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A Comprehensive review on Limonene: A Versatile Ingredient in the Cosmetic Industry

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ABSTRACT

A naturally occurring monoterpene hydrocarbon that is mostly isolated from citrus fruits, limonene has drawn a lot of interest in the cosmetics industry because of its many uses. This chemical has several advantages, such as antibacterial properties, a nice scent, and possible skin benefits. Limonene is a common option for fragrances in body care products, colognes, and perfumes because of its refreshing aroma. Its zesty scent improves customers' entire sensory experience by being frequently linked to freshness and cleanliness. Limonene has antibacterial action against a variety of microorganisms in addition to its aroma qualities, which makes it a possible inclusion in skincare products to help stop the growth of germs and fungus. Apart from its antibacterial and aroma qualities, limonene has also been researched for possible skin health advantages. According to some study, limonene may have antioxidant qualities that help shield the skin from harm brought on by free radicals. Its ability to increase skin suppleness and lessen wrinkle appearance has also been studied. To completely comprehend the mechanics underlying these possible advantages, more study is necessary. Because of its flexibility, limonene is used in a variety of cosmetic items, such as body lotions, soaps, hair care products, colognes, and fragrances. It is anticipated that limonene's use in cosmetics would rise in tandem with consumer desire for sustainable and natural components. However, it's crucial to remember that limonene might irritate certain people, so its application needs to be carefully thought out, particularly in products meant for delicate skin.

Keywords: *antibacterial, scent, limonene, cosmetics business, and skin benefits*

1. INTRODUCTION

Limonene is a naturally occurring compound classified as a terpene, a class of organic compounds found in many plants, especially in citrus fruits like oranges, lemons, and limes. This compound is notable not only for its fresh, citrusy scent but also for its extensive applications across various industries, including food cosmetics medicine and cleaning products drived from the rinds of citrus fruits. Limonene has become a staple in these industries due to its pleasant fragrance potent solvent properties and biological effects. [1] Chemically limonene is a hydrocarbon specifically a cyclic monoterpene with the molecular formula $C_{10}H_{16}$. There are two isomeric forms of limonene D-limonene and L-limonene D-limonene the most common isomer is the one predominantly responsible for the characteristic citrus aroma and is most commonly found in citrus fruits. L-limonene in contrast is found in other types of plants and gives off a more piny turpentine-like scent. These two forms of limonene differ only in their optical rotation meaning they are mirror images of each other. Its facile extraction and commercialisation are made possible by this seemingly little variation, which gives each form unique sensory experiences and applications in different sectors in citrus fruits and certain other plants. [5–8] In order to produce D-limonene, citrus fruit rinds are forcefully squeezed to liberate oils that are rich in this chemical. This method is known as cold pressing. As a superior way to separate limonene from other substances found in citrus oil, steam distillation can also be utilised, especially when purer forms of limonene are sought. The result is a versatile bioactive compound that has captured the interest of researchers and industries a like due to its unique properties and wide range of potential applications in the food industry. [9-12] A typical flavouring chemical that gives goods a crisp, citrussy taste is limonene.Its non-toxic nature makes it safe for consumption and it is often employed in beverages, candies and other flavoured goods. The cosmetic and personal care industries also make extensive use of limonene for its fragrance adding it to perfumes, lotions and shampoos to impart a pleasant fresh scent. Furthermore because limonene is an effective solvent it is widely used in cleaning products to dissolve oils fats and other organic substances making it a popular ingredient in household cleaners and degreasers. [13-16] It is commercial uses limonene has shown promise in several health-related applications. Studies have suggested that limonene may possess anti-inflammatory, antioxidant, and even anti-cancer properties. Limonene is sometimes used in

aroma therapy where it is believed to have mood-enhancing and stress-relieving effects. [17-20] Its versatility and biological effects continue to drive research into new and innovative uses making limonene a compound of interest that stands at the intersection of nature, industry, and science **botanical Origin and Production. [21-24].**

1.1 Overview of Limonene-

Original Source:

1. Found in: Citrus peels (lemon, orange, and lime)

2. Concentration: Orange peels, which have an essential oil level of up to 90% limonene **.**

Limonene is a colourless liquid hydrocarbon that is categorised as a cyclic terpene and has been discovered to have antiemetic properties. The more prevalent D isomer has a distinct orange scent. [1] It serves as a renewable solvent in cleaning goods and as a precursor to carvone in chemical synthesis. The lemon is the source of limonene's name because, like other citrus fruits, lemon rinds contain significant levels of this component, which gives them their distinct smell. One enantiomer of limonene, which is chiral, is produced by biological sources. Citrus fruit, the main industrial source, includes D-limonene ((+)-limonene), the (R)-enantiomer (CAS number 5989-27-5, EINECS number 227-813-5). The name D-Limonene refers to racemic limonene. Commercial D-limonene is extracted from citrus fruits using either steam distillation or centrifugal separation.

1.2 Chemical Properties of Limonene:

Citrus fruit peels naturally contain limonene, a chemical component that is especially abundant in lemon and orange peels. It belongs to the class of chemical molecules called terpenes, which are frequently found in plants. Known for its potent, pleasant citrus scent, limonene is frequently used in a variety of items, including cleaning supplies, fragrances, and food and drink flavouring agents. A detailed list of limonene properties at normal temperature and pressure (NTP) in both SI and US customary/Imperial units is given in the following in **Table 1**.

Table 1.Chemical Properties of Limonene.

Property	**Value**
Chemical Formula	**$C_{10}H_{16}$**
Structure	Monocyclic monoterpene with a single ring and two double bonds, providing stability and reactivity.
Isomers	**D-limonene:** Citrus-like aroma, Found predominantly in citrus fruits. **L-limonene:** Piny, turpentine-like odor, Present in some conifer species.
Chemical Abstracts Name	®-1-Methyl-4-(1-methylethenyl) cyclohexene
Synonyms	Cajaputene; carvene; cinene; (+)-dipentene; d-(+)-limonene; D-(+)-limonene; (+)-limonene; ®-limonene; ®-(+)-limonene; (+)-para-mentha-1,8-diene; ®-(+)-para-mentha-1,8-diene; 1-methyl-4-isopropenyl cyclohexene-1; Refchole
Description	Colourless liquid
Melting Point	-74.3 °C
Boiling Point	175.5-176 °C
Density	0.8411 g/cm³ at 20 °C/4 °C
Solubility	Insoluble in water; soluble in benzene, carbon tetrachloride, diethyl ether, ethanol, petroleum ether, and glycerine
Optical Rotation	~ +125.6°
Spectroscopy Data	Infrared, nuclear magnetic resonance, and mass spectral data have been reported
Stability	Oxidizes to form a film in air

Citrus species are exceedingly difficult to classify botanically because of the frequent hybridisation and introduction of many cultivars by cross-pollination. In order to produce fruit with desirable organoleptic and industrial qualities, such as seedless fruit, high juiciness, and the desired taste, hybrids are created. Identifying earlier cultivars, hybrids, and variations frequently

requires the use of the most recent molecular tools.[17] list the various varieties, cultivars, and hybrids that *C. Limon* produces, similar to those of many other widely distributed citrus species. The Overview of the various *C. Limon* cultivars, their origins, cultivation areas, and unique mentioned below in **Table-2.**

Table 2. Overview of the various *C. Limon* cultivars, their origins, cultivation areas, and unique characteristics.[17]

Cultivar Name	Origin	Cultivation Regions	Characteristics
***C. Limon* 'Bearss' (*C. Limon* 'Sicilian', Bearss lemon)**	Florida	Florida, Brazil	Grows quickly, highly productive, aromatic flowers, juicy fruit, sensitive to low temperatures.
***C. Limon* 'Berna' (*C. Limon* 'Verna', Verma lemon)**	Spain	Spain	Large specimens, no spines, blooms 2-3 times per year, varying fruit properties (Cosecha, Secundus, Rodrejos).
***C. Limon* 'Eureka' (Eureka lemon)**	California, Sicily	Mediterranean Basin, California, Australia, Argentina, South Africa, Israel	Oblong fruit, smooth skin, few stones, pink-shaded flowers.
***C. Limon* 'Femminello'**	Italy	Italy	Very productive, blooms and fruits year-round.
***C. Limon* 'Genova' (*C. Limon* 'Genoa')**	Italy	California, Florida, Chile	Spike-free, cold-resistant, dense foliage, smooth thin pericarp, yellow fruits with a marked tip.
***C. Limon* 'Interdonato'**	Italy	Italy	Large, oblong, cylindrical pointed fruit, thin smooth yellow pericarp, few seeds.
***C. Limon* 'Lisbon'**	Portugal	California, Arizona, Australia, Uruguay, Argentina	Long spines, thick skin, pink flowers, pale-yellow flesh.
***C. Limon* 'Monachello'**	Italy	Italy	Highly resistant to disease caused by *Phoma tracheiphila*.
***C. Limon* 'Primofiori' (*C. Limon* 'Fino', 'Mesero', 'Blanco')**	Spain	Spain	Productive, spiny variety, spherical/oval fruits with small wart at the end.
***C. Limon* 'Santa Teresa' (*C. Limon* 'Feminello Santa Teresa', 'Italian')**	Italy	Italy, North-West Argentina, Turkey	High essential oil content, large amount of juice, resistant to storage/transport.
***C. Limon* var. Variegata (*C. Limon* 'Eureka' var. Variegated, Pink-fleshed lemon)**	California	California	Mutation of 'Eureka', pink pulp and juice, yellow fruit with green stripes and variegated leaves.
***C. Limon* 'Villafranca'**	Sicily	Florida, Israel, North-West Argentina	Pink pulp and juice, yellow fruit with green stripes.

1.3 Cultivation and Harvesting of Citrus Plants:

- **Growth Requirements:** Citrus plants need warm sunny climates with well-drained soil making regions like the Mediterranean, southern U.S. and some parts of Asia ideal for growing citrus.
- **Harvesting and Processing:** Citrus fruits are harvested when they ripen and their peels are processed for essential oil extraction typically within a few days to retain the highest concentration of limonene. Limonene's versatility and eco-friendliness make it valuable across industries. Whether in food fragrance health or household products, limonene continues to be a naturally derived powerhouse. [25-28]

- **Appearance:** Limonene is a clear colorless to slightly, pale yellow liquid at room temperature.
- **Odor:** Limonene it has a strong fresh citrus-like fragrance characteristic of orange or lemon peels.
- **Taste:** Limonene is slightly bitter but has a refreshing citrus-like taste which is why it's sometimes used as a flavoring agent in foods.
- **Solubility:** Limonene is insoluble in water but dissolves well in alcohol oils and organic solvents (e.g. Ethanol, acetone). Its hydrophobic nature allows it to mix well with other oils and non-polar substances.
- **Density:** Approximately 0.84 g/mL at 20°C, making it lighter than water.
- **Boiling Point:** It has a relatively low boiling point of around 176°C (349°F), which facilitates its use in steam distillation processes.

2. PRODUCTION

2.1 Manufacturing process:

In nature, D-limonene is found in large quantities. More than 300 essential oils have been found to contain it [3]. D-limonene is a byproduct of the production of grapefruit, lemon, and orange juice [4]. It is extracted from these citrus fruits' peel oil, where its weight-based concentration can reach up to 97%. D-limonene is recovered by traditional extraction employing two techniques. While the FMC online extractor ("FMC in Line Extractor") recovers fruit oil during the juice extraction process, the brown oil extractor ("Brown Oil Extractor") recovers the oil prior to extracting the juice [5, 6]. Both procedures work by mechanically shattering the fruit's epicarp's essential oil-containing cells. Thus, an aqueous emulsion is produced, and centrifugation is used to isolate the essential oil. The Key Aspect s of Limonene mentioned below in **Fig 1.**

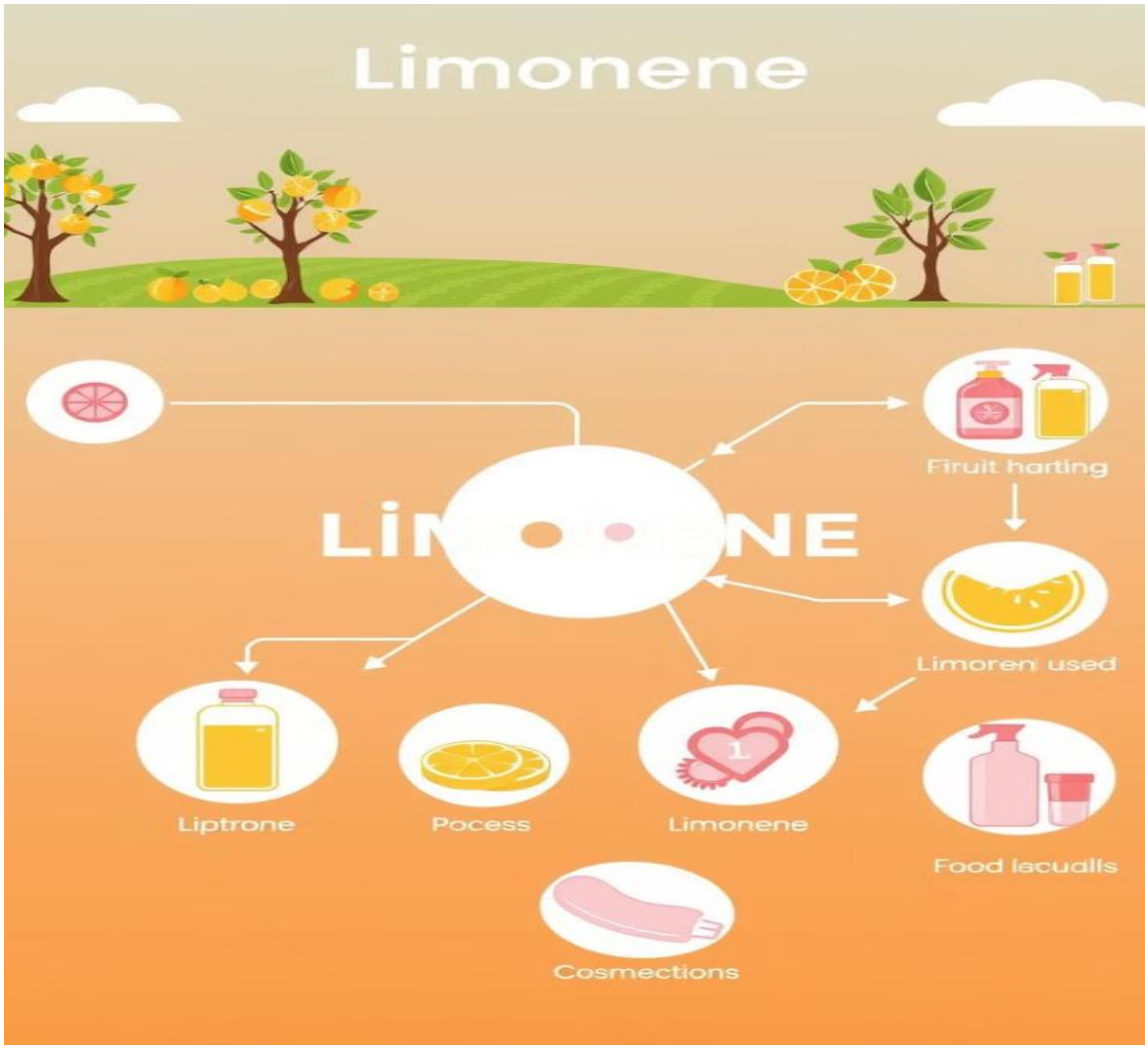

Fig. 1. Key Aspect of Limonene

2.2 Absorption, metabolism, and toxicity

2.2.1 Exposure to animals:

2.2.1.1 Animal toxicity: In mice and rats, oral d-limonene LD50s typically surpass 5g/kg body weight. Additionally, the rabbit's dermal LD50 is higher than 5g/kg body weight. In mice and rats, the intraperitoneal LD50s are 1.3g/kg and 4g/kg, respectively. In rats, 0.1g/kg (body weight) is the intravenous LD50 [7–11].

2.2.1.2 The impact of animals

1. Liver: Research on the effects of d-limonene on the liver in animals is especially important because it has been used as the foundation for the development of exposure limit value guidelines by organisations like Sweden and the American Industrial Hygiene Association (AIHA) [12–14]. The formation of multi-nucleus cells and cytomegaly in male mice, as well as increases in liver weights in rats and canines, are some of the many impacts. Furthermore, some research has shown that the rat's bile flow, cytochrome P450 levels, and the activity of various liver enzymes have all increased [7, 15–17].

2. Carcinogenicity: The US National Toxicology Program (NTP) has carried out a chronic toxicity study to assess its carcinogenic potential. Investigation of two animal species' gavages of d-limonene. For 103 weeks, male rats (n=50) were given d-limonene five days a week at dosages of 0, 75, and 150 mg per kilogramme of body weight; female rats were given doses of 0.30 and 600 mg/kg body weight. Furthermore, d-limonene doses of 0, 250, and 500 mg/kg body weight were given to male mice (n=50), whilst doses of 0, 500, and 1000 mg/kg body weight were given to female mice. NTP found that renal tubular cell hyperplasia, adenomas, and adenocarcinomas significantly increased in male rats alone [18]. (1990) US-NTP, D-Limonene Testing Status: https://ntp.niehs.nih.gov/testing/status/agents/ts-10071-t.html , However, additional research by Kim et al. [11], Sun et al. [20], and Crowell and Gould [19] revealed that d-limonene inhibits the development of several cancer types in mice and even suggests its potential for application as a treatment for human tumours.

3. Developmental and reproductive toxicity: There was no teratogenic or fetotoxic potential when rats and mice were exposed to 500 and 2900 mg/kg of d-limonene between days 9 and 15 of pregnancy, 500 and 2400 mg/kg between days 7 and 12 of gestation, and 250, 500, and 1000 mg/kg between days 6 and 18 of gestation in rabbits [9, 10, 21]. The percentage of frog embryos (Xenopus frog L.) that survive exposed to up to 114 parts per million of d-limonene in water have not been impacted by this treatment [9, 10, 21]. This was consistent with research by Kodama [22, 23] and Tsuji et al. [24], as well as the FAO/WHO report [7]. When supplied sub acutely in the diet of quail (Coturnix coturnix L.), D-limonene is mostly non-toxic. The lethal concentration 50 (LC50) of d-limonene in this bird is, in fact, greater than 5620 ppm. The LC50 of d-limonene in trout is 80 ppm, indicating that it is somewhat harmful to them. When it comes to Daphnia, D-limonene is categorised as "slightly toxic" due to its LC50 of 39 ppm in this tiny crustacean.

3. EXPOSURE OF HUMANS

As a synthetic flavouring, D-limonene is widely accepted to be safe for human consumption (US Food and Drug Administration, FDA, 1991). The International Agency for Research on Cancer, or IARC, [3] concluded that the tolerated daily intake (TDI) of d-limonene was 0.27 mg/kg body weight, or 16.2 mg for an adult weighing 60 kg. Foods naturally contain this amount of d-limonene, which is also added as a flavour.

3.1 Limonene's Applications and Therapeutic Benefits :

Limonene has been linked to and shown to have a number of medicinal benefits. The natural limonene found in essential oils has been shown to provide a variety of therapeutic benefits in various articles during the past 10 years (2009–2019).

3.1.1 Uses in Aroma and Perfumery:

1. **Scent:** Scent known for its fresh uplifting citrus fragrance limonene is widely used in perfumery and aromatherapy. It has a sweet orange-like aroma and can add zest and freshness to perfumes and scented products.
2. **Aromatherapy Benefits**: D-limonene in particular is believed to have mood-enhancing properties making it popular in aromatherapy for reducing stress and promoting mental clarity.

3. 1.2 Health Benefits and Uses:

1) **Digestive:** Limonene is known to have soothing effects on the stomach helping to reduce acid reflux and symptoms of indigestion.
2) **Anti-inflammatory and Antioxidant:** Some studies suggest that limonene has anti-inflammatory and antioxidant properties, which may support immune health and protect cells from oxidative damage.
3) **Anti-Cancer Potential:** Research is ongoing but preliminary studies have indicated that limonene may inhibit cancer cell growth in certain cancers, including skin and breast cancer.
4) **Antibacterial and Antifungal:** Limonene exhibits antimicrobial properties, which makes it useful in natural cleaning products and skincare formulations.

3.1.3 Industrial and Commercial Applications:

1. **Cleaning Products:** Because of its grease-cutting properties, limonene is used in environmentally friendly cleaners and degreasers especially as a solvent.
2. **Food Flavoring:** Limonene is a common additive in food and beverages imparting a citrusy flavor to candies soft drinks and baked goods.
3. **Insect Repellent:** Limonene's strong citrus scent deters insects making it an effective natural repellent.
4. **Pharmaceuticals:** Limonene it is used in some medications and supplements due to its therapeutic properties.

3.1.4 Safety and Environmental Impact:

1) **Generally Recognized as Safe (GRAS):** The U.S. Food and Drug Administration classifies limonene as safe when used in appropriate amounts though highly concentrated limonene can cause skin irritation in some individuals.
2) **Eco-friendly Solvent:** Unlike many petroleum-based solvents limonene is biodegradable and considered an environmentally friendly alternative.

3.1.5. Cosmetic Industry and Natural Ingredients: Limonene is a naturally occurring cyclic monoterpene with the molecular formula $C_{10}H_{16}$ is widely utilized in the cosmetic industry due to its pleasant citrus aroma and versatile properties. As a key component of essential oils derived from citrus fruits limonene is known for its fragrant qualities making it is a popular ingredient in perfumes skincare products and personal care items.

3.1.6. Properties and Benefits:

1. **Fragrance**: Limonene's fresh and uplifting scent makes it a favoured choice in the formulation of perfumes and scented products. It provides a natural alternative to synthetic fragrances aligning with the growing consumer demand for clean and eco-friendly beauty products.
2. **Solvent Properties:** Limonene acts as a natural solvent aiding in the formulation of products by effectively dissolving other ingredients. This property is particularly useful in cleaning products and formulations that require a stable mixture of oils and water.
3. **Antioxidant and Anti-Inflammatory Effects:** Limonene may exhibit antioxidant and anti-inflammatory properties making it beneficial in skin care formulations aimed at soothing and protecting the skin. These properties contribute to its use in products designed for sensitive or irritated skin.
4. **Mood Enhancement:** Limonene is often included in aromatherapy products due to its potential mood-enhancing effects. Its uplifting scent is believed to promote relaxation and reduce stress which is increasingly valued in cosmetics that aim to provide a holistic experience.

3.1.7. Applications in Cosmetics*:*

1) **Skincare Products:** Limonene is found in various skincare formulations including moisturizers serum and creams. Its ability to enhance the scent while providing potential skin benefits makes it an attractive ingredient for both mainstream and natural skincare brands.
2) **Hair Care:** In hair care products limonene is used for its fragrance and potential conditioning properties. It can help improve the overall sensory experience of shampoos and conditioners, making them more appealing to consumers.
3) **Makeup:** Many cosmetic brands incorporate limonene in their products to enhance the sensory appeal. Its use in makeup formulations such as foundations and lip products. Provides a pleasant scent that can enhance user experience.
4) **Natural and Organic Products:** With the increasing trend towards natural and organic cosmetics, limonene is favoured for its plant-based origin. It aligns with consumer preferences for products that utilize natural ingredients and avoid synthetic additives.

4. REGULATORY AND SAFETY CONSIDERATIONS:

While limonene is generally recognized as safe for use in cosmetics, it is essential to consider its potential to cause allergic reactions in sensitive individuals. The International Fragrance Association (IFRA) and other regulatory bodies have established guidelines on the maximum allowable concentrations of limonene in cosmetic products to ensure consumer safety. [29-32]

5. THE ROLE OF NATURAL FRAGRANCES:

Limonene, a naturally occurring cyclic monoterpene with the molecular formula $C_{10}H_{16}$, is a prominent component of natural fragrances, particularly in the cosmetic and food industries. Extracted primarily from the peels of citrus fruits, such as oranges and lemons, limonene is celebrated not only for its delightful citrus aroma but also for its versatile applications. Its role in

natural fragrances highlights the growing trend toward the use of plant-derived ingredients in consumer products. [33]

5.1. Fragrance Profile:

Citrus Aroma: Limonene is characterized by its fresh uplifting citrus scent, which makes it a favoured ingredient in perfumes scented candles and personal care products. Its aromatic profile contributes to a sense of cleanliness and vitality aligning with consumer preferences for invigorating and refreshing fragrances.

- **Natural Alternative**: As consumers increasingly seek natural alternatives to synthetic fragrances limonene serves as a prime example of a plant-based ingredient that enhances sensory appeal while maintaining a commitment to natural sourcing.

5.2. Therapeutic and Emotional Benefits:

- **Aromatherapy**: Limonene is often utilized in aromatherapy for its potential mood-enhancing properties. Inhalation of limonene-rich essential oils is believed to promote relaxation reduce stress and elevate mood making it is a popular choice in wellness products.
- **Emotional Connection**: The scent of limonene can evoke positive memories and emotions reinforcing its role in products designed to create a pleasurable sensory experience. Its association with fresh sunny citrus can transport users to pleasant environments enhancing their overall experience.

5.3. Functional Applications:

1. **Solvent Properties**: Its aromatic qualities, limonene acts as a natural solvent, aiding in the formulation of fragrances by helping to dissolve and blend various ingredients. This property is particularly valuable in cosmetic and cleaning products, where stable emulsions are essential.
2. **Preservative Qualities**: Limonene also possesses antimicrobial properties, which can contribute to the preservation of cosmetic formulations. This quality enhances the safety and longevity of products further promoting its use in the natural fragrance sector.

5.4 Sustainability and Sourcing:

1) **Renewable Resource:** Limonene is derived from the rinds of citrus fruits, a renewable resource that supports sustainable sourcing practices. As the demand for eco-friendly products rises limonene aligns with consumer preferences for natural ingredients that have minimal environmental impact.
2) **Biodegradability:** Natural fragrances like limonene are generally more biodegradable than synthetic alternatives reducing their ecological footprint and supporting sustainability in product formulations

6. CONCLUSION

In conclusion this review emphasises the medicinal benefits of natural limonene according to its safety (or possible toxicity) and different biological activity. Because of its wide mechanism of action, safety, and great availability in nature, limonene is a prospective preventive agent that may also be used in conjunction with anti-inflammatory and anti-infectious medications as a complementary treatment approach. The growing interest in using natural limonene, either in its native form or in its natural environment (essential oil), either by itself or in conjunction with other medications, to maximise the prevention and therapeutic management of a variety of diseases is supported by a sizable amount of scientific data in the literature. Additionally, one could anticipate less exposure to certain synthetic chemicals, which have negative consequences. Furthermore, its antioxidant action helps to neutralize free radicals, minimizing the effects of environmental contaminants and sun exposure on the skin, which is critical for avoiding premature aging. Despite its obvious advantages, there are a few issues that must be handled. One of the most pressing problems is allergenicity, as the presence of limonene in cosmetic formulations may cause skin irritation or allergic reactions in certain people. This has sparked concerns about its safety, particularly in leave-on cosmetics or those used on delicate parts of skin. However, regulatory agencies such as the European Union have imposed restrictions on its concentration in cosmetic formulas to reduce the risk of adverse responses. Furthermore, ongoing research into the formulation of products with lower allergen levels and increased stability is critical for the safe use of limonene.

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