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Unveiling the Indigenous Hill Lemon (*Citrus pseudolimon*): A Himalayan Citrus Resource for Health and Therapeutic Potential

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Abstract

Citrus pseudolimon (Hill Lemon) is a culturally important yet scientifically underexplored citrus species indigenous to the Himalayan region, representing a promising source of nutritional, functional, and pharmacologically relevant phytochemicals. Traditionally used as a food and ethnomedicinal resource, the species has attracted increasing interest because of its diverse phytochemical composition and reported biological activities. This review critically summarises the available literature on the taxonomy, botanical characteristics, distribution, traditional uses, nutritional profile, phytochemical constituents, and pharmacological potential of *C. pseudolimon*. Particular emphasis is placed on bioactive compounds, including phenolics, flavonoids, vitamin C, terpenoids, essential oils, organic acids, and other secondary metabolites, which may contribute to its antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and other health-promoting properties. According to comparative phytochemical investigations, *C. pseudolimon* has a distinct biochemical makeup that makes it an attractive natural resource for creating sustainable treatments and high-value health products.

Major Findings: *Citrus pseudolimon* (Hill Lemon) possesses a diverse phytochemical profile, including phenolics, flavonoids, vitamin C, terpenoids, and essential oils, supporting its potential antioxidant, antimicrobial, anti-inflammatory, and antidiabetic activities. Its distinctive biochemical composition highlights its promise for developing sustainable therapeutic agents and high-value health products.

Keywords: Antioxidant, *Citrus pseudolimon*, Galgal, Hill Lemon, Himalayan Citrus

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1. Introduction

Citrus is home to more than 160 species, including well-known fruits such as lemon (*Citrus limon*), orange (*Citrus sinensis*), lime (*Citrus aurantifolia*), grapefruit (*Citrus paradisi*), and mandarin (*Citrus reticulata*)[1]. Among the most widely cultivated fruit crops in the world, these species are highly regarded not only for their flavour and aroma but also for their nutritional content and therapeutic properties. Citrus fruits are an abundant source of vitamin C (ascorbic acid), flavonoids, carotenoids, limonoids, and essential oils, all of which contribute to their multifaceted biological properties[2]. The medicinal and pharmacological

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relevance of *C. pseudolimon* is primarily associated with its diverse phytochemical composition. Different parts of the plant, particularly the fruit, peel, juice, and essential oil, contain biologically important constituents such as ascorbic acid, phenolic acids, flavonoids, limonoids, terpenoids, essential oils, and organic acids[3,4]. These compounds have been associated with various biological properties, including antioxidant, antimicrobial, anti-inflammatory, hepatoprotective, gastroprotective, and metabolic regulatory activities. The high antioxidant potential of citrus-derived phytochemicals is particularly relevant because oxidative stress and chronic inflammation are implicated in several metabolic and degenerative disorders[5]. *Citrus pseudolimon* is cultivated to a limited extent across the foothills to higher elevations of the sub-temperate Himalayan region, where it is valued for its broad ecological adaptability and resilience under diverse climatic conditions. The species demonstrates considerable hardiness, with tolerance to both relatively high and low temperatures, and is reported to possess comparatively greater tolerance to citrus canker. Fruiting takes place from September to December after the flowering, which generally takes place between February and April[6,7].

Traditionally, the fruit juice and peel of this plant are used to treat stomach ailments, sore throats, coughs, and fevers, as well as liver ailments. In the Himalayan foothills, the fruit is prized for its high acidity, potent scent, and abundant vitamin C content, which makes it a favourite component of regional cooking and home cures. Its juice is used in rural areas as a natural preservative in pickles and fermented foods, as well as an appetiser and digestive aid[8,9]. Its pulp and peel are also used to make herbal tonics and traditional condiments that are thought to ward off seasonal illnesses, including fever, cough, and colds[10]. Through small-scale fruit processing, pickle manufacturing, and essential oil extraction, Hill Lemon economically supports the creation of sustainable livelihoods in hill states[11,12]. It is a promising crop for eco-horticulture and rural development projects in Himalayan regions due to its adaptability to marginal lands and resilience to climate volatility. In regions like Sirmaur, Kangra, Solan (Himachal Pradesh) and Pauri Garhwal (Uttarakhand), Galgal serves as a cash crop for small farmers, particularly in the off-season when other fruits are scarce[13,14]. The aromatic, cosmetic, and pharmaceutical sectors are interested in the peel oil containing high quantities of limonene and citral[15].

2. Materials and Methods

Data were collected from scientific databases including PubMed, Scopus, ScienceDirect, SpringerLink, Google Scholar, and Web of Science. Key search terms used in this study included "Galgal, Hill lemon, Himalayan Citrus, Essential oil, *C. pseudolimon*". The search was limited to focus on pharmacological as well as morphological studies of hill lemon. Comparative evaluation with other *Citrus* species was undertaken to highlight the uniqueness of *C. pseudolimon* in terms of its biochemical profile and therapeutic efficacy. Emphasis was placed on integrating traditional

Table 1. Morphological and botanical characteristics of Hill Lemon (*Citrus pseudolimon* Tanaka)[16-18]

Characteristic	Description
Common name	Lemon Hill, Galgal
Scientific name	*Citrus pseudolimon* Tanaka
Family	*Rutaceae*
Habitat	spiny, evergreen, medium-sized tree, 3-5m tall
Flowers	Fragrant and axillary, 2–3cm in diameter, with four to five white or pale pink petals; flowering mainly occurs in February to April.
Leaves	Simple, alternate, and aromatic, glossy dark green, ovate to elliptic,5–10cm in length and 3–6 cm in width, with oil glands visible.
Fruits	Medium to large-sized, ovoid to round berry, measuring 6–10cm in diameter. Fruits mature from September to December, having a yellowish-orange colour.
Seeds	Numerous, ovoid, and polyembryonic, enclosed in mucilaginous pulp, measuring about 8–10mm in length.

knowledge with modern scientific evidence to present a holistic view of the species' nutraceutical and pharmacological potential. With an emphasis on the therapeutic qualities of plants and their phytochemical components in the treatment of various diseases, the search strategy was created to cover a broad range of research papers, reviews, and preclinical and clinical studies, all in the English language. The search was restricted to English-language articles. Selected studies were systematically reviewed for the morphological and botanical characteristics of hill lemon (*Citrus pseudolimon* Tanaka), including Scientific name, Family, Habitat, flowering characteristics, fruit shape, size, colour, seed characteristics, and seasonal variations in flowering and fruiting (Table 1).

3. Morphological Description

A hill lemon is a medium-sized, evergreen shrub or small tree that grows 2 to 4 meters in height. It is native to the sub-Himalayan regions, especially the hilly areas of Himachal Pradesh and Uttarakhand, where it is widely cultivated for its hardy nature and high adaptability to cooler climates. The stem is woody, greenish-brown when young, and becomes grey or brown with age. The leaves of this plant are dark green in colour and glossy on the upper surface, measuring about 6-12cm in length and 3-5cm in width[19]. Flowers are small, white, about 2-3cm in diameter, with five petals. Petals are white on the upper side and slightly purplish on the outer surface. Flowering mainly occurs in spring to early summer (Feb-April)[20]. The fruit is medium to large, ovoid or ellipsoidal, resembling a typical lemon but slightly larger and rougher in texture. The pulp is juicy and acidic, divided into 10–12 segments. The juice is rich in citric acid and vitamin C, making it sour and refreshing[21]. The seeds are numerous, ovoid, and whitish, with a smooth surface[18]. The plant has a well-developed taproot system with extensive lateral roots that help it anchor firmly in hilly soils and tolerate moderate drought conditions.

3.1 Ecological Distribution and Cultivation of Hill Lemon

Hill Lemon, botanically known as *C. pseudolimon* Tanaka or *Citrus jambhiri* Lush (Figure 1), is native to the lower Himalayan region as well as nearby subtropical foothills. One of the most prevalent semi-wild citrus species in the North-Western Himalayas, it can be found in cultivated orchards, home gardens, and the edges of forests.

In India, the species is predominantly distributed in:

- Uttarakhand: Pauri Garhwal, Tehri, Dehradun, Almora, Nainital, Bageshwar, and Champawat districts.
- Himachal Pradesh: Sirmaur, Kangra, Solan, and Mandi districts.
- Jammu and Kashmir: Jammu region and parts of Arunachal Pradesh.
- Other Regions: It is also found in the Terai and Doon valleys, extending towards the lower elevations of Nepal and Bhutan[22,23].

In subtropical to warm-temperate regions, usually between 600 and 1,500 meters above sea level, hill lemons flourish. It can be grown in rainfed hilly regions since it thrives on well-drained loamy to sandy soils and can withstand mild drought and cold[24]. The plant prefers slightly acidic soils (pH 5.5–6.5), annual rainfall of 100–200 cm, and temperatures between 15 and 30°C[25]. Galgal contributes to soil conservation and agro-ecological sustainability in the Himalayan ecosystem because of its hardness, which allows it to thrive in marginal soils and degraded hill slopes. Here (Table 2) highlights key morphological, climatic, fruit, and economic differences between hill lemon (*Citrus pseudolimon* Tanaka) and common lemon (*Citrus limon*).

3.2 Cultivation Practices

3.2.1 Propagation

Hill lemon is propagated through seeds as well as vegetative methods such as budding and grafting. Vegetative propagation is preferred for maintaining uniform fruit quality. Rangpur lime and rough lemon are commonly used as suitable rootstocks[26].

3.2.2 Spacing and Planting

Planting is generally undertaken during June–July at a spacing of 4–5m. Pits of about 60 × 60 × 60cm are prepared and filled with fertile, well-drained soil mixed with sand and Farm Yard Manure (FYM). Intercropping with vegetables, legumes, ginger, or turmeric is common[27].

3.2.3 Soil and Site Selection

The crop performs well in well-drained sandy loam or loamy soils rich in organic matter, with a pH of 5.5–7.5 and temperatures of 20–30°C. Terracing or contour planting is suitable for Himalayan slopes[28].

3.2.4 Irrigation Management

Hill lemon plants are moderately drought-tolerant but sensitive to extended water scarcity or waterlogging. Therefore, it is crucial to maintain ideal soil moisture. Watering should be done every 7–10 days in the summer and every 15–20 days in the winter. Fruit set, fruit expansion, and flower initiation are critical processes that require sufficient moisture; moisture stress during these stages can result in flower and fruit drop, which affects production and quality[29].

3.2.5 Nutrient Requirement

FYM and balanced Nitrogen, Phosphorus and Potassium (NPK) fertilisation support healthy growth and fruit production. Split application of nitrogen along with phosphorus and potassium is recommended. Biofertilisers and micronutrients such as zinc, iron, and manganese can further improve plant health and nutrient availability[30,31].

3.3 Chemical Composition of Hill Lemon

Hill lemon offers diverse health and culinary applications through its essential oil, juice, pulp, and beverages. Its

Table 2. Distinguishing features of Hill Lemon and Common Lemon[32-35]

Features	Hill Lemon (*Citrus pseudolimon* Tanaka)	Common Lemon (*Citrus limon*)
Common Names	Hill lemon, *Galgal*	Lemon, *Jambira*
Habit	Medium-sized, evergreen shrub (2-3m tall)	Small to medium (3-6m tall)
Climatic Condition	Grows well in hilly regions.	Grows in plains and warmer climates.
Stem and Branches	Spiny and bushy	Less spiny and more open.
Leaves	Thick, glossy, dark green, elliptic to oblong with narrow winged petiole	Thin, light green, broadly elliptic with distinctly winged petiole.
Flowers	White on the upper side and purplish on the outer surface	White
Fruit	Medium to large, rough, thick rind	Small to medium, thin rind
Rind (Pericarp)	Thick and rich in essential oils	Thin and less aromatic
Juice Acidity (Citric Acid Content)	Slightly lower acidic	Higher acidity and sharper taste
Aroma	Strong, citrus aroma due to the presence of a high amount of essential oil	Pleasant but milder aroma
Flowering and Fruiting	Flowers: Feb-April Fruits: Oct-Dec	Flowers: Jan-March Fruits: July-Sep
Economic Importance	Used for making juices, pickles, essential oils, and traditional medicines.	Used for making beverages, pickles and for citric acid production



Figure 1. **(a).** Hill lemon (*Citrus pseudolimon* Tanaka), **(b).** Lemon (*Citrus limon*).

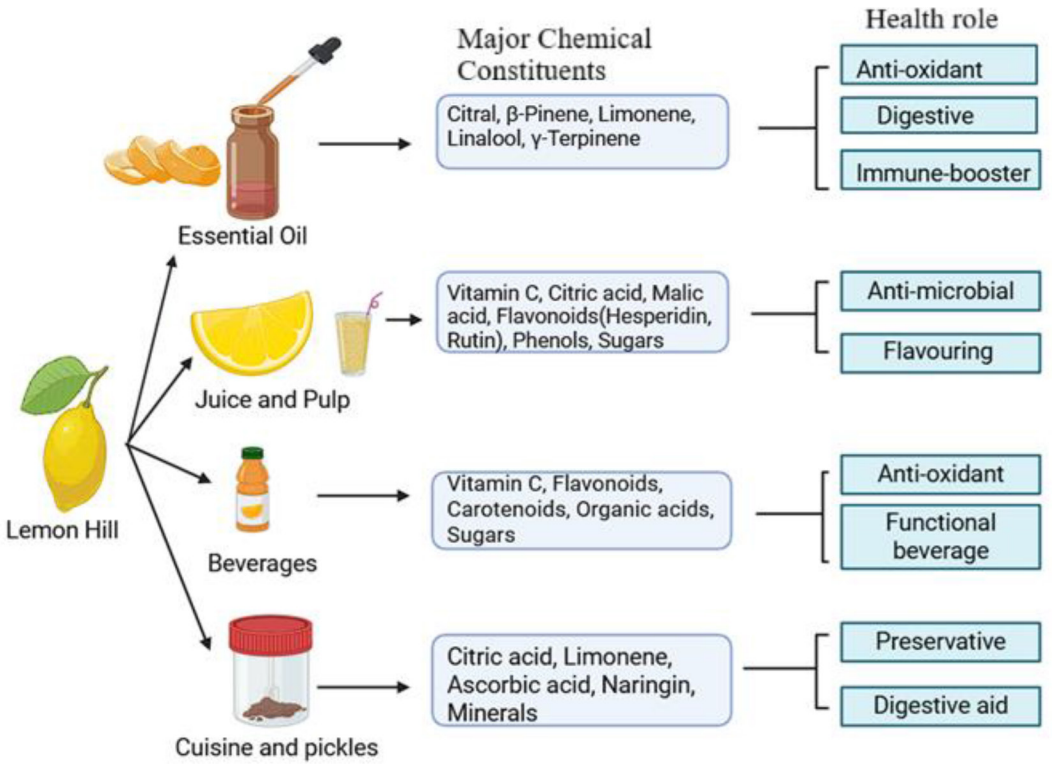


Figure 2. Major chemical constituents of Hill Lemon (*Citrus pseudolimon* Tanaka) and their associated health roles.

major constituents include limonene, citral, vitamin C, flavonoids, phenols, carotenoids, and organic acids. These contribute to antioxidant, antimicrobial, digestive, immune-supporting, flavouring, functional beverage, preservative, and digestive-aid properties (Figure 2).

4. Pharmacological Activities of *Citrus pseudolimon* Tanaka

Citrus pseudolimon Tanaka is a Himalayan citrus rich in phenolics, flavonoids, vitamin C, pectin, and essential oils dominated by terpenes such as limonene. Its bioactive constituents contribute to antioxidant, anti-inflammatory, antimicrobial, immunomodulatory, and antidiabetic properties. Organic acids such as citric and malic acids may support digestion and preservation, while flavonoids, phenolics, vitamins, and essential oils collectively contribute to its diverse pharmacological properties and traditional medicinal applications (Figure 3).

4.1 Antioxidant Activity

Hill lemon is a rich natural source of antioxidants that help protect the body against oxidative stress and cellular damage. Numerous bioactive substances, including vitamin C (ascorbic acid), flavonoids (hesperidin, naringin, rutin), phenolic acids (ferulic acid, caffeic acid, p-coumaric acid), and essential oils (limonene, citral, linalool), can be found in its juice, peel, and pulp. Together, these substances counteract dangerous molecules called free radicals, which cause inflammation, early ageing, and several chronic illnesses.

Citrus pseudolimon Methanolic Leaf Extract (CPMLE) and its *C. pseudolimon* ethyl acetate fraction (CPEALF) in streptozotocin-induced diabetic rats. Oral treatment with these preparations reduced oxidative stress and improved antioxidant defence, with increased Superoxide Dismutase (SOD) and reduced Glutathione (GSH) levels compared with untreated diabetic animals. At 400 mg/kg CPMLE, SOD and GSH activities reached 2.86 U/mg and 83.41µM, respectively, compared with 1.07 U/mg and 51.16µM in diabetic controls. These findings suggest that *C. pseudolimon* may exert antioxidant effects, in part, by strengthening endogenous antioxidant defences and reducing diabetes-associated oxidative stress[36,37].

Natural antioxidant enzymes including Glutathione Peroxidase (GPx), Catalase (CAT), and SOD are stimulated by the bioflavonoids in hill lemons. These enzymes are crucial for minimising oxidative damage by changing dangerous reactive oxygen species into innocuous molecules like oxygen and water[38].

4.2 Anti-inflammatory Activity

Hill lemon possesses strong anti-inflammatory properties due to the presence of bioactive phytochemicals such as flavonoids (hesperidin, naringin, rutin), limonoids, vitamin C, citral, and essential oils (limonene, linalool, β-pinene). By reducing the synthesis of pro-inflammatory mediators and boosting antioxidant defences, these substances aid in controlling the body's inflammatory reactions. The anti-inflammatory mechanism of hill lemon mainly works through two main pathways in preventing inflammation:

4.3 Inhibition of Inflammatory Enzymes

Enzymes like Cyclooxygenase (COX) and Lipoxygenase (LOX), which transform arachidonic acid into prostaglandins and leukotrienes, act as important mediators of pain, redness, and swelling and are the primary causes of inflammation in the body. The flavonoids and limonoids found in hill lemons interfere with the active site of COX and LOX enzymes, helping to prevent the conversion. As a result, there is a reduction in the production of prostaglandins and leukotrienes, which reduces pain and tissue inflammation by suppressing COX and LOX enzyme activity[39,40].

4.4 Suppression of NF-κB Pathway

The nuclear factor-kappa B (NF-κB) pathway is essential for regulating inflammatory genes. It produces more inflammatory cytokines, including TNF-α, IL-1β, and IL-6, when activated.

Hill lemons contain flavonoids, particularly naringin and hesperidin, which suppress Nuclear Factor kappa light chain enhancer of activated B cells (NF-κB) activation and stop it from moving to the nucleus, where it would typically cause the production of inflammatory genes[41,42].

4.5 Anti-diabetic Activity

The anti-diabetic activity of hill lemon is mainly attributed to its bioactive substances like flavonoids, phenols, Vitamin C, and essential oils, which are present in different parts such as peel, seed and leaves. Together, these organic components enhance overall metabolic balance and control blood glucose levels.

Hill lemon helps in lowering the blood sugar level by suppressing carbohydrate-digesting enzymes like

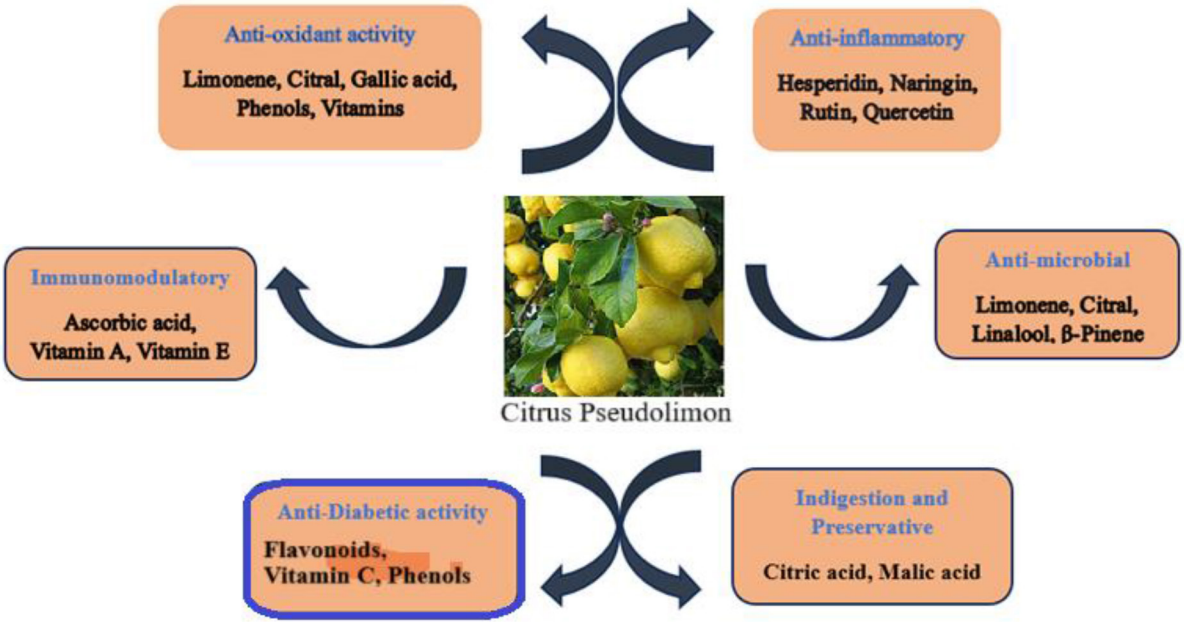


Figure 3. Bioactive compounds and pharmacological activities of *Citrus pseudolimon*.

α-amylase and α-glucosidase, which slow down the breakdown and absorption of sugars in the intestine[43]. This prevents abrupt rises in blood sugar following meals by causing a steady release of glucose into the system. Its flavonoids, such as eriocitrin, naringenin, and hesperidin, enhance insulin sensitivity and secretion, enabling the body to use glucose more efficiently[44]. Additionally, the antioxidant components in hill lemon boost the generation of insulin by shielding the pancreatic β-cells from oxidative damage brought on by free radicals.

The *in vitro* studies of hill lemon peel and juice extract showed significant inhibition of α-glucosidase and α-amylase enzymes, as examined in methanolic leaf extract and ethyl acetate fraction in type-2 diabetes, compared to acarbose, a standard drug. The *in vivo* antidiabetic studies were evaluated in streptozotocin-induced diabetic rats, which were induced by a single intraperitoneal injection. Oral administration of the lemon peel extract produced a remarkable improvement in several key biochemical and physiological parameters related to diabetes. The treatment significantly lowered fasting blood glucose levels, demonstrating the potent hypoglycemic action of the extract. This implies that by improving glucose utilisation and lowering its excessive buildup in the bloodstream, the bioactive chemicals found in lemon peels aid in blood sugar regulation. Furthermore, the extract significantly raised blood insulin levels, indicating that it may activate pancreatic β-cells or enhance their ability to secrete insulin. Normal glucose homeostasis is maintained in part by this increased insulin output[45].

4.6 Antimicrobial Activity

One of the most important biological characteristics of the Hill Lemon (*C. pseudolimon*) is its antibacterial action, which is mostly due to the abundance of essential oils, flavonoids, phenolic compounds, and organic acids found in the peel, juice, and seeds. Hill Lemon is a useful natural antibacterial agent because these bioactive components cooperate to prevent the growth of different bacteria, fungi, and other harmful pathogens. The essential oils extracted from the peel of Hill Lemon, particularly limonene, citral, β-pinene, linalool, and terpinene, exhibit strong bactericidal and fungicidal properties[46,47].

To assess the antimicrobial efficacy, the researchers employed the agar well diffusion method, a common laboratory procedure in which wells are made in agar plates inoculated with microbial cultures, and the plant extract is placed into these wells to examine inhibition zones. The extract of lemon peel was tested against a Gram-positive bacterium (*Staphylococcus aureus*) and a Gram-negative bacterium (*Escherichia coli*). The findings demonstrated a strong inhibitory action against every microbe examined, suggesting that the lemon peel extract possesses strong, all-around antibacterial properties[48]. A comparative study of the *C. pseudolimon* peel and juice extracts against *S. aureus* and *E. coli* showed greater antimicrobial activity in the juice extract, with inhibition zones of 18 and 24mm, respectively. Although the peel contained higher levels of flavonoids, phenolics, and tannins, it showed no significant antibacterial activity against the tested strains[49].

4.7 Immunomodulatory Activity

The body's natural defence system against illnesses, poisons, and viruses is the immune system. Coordination of multiple biological processes, such as cellular immunity, inflammatory control, and antioxidant defence, is necessary for an effective immune response[50]. Hill Lemon (*C. pseudolimon*) has immunomodulatory properties due to its rich proportion of vitamins, minerals, and phytochemicals. Vitamin C, flavonoids (including hesperidin, naringenin, and eriocitrin), phenolic acids, and essential oils are all abundant in hill lemons and are crucial for boosting immune function and preserving immunological homeostasis[51]. One of the most prevalent ingredients in hill lemons, vitamin C, strengthens the body's defences against infection by boosting the generation and function of white blood cells, such as lymphocytes and phagocytes. Additionally, it functions as a potent antioxidant, neutralising free radicals and lowering oxidative stress on immune cells to preserve their effectiveness[52].

Furthermore, by preventing the growth of dangerous germs and stimulating immune cell activity, the essential oils of hill lemons, such as limonene and citral, show immune-boosting properties. By encouraging good bacteria, the presence of bioactive substances also promotes gut health and enhances immunological control[53].

5. Conclusion

Citrus pseudolimon (Hill Lemon/Galgal) is an underutilised Himalayan citrus species with considerable nutritional, phytochemical, medicinal, and pharmacological potential. The available literature indicates that its fruits, peel, leaves, seeds, and essential oils contain diverse bioactive constituents, including phenolics, flavonoids, vitamin C, terpenoids, limonoids, and essential oils. These constituents are associated with promising antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and other biological activities. In particular, preclinical studies have demonstrated antioxidant and antidiabetic effects in experimental models, while antimicrobial investigations have shown activity of the juice extract against *S. aureus* and *E. coli*. Despite these encouraging findings, the pharmacological evidence for *C. pseudolimon* remains at an early stage and is substantially less developed than that for extensively studied citrus species.

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Author Contribution

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