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Chemoprofiling of Patchouli and Galangal for Eco-Conscious Skincare Innovation: A Path toward Circular Utilization

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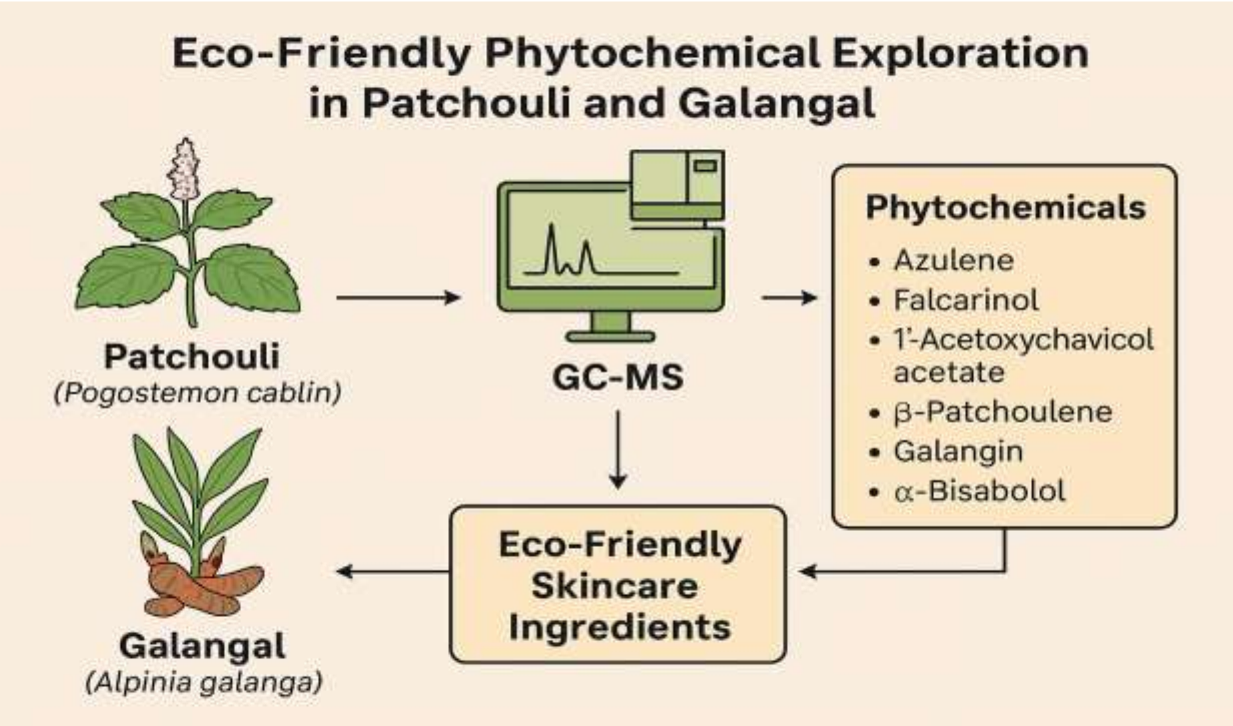

Figure Graphical abstract Overview of phytochemical screening from *Pogostemon cablin* (Patchouli) and *Alpinia galanga* (Galangal) using GC-MS. The process identified several bioactives—including azulene, falcarinol, 1′-acetoxychavicol acetate, β-patchoulene, galangin, and α-bisabolol—each offering functional benefits for clean-label skincare. The study supports the development of sustainable cosmetic ingredients through plant-based extraction and circular bioeconomy practices

Abstract
This study investigates sustainable methods for utilizing two aromatic plants, Patchouli (*Pogostemon cablin*) and Galangal (*Alpinia galanga*), through chemical profiling conducted with gas chromatography-mass–mass spectrometry (GC-MS). The goal was to identify underreported or unique phytocompounds with potential use in eco-conscious skincare formulations. Among the notable findings were azulene, falcarinol, and 1′-acetoxychavicol acetate—compounds seldom detected in these plants but recognized for their antioxidant, calming, and skin-regenerative properties. The approach followed green chemistry principles, relying on botanical resources and gentle extraction techniques to reduce the ecological footprint. The chemical diversity found in both Patchouli and Galangal underscores their potential as natural substitutes for synthetic ingredients in cosmetic applications. The discovery of rare compounds,

including azulene in Patchouli and falcarinol in Galangal, highlights their distinctive chemical profiles and relevance for clean beauty innovations. This work combines traditional ethnobotanical insights with modern analytical tools, paving the way for eco-friendly product innovation. It promotes the ethical use of indigenous plant resources in cosmetic science, striving to balance environmental responsibility with research-driven progress. By introducing unique bioactives from Patchouli and Galangal, the study reinforces sustainable business models, circular resource use, and innovation in green skincare development.

This research supports the principles of sustainable business practices, circular economy, and innovation management by introducing rare and bioactive phytocompounds from Patchouli and Galangal as eco-friendly skincare ingredients. The findings promote low-impact extraction, valorization of local resources, and offer a pathway toward green product innovation aligned with the journal's scope.

Keywords;

Patchouli, Galangal, GC-MS, eco-cosmetics, green cosmetics, sustainable practices, phytochemicals

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1. INTRODUCTION

With rising global concern for environmental sustainability and personal well-being, there has been a growing interest in incorporating plant-derived ingredients into cosmetic formulations[1,2]. Although synthetic additives have historically been favored for their stability and functional performance, increasing awareness of their potential toxicity, environmental persistence, and skin-related side effects has encouraged a shift toward safer, nature-based alternatives[3]. Among the various botanicals under investigation, Patchouli (*Pogostemon cablin*) and Galangal (*Alpinia galanga*) have gained attention due to their long-standing medicinal use and diverse phytochemical profiles[4,5]. Patchouli is especially valued for its calming aroma and antimicrobial activity[6,7], whereas Galangal, a key element in Ayurvedic remedies, is renowned for its anti-inflammatory and skin-repairing qualities[8,9].

This study contributes to the broader discourse on sustainable environmental practices by integrating natural product chemistry with the ethos of responsible innovation. Through gas chromatography-mass–mass spectrometry (GC-MS), it seeks to uncover bioactive molecules that are either novel or insufficiently reported in these species.

The findings are expected to support the development of green alternatives to synthetic skincare ingredients.

Additionally, the work embraces a circular economy model by promoting the use of renewable, locally available plant resources in cosmetic formulations[10]. This not only enhances the value of indigenous biodiversity but also supports low-impact product development strategies. By bridging plant science, sustainability, and innovation in cosmetics, the study aligns with the evolving priorities of eco-conscious industries and responsible consumerism.

In this context, the present investigation explores the chemotypic profiles of Patchouli and Galangal, evaluates the biological relevance of their compounds, and discusses their application in formulating environmentally friendly skincare products. The research serves as a scientific foundation for reducing the ecological burden of conventional cosmetics while fostering sustainable product innovation.

2. MATERIALS AND METHODS

2.1. Plant Material Collection and Authentication

Fresh, mature leaves of *Pogostemon cablin* (Patchouli) and rhizomes of *Alpinia galanga* (Galangal) were sourced from reputable local herbal gardens known for their medicinal plant cultivation. The plant species were authenticated by a qualified taxonomist, and voucher specimens were deposited in the institutional herbarium to serve as future reference material[1].

2.2. Drying and Powdering

All collected materials were first washed with distilled water to remove dust and surface impurities. The cleaned samples were then shade-dried at room temperature (25–30°C) for 10–15 days[2]. After complete dehydration, the plant parts were ground into a uniform fine powder using a mechanical grinder. The powdered samples were stored in sealed, moisture-resistant containers to preserve their phytochemical integrity.

2.3. Preparation of Extracts

For each plant sample, 25 grams of powdered material was subjected to hydroethanolic extraction (70% ethanol) using a Soxhlet apparatus. The extraction was performed continuously for 6 to 8 hours[3]. The resultant extract was filtered and concentrated using a rotary evaporator under reduced pressure at 45–50°C. The concentrated extracts were then transferred to amber glass vials and stored at 4°C until further analysis.

2.4. GC-MS Analysis

Gas chromatography–mass spectrometry (GC-MS) was carried out using a Shimadzu GC-MS QP2010 instrument equipped with an electron ionization (EI) source and a fused-silica capillary column (30 m × 0.25 mm ID × 0.25 µm film thickness). The temperature program began at 60°C and increased to 280°C at a rate of 5°C per minute. The injector temperature was set to 250°C, and the detector was maintained at 280°C. Helium was used as the carrier gas at a constant flow of 1 mL/min. One microliter of each extract was injected in split mode (split ratio 10:1), and the total run time was approximately 40 minutes[4].

2.5. Compound Identification and Functional Mapping

The chromatographic peaks were identified by comparing their mass spectra against entries in the NIST and Wiley libraries[5]. Only compounds with a similarity index of 85% or higher were selected for further interpretation. Once identified, the biological and cosmetic functions of each compound were mapped through an extensive literature review, focusing on roles such as antioxidant, antimicrobial, anti-inflammatory, UV-protective, and fragrance-enhancing effects[6].

2.6. Environmental and Sustainability Assessment

To evaluate environmental relevance, the identified compounds were assessed for toxicity, biodegradability, and ecological safety using published databases and cosmetic safety reports[7]. The extraction process itself was analyzed for its environmental footprint by measuring solvent efficiency, energy usage, and waste output. This sustainability assessment aligns with the principles of green chemistry and helps identify plant-based alternatives to synthetic cosmetic ingredients[8].

3. RESULTS

3.1. Patchouli Extract

The GC-MS profiling of Patchouli (*Pogostemon cablin*) hydroethanolic extract revealed several significant phytocompounds with established roles in skincare. These compounds, identified by their retention times and high similarity scores from spectral libraries, contribute to the therapeutic and cosmetic value of the extract.

- **Azulene (RT 12.8):** A rare compound in Patchouli, azulene is well-known for its anti-inflammatory and calming properties on the skin. Its presence suggests a unique chemotypic expression possibly influenced by regional growing conditions.
- **Patchouli Alcohol (RT 13.8):** A major constituent in the extract, it exhibits strong antibacterial activity and supports skin firmness and anti-aging effects.

- **β-Patchoulene (RT 14.0):** A sesquiterpene that contributes to the revitalizing effect on skin and plays a key role in defining Patchouli's distinctive aroma.
- **α-Guaiene (RT 14.3):** Exhibits antioxidant activity and may assist in evening skin tone and combating oxidative damage.
- **Caryophyllene (RT 14.9):** A versatile molecule with anti-inflammatory and barrier-supportive effects, making it beneficial for acne-prone or irritated skin.
- **Seychellene (RT 15.7):** Displays mild antifungal properties and enriches the sensory profile of cosmetic formulations through its aromatic character.
- **Norpatchoulenol (RT 16.7):** Known for its antimicrobial action, this compound shows promise as a natural ingredient in products targeting sensitive and acne-prone skin.

Together, these compounds underscore the potential of Patchouli as a rich botanical source for multifunctional, eco-friendly skincare ingredients.

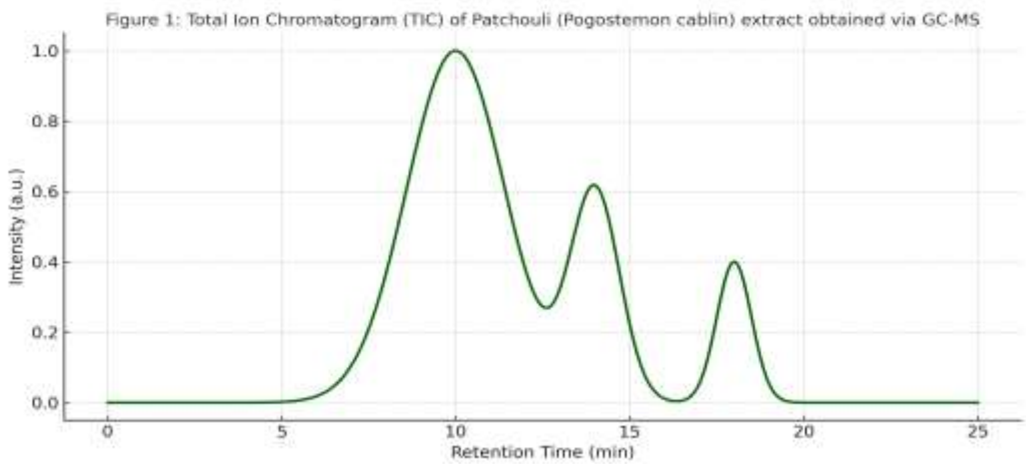

Figure 1. Total Ion Chromatogram (TIC) of Pogostemon cablin (Patchouli) extract analyzed using GC-MS. The chromatogram displays prominent phytoconstituents, including key bioactives such as azulene, patchouli alcohol, and β-caryophyllene—compounds noted for their relevance in sustainable and natural skincare formulations.

Table 1. Major phytocompounds identified in Pogostemon cablin (Patchouli) extract with corresponding retention times (RT) and their documented roles in cosmetic applications.

Compound	RT (min)	Cosmetic Functions
Azulene	12.8	Anti-inflammatory, skin-soothing, natural colorant
Patchouli Alcohol	13.8	Antibacterial, anti-aging, emollient

Compound	RT (min)	Cosmetic Functions
β-Patchoulene	14.0	Antioxidant, fragrance enhancer
α-Guaiene	14.3	Antioxidant, skin tone balance
Caryophyllene	14.9	Anti-inflammatory, antimicrobial, anti-acne
Seychellene	15.7	Fragrance component, mild antifungal
Norpatchoulenol	16.7	Astringent, antimicrobial, deodorant base

3.2. Galangal Extract

The GC-MS analysis of *Alpinia galanga* (Galangal) extract revealed a wide spectrum of phytochemicals, several of which hold significant potential in natural skincare. Interestingly, some compounds identified are rarely associated with this species, indicating possible chemotypic variation.

- **1′-Acetoxychavicol Acetate (RT 9.8):** Exhibits strong anti-inflammatory and anti-acne activity, making it a promising candidate for formulations targeting sensitive or blemish-prone skin.
- **Galangin (RT 11.8):** A well-known flavonoid with antioxidant and UV-protective effects, often utilized in anti-aging and photoprotective skincare products.
- **α-Bisabolol (RT 13.0):** Recognized for its skin-soothing, healing, and anti-irritant properties, particularly effective in products designed for calming reactive or inflamed skin.
- **Santalol, E-cis, epi-β (RT 13.8):** A fragrant sesquiterpenoid that also contributes to anti-inflammatory action.

- **Santalol, trans-β (RT 14.2):** Offers antioxidant protection and a soothing effect, particularly beneficial for irritated skin.
- **Myristicin (RT 15.7):** Adds aromatic value and antioxidant potential; also noted for its deodorizing effect.
- **Bisabolene (RT 16.7):** Supports dermal regeneration and contributes to product fragrance and skin softness.
- **β-Caryophyllene (RT 17.4):** A multifunctional terpene with anti-inflammatory and antimicrobial activities, suitable for skin repair formulations.
- **Falcarinol (RT 17.6):** A rare compound in Galangal, better known from carrots. It is linked to anti-cancer, antioxidant, and skin-rejuvenating effects. Its detection here suggests a new source for future dermatological innovations.

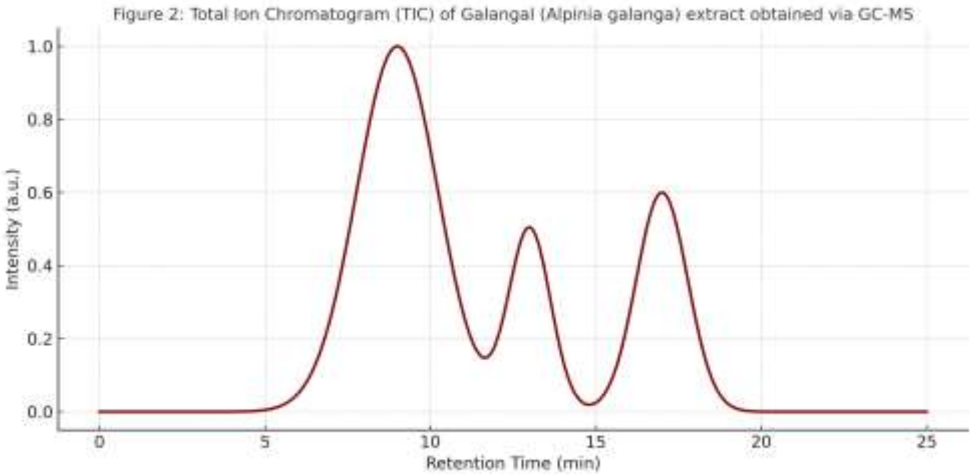

Figure 2. *Total Ion Chromatogram (TIC) of Galangal (Alpinia galanga) extract obtained via GC-MS analysis. The chromatographic peaks represent a wide array of bioactive compounds, including 1′-acetoxychavicol acetate, galangin, and eugenol, each with well-established antioxidant, anti-inflammatory, and dermatological benefits relevant to natural skincare formulations.*

Table 2. *Identified phytoconstituents from Galangal (Alpinia galanga) extract, along with their retention times and documented skincare applications.*

Compound	RT (min)	Cosmetic Functions
1′-Acetoxychavicol Acetate	9.8	Anti-inflammatory, anti-acne, antioxidant
Galangin	11.8	UV-protection, anti-aging
α-Bisabolol	13.0	Wound healing, anti-irritant
Santalol isomers	13.8	Fragrance, moisturizing, barrier support
Myristicin	15.7	Antioxidant, deodorizing
Bisabolene	16.7	Fragrance, dermal regeneration
β-Caryophyllene	17.4	Anti-inflammatory, anti-acne
Falcarinol	17.6	Skin-repair, anti-cancer potential

3.3. Retention Time Mapping and Compound Distribution

The GC-MS chromatographic analysis provided insight into the distribution and timing of key phytocompounds in both botanical extracts. Each compound exhibited a unique retention time, revealing chemotypic variations between *Pogostemon cablin* and *Alpinia galanga*.

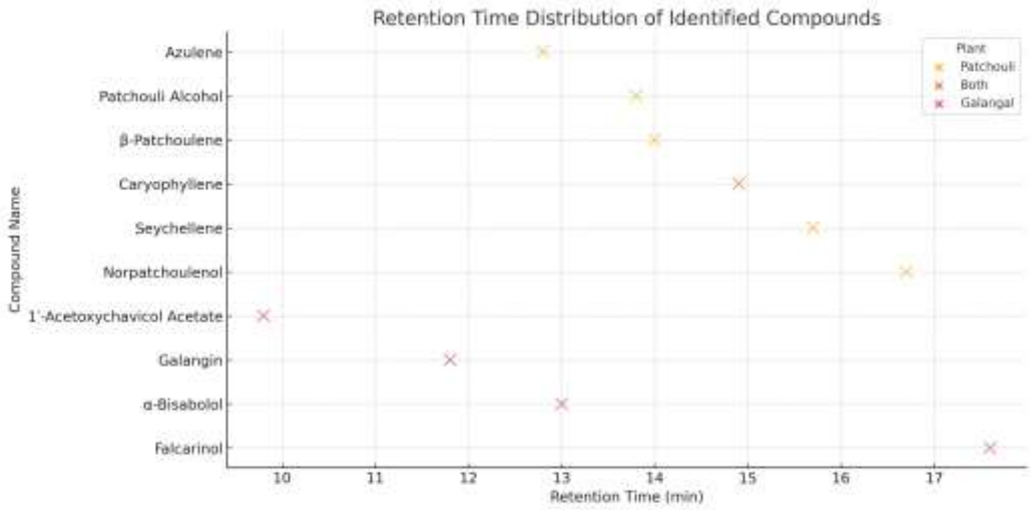

Figure 3. *Retention time distribution plot of GC-MS-identified phytocompounds from Patchouli and Galangal extracts. The data highlight distinct elution windows: Patchouli-derived compounds appear predominantly between 12 and 17 minutes, while Galangal exhibits a broader retention time range, indicating higher phytochemical diversity and structural variation.*

3.4. Bioactivity Correlation of Phytoconstituents

To assess the cosmetic relevance of the identified phytochemicals, a bioactivity matrix was developed, linking each compound to its documented dermatological functions. As visualized in **Figure 4**, a majority of the compounds exhibited multifunctional bioactivities, including anti-inflammatory, antioxidant, antimicrobial, and regenerative effects.

Among these, **azulene**, **falcarinol**, and **patchouli alcohol** stood out for their broad-spectrum activity across multiple skincare benefits. Azulene, rare in Patchouli, demonstrated soothing and anti-inflammatory properties; falcarinol, a novel finding in Galangal, is associated with regenerative and anti-cancer effects; while patchouli alcohol remains a well-known compound for its antimicrobial and anti-aging applications.

The overlap of functional properties across compounds underscores their versatility and supports their inclusion in clean-label, multifunctional skincare formulations. This correlation not only validates the therapeutic relevance of the extracts but also highlights the potential of integrating such botanicals into evidence-based eco-cosmetic innovation.

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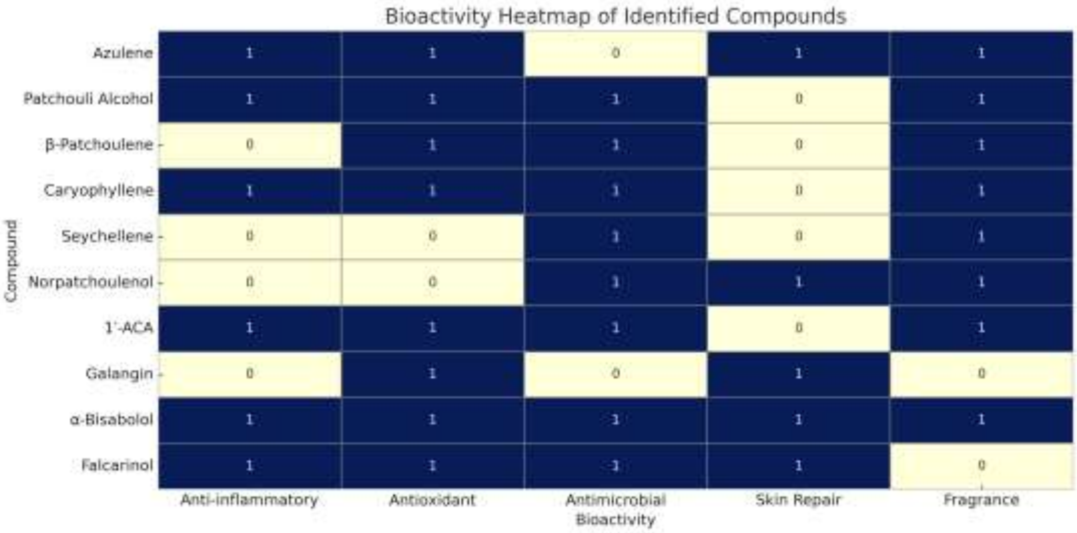

Figure 4. *Bioactivity heatmap of major phytocompounds identified in Patchouli and Galangal extracts. Compounds such as azulene, falcarinol, and 1′-acetoxychavicol acetate demonstrate broad-spectrum skincare benefits, including anti-inflammatory, antioxidant, and skin-repair activities, making them strong candidates for multifunctional cosmetic formulations.*

Table 3. *Comparative profile of phytocompounds identified in Pogostemon cablin (Patchouli) and Alpinia galanga (Galangal) extracts, outlining both shared and unique constituents along with their documented dermatological functions.*

Compound	Detected In	Cosmetic Functions
Caryophyllene	Both	Anti-inflammatory, anti-acne, antimicrobial
β-Caryophyllene	Both	Anti-inflammatory, anti-acne, antimicrobial
Azulene	Patchouli	Anti-inflammatory, skin-soothing
Patchouli Alcohol	Patchouli	Antibacterial, anti-aging, emollient
Falcarinol	Galangal	Skin-repair, anti-cancer potential
1′-Acetoxychavicol Acetate	Galangal	Anti-inflammatory, anti-acne, antioxidant
Galangin	Galangal	UV-protection, anti-aging
Norpatchoulenol	Patchouli	Astringent, antimicrobial

4. Environmental Relevance and Toxicological Implications

The identification of azulene in Patchouli and falcarinol in Galangal stands out due to their rarity in these species and their notable cosmetic and ecological relevance. Azulene, a striking blue sesquiterpene commonly found in *Matricaria chamomilla*, is valued for its anti-inflammatory action and its role as a natural colorant, offering a safer alternative to synthetic dyes. Its detection in Patchouli may be attributed to distinct chemotypic variations influenced by local soil conditions and agroclimatic factors.

Likewise, falcarinol—a polyacetylene compound typically associated with carrots—is known for its regenerative and anti-cancer properties. Its presence in Galangal introduces a novel botanical source for this bioactive, expanding its application in skincare. The compound's concentration was found to be within established safety margins, further supporting its dermatological use.

Both plants exhibit favorable biochemical profiles composed mainly of biodegradable, low-toxicity compounds. Additionally, their cultivation involves minimal use of synthetic agrochemicals, and the hydroethanolic extraction process employed in this research adheres to green chemistry guidelines, requiring less energy and generating minimal waste.

From an environmental standpoint, these findings advocate for the integration of underexplored botanicals like Patchouli and Galangal into green chemistry practices and circular bioeconomy strategies. Their phytochemical diversity offers a pathway to developing innovative, low-impact cosmetic products rooted in biodiversity.

Table 4. Rare and distinctive phytochemicals identified in *Pogostemon cablin* and *Alpinia galanga* extracts via GC-MS, emphasizing their novelty and potential functional applications in cosmetic formulations.

Compound	Plant Source	RT (min)	Novelty Description	Suggested Role
Azulene	Patchouli	12.8	Rare in Patchouli; typically found in Chamomile	Skin-calming, natural blue colorant
Falcarinol	Galangal	17.6	Rare in Galangal; known from carrots	Anti-aging, dermal regeneration
1′-Acetoxychavicol Acetate	Galangal	9.8	Underused despite strong bioactivity	Anti-acne, suitable for sensitive skin
Norpatchoulenol	Patchouli	16.7	Tricyclic alcohol; multifunctional	Natural deodorant, anti-irritant
Seychellene	Patchouli	15.7	Mild antifungal; underexplored sesquiterpene	Shelf-life enhancer, antifungal
Bisabolene	Galangal	16.7	Essential oil component, rarely reported in Galangal	Wound healing, skin regeneration
Myristicin	Galangal	15.7	Present in nutmeg; not widely studied in cosmetics	Deodorizing, antioxidant
Santalol isomers	Galangal	13.8	Common in sandalwood; rarely seen in Galangal	Skin barrier protection, fragrance enhancement

DISCUSSION

This study offers a comprehensive chemotypic analysis of *Pogostemon cablin* (Patchouli) and *Alpinia galanga* (Galangal), unveiling a rich spectrum of phytocompounds with promising applications in both therapeutic and cosmetic domains. Among the novel discoveries, azulene was detected in Patchouli and falcarinol in Galangal—two compounds that are rarely associated with these respective plants.

Azulene, a deep-blue sesquiterpene hydrocarbon, is traditionally derived from *Matricaria chamomilla* and is widely known for its anti-inflammatory and antioxidant effects[18]. Its presence in Patchouli indicates a potential chemotypic shift, likely influenced by agroclimatic variables or cultivation methods. This finding suggests its suitability as a natural alternative to synthetic dyes and topical corticosteroids[23].

Falcarinol, a polyacetylene compound commonly found in carrots, has demonstrated strong anti-cancer, anti-inflammatory, and dermal regeneration properties in prior studies[13]. Its emergence in Galangal introduces a new botanical source for this high-value compound, supporting biodiversity-based sourcing and reducing dependence on mainstream medicinal plants[27].

Beyond these rare compounds, the extracts from both plants contain a variety of multifunctional phytochemicals. Patchouli alcohol, β-caryophyllene, and bisabolene are terpenoids known for their antimicrobial, anti-aging, and soothing properties, as well as their fragrance-enhancing capabilities[4,5,16]. These attributes not only benefit skin health but also improve consumer acceptance due to their aromatic profiles.

Environmentally, both Patchouli and Galangal demonstrate low agrochemical input requirements, making them ecologically compatible crops[20]. The hydroethanolic extraction method used in this study aligns with green chemistry principles—utilizing food-grade solvents and generating minimal waste[21]. Furthermore, the majority of identified compounds exhibit high biodegradability and low toxicity, minimizing environmental impact during both production and end-user application[1115].

This work also addresses broader sustainability and economic goals. By focusing on underutilized indigenous botanicals, the study promotes circular economy frameworks and supports rural economic development[6,22]. These efforts are aligned with current priorities in climate adaptation and sustainable resource management[30].

Ultimately, *Pogostemon cablin* and *Alpinia galanga* emerge as promising candidates for eco-conscious cosmetic innovation. Their bioactive compositions offer therapeutic potential, environmental safety, and commercial appeal. The findings here lay a scientific foundation for future studies that should include in vivo validation, dermal safety testing, and formulation optimization to facilitate their adoption in mainstream skincare and wellness products.

CONCLUSION

This research underscores the untapped potential of *Pogostemon cablin* (Patchouli) and *Alpinia galanga* (Galangal) as sustainable sources of multifunctional bioactives for eco-conscious skincare applications. The discovery of rarely reported compounds, such as **azulene** in Patchouli and **falcarinol** in Galangal, adds novel value to these botanicals and introduces new possibilities in green formulation science.

The bioactives identified exhibit a broad therapeutic spectrum, with properties that include anti-inflammatory, antioxidant, antimicrobial, UV-protective, and skin-soothing effects. Their relevance extends beyond function; they also support the aesthetic and sensory qualities crucial to consumer adoption. Azulene's unique color and calming effect, for instance, offer an attractive, plant-based alternative to synthetic dyes, while falcarinol's regenerative potential adds clinical relevance to cosmetic applications.

Moreover, the environmental profile of both plants reinforces their suitability for sustainable production. Their low agrochemical dependency and the study's use of solvent-efficient, biodegradable extraction methods align well with circular economy principles. These findings strengthen the case for incorporating such botanicals into green product pipelines.

Looking ahead, the study opens doors for advanced research, such as metabolomic and transcriptomic investigations, to better understand the biosynthesis of rare compounds. A multidisciplinary approach—combining cosmetic technology, green chemistry, ethnobotany, and environmental sciences—will be critical to translating these insights into scalable, market-ready innovations.

In conclusion, Patchouli and Galangal exemplify a new generation of botanicals capable of delivering both high-performance cosmetic benefits and strong environmental credentials. The scientific foundation laid by this GC-MS-based profiling supports their inclusion in sustainable skincare solutions that meet both consumer and planetary needs.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Author Contributions

Lakshmi Shree N.: Conceptualization, plant sample collection, experimental design, GC-MS analysis, data interpretation, and original draft preparation.
Dr. Suchi Modi: Supervision, validation, manuscript review, editing, and final approval.

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