

## Cosmetological applications of *Citrus limon*: A mini-review

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*Citrus limon* has gained attention in cosmetology for its diverse bioactive compounds. This review explores its cosmetological applications, emphasising antioxidant, anti-inflammatory, antimicrobial, skin-brightening, preservative, and substance-penetrating properties. The genus *Citrus* is briefly described, followed by details on *C. limon*'s botanical features, distribution, phytochemical composition, and biological activities. Lem1, a natural compound from *C. limon*, exhibits strong antioxidant activity, making it a potential ingredient for natural anti-ageing skincare. *C. limon*'s potent antimicrobial properties make it effective against various bacteria, addressing skin issues like acne and serving as a natural preservative in cosmetics. Rich in limonene and vitamin C, *C. limon* inhibits tyrosinase activity and reduces melanin formation, showing promise in cosmetics for controlling skin pigmentation and promoting even-toned, brighter skin. Safety considerations in cosmetic use are also addressed. Overall, *C. limon* is a valuable natural ingredient, enhancing efficacy and safety in cosmetic products.

**Keywords:** Anti-inflammatory, Antimicrobial, Antioxidant, *Citrus limon*, Lemon, Skin-brightening

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### Introduction

*C. limon* holds multifaceted applications in various fields, including healthcare, culinary arts, and agriculture. In healthcare, lemon's rich content of vitamin C and flavonoids is recognised for its potential for antioxidant effects, immune system enhancement, and protection against cardiovascular diseases. Lemon juice is historically employed to combat scurvy and obesity and as a preventative measure against AIDS. Additionally, lemon has been linked to preventing kidney stones and is used to address menstrual disorders in women. In agriculture, lemon peels contribute to soil health and plant growth as a bio-fertiliser component, aiding nutrient availability and soil fertility. Using bio-fertilisers with lemon components enhances sustainability in farming, reduces reliance on chemical fertilisers, and fosters eco-friendly practices<sup>1</sup>.

Recently, lemons have been widely used in cosmetics and are frequently reported to function as skin-conditioning agents<sup>2</sup>. With its rich reservoir of

bioactive compounds and antioxidants, *C. limon* poses great antioxidants, anti-inflammatory, antimicrobial, skin-brightening, preservative, and substance-penetrating properties, which show high potential for skincare and cosmetic formulations<sup>3</sup>.

This article aims to review the existing scientific research on *C. limon*, focusing on its cosmetic applications. It aims to provide a comprehensive analysis of the bioactive compounds found in lemon that are pertinent to cosmetology, such as antioxidants, anti-inflammatory agents, and antimicrobial components. This study also evaluates the effectiveness of *C. limon* in skincare formulations, particularly in enhancing skin health and brightness, as well as its role as a preservative and substance-penetrating agent. Lastly, this study provides insights into the development of innovative cosmetic formulations that incorporate *C. limon*, including nanoparticles, which address the evolving preferences of consumers seeking natural and sustainable skincare solutions.

### Botanical description, geographical distribution, and phytochemistry of *C. limon*

*C. limon*, belonging to the family Rutaceae and subfamily Aurantioidae, typically grows as a shrub to

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medium-sized trees. It can reach a height of 10 to 20 ft under ideal conditions. The leaves of *C. limon* are elliptical or ovate in shape, alternate in arrangement, and are typically 2 to 4 inches long. They have a glossy appearance and are dark green on the upper surface and lighter green underneath. Lemon trees produce fragrant, white, or pale pink flowers that are typically 0.8 to 1.6 inches in diameter. The fruit is an elongated, oval, pointed green hesperidium that turns yellow during ripening. Inside lemon, it contains a succulent pulp divided into segments. The outermost layer of the fruit (pericarp) consists of a thin exocarp covered in a waxy substance. Beneath this layer lies the outer portion of the mesocarp (flavedo), which contains oil sacs and carotenoid dyes. The inner part of the mesocarp (albedo) is composed of a spongy, white parenchyma tissue. The 'flesh of the fruit' or endocarp is segmented by the spongy, white mesocarp tissue. The seeds are polyembryonic, appearing pale whitish to greenish, and have a flattened, angular shape<sup>3,4</sup>.

*C. limon* is native to southwestern China, northeastern India, and northern Burma but is now cultivated in more than 140 countries, including Turkey, Mexico, the United States, Argentina, Iran, Brazil, Italy, Spain, and Asia. Nowadays, *C. limon* has been widely cultivated and adapted to various climates worldwide, making it a globally distributed fruit tree. *C. limon* grows best in tropical and subtropical humid regions of the world. It achieves its highest flesh quality in subtropical humid climates or drier areas, such as Mediterranean climates<sup>4,5</sup>.

*C. limon* juice extract is rich in phytochemicals such as alkaloids, flavonoids, phenols, quinines, terpenoids and carotenoids. The flavonoids are known to show antioxidant activity through scavenging or chelating modes of action. The phenolic and flavonoids are responsible for their antioxidant activity, which might play important roles in cosmetological aspects<sup>6</sup>. Flavonoids are one of the most abundant phytochemicals found in lemons, where over 250 flavonoids have been identified in citrus. These flavonoids can be structurally categorised into flavanones, flavones, flavanols, and anthocyanins, present in either aglycone or glycoside forms. Flavanones (e.g., hesperidin) are the major polyphenols found in lemon, while kaempferol and quercetin are the main flavanols found in lemon. A study has found that p-coumaric acid and ferulic acid are among the major phenolic acids in Eureka lemon<sup>7</sup>.

## **Biological activity of *C. limon* for cosmetological applications**

### **Antioxidant activity**

A study revealed that besides scavenging free radicals, the antioxidant properties of flavonoids found in *C. limon* (hesperidin and hesperetin) could enhance the body's antioxidant defences by activating the ERK/Nrf2 signalling pathway. This means that hesperidin and hesperetin not only directly neutralise harmful free radicals but also stimulate the body's own mechanisms for antioxidant protection, making them more effective in combating oxidative stress. Furthermore, vitamin C present in *C. limon* plays a crucial role in preventing the formation of free radicals and protects DNA from mutations<sup>8</sup>. Vitamin C can reduce lipid peroxidation, a process where free radicals attack lipids, in situations such as status epilepticus induced by pilocarpine in adult rats, leading to reduced oxidative damage to neural tissue<sup>3</sup>.

Research has found that Lem1, a natural compound derived from lemon essential oil, exhibits potent antioxidant activity and can effectively inhibit free radical-mediated reactions *in vitro* and *in vivo*. One significant finding is that the topical application of Lem1 on the skin of healthy volunteers significantly enhances the skin's antioxidative potential. This highlights the potential of Lem1 as a natural antioxidant in anti-ageing skincare, demonstrating its effectiveness in protecting the skin from oxidative stress<sup>9</sup>.

Another study assessed the antioxidant activity of *C. limon* essential oil using 2,2-diphenyl-1-picrylhydrazyl (DPPH) and  $\beta$ -carotene bleaching assays. The result showed that chemical compounds present in lemons, such as limonene and  $\beta$ -Pinene, exhibited excellent DPPH radical scavenging ability, with an IC<sub>50</sub> of 15.056  $\mu$ g/mL. Lemons also demonstrated strong inhibition of  $\beta$ -carotene, with an IC<sub>50</sub> of 40.147  $\mu$ g/mL. These results indicate its strong ability to neutralise free radicals, which are associated with oxidative stress and damage to cells and tissues. This antioxidant potential makes lemon essential oil a potential candidate for cosmetics and skincare formulations<sup>10</sup>.

Lemon fruit extracts have been scientifically proven to possess significant antioxidant properties to inhibit oxidative stress in skin cells, including keratinocytes and fibroblasts, making them valuable ingredients in anti-ageing cosmetics. They are often incorporated into cosmetic formulations using carriers

like hyalurosomes and glycerosomes, which enhance their antioxidant properties. The presence of vitamin C in lemons works synergistically with vitamin E, creating a potent antioxidant combination. This duo can be used in anti-ageing products to reduce fine wrinkles<sup>3</sup>. All these findings have highlighted the multifaceted antioxidant capabilities of compounds found in *C. limon*, making it a valuable natural source of antioxidants with potential cosmetological uses.

#### Anti-inflammatory activity

The anti-inflammatory properties of lemon are highly valued in cosmetology due to reasons such as helping soothe and reduce redness and irritation of the skin caused by inflammation and relieving sensitivity. Various *in vitro* and *in vivo* studies have been conducted to evaluate the effectiveness of chemicals present in lemon in reducing inflammatory targets, including NF- $\kappa$ B, iNOS, and COX-2. A study found that extracts from citrus peels exhibited remarkable inhibitory effects on pro-inflammatory mediators (PGE2 and NO) in activated cells. The study also found that polymethoxy flavones, particularly nobiletin, have contributed to the anti-inflammatory properties of citrus peel extracts<sup>11</sup>.

Another study shows that the phytochemicals present in lemon essential oils, such as limonene and  $\gamma$ -terpinene, pose great anti-inflammatory properties. The *in vitro* analysis revealed that lemon essential oils demonstrated anti-inflammatory properties by reducing cell migration, cytokine production and carrageenan-induced protein extravasation. Interestingly, similar anti-inflammatory effects were observed with pure limonene, suggesting that the anti-inflammatory effect of *C. limon* may be attributed to their high limonene content. These findings suggest the potential cosmetological benefits of these essential oils as natural anti-inflammatory agents<sup>12</sup>.

#### Antimicrobial activity

Lemon-derived products have long been credited with having a positive effect on acne-prone skin. This may be due to lemon's antimicrobial activity. Lemons have been shown to inhibit the growth of Gram-positive bacteria (*Staphylococcus capitis*, *Micrococcus luteus*, *Bacillus subtilis*) and Gram-negative bacteria (*Pseudomonas fluorescens*, *Escherichia coli*)<sup>3</sup>.

A study has shown that the acetone and ethanol extracts of lemon pose antimicrobial efficacy against microbes associated with skin diseases. The results

showed that the acetone extract displayed the highest antibacterial activity, particularly against *Enterococcus faecalis* and *B. subtilis*. *Salmonella typhimurium*, a Gram-negative bacteria, and *B. subtilis*, a Gram-positive bacteria, were also susceptible to the extracts. Both extracts also have an inhibitory effect against fungi such as *Candida glabrata*. The lemon extracts exhibited a broad spectrum antibacterial activity and have comparable efficacy to the synthetic antioxidants. This highlights the cosmetological and medicinal value of *C. limon* as a potentially effective and safe antibacterial drug to counter skin problems<sup>13</sup>.

Methanolic extract from lemon fruit peel also showed antimicrobial properties, and the phytochemical analysis revealed the presence of alkaloids, flavonoids, and tannins. The extract exhibited significant antimicrobial activity against *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans*<sup>14</sup>. Another study confirmed that *C. limon* essential oil promoted a 100% reduction in the growth of *C. albicans*<sup>3</sup>.

Additionally, when added to peeled shrimp, lemon essential oils showed strong inhibitory effects against aerobic and lactic acid bacteria. The lemon EO-treated shrimp also had lower total volatile basic nitrogen (TVB-N) values, indicating better freshness. This study reveals that lemon essential oils can extend the shelf-life of peeled shrimp by controlling microbial growth and preserving product quality<sup>15</sup>. While the study primarily focuses on the use of lemon essential oils to extend the shelf-life of peeled shrimp, there is a potential connection to cosmetology in the context of skincare and cosmetic formulations. In this context, lemon essential oils showed the potential to serve as natural preservatives, which can be applicable in formulations to extend the shelf-life of cosmetic products and maintain the freshness and quality of cosmetic products over time, ensuring the product remains effective and safe for use.

#### Skin-brightening activity

Scientific studies on mouse melanoma B16BL6 cells have shown that a chemical compound present in lemon peel essential oils (limonene) plays an important role in the inhibition of melanogenesis<sup>16</sup>. Another study showed that lemon essential oil and its volatile components (citral, beta-pinene and d-limonene) effectively inhibited tyrosinase activity through non-active-site-inhibition mechanisms by steric effects and oxygen radical scavenging. These

bioactive compounds showed a synergistic inhibitory effect on tyrosinase activity. The results suggested that lemon essential oil and its components have potential applications in the cosmetic industries due to their ability to inhibit tyrosinase activity, which is relevant in controlling skin pigmentation and melanin-related cosmetic concerns<sup>17</sup>.

Based on a few studies, vitamin C presence in lemon demonstrated notable anti-pigmentary and UV-protective effects, contributing to more even-toned and healthier-looking skin<sup>18–20</sup>. Vitamin C can interact with copper ions at tyrosinase-active sites, inhibiting the activity of the enzyme tyrosinase, thus reducing melanin formation and making it effective in addressing hyperpigmentation issues such as melasma. Clinical studies using topical formulations with vitamin C have reported a significant reduction in pigmentation over time. Vitamin C also protects the skin from the harmful effects of UV radiation. It inhibits the reduction of CD1a-expressing Langerhans cells in the epidermis, which is crucial in initiating a protective immune response. By preventing cell reduction, especially upon UV exposure, vitamin C helps maintain the skin's immune defence against UV damage<sup>18,19</sup>.

#### Natural preservative

The bioactive components of lemon essential oil, including flavanones and terpenes, pose great preservative effects due to their antibacterial and antioxidant activities. Various studies have shown that the polyphenol content present in lemon can act as an effective natural preservative agent alternative to synthetic preservatives such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), which can help to extend the shelf life of cosmetic products by inhibiting the growth of harmful microorganisms<sup>13,14</sup>. Additionally, the phenolic compounds found in lemon can act as antioxidants, preventing oxidation and degradation of cosmetic formulations, which is crucial for maintaining the product's freshness<sup>21</sup>.

A study has proven the antimicrobial properties of lemon essential oil against various microorganisms commonly found in cosmetic products and their potential use as components of a preservative in body milk. The study found that lemon oil has inhibitory effects against microorganisms such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Candida species*, and *Aspergillus niger*. Combining lemon essential oil with synthetic preservatives also

produces a synergistic effect, significantly reducing the required concentration of the synthetic preservative—up to 8.5 times lower—while maintaining effective antimicrobial activity. This showed that lemon oil can be combined with synthetic preservatives to enhance the efficacy of the overall preservative system<sup>22</sup>.

#### Enhanced substance penetration

Limonene, a natural compound found in lemons, has been reported to enhance the permeation of hydrophilic and lipophilic drugs through the skin and has remarkable penetration enhancement activity<sup>23,24</sup>. Limonene can be incorporated into various formulations, such as liposomes, microemulsions, nanoemulsions, microemulgels, and transdermal patches, to target deeper layers of the skin. Moreover, when combined with other penetration enhancers like Tween 80 or incorporated into specific delivery systems like solid lipid nanoparticles (SLN), limonene exhibits a synergistic effect and further enhances its permeation-enhancing capabilities<sup>25</sup>. Limonene's ability to improve drug penetration through the skin can optimise skin permeation and enhance the effectiveness of various topical cosmetic products.

In a study, lemon essential oils have shown penetration-enhancing properties of various lipid-soluble and water-soluble vitamins. Various chemical compounds such as D-limonene,  $\alpha$ -pinene, and p-cymene presence in lemon oil play important roles in this permeability-enhancing effects. These compounds facilitated the penetration of vitamins through the skin when incorporated into either W/O or O/W emulsions. Vitamins B6, C, and A exhibited enhanced skin penetration in the presence of lemon oil, with permeability coefficients several times higher than those without lemon oil. For instance, vitamin E penetration was enhanced by a factor of nine. This property highlighted the potential of lemon oil in delivering vitamins topically for skin protection and anti-ageing purposes, offering its benefits in cosmetic and skincare products<sup>26</sup>.

Table 1 shows the biological activities of *C. limon* in cosmetics as reported in past studies, while Fig. 1 showcases some of the chemical compound structures found in *C. limon*.

#### *C. limon* in cosmetic products and limitations

The cosmetological use of *C. limon* has gained significant popularity in the beauty and skincare

Table 1 — Biological activities of <i>C. limon</i> in cosmetics			
Activity	Chemical compounds	Mechanism of action	References
Antioxidant	Hesperidin, hesperetin, vitamin C and Lem1	<ul style="list-style-type: none"> <li>• Activate ERK/Nrf2 signaling pathway</li> <li>• Reduce lipid peroxidation and protects DNA from mutations</li> <li>• Scavenge and neutralise harmful free radical</li> </ul>	3,9,10
Anti-inflammatory	Nobiletin, limonene, and $\gamma$ -terpinene	<ul style="list-style-type: none"> <li>• Inhibit pro-inflammatory mediators such as PGE2 and NO</li> <li>• Inhibit cytokine production</li> <li>• Reduce cell migration and reduce inflammation</li> </ul>	11,12
Antimicrobial	Alkaloids, flavonoids, and tannins	<ul style="list-style-type: none"> <li>• Inhibit growth of <i>Staphylococcus aureus</i>, <i>Escherichia coli</i>, and <i>Candida albicans</i></li> <li>• Broad spectrum antibacterial activity against both Gram-positive and Gram-negative bacteria</li> </ul>	3,13,15
Skin brightening	Citral, $\beta$ -pinene, d-limonene, and vitamin C	<ul style="list-style-type: none"> <li>• Non-active site inhibition mechanisms inhibit tyrosinase activity</li> <li>• Inhibit melanogenesis and reduce pigmentation</li> <li>• Inhibit reduction of CD1a-expressing Langerhans cells in epidermis</li> <li>• UV radiation protection</li> </ul>	16–19
Preservative	Flavanones, terpenes, polyphenols (BHA and BHT)	<ul style="list-style-type: none"> <li>• Inhibit growth of harmful microorganisms</li> <li>• Prevent oxidation and degradation of cosmetic formulation</li> </ul>	13,14,20,21
Enhanced substance penetration	D-limonene, $\alpha$ -pinene, p-cymene	<ul style="list-style-type: none"> <li>• Facilitate passage of both hydrophilic and lipophilic drugs through skin barrier</li> <li>• Enhanced permeation of drugs and vitamins through skin</li> </ul>	22,25

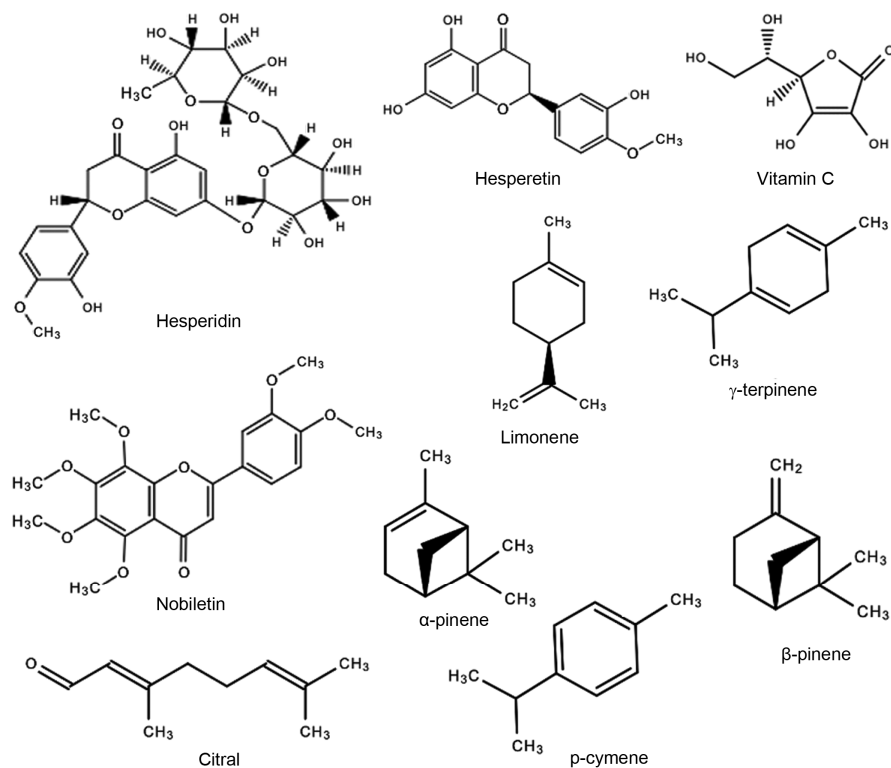


Fig. 1 — Structures of some compounds found in *C. limon*.

industry. Lemon is known for its diverse applications in cosmetic products, from skin-brightening formulations, skincare, and haircare to invigorating fragrances. Lemon essential oil exhibits antimicrobial

activity when incorporated into oil-in-water body milk formulations, which helps to preserve the product's integrity and prevent the growth of harmful microorganisms. Also, lemon essential oil can

increase the effectiveness of preservative systems that reduce the reliance on synthetic chemical preservatives<sup>22</sup>.

Lemon essential oil can also be incorporated into cosmetic products such as lotions, creams, and serums to provide aromatherapy benefits. Its mood-elevating properties can contribute to the overall sensory experience of using cosmetics, promoting relaxation and emotional well-being. Lemon essential oil's pleasant scent can enhance the fragrance of cosmetic products, making them more appealing to consumers. It can be a natural and refreshing fragrance component in various skincare and haircare products<sup>27</sup>.

Also, lemon essential oil has a skin-brightening and rejuvenation effect. It can help to improve skin complexion, reduce blemishes, and promote healthier-looking skin. The antiseptic and astringent properties of lemon essential oil can benefit skincare products, particularly for individuals with oily or blemish-prone skin. It can help control excess oil production and maintain skin cleanliness. Given the growing interest in natural and organic cosmetic products, lemon essential oil can be used as a natural ingredient, aligning with the trend of clean and green beauty<sup>27</sup>.

Apart from that, *C. limon* bud extract and flower water can act as humectants in cosmetic products, helping to retain moisture in the skin. Lemon peel extracts serve as emollients and skin protectants in cosmetic products, helping to soften and protect the skin. Lemon peel powder can also be used as an absorbent in cosmetics to control product viscosity. Lemon-derived products, especially essential oils and extracts, are recommended for anti-ageing cosmetics due to their significant antioxidant effects. Lemon essential oil also poses depigmenting effects and can be used in cosmetic products to address skin

pigmentation concerns. Lastly, *C. limon* essential oil can enhance the penetration of active substances through the skin and improve the delivery of the desired ingredients<sup>3</sup>.

The cosmetological uses of *C. limon* are shown in Fig. 2.

While *C. limon* offers a wide array of benefits in cosmetic products, limitations related to skin sensitivity, allergenicity, photosensitivity, and safety precautions need to be carefully considered in its cosmetological applications. The limitations of using lemon-derived ingredients in cosmetics primarily revolve around their potential to cause skin irritation and photosensitivity. Lemon oils and extracts, if used in high concentrations, can be allergenic and irritating to the skin<sup>28</sup>. Overcoming these limitations may involve using nanoparticles for controlled release and enhanced penetration. A recent study explores the synthesis of zinc oxide nanoparticles (ZnONPs) and titanium dioxide nanoparticles (TiO<sub>2</sub>NPs) using lemon fruit extract and their potential application in combating phytopathogenic bacteria<sup>29</sup>. By encapsulating lemon-derived compounds within nanoparticles, controlled release and targeted delivery to the skin can be achieved, which helps to reduce the likelihood of irritation of the skin<sup>30</sup>. It also helps to enhance the penetration into the skin, potentially making them more effective. Moreover, nanoparticles can provide a protective barrier that minimises direct exposure to UV radiation, counteracting the photosensitising effects of lemon<sup>31,32</sup>. By using well-designed nanoparticle formulations, cosmetic products can harness the advantages of lemon while mitigating its limitations and offering safer and more effective solutions for skin care.

<p><b>Skin-brightening</b></p> <ul style="list-style-type: none"> <li>• Depigmenting effects</li> <li>• Addresses skin pigmentation concerns</li> </ul>	<p><b>Haircare</b></p> <ul style="list-style-type: none"> <li>• Fragrance</li> <li>• Natural ingredient</li> </ul>		<p><b>Aromatherapy</b></p> <ul style="list-style-type: none"> <li>• Mood-elevating benefits</li> <li>• Enhances product fragrance</li> </ul>	<p><b>Oil control</b></p> <ul style="list-style-type: none"> <li>• Controls excess oil production</li> <li>• Maintains skin cleanliness</li> <li>• Beneficial for oily or blemish-prone skin</li> </ul>
<p><b>Preservative</b></p> <ul style="list-style-type: none"> <li>• Prevents microbial growth in oil-in-water formulations</li> </ul>	<p><b>Emollient</b></p> <ul style="list-style-type: none"> <li>• Lemon peel extracts</li> <li>• Serves as skin protectants</li> </ul>	<p><b>Moisturizing agent</b></p> <ul style="list-style-type: none"> <li>• Lemon bud extract and flower water</li> <li>• Acts as humectants to retain moisture</li> </ul>	<p><b>Anti-ageing</b></p> <ul style="list-style-type: none"> <li>• Antioxidant effects</li> <li>• Recommended for anti-ageing cosmetics</li> </ul>	<p><b>Penetration enhancer</b></p> <ul style="list-style-type: none"> <li>• Enhances skin penetration of active substances</li> <li>• Delivers desired ingredients into the skin</li> </ul>

Fig. 2 — Cosmetological uses of *C. limon*.

### Safety issues

The bioactive compounds of lemons generally show a good safety profile in animal toxicological evaluation and are recognised as safe<sup>33,34</sup>. However, lemon should not be used in high concentrations directly on the skin. In preparations that stay on the skin, the *C. limon* essential oil concentration should not exceed 2%. Recent studies have shown that D-limonene has an allergenic and irritating effect on the skin when used in excess<sup>35</sup>. It is essential to use lemon-derived ingredients in safe concentrations and follow recommended guidelines for dilution to prevent irritation. Individuals with sensitive skin should exercise caution when using cosmetics with lemon-derived ingredients. Conducting a patch test on a small area of skin before applying a product to the face or body is a good practice to assess any potential adverse reactions. If irritation or allergies occur, discontinuation of the product is recommended. In addition, after applying cosmetics containing *C. limon* oil, it is crucial to avoid exposing the skin to sunlight. This is because lemon contains photosensitising, such as psoralens and furocoumarins that can make the skin more sensitive to sunlight. When applied topically and exposed to UV radiation, these compounds can lead to phototoxic reactions, including redness, blistering, and skin discoloration<sup>28</sup>. To mitigate this risk, products containing lemon oil or extracts should include appropriate warnings and instructions for use. Additionally, individuals using such products should be advised to use sunscreen and avoid direct sun exposure after application. For example, these products can be used in the evening, at night, or when individuals are not outdoors.

In summary, while lemon-derived ingredients can benefit cosmetics and skincare products, it is essential to be aware of potential safety concerns, particularly related to photosensitivity, skin irritation and allergies. To use lemon-containing cosmetics safely, follow product instructions and choose products from trusted brands with a track record of safety and quality control. One should consult with a dermatologist or skincare professional if any skin condition or adverse effect occurs.

### Conclusion and future perspectives

*C. limon* is rich in a wide array of bioactive compounds, including hesperidin, nobletin and limonene, which can benefit various skincare and cosmetic formulations. The present review has shown that *C. limon* poses antioxidant, anti-inflammatory,

antimicrobial, skin-brightening, preservative, and substance-penetrating activities. Numerous studies have provided empirical evidence supporting its use in cosmetic formulations. Its multifaceted cosmetological benefits have the potential to enhance the efficacy and safety of cosmetic products, catering to the evolving preferences of consumers seeking natural and sustainable skincare solutions. Further research and innovation in incorporating *C. limon* into cosmetic formulations hold promise for the future of cosmetology, leading to advanced formulations that harness the full potential of lemon's bioactive compounds. Advancements in nanotechnology may enable the development of nanoemulsions and nanoparticles that enhance the stability and bioavailability of *C. limon* extracts in cosmetic products.

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