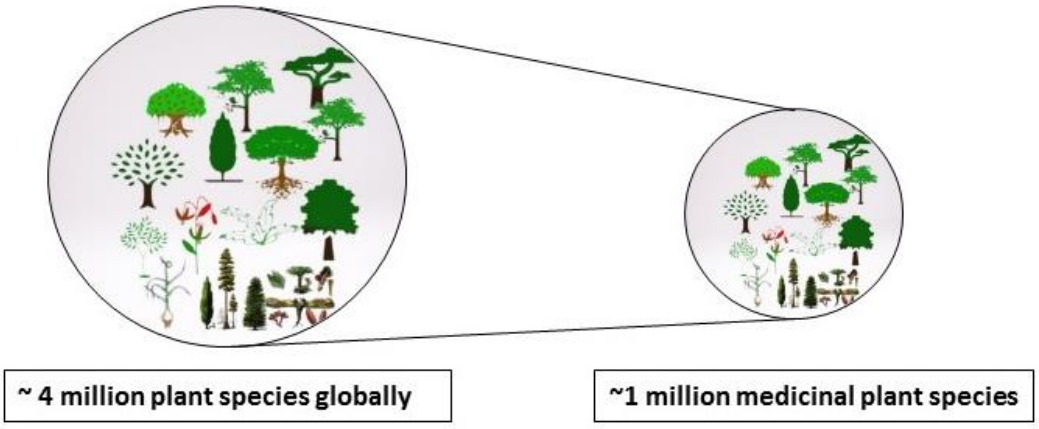

Fig. 1: Medicinal plants around the globe

Essential oils in plants

While essential oils had been used for religious purposes approximately 6000 BC ago, their therapeutic use is recorded to gain popularity after 1910. In the late 1970s as the clinical and therapeutic use of oil came into focus, schools were opening in Britain to study these essential oils [17]. In the European Pharmacopeia 7th edition, essential oil is defined as "Odorant products, which have the complex composition, and obtained from plant raw extract, either extracted by the steam of water, dry distillation or a suitable mechanical method without heating" [18].

Essential oils (volatile oils) are aromatic and oily liquids in nature collected from different plants of plants (wood, bark, leaves, twigs, seed, fruits, buds, roots, and flowers). They can be collected by the means of expression, extraction, or fermentation.

For commercial production of essential oil, the most common method is steam distillation [19, 20]. To separate the essential oil from the aqueous phase, a physical method is used typically which has no significant effect on the chemical composition of oil [18]. However, environmental conditions, plant

genotype and chemo-type and variation in species or sub-species influence the chemical composition of this oil [7, 21].

Moreover, the essential oil is also known as secondary metabolites in a plant that possesses a mixture of complex organic compounds that are volatile such as hydrocarbon groups (terpenes and sesquiterpenes), oxygenated groups (phenols, ether phenols, aldehydes, ketones, lactones, ethers, esters, alcohols, etc) [22-27] (**Fig. 3**). Generally, all essential oils have two or three major constituents with the highest percentage in concentrations (20%-70%) as compared to the other constituents that are present in trace amounts [18].

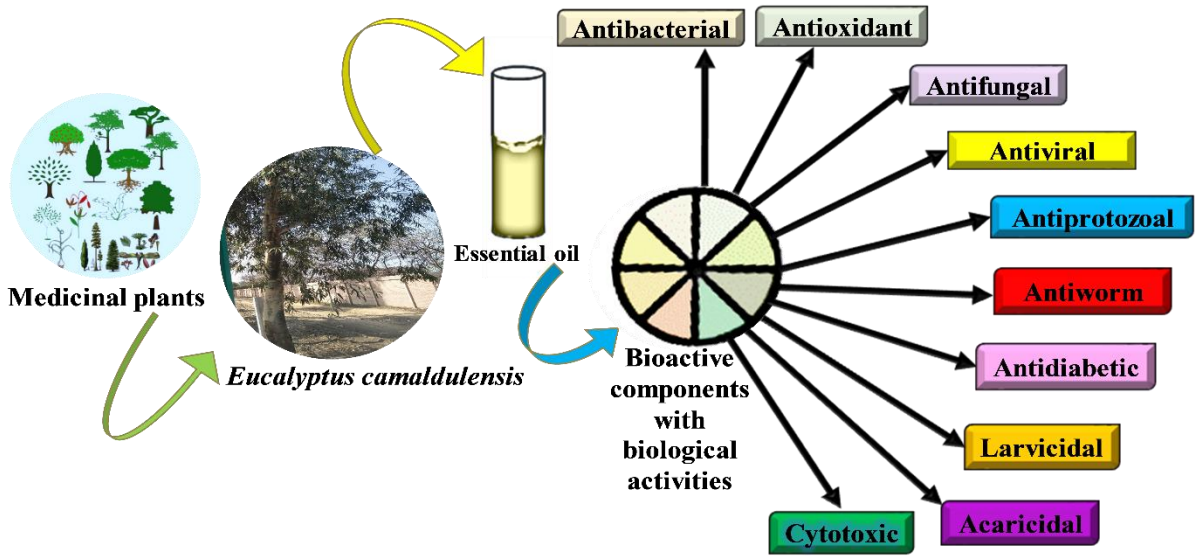

Fig. 2: Medicinal effect of *Eucalyptus camaldulensis* to treat (directly or indirectly) certain illnesses

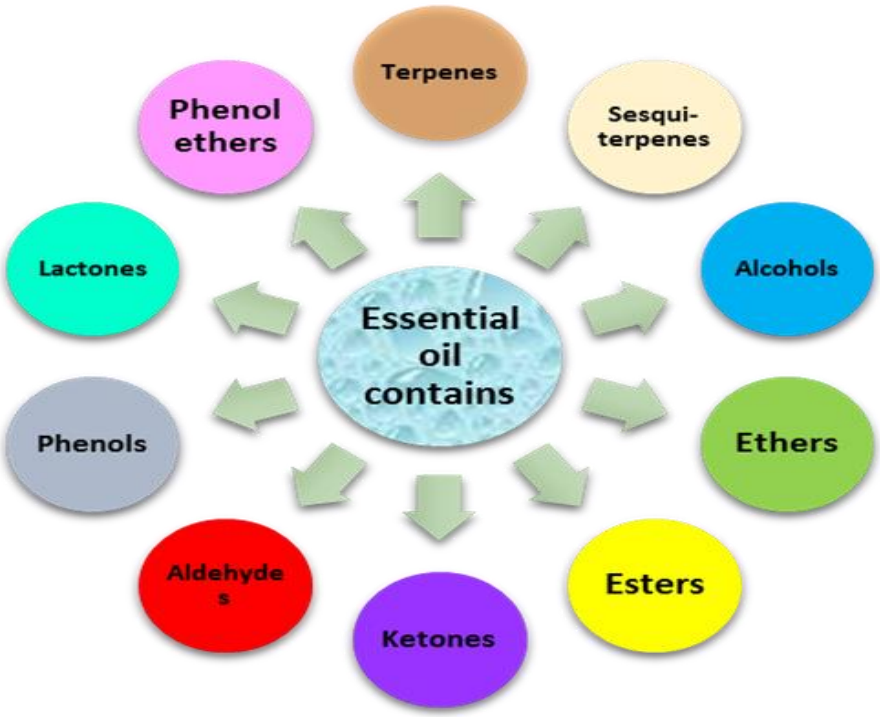

Fig: 3: Essential oils components in plants

Medicinal properties of essential oils

Essential oils have certain biological activities such as antibacterial, insecticidal, antifungal, antiviral insecticidal and antioxidant properties. Some have shown the potential against cancerous cells while some are used in aromatherapy, perfume and food industries [19, 28-31].

The essential oil has found widespread use for treating different infectious diseases of the skin, urinary tract, respiratory system and gastrointestinal systems. For example, tea tree essential oil is beneficial for treating acne and other skin infections [32].

A significant characteristic of essential oil and their constituents is hydrophobicity or lipophilicity, which enables them to pass through lipids of bacterial cell membrane and mitochondria, hence destroying the cell structure that eventually leads to bacterial death by leakage of critical components of cells and ions to great extent [33-35].

Additionally, significant scientific evidence indicated that under conditions of oxidative stress, ROS (reactive oxygen species) such as hydroxyl, superoxide, and peroxyl radicals are generated by the components present in essential oil and the balance between oxidation and anti-oxidation is considered to be critical for maintaining a healthy biological system. Thus, it can be expected that various compounds in these oils have general as well as specific activity against microbes [19, 36-40].

Extraction and isolation techniques for essential oil

Extraction, distillation and pressing are principle methods for extracting desired components from EOs [41]. Several advanced extraction techniques; including supercritical fluid extraction, subcritical extraction liquid, solvent-free microwave extraction and conventional techniques; hydrodistillation, steam distillation, hydro-diffusion, and solvent extraction are available for extraction [39, 42-46] (**Fig. 4**).

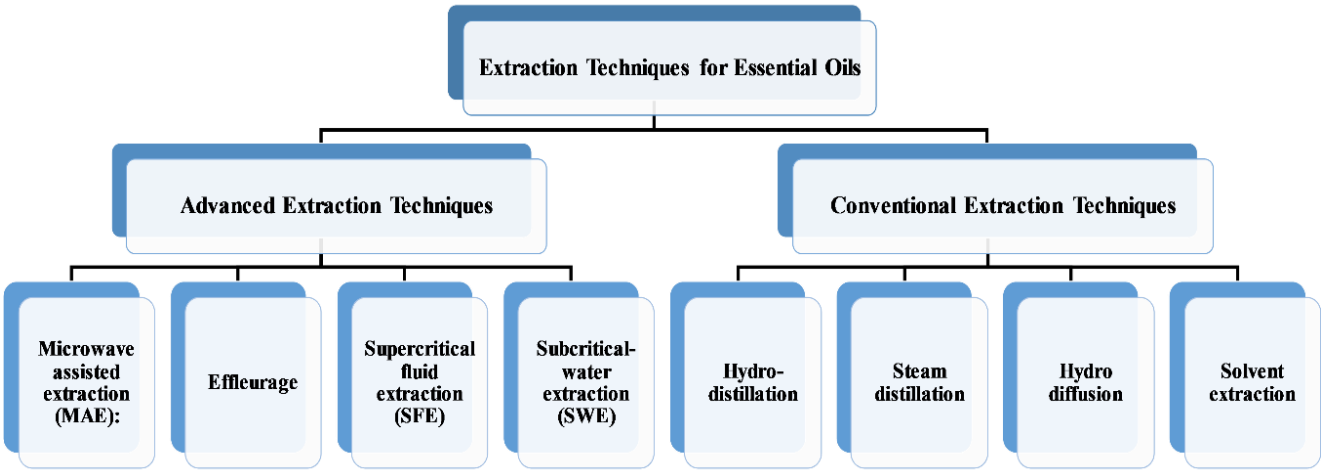

Fig. 4: Extraction methods for essential oil

Each method exhibits discrete advantages and determines the biological and physicochemical properties of the essential oil [18, 21, 47]. Significant factors for solid-liquid extractions include a suitable solvent system, the solvent-to-herbs ratio, the sizes of ground and dried herb materials, the duration, temperature and agitation rate [48].

Genus Eucalyptus

Eucalyptus is evergreen, perennial, woody shrubs to tall trees that grow rapidly to the gigantic sized tree. A French botanist, L' Heritier, first introduced the Genus *Eucalyptus* [49]. The acacia genus *Eucalyptus* is considered the second-largest genera that include 900 species and subspecies identified throughout the globe [50]. Systematically the genus is placed under the Kingdom: Plantae; Class: Magnoliopsida; Order: Myrtales and Family: Myrtaceae and Genus: Eucalyptus [49]. The species of the genus *Eucalyptus* are forest trees and shrubs native to Tasmania and Australia. The genus was successfully planted in other parts of the world for various purposes. *Eucalyptus* species presently occur in most tropical and subtropical regions and became an important widely planted genus [7].

Medicinal properties of Eucalyptus

From ancient times, Eucalyptus has been used by aboriginal people for multiple purposes but mostly for food and medicine [7, 49]. As its essential oil possesses significant medicinal properties, several of its species are used for aromatherapy in Japan and Europe [8]. Eucalyptus trees grow rapidly which makes them an important hardwood forest crop that is used in the paper and pulp industry. Eucalyptus timber is used for fuel and construction, while its gum is used to treat diarrhea [51].

Eucalyptus oil is used as a solvent/sealer in dentistry and as a disinfectant while its products are also used topically to relieve muscle pain [52]. More than 300 species of this genus contain volatile oils in their leaves including *Eucalyptus citriodora, Eucalyptus tereticornis, Eucalyptus globulus, Eucalyptus melanophloia, Eucalyptus crebra, Eucalyptus microtheca* and *Eucalyptus camaldulensis* [53]. Global production of Eucalyptus essential oils (EOs) is roughly 3000 tons and the major EOs producers of Eucalyptus are Portugal, Chile, Spain, China and South Africa. Eucalyptus EOs are used for fragrance in cosmetics, detergents, soaps, lotions, perfumes and in household products. They are also used in food items and beverages such as soft drinks, confectionaries, baked goods, meat products and ice creams as a flavoring agent [51]. The essential oils of Eucalyptus species also possess significant biological properties including antimalarial, antiseptic, diaphoretic, analgesic, disinfectant, anti-inflammatory, antibacterial and antioxidant properties [19, 29-31, 54].

Eucalyptus camaldulensis

E. camaldulensis (**Fig. 5**) is a worldwide extensively distributed *Eucalyptus* species. It is formerly *Eucalyptus rostrata* Schl. and it is a tree by habit. Redgum, long beak eucalyptus, river gum, Murray red gum, and red river gum are such common names for this species. The name of this species originated from the name of L'Hortus Camaldulensis di Napoli; a private garden near the Camaldoli monastery adjacent to Naples. This place was the first-ever source of this plant. Frederick Dehnhardt (Chief Gardener at the Botanic Gardens in Naples), describes this specie in 1832 [2]]. This species has two varietal forms i.e., *E. camaldulensis* var. *camaldulensis* and *E. camldulensis* var. *obtuse.* A sub-species *E. camaldulensis* subsp. *simulata* found in the North Queensland, is recognised as a hybrid of *E. tereticornis* Smith and *E. camldulensis* var. *obtuse* [55] (**Table 1**).

Fig. 5: *Eucalyptus camaldulensis* tree, bark, leaves, and fruits

Ethnomedicinal importance of Eucalyptus camaldulensis

Native societies in Australia have known the medicinal potential of the *E. camaldulensis* plant and they used it for treating a wide range of diseases such as respiratory diseases (trachalgia, asthma, laryngitis, sore throat, coughs, laryngalgia, pharyngitis and common cold) [56, 57] and gastrointestinal diseases (diarrhoea, ulcer, colic and dysentery) [58]. They used it to treat open wounds, cuts, bleeding [59-61] other

Table 1. Distinctive properties of *E. camaldulensis* subspecies

Distinctive characteristics	Taxon		
	E. camaldulensis* var. *camaldulensis	***E. camaldulensis* var. *obtusa***	***Eucalyptus camaldulensis* subsp. *simulata***
Bark	Rough at the base, grey, white-colored	Seasonally powdered, whitebark	Smooth at the base, grey, white colored
Leaves	Non-glaucous, narrowly lanceolate, green, juvenile leave	Dull-glossy green, mature leaves with densely-very densely reticulate venation	Adult green, densely reticulate, lanceolate or ovate juvenile leaves
Operculum	0.3-0.7 cm long with a strong beak	0.4-0.7 cm long, glaucous, round-obtusely conical juvenile growth	horn-shaped, 0.9-1.6 cm long

then to wash the open wounds [62] while its decoction was used to heal muscle spasms, [63] pains, and aches in joints and teeth [64]. They used smoke baths for patients with cold, sickness, fever and flu [65]. A smoke bath is a folk remedy where the patient is surrounded by young burning leaves of smoke [2, 66, 67]. Its leaves are also helpful in relieving pain during childbirth beside it increases milk production in mothers [60, 68].

Recent research studies on *E. camaldulensis* have confirmed its traditional usefulness and medicinal potential for various ailments [69-75]. Decoction of its leave is effective for respiratory and urinary tract infections [UTIs] while its essential oil possesses astringent, anaesthetic and antiseptic properties [58]. Leaf extract of *E. camaldulensis* has also shown potential for treating ulcers by decreasing gastric acid production in animal models [*Rattus norvegicus domesticus*]. *Eucalyptus camaldulensis* extracts and oils can also serve as food preservatives as an alternative to synthetic preservatives and chemicals due to their antioxidant properties [2].

Eucalyptus camaldulensis essential oil

Eucalyptus camaldulensis comprises essential oil and its essential oil possesses various biological properties including antioxidant, antimicrobial, antiseptic, insecticidal, nematicidal, herbicidal, acaricidal and wound healing properties [58]. These properties are exhibited due to the presence of certain bioactive components present in its essential oil [76, 77]. *E. camaldulensis* essential oil is also used as a chemotherapy agent, soap-making agent, grease remover and to treat gastrointestinal and respiratory disorders [8]. According to Ghasemian, et al. (2019), the main constituent of its essential oil is 1,8-cineole or eucalyptol which is 92% of the total oil compounds. Some tropical species of *E. camaldulensis* have a high concentration of 1, 8-cineole in their leaves essential oil that is used in various commercial products. This oil is used in perfumes, cosmetics, food, medicine and pharmaceutics industries. Eucalyptol is a terpene in nature that is extensively used in the food and cosmetic industry as terpenes are approved by US Food and Drug Administration (FDA). Antimicrobial studies on 1,8-cineole suggested that it is effective against both gram-positive and negative bacterial strains [32]. According to literature, the essential oil from *E. camaldulensis* has a low density i.e ~0.92g/ml. The oil is liquid at room temperature to even at -20 ^{o}C. Generally, it is pale yellow against a white background with a watery viscosity. It is reported to have a very distinct clear, sharp, pine/minty smell. This oil is soluble in solvents including DMSO (Dimethyl sulfoxide), DCM (Dichloromethane), and ethanol while insoluble in water [78].

Physical properties of essential oil

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Chemical composition of Eucalyptus camaldulensis essential oil

E. camaldulensis essential oil is about 5% of the total leaf mass. Multiple factors like genotype, soil characteristics, seasonal change and water availability influence the composition and yield of the essential oil. Hence, significant variations in results can be observed in research reports on this essential oil. According to Ghasemian et al. (2019) the key component of *E. camaldulensis* EO is 1,8-cineol or eucalyptol forming 92% of oil [32]. Essential oil yield in *E. camaldulensis* leaves from Pakistan is reported to be 0.90–0.98%.

All the essential oil components are terpenes in nature that can be further classified based on isoprene units, monoterpenes (C_5H_8), sesquiterpenes ($C_{10}H_{16}$) and extended chains comprising isoprene units ($C_{15}H_{24}$). Terpenoids (Oxygenated terpenes) are present in the oil [32]. As per literature, *E. camaldulensis* EOs are rich in 1,8-cineole (eucalyptol), terpinen- 4-ol and *trans*-pinocarveol along with some monoterpenes including γ-terpinene, β-pinene, α-thujene and p-cymene. Sesquiterpenes, however, are relatively low in concentration. According to Ghasemian et al., throughout the year essential oil composition had monoterpenes concentrations of about 34.6–56.3% while sesquiterpene and oxygenated sesquiterpenes had concentrations of 6.6–16.5% and 2.1–11.1% respectively [32].

According to Mubarak et al., (2015) the major components in *E. camaldulensis* oil were *γ*-Terpinene-72.5%, *o*-Cymene-14.6% and Terpinen-4-ol- 6.7% respectively [7]. In a study by Dhakad et al., (2018) complex composition of *E. camaldulensis* oil under different distillation methods was observed with fifty-four constituents (largely monoterpenes and sesquiterpenes) forming 95% of the oil. The mean yield was 0.25% which is very low and the chief components were 1,8-cineole-16.2% and α-pinene-15.6% [8]. Basak et al., (2010) identified 29 components forming 99.10% of the total essential oil. Some of these chief constituents were *p*-cymene-68.43%, 1,8-cineole-13.92%, 1-(S)-α-pinene-3.45%- and R-(+)- limonene-2.84% [51] (**Fig. 6**).

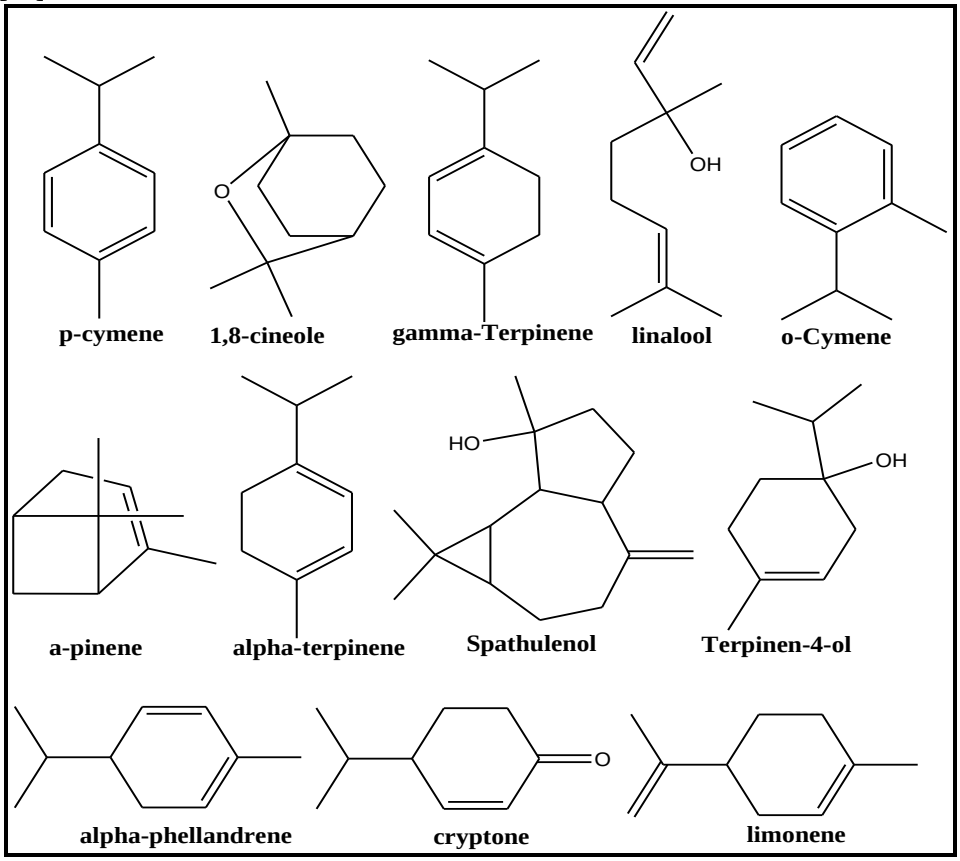

Fig. 6: Structure of major components in *E. camaldulensis* essential oil

In another study it was reported that essential oil of *E. camaldulensis* consisted of thirteen types of compounds named as linalool-17.0%, p-cymene-12.2%, 1,8-cineole-16.1%, -farnesol-11.1%, -terpinene-10.7%, phenythyl acetate-7.1%, paraldehyde-5.3%, geranial-6.6%, terpinene-4-ol-5.3%, and p-ment-1-en-3, 8-diol-5.1% [53]. Gakuubi *et al.,* (2017) reported the main components of EO were 1,8-cineole-16.2%, *α*-pinene-15.6%, *α*-phellandrene-10.0%, and p-cymene-8.1% [79].

Elaagib et al. (2012) analysed the chemical constituents of *E.camaldulensis* essential oil and found that γ-terpinene was present 63.8% , *o*-Cymene-22.5%,, Terpinen-4-ol-9.5% and Terpinolene 1.3% [80]. Chahomchuen et al., (2020) identified 24 compounds in *E. camaldulensis* essential oil and the key components were 1,8-cineole-31.08%, α-

terpinene-22.04%, α-phellandrene-21.06%, o-cymene-5.74%, α-pinene-3.03% and α-terpinolene-2.05% [81]. Chalchat et al., (2001) studied the essential oil of *Eucalyptus camaldulensis* from Jerusalem *and* found that the key components were p-cymene-24.2%, Spathulenol-l7.5%) and cryptone-6.9% [82] (**Table 2**).

Table 2: Major chemical constituents of *Eucalyptus camaldulensis* essential oil reported by different researchers

Sr. #	Compound name	% Composition	References
1	γ-Terpinene	72.5%	
2	*o*-Cymene	14.6%	[7]
3	Terpinen-4-ol	6.7%	
1	1,8-cineole	(16.2%)	
2	α-pinene	(15.6%)	[8]
1	*p*-cymene	(68.43%)	
2	1,8-cineole	(13.92%)	[51]
3	1-(S)-α-pinene	(3.45%)	
1	linalool	(17.0%)	
2	1,8-cineole	(16.1%)	[53]
3	p-cymene	(12.2%)	
1	1,8-cineole	(16.2%)	
2	α-pinene	(15.6%)	[79]
3	α-phellandrene	(10.0%)	
1	γ-terpinene	(63.8%)	
2	*o*-Cymene	(22.5%)	[80]
3	Terpinen-4-ol	(9.5%)	
1	1,8-cineole	(31.08%)	
2	α-terpinene	(22.04%)	[81]
3	α-phellandrene	(21.06%)	
1	p-cymene	(24.2%)	
2	Spathulenol	(l7.5%)	[82]
3	cryptone	(6.9%)	

According to Sabo et al. (2019), *E. camaldulensis* EOs can be divided into two different types depending upon their concentration. Type I essential oil are rich in cineole concentration containing 80-90% of 1,8-cineole and pinene while Type II EO has a relatively low concentration of cineole in it. Examination of two Eucalyptus species *E. camaledulensis* var. *obtuse* and *E. camaledulensis* var. *camaldulensis* revealed that their major components were cryptone-14%, p-cymene-22%, spathulenol-17% and 1,8- cinole-52%, α-pinene-15%, aromadendrene-3% respectively. This analysis indicates that these essential oils belong to different categories hence different subspecies [2]].

According to Sabo *et., al* (2019) *Eucalyptus camaldulensis* EOs can be divided into two different types depending upon their concentration. Type I essential oil are rich in cineole concentration containing 80-90% of 1,8-cineole and pinene while Type II EO has a relatively low concentration of cineole in it. Examination of two Eucalyptus species *Eucalyptus camaledulensis* var. *obtuse* and *Eucalyptus camaledulensis* var. *camaldulensis* revealed that their major components were p-cymene-22%, cryptone-14%, spathulenol-17% and 1,8-cinole-52%, α-pinene-15%, aromadendrene-3% respectively. This analysis indicates that these essential oils belong to different categories hence different subspecies (**Table 3**) [2].

Table: 3. Major constituents of different variations in *Eucalyptus camaldulensis* subspecies [2]

Eucalyptus camaledulensis var. camaldulensis	Eucalyptus camaledulensis var. obtuse
p-cymene (22%)	1,8- cinole (52%)
cryptone (14%)	α-pinene (15%)
spathulenol (17%)	aromadendrene (3%)

Eucalyptol is a major bioactive component

One of the main components of *E.camaldulensis* essential oil is Eucalyptol. Its chemical nature makes it biologically active and enables it to interact with cells. Eucalyptol increases the permeability of the cell membrane and by coupling with impenetrable drugs, it allows their entry into the cell. This mechanism can be used in combining drugs with cineol that can bind with hydrophilic as well as lipophilic compounds (**Fig. 7**) [32].

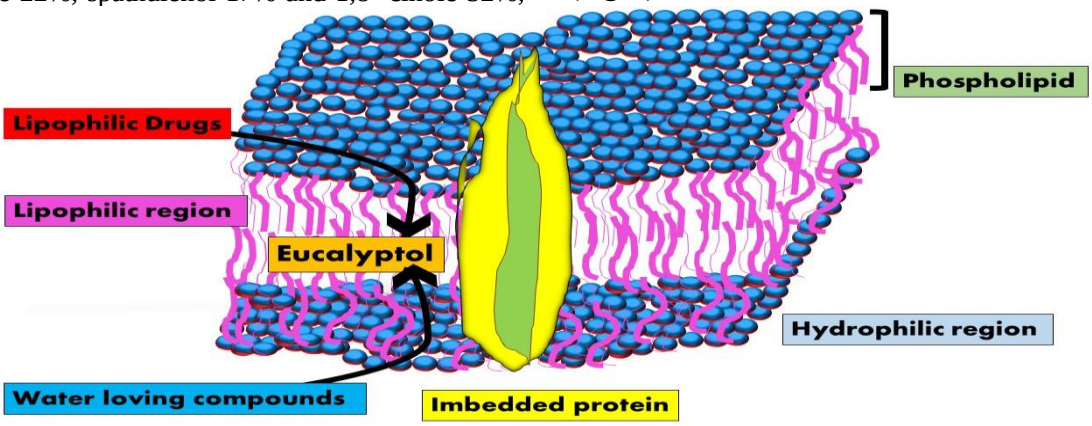

Fig. 7: Coupling of Eucalyptol (1,8-cineole) with different types of drugs and their penetration in plasma membrane.

This substance has shown significant, long-lasting and broad-spectrum antimicrobial activity against both types of bacteria (gram-positive & gram-negative). 1,8-cineole is licensed to be used in the cosmetic and food industry for a long. It is terpene in nature and terpenes are safe to use organic compounds that have been approved by the US Food and Drug Administration (FDA) [32].

Eucalyptol is effective against respiratory diseases [40, 83] as it reduces the duration, frequency and severity of inflammation in the respiratory tract like menthol. It activates the nasal receptors and decongests the upper portion of the respiratory tract by stimulating the bronchial epithelium and reducing the mucolytic effect [50].

Pharmacological activities of Eucalyptus camaldulensis

E. camaldulensis has shown several biological activities (antioxidant, anti-fungal, anti-bacterial and anti-larval activity, pesticidal, antiviral, cytotoxic, larvicidal, antiprotozoal, antidiabetic, and acaricidal) due to the active components present in its essential oil [7, 30, 84-91]. Among these activities, some are reported below.

Antibacterial activity

Eucalyptus camaldulensis plant EOs have shown efficacy against a variety of bacteria [2]. They are active against both Gram-positive and Gram-negative bacteria [19]. According to Sabo et al. (2019), the comparative analysis between *Eucalyptus camaldulensis* EOs with other species of this genus reveals it is more effective against bacteria [2]. Vashit et al. (2012) reported excellent inhibition of *S. aureus* and *E. coli* by leaves essential oil of this plant [92].

The same results were found by El Baz et al. (2105) on bacterial species including *Escherichia coli*, *Candida albicans* and *L. monocytogenes*. Its activity against microbes is due to the presence of eucalyptol and α-pinene. Some shreds of evidence also suggest that other functional groups such as terpenes, alcohol, ketones and phenol in plant material are associated with antibacterial characteristics [19]]. In a study by Dhakad *et., al* (2015) it was reported that the bioassays from *E. camaldulensis* leave EOs exhibited more antimicrobial activity against gram-positive bacterial strains than the negative strains. Furthermore, the activity is usually increased with an increase in the concentration of essential oil [8].

Antioxidant activity

Phenolic groups in Eucalyptus oil impart antioxidant properties due to their radical scavenging activity [52]. Oxidative stress causes aging and other degenerative processes which can be controlled by antioxidants proven by clinical experiments. However, synthetic oxidants are harmful due to their carcinogenic and liver-damaging effects and the trend is shifting towards natural antioxidants. Epidemiological study reports have indicated erythrocyte membrane lipids, diabetic tissue and plasma lipoproteins undergo high lipid peroxidation. This can be controlled by *Eucalyptus camaldulensis e*ssential oil as compared to positive standards. It inhibits lipid peroxidation (non-enzymatic) in rat liver [51].

Antifungal activity

Essential oil from *E. camaldulensis* leaves also serves as an antifungal agent. It is effective against wood rot fungi, household molds, and phytopathogenic fungi [2]. Crude oil acts as fungistatic where it inhibits the growth of mycelium in *Phaeoramularia angolensis* at 6000-65000 ppm [92].

Antiviral activity

Essential oil from *E. camaldulensis* has exhibited efficacy against several viruses [2]. Reports have confirmed its activity against Rotavirus, herpes virus type-1, Coxsackievirus B4 and Wastrain [8]. RNA viruses are also affected by this essential oil [19].

Antiprotozoal activity

E. camaldulensis EO has been tested active against protozoans due to its multi-component nature. *In vitro* antitrypanosomal activity has shown that essential oil targets several sites of these microorganisms in a short time in dose-dependent manner [2]].

Anti-worm activity

Bioactive fractions of essential oil exposure to *Schistosoma mansoni* worms showed extensive deformation and severe swelling in treated worms which seizes their activity against animals. Hence, *Eucalyptus camaldulensis* essential oil is toxic to these worms [19].

Antidiabetic activity

In vitro assessments have shown antidiabetic activities of *E. camaldulensis* (EO) by the inhibition of α-amylase and α- glucosidase [8]. In another study, it was confirmed that in the presence of *E. camaldulensis* Eos, inhibition of α-amylase and α-glucosidase takes place by a non-competitive mechanism [51].

Larvicidal/Nematocidal activity

Nematodes are plant parasites that infest all types of food crops. They reduce crop yield and result in huge great economic losses every year. Nematodes annually cause approximately worth 78 billion US$ crop loss worldwide. Eucalyptus oils have demonstrated nematicidal activity in different experiments [93]. In *Meloidogyne exigua* (a coffee plant parasite) the hatching at (J2) second stage juveniles is severely affected by *E. camaldulensis* essential oil and the larval mortality rate is increased due to the presence of nematicidal components [8].

Acaricidal activity

Free-living parasites such as ticks and mites can be effectively dispelled by active components in essential oils. Cineole-rich essential oil has demonstrated effectiveness against *Tetranychus urticae*, *Dermatophagoides pteronyssinus*, *Phytoseiulus persimilis* and *Varroa Jacobson* [93]].

Cytotoxic activity

Several studies have been conducted to investigate the cytotoxic activity of essential oils against cancer cell lines [8]. Al-Fatimi et al. (2105) reported that *E. camaldulensis* oil has considerable cytotoxic activity against cancerous cells [94]. Eualyptus essential oil also reduces cancer cells as it has anti-cancerous activity [95] by inhibiting the migration or invasion of the cancerous cell to healthy cells and causing the death of infected cells [96-98] Mubarak et al. (2010) found that *E. camaldulensis* leaves essential oil exhibited cytotoxic activity against three tested cancer cell lines; HL-60, WEHI-3, and HT-29. With an IC50 value of 16.1, the most sensitive cells were WEHI-3. The essential oil demonstrated less cytotoxic efficacy in HT-29 and HL-60 cells with IC_{50}=50.5 and 42.1, respectively). RAW 264.7 cells were also less affected by this essential oil [7]. Pre-clinical trials are required to determine the pathway of eucalyptus extract and its potential against tumors [99, 100].

Conclusion and future prospect

Eucalyptus camaldulensis and its essential oil have proven to exhibit multiple biological functions from ethnomedicinal uses to ethnopharmacological activities. Studies have indicated that this plant indeed has marvelous healing potential hidden in its oil that can revolutionize not only medicine but the human future as well. Further research is needed to make the best use of already known properties, and explore its novel applications and commercial benefits.

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Conflict of interest

The authors declare no conflict of interest.

References

[1] Stefanello MÉA, Pascoal AC, Salvador MJJC, biodiversity. Essential oils from neotropical Myrtaceae: chemical diversity and biological properties. 2011;8(1):73-94.
[2] Sabo VA, Knezevic P. Antimicrobial activity of Eucalyptus camaldulensis Dehn. plant extracts and essential oils: A review. Industrial crops and products 2019;132:413-429.
[3] Mabberley DJ. The plant-book: a portable dictionary of the vascular plants: Cambridge university press; 1997.
[4] Ali N, Ahmed G, Ali Shah SW, Shah I, Ghias M, Khan IJBc, medicine a. Acute toxicity, brine shrimp cytotoxicity and relaxant activity of fruits of callistemon citrinus curtis. 2011;11(1):1-8.
[5] Coppen JJ. Eucalyptus: the genus Eucalyptus: CrC Press; 2002.
[6] Batish DR, Singh HP, Kohli RK, Kaur SJFe, management. Eucalyptus essential oil as a natural pesticide. 2008;256(12):2166-2174.
[7] Mubarak EE, Landa ZA, Ahmed IFA, Ahmed ABA, Taha RM. Essential oil compositions and cytotoxicity from various organs of Eucalyptus camaldulensis. International Journal of Agriculture and Biology 2015;17(2):320-326.
[8] Dhakad AK, Pandey VV, Beg S, Rawat JM, Singh A. Biological, medicinal and toxicological significance of Eucalyptus leaf essential oil: a review. Journal of the Science of Food and Agriculture 2018;98(3):833-848.

[9] Shedoeva A, Leavesley D, Upton Z, Fan C. Wound healing and the use of medicinal plants. Evidence-Based Complementary and Alternative Medicine 2019;2019.
[10] Schmelzer GH, Gurib-Fakim A. Medicinal plants: Prota; 2008.
[11] Van Wyk B-E, Wink M. Medicinal plants of the world: CABI; 2018.
[12] Petrovska BBJPr. Historical review of medicinal plants' usage. 2012;6(11):1.
[13] Jamshidi-Kia F, Lorigooini Z, Amini-Khoei H. Medicinal plants: Past history and future perspective. Journal of herbmed pharmacology 2018;7(1).
[14] Gurib-Fakim AJMaoM. Medicinal plants: traditions of yesterday and drugs of tomorrow. 2006;27(1):1-93.
[15] Bajaj YPS. Medicinal and Aromatic Plants I: Springer Science & Business Media; 2012.
[16] Miguel MGJF, Journal F. Antioxidant activity of medicinal and aromatic plants. A review. 2010;25(5):291-312.
[17] Manion CR, Widder RM. Essentials of essential oils. American Journal of Health-System Pharmacy 2017;74(9):e153-e162.
[18] Aziz ZA, Ahmad A, Setapar SHM, Karakucuk A, Azim MM, Lokhat D, Rafatullah M, Ganash M, Kamal MA, Ashraf GM. Essential oils: extraction techniques, pharmaceutical and therapeutic potential-a review. Current drug metabolism 2018;19(13):1100-1110.
[19] El-Baz FK, Mahmoud K, El-Senousy WM, Darwesh O, El Gohary A. Antiviral–antimicrobial and schistosomicidal activities of Eucalyptus camaldulensis essential oils. Int J Pharm Sci Rev Res 2015;31(1):262-268.
[20] Hanif MA, Nisar S, Khan GS, Mushtaq Z, Zubair M. Essential oils. Essential oil research: Springer; 2019. p. 3-17.
[21] Figueiredo AC, Barroso JG, Pedro LG, Scheffer JJJF, journal F. Factors affecting secondary metabolite production in plants: volatile components and essential oils. 2008;23(4):213-226.
[22] Morsy NJMGC. Phytochemical analysis of biologically active constituents of medicinal plants. 2014;13(1):7-21.
[23] Hussain I, Ullah R, Khurram M, Ullah N, Baseer A, Khan FA, Khattak M, Zahoor M, Khan J, Khan NJAJoB. Phytochemical analysis of selected medicinal plants. 2011;10(38):7487-7492.
[24] Yadav R, Agarwala MJJop. Phytochemical analysis of some medicinal plants. 2011;3(12).
[25] Njoku VO, Obi CJAjop, chemistry a. Phytochemical constituents of some selected medicinal plants. 2009;3(11):228-233.
[26] Phillipson JDJP. Phytochemistry and medicinal plants. 2001;56(3):237-243.
[27] Saxena M, Saxena J, Nema R, Singh D, Gupta AJJop, phytochemistry. Phytochemistry of medicinal plants. 2013;1(6).
[28] Lucia A, Audino PG, Seccacini E, Licastro S, Zerba E, Masuh HJJotAMCA. Larvicidal effect of Eucalyptus grandis essential oil and turpentine and their major components on Aedes aegypti larvae. 2007;23(3):299-303.
[29] Ramezani H, Singh H, Batish D, Kohli R, Dargan JJNzpp. Fungicidal effect of volatile oils from Eucalyptus citriodora and its major constituent citronellal. 2002;55:327-330.
[30] Trigg JJJotAMCA-MN. Evaluation of a eucalyptus-based repellent against Culicoides impunctatus (Diptera: Ceratopogonidae) in Scotland. 1996;12(2):329-330.
[31] Yang Y-C, Choi H-Y, Choi W-S, Clark J, Ahn Y-JJJoA, Chemistry F. Ovicidal and adulticidal activity of Eucalyptus globulus leaf oil terpenoids against Pediculus humanus capitis (Anoplura: Pediculidae). 2004;52(9):2507-2511.
[32] Ghasemian A, Eslami M, Hasanvand F, Bozorgi H, Al-Abodi HR. Eucalyptus camaldulensis properties for use in the eradication of infections. Comparative immunology, microbiology and infectious diseases 2019;65:234-237.
[33] Chouhan S, Sharma K, Guleria S. Antimicrobial activity of some essential oils—present status and future perspectives. Medicines 2017;4(3):58.
[34] Nazzaro F, Fratianni F, De Martino L, Coppola R, De Feo VJP. Effect of essential oils on pathogenic bacteria. 2013;6(12):1451-1474.
[35] Saad NY, Muller CD, Lobstein AJF, Journal F. Major bioactivities and mechanism of action of essential oils and their components. 2013;28(5):269-279.
[36] Koroch AR, Rodolfo Juliani H, Zygadlo JAJF, fragrances. Bioactivity of essential oils and their components. 2007:87-115.
[37] Bakkali F, Averbeck S, Averbeck D, Idaomar MJF, toxicology c. Biological effects of essential oils–a review. 2008;46(2):446-475.
[38] Djilani A, Dicko AJN, well-being, health. The therapeutic benefits of essential oils. 2012;7:155-179.
[39] de Groot AC, Schmidt EJD. Essential oils, part III: chemical composition. 2016;27(4):161-169.
[40] Juergens UR, Dethlefsen U, Steinkamp G, Gillissen A, Repges R, Vetter HJRm. Anti-inflammatory activity of 1.8-cineol (eucalyptol) in bronchial asthma: a double-blind placebo-controlled trial. 2003;97(3):250-256.
[41] Zhang Q-W, Lin L-G, Ye W-C. Techniques for extraction and isolation of natural products: a comprehensive review. Chinese medicine 2018;13(1):20-46.
[42] Stratakos AC, Koidis A. Methods for extracting essential oils. Essential oils in food preservation, flavor and safety: Elsevier; 2016. p. 31-38.
[43] Li Y, Fabiano-Tixier A-S, Chemat FJEoariGC. Essential oils: from conventional to green extraction. 2014:9-20.
[44] De Castro ML, Jiménez-Carmona M, Fernandez-Perez VJTTiAC. Towards more rational techniques for the isolation of valuable essential oils from plants. 1999;18(11):708-716.
[45] El Asbahani A, Miladi K, Badri W, Sala M, Addi EA, Casabianca H, El Mousadik A, Hartmann D, Jilale A, Renaud FJIjop. Essential oils: From extraction to encapsulation. 2015;483(1-2):220-243.
[46] Handa SJEtfm, plants a. An overview of extraction techniques for medicinal and aromatic plants. 2008;1:21-40.
[47] Fadel H, Marx F, El-Sawy A, El-Ghorab AJZfLu-FA. Effect of extraction techniques on the chemical composition and antioxidant activity of Eucalyptus camaldulensis var. brevirostris leaf oils. 1999;208(3):212-216.

[48] Mohammad Azmin SNH, Abdul Manan Z, Wan Alwi SR, Chua LS, Mustaffa AA, Yunus NAJS, Reviews P. Herbal processing and extraction technologies. 2016;45(4):305-320.
[49] Salehi B, Sharifi-Rad J, Quispe C, Llaique H, Villalobos M, Smeriglio A, Trombetta D, Ezzat SM, Salem MA, Zayed A. Insights into Eucalyptus genus chemical constituents, biological activities and health-promoting effects. Trends in Food Science & Technology 2019;91:609-624.
[50] Vecchio MG, Loganes C, Minto C. Beneficial and healthy properties of Eucalyptus plants: A great potential use. The Open Agriculture Journal 2016;10(1).
[51] Basak SS, Candan F. Chemical composition and in vitro antioxidant and antidiabetic activities of Eucalyptus camaldulensis Dehnh. essential oil. Journal of the Iranian Chemical Society 2010;7(1):216-226.
[52] Zhang J, An M, Wu H, Stanton R, Lemerle D. Chemistry and bioactivity of Eucalyptus essential oils. Allelopathy Journal 2010;25(2).
[53] Ghaffar A, Yameen M, Kiran S, Kamal S, Jalal F, Munir B, Saleem S, Rafiq N, Ahmad A, Saba I. Chemical composition and in-vitro evaluation of the antimicrobial and antioxidant activities of essential oils extracted from seven Eucalyptus species. Molecules 2015;20(11):20487-20498.
[54] Katooli N, Maghsodlo R, Razavi SEJJoPB, Science C. Evaluation of eucalyptus essential oil against some plant pathogenic fungi. 2011;3(2):41-43.
[55] Brokker M, Kleinig D. Field Guide to Eucalypts: Volume 3-Northern Australia: Inkata Press; 1994.
[56] Khan N, Fahad S, Faisal S, Akbar A, Naushad MJAaS. Socio-Economic and Medicinal Review of Eucalyptus Tree in the World. 2020.
[57] Mongkholrattanasit R, Kryštůfek J, Wiener J, Studničková JJNd. Natural dye from eucalyptus leaves and application for wool fabric dyeing by using padding techniques. 2011:57-78.
[58] Ullah F, Baloch M, Ullah S, Kabir M, Khan NHJBL. Eucalyptus plantation in Pakistan: Holistic View of Environmental-Socioeconomic and Medicinal Perspective. 2022;8(1):41-49.
[59] Dhakad AK, Pandey VV, Beg S, Rawat JM, Singh AJJotSoF, Agriculture. Biological, medicinal and toxicological significance of Eucalyptus leaf essential oil: a review. 2018;98(3):833-848.
[60] Vuong QV, Chalmers AC, Jyoti Bhuyan D, Bowyer MC, Scarlett CJJC, biodiversity. Botanical, phytochemical, and anticancer properties of the Eucalyptus species. 2015;12(6):907-924.
[61] Khan K, Ullah S, Ullah A, Khan S, Saragih MYJBIR, Humanities CI, Sciences S. Impact of Farmforestry on Socio-Economic Condition of Farming Communities in District Mardan, Pakistan. 2020;3(4):2649-2661.
[62] Carrilho M, Teixeira D, Santos-Reis M, Rosalino LMJFE, Management. Small mammal abundance in Mediterranean Eucalyptus plantations: how shrub cover can really make a difference. 2017;391:256-263.
[63] Brezáni V, Leláková V, Hassan ST, Berchová-Bímová K, Nový P, Klouček P, Maršík P, Dall'Acqua S, Hošek J, Šmejkal KJV. Anti-infectivity against herpes simplex virus and selected microbes and anti-inflammatory activities of compounds isolated from Eucalyptus globulus labill. 2018;10(7):360.
[64] Alashbal LA, Jafar ZJ, Aldhaher ZAJJoP, Microbiology A. Antimicrobial Effect of Eucalyptus Oil as a Root Canal Filling Material for Primary Teeth in Comparison with other Filling Materials against C. albicans and Streptococcus spp. 2019;13(3):1537-1543.
[65] Lucas S, Leach M, Kumar SJCTiM. Complementary and alternative medicine utilisation for the management of acute respiratory tract infection in children: A systematic review. 2018;37:158-166.
[66] Williams C. Medicinal Plants in Australia Volume 2: Gums, Resins, Tannin and Essential Oils: Rosenberg Publishing; 2011.
[67] Clarke PA. Discovering aboriginal plant use: the journeys of an Australian Anthropologist: Rosenberg Publishing; 2014.
[68] Mathew C, Tesfaye W, Rasmussen P, Peterson GM, Bartholomaeus A, Sharma M, Thomas JJP. Mānuka oil—a review of antimicrobial and other medicinal properties. 2020;13(11):343.
[69] Ebadollahi A, Setzer WNJNPC. Analysis of the essential oils of Eucalyptus camaldulensis Dehnh. and E. viminalis Labill. as a contribution to fortify their insecticidal application. 2020;15(9):1934578X20946248.
[70] Ghalem BR, Mohamed BJAjoP, pharmacology. Antibacterial activity of leaf essential oils of Eucalyptus globulus and Eucalyptus camaldulensis. 2008;2(10):211-215.
[71] Shagal M, Kubmarawa D, Tadzabia K, Dennis KJAJoP, Chemistry A. Evaluation of phytochemical and antimicrobial potentials of roots, stem-bark and leaves extracts of Eucalyptus camaldulensis. 2012;6(5):74-77.
[72] Barra A, Coroneo V, Dessi S, Cabras P, Angioni AJNPC. Chemical variability, antifungal and antioxidant activity of Eucalyptus camaldulensis essential oil from Sardinia. 2010;5(2):1934578X1000500232.
[73] Negahban M, Moharramipour SJJoAe. Fumigant toxicity of Eucalyptus intertexta, Eucalyptus sargentii and Eucalyptus camaldulensis against stored-product beetles. 2007;131(4):256-261.
[74] Knezevic P, Aleksic V, Simin N, Svircev E, Petrovic A, Mimica-Dukic NJJoe. Antimicrobial activity of Eucalyptus camaldulensis essential oils and their interactions with conventional antimicrobial agents against multi-drug resistant Acinetobacter baumannii. 2016;178:125-136.
[75] Babayi H, Kolo I, Okogun J, Ijah U. The antimicrobial activities of methanolic extracts of Eucalyptus camaldulensis and Terminalia catappa against some pathogenic microorganisms. 2004.
[76] Sani I, Abdulhamid A, Bello FJJos, Research i. Eucalyptus camaldulensis: Phytochemical composition of ethanolic and aqueous extracts of the leaves, stem-bark, root, fruits and seeds. 2014;3(5):523-526.
[77] Siddiqui BS, Sultana I, Begum SJP. Triterpenoidal constituents from Eucalyptus camaldulensis var. obtusa leaves. 2000;54(8):861-865.
[78] Gakuubi MM. Steam distillation extraction and chemical composition of essential oils of Toddalia asiatica L. and

Eucalyptus camaldulensis Dehnh. Journal of Pharmacognosy and Phytochemistry 2016;5(2):99.
[79] Gakuubi MM, Maina AW, Wagacha JM. Antifungal Activity of Essential Oil of Eucalyptus camaldulensis Dehnh. against Selected Fusarium spp. International Journal of Microbiology 2017;2017:8761610.
[80] Elaagib E, Taha RM, Mohajer S. Chemical Composition and Antimicrobial Activity of Eucalyptus camaldulensis Dehnh Essential Oil from Malaysia. Malaysian Journal 2012:111-115.
[81] Chahomchuen T, Insuan O, Insuan W. Chemical profile of leaf essential oils from four Eucalyptus species from Thailand and their biological activities. Microchemical Journal 2020;158:105248.
[82] Chalchat J-C, Kundakovic T, Gomnovic M. Essential oil from the leaves of Eucalyptus camaldulensis Dehn., Myrtaceae from Jerusalem. Journal of Essential Oil Research 2001;13(2):105-107.
[83] De Vincenzi M, Silano M, De Vincenzi A, Maialetti F, Scazzocchio BJF. Constituents of aromatic plants: eucalyptol. 2002;73(3):269-275.
[84] Su Y-C, Ho C-L, Wang E, Chang S-TJTJoFS. Antifungal activities and chemical compositions of essential oils from leaves of four eucalypts. 2006;21(1):49-61.
[85] Toloza AC, Zygadlo J, Cueto Gm, Biurrun F, Zerba E, Picollo MIJJome. Fumigant and repellent properties of essential oils and component compounds against permethrin-resistant Pediculus humanus capitis (Anoplura: Pediculidae) from Argentina. 2006;43(5):889-895.
[86] Cheng S-S, Huang C-G, Chen Y-J, Yu J-J, Chen W-J, Chang S-TJBt. Chemical compositions and larvicidal activities of leaf essential oils from two eucalyptus species. 2009;100(1):452-456.
[87] Cimanga K, Kambu K, Tona L, Apers S, De Bruyne T, Hermans N, Totté J, Pieters L, Vlietinck AJJJoe. Correlation between chemical composition and antibacterial activity of essential oils of some aromatic medicinal plants growing in the Democratic Republic of Congo. 2002;79(2):213-220.
[88] Trigg J, Hill NJPR. Laboratory evaluation of a eucalyptus-based repellent against four biting arthropods. 1996;10(4):313-316.
[89] Saad E-Z, Hussien R, Saher F, Ahmed ZJJoZUSB. Acaricidal activities of some essential oils and their monoterpenoidal constituents against house dust mite, Dermatophagoides pteronyssinus (Acari: Pyroglyphidae). 2006;7(12):957-962.
[90] Ashraf A, Sarfraz RA, Mahmood A, ud Din MJIC, Products. Chemical composition and in vitro antioxidant and antitumor activities of Eucalyptus camaldulensis Dehn. leaves. 2015;74:241-248.
[91] Siramon P, Ohtani YJJows. Antioxidative and antiradical activities of Eucalyptus camaldulensis leaf oils from Thailand. 2007;53(6):498-504.
[92] Vashist H, Jindal A. Antimicrobial activities of medicinal plants–Review. Int J Res Pharm Biomed Sci 2012;3(1):222-230.
[93] Batish DR, Singh HP, Kohli RK, Kaur S. Eucalyptus essential oil as a natural pesticide. Forest ecology and management 2008;256(12):2166-2174.
[94] Al-Fatimi M, Friedrich U, Jenett-Siems KJF. Cytotoxicity of plants used in traditional medicine in Yemen. 2005;76(3-4):355-358.
[95] Zein N, Mohamed EK, ELSayed FEJWJoPr. Anti-Proliferative effect of Eucalyptus camaldulensis against ehrlich ascites carcinoma (EAC) cells in Swiss Albino Mice in vivo. 2015;4(4):272-286.
[96] Safaeinejad Z, Kazeminasab F, Kiani-Esfahani A, Ghaedi K, Nasr-Esfahani MHJEjomc. Multi-effects of resveratrol on stem cell characteristics: effective dose, time, cell culture conditions and cell type-specific responses of stem cells to resveratrol. 2018;155:651-657.
[97] Guerra ÂR, Soares BI, Freire CS, Silvestre AJ, Duarte MF, Duarte IFJJoPR. Metabolic effects of a Eucalyptus bark lipophilic extract on triple negative breast cancer and nontumor breast epithelial cells. 2020;20(1):565-575.
[98] Mohammed W, Soud S, Hameed A, Hussein NJAoRI. Assessment of the Cytotoxic Activity of Alcoholic Extract of Eucalyptus camaldulensis on Breast Cancer Cell Line. 2021;76(5):1307-1314.
[99] Adnan MJJPP. Bioactive potential of essential oil extracted from the leaves of Eucalyptus globulus (Myrtaceae). 2019;8(1):213-216.
[100] Bhuyan DJ, Sakoff J, Bond DR, Predebon M, Vuong QV, Chalmers AC, van Altena IA, Bowyer MC, Scarlett CJJIVC, Biology-Animal D. In vitro anticancer properties of selected Eucalyptus species. 2017;53(7):604-615.