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# Derivatization of essential oil of eucalyptus to obtain valuable market products – A comprehensive review

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## Abstract

Eucalyptus essential oil constitutes volatile organic compounds that are abundantly found in its flowers, bark, seeds, roots, fruits and wood. Therefore, about 900 species of genus eucalyptus naturally exists, among which approximately 300 contain volatile essential oils in their leaves. Around 20 species have a very high content of 1,8-cineole that are economically favorable and extensively used in number of marketable products of commercial importance. Nevertheless, eucalyptus is known to show many biological activities like anti-oxidant, anti-septic and anti-microbial effects and chemotherapeutic potentials that helps to treat number of respiratory problems and gastrointestinal disorders. Eucalyptus species vary in their chemical compositions that is significantly affects their biological activities and medicinal uses. Some most common eucalyptus species that are discussed in this review include *Eucalyptus polybractea*, *Eucalyptus globulus*, *Eucalyptus grandis*, *Eucalyptus robusta*, *Eucalyptus oleosa*, *Eucalyptus tereticornis*, *Eucalyptus viridis*, *Eucalyptus camaldulensis* and *Eucalyptus deglupta*. This review also discusses the process of derivatization that deal with the change of chemical structures of a naturally occuring compound into single and more valuable market products. Exact chemical composition of these derivatives is of great interest and a hot topic of current scientific investigations now-a-days. The 1-8 cineole, α-terpinene, γ-terpinene, carvacrol and thymol, eugenyl acetate and limonene are the derivatized products of eucalyptus that have improved biological activities.

**Keywords:** Eucalyptus, derivatization, therapeutic potentials, 1-8 cineole, α-terpinene, γ-terpinene, carvacrol, thymol, eugenyl acetate, limonene

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## 1. Introduction

Essential oils of different plant sources are the most valuable products of agriculture-founded industries. Plants have several roles primarily in the food industries, cosmetics, health and agriculture. Essential oil of aromatic plants has found to be useful as flavoring mediators in the cosmetics, perfumes, drinks and food products and used in the food preservation [1]. Large-scale phytochemical examinations have directed to the description and recognition of main ingredients of essential oils which have inclusive concern particularly to the pharmaceutical trades and cosmetics. There is a rising importance in essential oils and their ingredients, predominantly for their wide-ranging anti-microbial actions which can afford for example, another useful component to encompass the shelf life of food crops and confirm microbial protection for consumers [2].

Essential oil extracted from plants belonging to numerous genera is classified in about sixty groups. The most important plant groups are Myrtaceae family that are acknowledged for their capability to yield essential oil of great industrial importance and high medicinal value [3]. The constituents of essential oil of plants are further divided into two separate chemical groups including phenylpropanoids and terpenes. In the essential oils, terpenes and their oxygenated by-products are most usual and plentiful, however some classes comprises of high contents of the phenylpropanoids. When these composites are found in essential oil of plant, they give a specific flavor and aroma to plants [4].

Eucalyptus is a varied species of flowering trees and shrubs in the myrtle family Myrtaceae. Members of this genus dominate the tree vegetation of Australia and founded that eucalyptus is the highest recognized flowering plant on the earth. Eucalyptus forests covered about 92,000,000 hectares (227,336,951 acres) of Australia whereas three fourth part of the Australia is covered by natural forest. There are more than 700 species of eucalyptus and many of them are native to Australia. One specie that is *Eucalyptus deglupta* is found in the northern parts of the Philippines

among which 15 species are found outside the Australia while just nine are exclusively non-Australian [5].

Essential oils obtained from the eucalyptus have numerous commercial and medicinal usages. The oils own several bioactivities such as insecticidal, herbicidal, anti-microbial, anti-viral and fungicidal actions. The key ingredients are sesquiterpenes and monoterpenes that is β-pinene, α-pinene, p-cymene, 1,8-cineole, limonene and α-terpineol. Eucalyptus oils are extensively used as flavoring agents in food industry and in the aroma industry for example in perfumes, lotions, detergents, creams and soaps [6]. Single distilled oil consists of large number of chemical mixtures in different amounts as compared to double distilled oils. For example, oil of *Eucalyptus globulus* is formed with 60% cineole and 40% other components. It consists of 80% cineole and 20% of other compounds after refinement. This means second distillation have tapped off 20% of other compounds. The outcome is that basic oil has a diverse or broader variety of actions than the other advanced oil [7].

Eucalyptus oils are gaining cumulative attention because of its marketable claims mainly as traditional medicines, scents and insect repellents. Despite of this profitable projection, partial eucalyptus types have been considered. Since biological actions and chemical constituents of eucalyptus oils differs significantly among species so various other least studied species deserves more attention. The association among the chemical conformation and biological activity has been described in detail so far in number of experimental investigations but the type of material and effect on the mode of action of eucalyptus oil is quite inadequate. The biological activity of eucalyptus oils on plants decreases water soluble carbohydrates, acid soluble carbohydrates, cell survival, RNA contents and chlorophyll contents. Considering the chemical composition of eucalyptus oils and its associated biological activities, significant variations are found among species that deserves further attention [8].

Essential oils consist of chief bioactive ingredients like limonene, eugenol, α-pinene, p-cymene and 1,8-cineole. The essential oils of eucalyptus and their chief ingredients show harmfulness in contrast to an extensive range of microbes consisting of fungi, bacteria and post-harvest and soil-borne pathogens [9]. Classical therapists use eucalyptus to treat various diseases for instance, stiffness, neuralgia, pneumonia, aching, throats, bronchitis, flu, infections and colds [10]. Eucalyptus leaf oil work as a natural pain reliever and preserves the zone free from contamination. This therapeutic effect is because of the cineole content which simply infiltrates the tissues [11]. So, eucalyptus leaf essential oil is also recommended to a patient who is suffering from stiff muscles, sprained ligaments and tendons, rheumatism, lumbago, fibrosis, aches and even nerve pain. This is a major cause for its effective working in pain release and decongestants products and useful for release of muscular pain [12].

The process of derivatization involves conversion of a natural chemical compounds into its derived products that are frequently required for ultimate determination in direction to raise the detectability and stability of the removed and decontaminated phytohormones. This method is principally cast-off when phytohormones are quantified and characterized through physical techniques for example mass spectrometery and chromatography, also useful for bioassay procedures for instance immunoassay. Usually, functional group contributes in the derivatization reaction and transforms the composite to a derivate with better physicochemical features which can be cast-off for the separation or quantification of the unique composite [13].

Derivatization reactions are meant to transform the analyte for detectability in gas chromatography and numerous other instrumental analytical procedures. Derivatization in gas chromatographic examination can be distinct as a practical method that mostly alters an analyte's functionality in directive to allow chromatographic separations. An altered analyte in this instance will be the product which is identified as the derivative. The derivative may have comparable or carefully linked structure but not the similar as the unique non-modified chemical composite. Volatility of illustration is a condition for the gas chromatographic investigations. Derivatization will reduce highly polar ingredients to suitable volatile components so that they can be eluted at specific temperatures without thermal disintegration and molecular re-arrangement [14].

Eucalyptus oil is pain-relieving and extremely volatile in nature that is why it is simply absorbed through nerves and muscles. Terpineol is a constituent of *Eucalyptus globulus* oil which is extensively used in aromatherapy. Eucalyptus essential oil is an active suppressor (1,8-cineole) of cytokines and is appropriate for longstanding treatment of inflammation in steroid-sensitive illnesses. Volatile composites of the leaf essential oils have the anti-microbial activity over the mutual effect of direct vapor absorption via microorganisms and an indirect effect by the medium that absorbed the vapor [15].

The derivatives of thymol, carvacrol and eugenol synthesized the following chemical constituents: 4-(hydroxymethyl)-5-isopropyl-2-methylphenol, 4,4'-methylenebis(5-isopropyl-2-methyl)phenol, 4-allyl-6-(hydroxymethyl)-2-methoxyphenol and 4-(hydroxymethyl)-2-isopropyl-5-methylphenol. The obtained derivatives showed remarkably better anti-oxidative properties and improved herbicidal activity in comparison with the pure eucalyptus oil [16]. Eucalyptus species produce mixtures of odorous and volatile compounds. These mixtures play important role in nature and have been utilized by mankind for different purposes, such as pharmaceuticals, agrochemicals, aromatherapy and food flavorants [17].

**2. Chemical Constituents of Essential Oil**

Essential oils are aromatic liquids that are extracted from aromatic plant materials. They can be biosynthesized as secondary metabolites in various plant structures. They are complex mixtures of terpenes, alcohols and phenolics that are volatile compounds. Therefore, these oils are extremely complex and may comprise oxygenated compounds [18]. They are widely used in medicines, aromatherapy, perfumery, cosmetics, flavoring agents and household cleaning products. These oils are valuable in the food industries and fragrance. More than 250 types of essential oils are isolated from aromatic plants. Various types of these oils are produced by large number of countries [19].

Essential oils are volatile oils that consist of aromatic components that comprised of various chemical composites. For example, ketones, hydrocarbons, alcohols, phenols and esters [20]. They have the anti-viral activities without showing any harmful effects. They also possess anti-bacterial potentials against many pathogenic bacterial strains [21]. Essential oil is the combination of terpenes and phenylpropanoids. Terpenes are classified to the number of isoprene units in their structure, for example, hemiterpenes (one unit), monoterpenes (two units), sesquiterpenes (three units), di-terpenes (four units) and so on. Mostly these oils are complex mixtures of monoterpenes ($C_{10}H_{16}$) and sesquiterpenes ($C_{15}H_{24}$) [22].

Phenylpropanoids contain one or more $C_6$-$C_3$ units, with $C_6$ being a benzene ring. Generally they have a methyl ether functional group that is attached to the ring, and a propenyl tail (three carbon chain with one C=C bonded to the ring by one end). Most phenylpropanoids found in essential oil are ethers, phenol and mostly the side chain is shortened ($C_1$). Their major representatives in the essential oil include the oxygenated hydrocarbons anethole, safrole and eugenol. They have carbon-carbon double bond in the side chain [23].

**3. Eucalyptus**

Eucalyptus is the large genus of the family Myrtaceae that includes 900 species and subspecies. One of the most important essential oil is eucalyptus oil (Eucalyptol $C_{10}H_{18}O$). This oil is extracted from fresh leaves of eucalyptus. This oil possesses excellent biological activities such as anti-fungal, anti-viral and anti-bacterial effects. These also have a long history of applications against the effects of influenza, cold, other respiratory infections, sinusitis and rhinitis [24].

**4. Geographical Location of Eucalyptus**

Eucalyptus that is native to Australia has worldwide range of hardwood products and ornamental materials. Due to their ability of fast growth and tolerance to harsh environments, they showed many effective adaptations that are indeterminate growth, lignotubers, soil acidity, low fertility, drought, coppicing and insect resistance which have been proved to be very fruitful [34]. Throughout the world, eucalyptus is highly valuable and widely planted specie. They are mostly grown as exotic plantation species in the tropical and subtropical areas in South America, Africa, Australia and Asia and in more moderate areas of Europe and South and North America [35].

In 1878, different types of eucalyptus species were introduced to the South. However, no substantial and viable plantations were well-known throughout the twentieth century. In California, interest in eucalyptus wood came about because of perceptions that the boats from Australia were far better than those produced from local wood in the United States. Analysis about the wood source recognized blue gum tree (*Eucalyptus globulus*) as ideal species. In 1870, the State Board of Agriculture was upholding the requirement for artificial forests, with unique importance of eucalyptus to cover zones of infertile territory and to deliver wood for the assembling of agriculture implements, wagons and carriages [36].

Eucalyptus is a fast-growing forest tree with high potential of biomass carbon sequestration and soil nutrient depletion. Its development in mixed forest communities would improve the ecological functions of eucalyptus plantations [44]. Furthermore, various influences contribute in the achievement of eucalyptus, these influences are the ability to grow in a wide range of soils and environments, large biomass production and the fast growth rate, better wood quality for short cellulose fibers which are appropriate for pulp production, mainly for tissue and paper [45].

In growth, eucalyptus species are not consistent and the variation is significantly dependent on the circumstances under which they are grown. However they depends on the site, selection of types and their sources from where it is taken [46]. However, it is essential to consider the development patterns of different eucalyptus clones. Therefore, seedlings described that all the clones performed similar function at this site when contrasted to the limited landraces. However, the local *Eucalyptus tereticornis* and *Eucalyptus camaldulensis* landraces had the lowest height of about 11.99 m and 11.58 m, while the clone gas chromatography had a height of about 17.15 m respectively.

Pest and drought are primary components that disturb the productivity and establishment of eucalyptus plantations in many forests. By the study of plant development, biological responses, including relative water potential, water content, lipid peroxidation and photosynthetic pigments, it is interesting to explore drought disease interaction in eucalyptus that are usually involved in the plant growth [47]. However, the assessment between drought-non-primed and drought-primed plants indicated a slight protection against a fungal infection especially for drought-primed plants [48].

**5. Derivatization of Essential Oil**

Derivatization is a process in which chemical constituents of essential oils are chemically altered, making a new compound which has properties that are appropriate

for the gas chromatography mass spectrometric analysis. This process highly reduces the polar materials to be sufficiently volatile so that, it can be eluted at specific temperatures without molecular rearrangement or thermal breakdown. These compounds have same chemical structures but there is a change in functional group of reacting compounds. GC and GC/MS has been performed on both the qualitative and quantitative data for the essential oils. Therefore GC/MS is used to isolate the volatile organic compounds and derivatization also allows the study of compounds for the adjustment of the functional group of a molecule [56].

**6. Derivatives of Eucalyptus Essential Oil**

**6.1: α-Terpineol**

In eucalyptus essential oil, terpineol is present that is a naturally occurring unsaturated monocyclic mono-terpenoid alcohol. However, in industrial field, α-terpineol plays a very significant role. It has a pleasant fragrance that is like lavenders and it is usually a mutual ingredient in cosmetics, aromatic scents and perfumes. The α-terpineol has an extensive range of biological applications such as anti-hypertensive, anti-nociceptive, anti-oxidant, anti-cancer, anti-convulsant and anti-ulcer compounds [68]. The α-terpineol usually occurs in active forms. However, α-terpineol is also considered as a vital marketable product and found in excess in all essential oils. Despite of this, β-, γ- and δ-terpinols do not exist very frequently in nature. The α-terpineol involves in a very extensive assortment of diverse biological actions in plants, animals and humans. It is the most popular fragrant ingredient used in household cleaning products, perfumes, cosmetics and used to flavor beverages and foods. They also have several important medicinal and biological properties [69].

**6.1.1: 1,8-Cineole (Eucalyptol)**

One of the main components of essential oil of eucalyptus that are used as aromatic compound is "eucalyptol" which belongs to monoterpenes. In variety of plants, eucalyptol is present in large amounts and this component is commonly used for manufacturing of cosmetic products. They are also used as a nasal decongestant, anti-cough agent, to enhance penetration of drugs and in aromatherapy [57]. However, in human and rat liver, eucalyptol is absorbed and metabolized to 2-exo-hydroxy-1,8 cineole by microsomes. Despite of this, it is not clear while this substance either metabolized by humans in-vivo. Eucalyptol diffuses faster by inhalation neither by oral administration nor through the skin. After inhalation, about 5 minutes later, its presence can be easily detected in blood and it reaches to its highest concentration within 18 minutes [58].

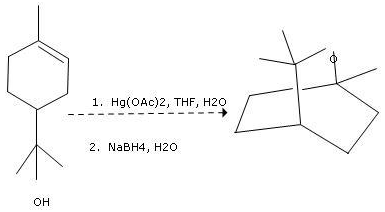


Fig 1 Conversion of α-terpineol to eucalyptol

There are many applications of eucalyptol such as they are used as anti-inflammatory agents, in the treatment of asthma, sinusitis and gastric inflammation and in the neurodegenerative diseases like Alzheimer's disease. They possess anti-septic activities and mostly found active against some of the hospital pathogens. They have anti-fungal activities and increase respiratory function during allergy or infection and they interact in efficient way with the skin [59].

**6.2: p-Cymene**

Over 100 different species of eucalyptus found naturally possess p-cymene that is a monoterpene and used in food purposes or medicines. It also possess the biological activities like anti-oxidant, anxiolytic, anti-microbial, anti-inflammatory and anti-cancer [60]. The p-cymene is a main constituent of essential oil extracted by the process of hydro-distillation and steam-distillation of the medicinal and edible plants. It is an alkyl-substituted aromatic hydrocarbon that is found in nature, whose benzene ring features the substitution of a methyl and an isopropyl group. This chemical constituent of plants is considered to be the most important monoterpene compound that is most commonly found in aromatic plants. Herbal drugs have p-cymene that is obtained from traditional medicinal plants. Despite of this it is the main component of leaves of eucalyptus (Myrtaceae) [61].

**6.2.1: Thymol**

Thymol is natural monoterpene derivative of cymene that is phenolic compound. They derive from a hydride of a p-cymene. These are member of mono-terpenoid and phenols. They can act as a volatile oil component. They possess different pharmacological properties such as anti-inflammatory, analgesic, anti-fungal, anti-septic, anti-oxidant and anti-tumor activities. They can be used in traditional medicines and have ability to protect against different metabolic disorders. Cervical disease is a malignant growth emerging from the cervix because of unusual cell development that has the capacity to attack or spread to different parts of the body. Thymol (30.5–244 ng/mL) induced cytotoxicity by restraining the development of HeLa cells in a concentration dependent way [62].

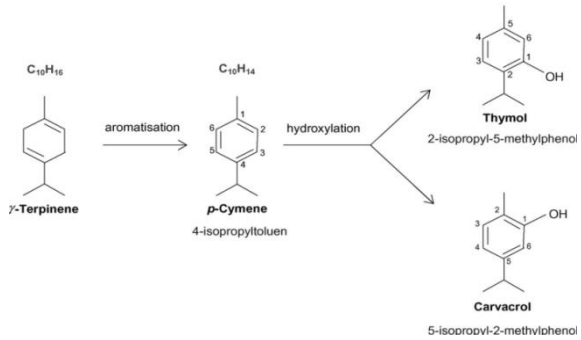


Fig 2 Conversion of γ-terpinene into thymol and carvacrol

**6.2.2: Carvacrol**

Carvacrol is a phenolic monoterpene found in essential oils. Carvacrol has a wide range of bioactivities with clinical applications such as anti-microbial, cell reinforcement and anti-cancer activities. Carvacrol anti-microbial action is higher than that of other unstable mixes present in essential oils because of the presence of the free hydroxyl group, hydrophobicity and the phenol moiety [63]. After thymol, carvacrol is the important phenolic constituent of the essential oil. Carvacrol can restrain the development of both gram-positive and gram-negative microscopic organisms. These compounds possess anti-fungal and anti-biofilm effects. Carvacrol can be applied as an alternative to anti-microbial operator against anti-infection safe pathogenic microbes. In this manner, carvacrol is suggested for potential restorative use; however, more research is required on poisonous efficiency and reactions of the compounds [64].

**6.3: Eugenol**

Essential oil of the plants that belongs to the family Myrtaceae naturally possesses the eugenol that is hydroxyphenyl propene. It is the main component of eucalyptus oil and known to have number of applications in cosmetics and food as a flavoring agent. Eugenol ($C_{10}H_{12}O_2$) is phenolic aromatic constituent with a pleasant taste and odor, belongs to allyl-benzene class of phenylpropanoids. Recent evidences support that eugenol show beneficial effects on human health. By showing anti-inflammatory and anti-oxidant properties [65]. It has anti-microbial properties according to literature and is active against a wide range of gram positive bacteria, gram negative bacteria and fungi. These are helpful for humans and can target various types of micro-organisms that are responsible for disease of oral cavity and food borne pathogens. It is bioactive compound with the broad spectrum anti-microbial activity against both sessile cells and planktonic that belongs to the human pathogens and food-decaying micro-organisms [66].The derived products are produced by esterification reactions in the hydroxyl group of eugenol with various carboxylic acids and furthermore by expansion reactions in the double bond of the allyl group. The derivatives had a promising anti-bacterial potential, including a lower least inhibitory grouping of 500µg/mL than eugenol (1000 µg/mL). Furthermore, derived products were dynamic against bacterial strains (*Escherichia coli* and *Staphylococcus aureus*) where eugenol itself demonstrated no action, consequently expanding the range of anti-bacterial activity. With respect to the anti-oxidant action, it was seen that derivatives that undergo esterification reactions in the hydroxyl group of the eugenol more specifically phenolic portion brought a significant decrease of the cancer prevention activity [67].

**6.3.1: Eugenyl Acetate**

Eugenyl acetate (4-allyl-2-methoxifenol acetate) is the product of eugenol, which can be acquired normally in the essential oil. This is a light yellow fluid compound, believed safe to be utilized in nutritional items by Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) [68]. Eugenyl acetate was acquired by the acetylation of acidic anhydride with eugenol. Enzymatic esterification of the essential oil involves incredible logical and technological interest because of outstanding drawbacks of the chemical catalyzed route just as the potential utilization of created compounds as normal anti-microbial [68].

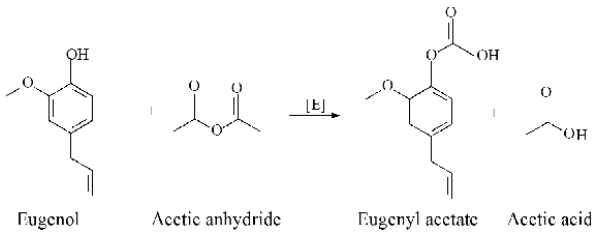


Fig 3 Conversion of eugenol to eugenyl acetate

**6.4: α-Pinene**

Essential oil of eucalyptus have another major monoterpene that is known as "α-pinene" and a hydrocarbon group of sesquiterpene with a strong turpentine smell [58]. It has been commonly used as a food flavoring component [59]. Drug administration and U.S food authority recognized that it is safe as a food additive. Furthermore, it is reported that α-pinene have biological properties like hypertensive potentials, anti-microbial activities and anti-inflammatory effects [60]. Eucalyptus oil has the mixture of α-isomer and α-pinene. The concentration of the chemical constituents that are present in the oil depends on the availability of sunlight and temperature. Several essential oils possess α-pinene and exhibit anti-microbial properties. They also act as a broad spectrum anti-biotic and acetyl cholinesterase inhibitor as well [61].

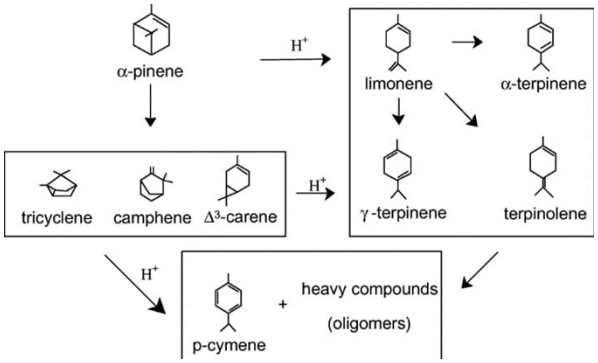

Fig 4 Conversion of α-pinene into limonene and other derivatives

**6.4.1: Limonene**

Limonene is one of the most common compounds that is monoterpene hydrocarbon present in the essential oils of aromatic plants. In different plants, the presence of this compound plays an important role in the biosynthesis of other monoterpenes and also play defensive role against number of herbivores [69]. The d-limonene ($C_{10}H_{16}$) is major constituent of eucalyptus oil and ethereal oils and it is the hydrocarbon of monoterpene sub-group. Limonene has been extensively investigated because of its applications in medicinal and fragrance industries. In different terpene mixtures, limonene has been widely used as a cheap and non-invasive treatment for cholesterol stones in the bile ducts and gall bladder and for ureteric stones [70].

**6.4.2: α-terpinene**

The α-terpinene (1-isopropyl-4-methylcyclohexa-1,3-diene) is normally occurring cyclic monoterpene delivered in the secondary metabolism of plants. It has been recognized in various plant extracts and is available in a few usually utilized essential oils. The α-terpinene is isolated from natural source [71]. It has aroma and flavoring properties yet is for the most part used to present pleasant odor to industrial liquids. The α-terpinene is found in all spices. The α-terpinene is a constituent of various essential oils. Terpinene are three isomeric hydrocarbons that are classified as terpenes. Each of these compounds has the same molecular formula and carbon framework, but they differ in the position of carbon-carbon double bonds. The α-terpinene has been isolated from cardamom and marjoram oils and from other natural sources [72].

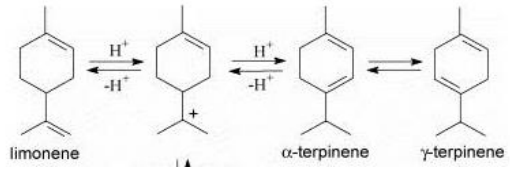


Fig 5 Conversion of limonene into α-terpinene and γ-terpinene

**6.4.3: γ-Terpinene**

The γ-terpinene is one of three isomeric monoterpenes contrasting in the places of their two double bonds (α-and β-terpinene being the others). In γ-terpinene the double bonds are at the 1-and 4-places of the p-menthane skeleton. The γ-terpinene, of volatile essential oil is derived from components of essential oil that shows excellent anti-microbial properties against various human pathogens. It is isolated from various plant species [73]. The anti-oxidant, anti-inflammatory and anti-proliferative activities of γ-terpinene are extensively studied so far. It is utilized in food as an ingredient, in the generation of peppermint and lemon essential oil, in the production of pharmaceutical medications and even in aromas. The essential oil of *Melaleuca alternifolia* contains appreciable concentration of γ-terpinene which shows anti-inflammatory, anti-microbial anti-oxidant and anti-proliferative properties. The γ-terpinene and δ-terpinene are separated from different plants. The γ-terpinene forms a major part of citrus essential oil [74].

Table 1: Percentage Composition of Different Species of Eucalyptus

| Sr. No | Plant Species | Composition | Percentage | References |
|---|---|---|---|---|
| 1 | *Eucalyptus camaldulensis* | p-cymene | 42.1% | [25] |
| | | Eucalyptol | 14.1% | |
| | | α-pinene | 12.7% | |
| | | α-terpinol | 10.7% | |
| 2 | *Eucalyptus deglupta* | β-pinene | 32.06% | [26] |
| | | Benzene | 15.58% | |
| | | Limonene | 14.61% | |
| | | α-pinene | 14.04% | |
| | | Aromadendrene | 5.46% | |
| 3 | *Eucalyptus globulus* | 1,8-cineole | 50.30% | [27] |
| | | p-cymene | 27.22% | |
| | | α-pinene | 17.85% | |
| | | Cryptone | 17.80% | |
| | | Spathulenol | 17.00% | |
| 4 | *Eucalyptus grandis* | α-Pinene | 29.69% | [28] |
| | | p-Cymene | 19.89% | |
| | | 1,8-cineole | 12.80% | |
| | | α-Terpineol | 6.48% | |
| | | Borneol | 3.48% | |
| | | D-Limonene | 3.14% | |
| 5 | *Eucalyptus robusta* | p-cymene | 54.2% | [29] |
| | | γ–terpinene | 43.8% | |

| | | | | |
|---|---|---|---|---|
| 6 | *Eucalyptus oleosa* | 1,8-cineole<br>Spathulenol<br>γ-eudesmol | 47.0%<br>16.1%<br>15.0% | [30] |
| 7 | *Eucalyptus tereticornis* | α-pinene<br>1,8-cineole<br>Geraniol | 28.53%<br>19.48%<br>9.78 % | [31] |
| 8 | *Eucalyptus viridis* | 1,8-cineole<br>α-pinene<br>Trans-pinocarveol | 84.7%<br>4.4%<br>2.2% | [32] |
| 9 | *Eucalyptus polybractea* | 1,8-cineole<br>p-cymene<br>β-pinene<br>Limonene<br>α-pinene<br>Terpinene-4-ol | 91.7%<br>2.75 %<br>2.3 %<br>1.3 %<br>1.2 %<br>0.92% | [33] |

Table 2: Estimates of approximate area of eucalyptus plantations in the countries with the largest plantation areas (Source: Eldridge 1984)

| Country | Area (1,000 ha) | Plant species | References |
|---|---|---|---|
| Angola | 390 | *Eucalyptus tereticornis* | [37] |
| Argentina | 240 | *Eucalyptus grandis* | [38] |
| Brazil | 2,500 | *Eucalyptus grandis* | [39] |
| Chile | 60 | *Eucalyptus globulus* | [40] |
| Morocco | 180 | *Eucalyptus camaldulensis* | [41] |
| South Africa | 470 | *Eucalyptus grandis* | [42] |
| Spain | 390 | *Eucalyptus globulus* | [43] |

Table 3: Bioactivities of essential oils of eucalyptus species

| Species | Bioactivities | References |
|---|---|---|
| *Eucalyptus camaldulensis* | Anti-Microbial Activity<br>Anti-Fungal Activity<br>Anti-Oxidative Activity<br>Anti-Nociceptive Activity | [49] |
| *Eucalyptus globulus* | Anti-Microbial Activity<br>Anti-Fungal Activity<br>Insecticidal Activity<br>Anti-Viral Activity | [50] |
| *Eucalyptus robusta,* | Anti-Microbial Activity<br>Fungi Toxic Properties | [51] |
| *Eucalyptus tereticornis* | Anti-Bacterial Activity<br>Anti-Fungal Activity<br>Anti-Inflammatory<br>Analgesic Effects | [52] |
| *Eucalyptus grandis* | Larvicidal Activity<br>Anti-Microbial Activity<br>Anti-Fungal Activity | [53] |
| *Eucalyptus oleosa* | Anti-Oxidative Activity<br>Anti-Bacterial Activity | [54] |
| *Eucalyptus deglupta* | Anti-Bacterial Activity<br>Anti-Microbial Activity | [55] |

**7. Summary**

Essential oils are made up of complex natural compounds that are volatile in nature. It has a strong fragrance and usually formed by aromatic plants. Essential oils can consist of about 20-60 components that have different concentrations. Essential oils are natural products which have many stimulating applications. About 700 species of genus eucalyptus, family Myrtaceae is found in nature that is native to Australia and throughout the world. It consists of magnificent, tall and evergreen trees that has a

strong fragrance and rich in oil and also has an exceptional source of commercially important eucalyptus oil that have extensive use in pharmaceutical industry. The common eucalyptus species discussed in this article are *Eucalyptus camaldulensis*, *Eucalyptus deglupta*, *Eucalyptus globulus*, *Eucalyptus grandis*, *Eucalyptus robusta*, *Eucalyptus oleosa*, *Eucalyptus tereticornis*, *Eucalyptus viridis* and *Eucalyptus polybractea* that consists of different components like 1,8-cineol, α-pinene, p-cymene eudesmol, benzene and geraniol. There are many derivatives of eucalyptus oil some of them are limonene, α-terpinene, γ-terpinene, eugenyl acetate, carvacrol and thymol. All the derivatives of natural sources possess better anti-fungal, anti-bacterial and anti-microbial potentials.

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