

Phytochemical constituents of *Lallemantia royleana* (balangu) essential oil: A review

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ABSTRACT: The aromatic plant *Lallemantia royleana* which is typically named as balangu in the Lamiaceae family. It is an abundant source of biologically active compounds such as terpenoids. Owing to the expanding attention in its phytochemical profile and prospective pharmacological effects, the current review aims to summarize some of crucial compounds in essential oil of *Lallemantia royleana*. A narrative literature search was conducted using PubMed, Scopus, Web of Science, and Google Scholar with the keywords "*Lallemantia royleana*", "essential oil", "GC-MS", "volatile compounds", and "biological activities" covering studies published between 2003 and 2025. The present research was reviewed to detect the main volatile oil chemicals and outline their documented pharmacological properties. The reviewed research frequently identified some of crucial chemicals which are classified as oxygenated terpenoids and are found majorly in the essential oils of *Lallemantia royleana* (e.g., trans-pinocarvyl acetate, pinocarvone, verbenone, and β -citral). They are assumed to play a part in the herb antioxidant, antimicrobial (antifungal and antibacterial), and sedative properties. However, the biological participation of single chemical and their prospective synergistic interplay are still to be described. The evidence outlined in the current review is mainly obtained from phytochemical analysis of essential oil in the plant (GC/MS) and in vitro experimental study. This review has some restrictions such as its narrative pharmacological activity according to data collected from previously published studies, the reviewed approach, the lack of a systematic literature selection, selection method, and the small number of available researches. Overall, the existing evidence indicates that *Lallemantia royleana* essential oil is an encouraging source of biologically active compounds with prospective therapeutic and industrial utilizations. However, more consistent phytochemical assessments and properly structured clinical research are needed to validate its effectiveness and safety profile.



Keywords: *Lallemantia royleana*, balangu, essential oil, phytochemicals, monoterpenes, biological activity

1. INTRODUCTION

Natural sources have served as therapeutic reservoirs for thousands of years, and many contemporaries from bioactive compounds initially identified through traditional medical practices. Medicinal plants continue to play a vital role in health care worldwide, particularly in developing countries, where more than 80% of population relies on plant-based remedies for primary health needs [1]. *Lallemantia royleana*, commonly known as balangu and local referred to Tukhmalanga in Pakistan belong to the family lamiaceae (Labiatae). This important medical species is indigenous to tropical regions including Afghanistan, Pakistan, and India. In Pakistan its seeds are extensively cultivated especially in areas such as Chistian, Attock and Layyah. The plants are also distributed across several countries including (Turkey, Iran, and Western Siberia in the Russian Federation) [2-5]. Traditionally, the plant have been utilized in a wide range of herbal formulations due to their calming, cooling-effect, sedative, and gastrointestinal characteristics. Conventional practices have also incorporating the regulation of respiratory ailments, inflammatory conditions, and skin-associated disorders [6–15]. However, these ethnomedicinal utilizations mainly reflect traditional experience, and numerous of the documented therapeutic activities need more confirmation through well-controlled scientific evaluations. Latest studies have revealed that *L. royleana* incorporates volatile oils rich in volatile bioactive chemicals, which may play a part in

its documented biological properties. The chemical profile of these volatile oils has demonstrated significant variability among previous research, which may be linked with variations in geographical location, climatic factors, and extraction processes. Many volatile components found in the oil have been documented to demonstrate pharmacological effects, incorporating antioxidant, antimicrobial, and anti-inflammatory effects, revealing that their valuable participation in the pharmacological implications of this plant. In spite of the growing attention in *L. royleana*, an extensive evaluation combining the predominant volatile chemicals detected in its essential oil, their biological importance, and the restrictions of present evidence are still limited. In addition, available researches are frequently established through the chemical profiling and preliminary in vitro investigation, while additional evaluations are necessary to evaluate the biological effectiveness, safety profile, and significant utilizations. For this reason, this narrative review is designed to outline and explore the main chemical components detected in the volatile oils of *L. royleana*, with specific focus on usually detected chemicals, their valuable biological properties, variability among research, and the present restrictions in existing evidence. This review specifically concentrates on essential oil analysis and does not incorporate other extracts or non-volatile phytochemical components.



FIGURE 1- *Lallemantia royleana* [4]

2. LITERATURE SEARCH METHODOLOGY

This narrative review was derived from scientific publications carried out using electronic source, incorporating PubMed, Scopus, Web of Science, and Google Scholar. The survey was conducted up to [2025] using set of keywords such as "*Lallemantia royleana*", "essential oil", "GC-MS", "volatile compounds", and "biological activities". Pertinent primary articles and reviews examining the essential oil profile, chemical variation, and pharmacological activities of *L. royleana* were considered. Repeated, irrelevant, or inadequate valuable studies were omitted. The titles, abstracts, and whole texts of these studies were evaluated for applicability. No standardized quality evaluation was carried out, as this search describes a narrative review rather than a systematic review.

3. TAXONOMICAL CLASSIFICATION

Table 1. -Taxonomic classification of *Lallemantia royleana* (Benth) [4,5,8]

Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Lamiales
Family	Lamiaceae
Genus	<i>Lallemantia</i>
Species	<i>royleana</i>
Scientific name	<i>Lallemantia royleana</i>

4. PLANT FAMILY (LAMIACEAE)

The family Lamiaceae is also referred to as Labiatae commonly renowned as the mint or dead nettle family belongs to the sequence Lamiales. It comprises dicotyledonous flowering plants with a broad globe distribution particularly concentrated in the Mediterranean region and Southwest Asia. The expanded classifications of Lamiaceae include approximately 236 genera and between 6,900 and 7,200 species while the world checklist records 7,534 species. Members of this family are predominantly herbal, subshrubs or shrubs and are typically aromatic. The indumentum varies and is often composed of simple hairs or glandular hairs. Glandular dots are often scattered throughout the plant surface. The glandular hairs are responsible for the production and storage of essential oils. Stems are generally vertical, slantingly upward-growing or trailing. Leaves are typically simple and range from entire to deeply divided. They are commonly arranged opposite or in whorls. Bracts are typically leaf-like at the base and progressively diminish in size upwards becoming bracteole-like. Flowers are generally bisexual and zygomorphic though are rarely unisexual or actinomorphic. The fruit is most often composed of four dry nutlets. Seeds generally lack endosperm or contain only minimal amounts [16].

5. MORPHOLOGICAL CHARACTERISTICS

Lallemantia royleana is an annual herb that may be branched or un-branched from the base. The stems are erect, quadrangular and covered with dense, short, and retrorse glandular hair. The leaves are simple, oblong-obovate with a cuneate base and bear short hairs and scattered sessile oils gland on the lower surface. The flowers are arranged in clusters close to the leaf axillary regions. The calyx is tubular, ribbed, and covered with short glandular hair. The corolla is pale lilac to bluish or whitish to pink and slightly exceeds the calyx with shorter upper lip compared to the lower lip [17]. The aerial parts of the plant are shown in figure 2.



FIGURE 2. - Aerial parts and seeds of *Lallemantia royleana* [17]

6. SOME COMPOUNDS IN THE ESSENTIAL OILS OF *Lallemantia royleana* WITH THEIR PHARMACOLOGICAL ACTIVITIES

6.1 PINOCARVONE

Pinocarvone is an oxygenated bicyclic monoterpene ketone having the molecular formula $C_{10}H_{14}O$ and a molecular weight of approximately 150.22 g/mol. It is composed of a pinane skeleton possessing a ketone functional group and an exocyclic double bond, which participate to its distinctive chemical behavior. Pinocarvone has been recognized as an essential compound of many aromatic herbs and volatile oils, incorporating *Lallemantia royleana*, where pinocarvone was documented as one of the predominant chemicals of the volatile oil. The biological properties of purified pinocarvone have not been considerably assessed relative to other monoterpenes. Existing reports concerning its pharmacological importance is primarily obtained from research of essential oils compromising this chemical rather than from report of the isolated compounds. Therefore, investigated antimicrobial and other biological activities of such volatile oils cannot be specifically ascribed to pinocarvone alone. More studies are crucial to explicit its particular pharmacological criteria and mode of action [18].

6.2 TRANS-PINOCARVYL ACETATE

Trans-pinocarvyl acetate is a naturally occurring monoterpene ester known as a component of many volatile oil from aromatic and medicinal herbs. Modern reports have underlined its significant pharmacological influence because of its participation to the biological functions of volatile oils. Essential oils abundant in pinocarvyl acetate have shown encouraging antimicrobial effect against several pathogenic microorganisms, especially Gram-positive bacteria. Furthermore, pinocarvyl acetate-incorporating essential oils have demonstrated trypanocidal functions against

Trypanosoma cruzi, indicating significant employments in the growing of antiparasitic agents. In addition, nanoencapsulation reports have shown that formulations comprising pinocarvyl acetate may demonstrate progressive stability, improvement in biological activity, and reduction in cytotoxicity, encouraging its crucial utilization in pharmaceutical and nutraceutical employments. Although extra assessments are needed to verify its clinical effectiveness and tolerability, recent data reveal that pinocarvyl acetate is a bioactive natural chemical with important therapeutic effectiveness [19].

6.3. CARVACROL

Carvacrol (chemical name: 5-isopropyl-2-methylphenol) is a monoterpenoid phenol (a natural phenolic compound). The existence of a phenolic hydroxyl (OH) group contributes significantly to its biological activities, particularly its antimicrobial and antioxidant properties. Due to its hydrophobic (lipophilic) character, carvacrol can easily interact and disrupt the lipid membranes of bacterial and fungal cells. Numerous studies have demonstrated the antimicrobial efficacy of carvacrol against a broad spectrum of microorganisms, including *Staphylococcus aureus*, *Escherichia coli*, *Salmonella* spp, and *Shigella*. In addition, it exhibits antifungal activity against *Candida albicans* and several mold species by increasing membrane permeability and causing leakage of intracellular constituents. Traditionally, carvacrol-containing plants have been employed in ethnomedicine for the treatment of skin infections, wound healing, and oral microbial diseases. It has been reported to reduce oxidative stress through inhibition of lipid peroxidation and modulation of antioxidant enzymes such as superoxide dismutase (SOD), glutathione peroxidase (GPx), and catalase (CAT). Furthermore, it may suppress pro-inflammatory cytokines and regulate immune response [20].

6.4 P-CYMENE

p-Cymene is an aromatic hydrocarbon (alkylbenzene) with the chemical formula $C_{10}H_{14}$. Its structure consists of; a benzene ring, a methyl ($-CH_3$) group, and an isopropyl ($CH(CH_3)_2$) group in the para positions (opposite each other on the benzene ring). p-Cymene is officially evaluated as a flavoring agent in foods, and at accepted intake levels it poses no safety concerns. It occurs naturally in essential oils and plant-derived foods such as spices, herbs (e.g., cumin, thyme) and citrus peels, contributing to aroma and taste. Studies show p-cymene has antioxidant activity, reducing lipid peroxidation, and scavenging of reactive oxygen species (ROS) [21]. It exhibits antimicrobial effects against various microbes in laboratory settings [22].

6.5 VERBENONE

Verbenone is a naturally occurring organic compound classified as a monoterpene with a bicyclic ketone structure. IUPAC name: 4,6,6 trimethylbicyclo [3.1.1]hept-3-en-2-one. The structure of a bicyclic heptane skeleton with two chiral centers and an enone (α,β -unsaturated ketone) functional group. Chemically it consists of a rigid bicyclic ring system with a ketone group that contributes to its reactivity and strong odor profile. Verbenone hydrazine 3a-3e estimated an analgesic activity up on local administration of its ointment formula in the concentration of 2% w/w. Experimental models were subjected to chemically stimulated pain via subcutaneous injection of transient receptor potential vanilloid 1 (TRPV1) and transient receptor potential ankyrin (TRPA1) selective agonists—capsaicin and allyl isothiocyanate (AITC) with succeeding recognition of pain index. The compound also possesses anticonvulsant criteria which were detected by intravenous injection of 1% aqueous solution of pentylenetetrazol (PTZ) into a tail vein [23].

6.6 β -CARYOPHYLLENE

β -Caryophyllene ($C_{15}H_{24}$) is a bicyclic sesquiterpene hydrocarbon. The feature assumed to contribute to its biological activities is that it has an exceptional cyclobutane ring fused to a cyclohexane ring, this also give the structure a distinctive characteristics for cannabinoids receptor affinity. It acts as a targeted agonist of cannabinoid type-2 (CB2) receptor. This receptor has crucial roles in the immune and inflammatory control [24]. A marked anti-inflammatory effect was exhibited in some preclinical models through regulation of some mediators involved in the inflammatory processes such as tumor necrotic factor- α (TNF- α), interleukin1-beta (IL-1 β), and cyclooxygenase-1/2 (COX). This compound can decrease the generation of reactive oxygen species (ROS) and promoting the cellular defense mechanism, these effects resulting in considerable antioxidant properties. The compound also demonstrated antibacterial activity against some gram positive and gram negative bacteria [25].

Table 2. - Reported phytochemical constituents in the essential oil of *Lallemantia royleana* and their pharmacological activity compiled from different studies

Compound	Chemical classification	Percentage %	Plant material	method	Evidence type	Main pharmacological effect	References
Trans-pinocarvyl acetate	Monoterpene ester	26	Aerial parts	GC/MS	Essential oil	Antimicrobial	19,39
p-Cymene	Monoterpene hydrocarbon	0.21	Aerial parts	GC/MS	Isolated compound	Anti-inflammatory, antioxidant, and antimicrobial	22,40
Verbenone	Monoterpene ketone	7.1-16.4	Aerial parts	GC/MS	Individual stereoisomer of verbenol and verbenone	Antimicrobial	23,39
β -Caryophyllene	Sesquiterpene hydrocarbon	11	Aerial parts	GC/MS	Isolated compound	Anti-cancer, and antioxidant	25,39
1,8-Cineole (Eucalyptol)	Oxygenated monoterpene oxide	0.3	Aerial parts	GC/MS	Isolated compound	Expectorant and anti-inflammatory	26,39
β -citral	Monoterpene aldehyde	9.15	Aerial parts	GC/MS	Isolated compound	Antimicrobial and pesticide	27,40
β -cubebene	Sesquiterpene hydrocarbon	2.1-8.9	Aerial parts	GC/MS	Isolated compound	anti-inflammatory	28,39
β -pinene	Monoterpene hydrocarbon	1.5	Aerial parts	GC/MS	Isolated compound	Anti-inflammatory and antimicrobial	29,39
Carvacrol	Phenolic monoterpene	1.5-1.6	Aerial parts	GC/MS	Isolated compound	antimicrobial	30,40
Cis-carveol	Monoterpene alcohol	3.5-4.8	Aerial parts	GC/MS	Isolated compound	Antibacterial	31,39
E- β -Ocimene	Monoterpene hydrocarbhone	15.67	Aerial parts	GC/MS	Essential oil	Anti-inflammatory and antioxidant	32,40
Limonene	Monoterpene hydrocarbhone	0.38	Aerial parts	GC/MS	Isolated compound	Antioxidant and anti-inflammatory	33,40
Linalool	Monoterpene alcohol	3.4	Aerial parts	GC/MS	Isolated compound	Sedative, anti-inflammatory, and antioxidant	34,39
Nerol	Monoterpene alcohol	12.72	Aerial parts	GC/MS	Isolated compound	Antioxidant and calming	35,40
Pinocarvone	Oxygenated monoterpene ketone	20	Aerial parts	GC/MS	Essential oil	Antifungal and antioxidant	36,39
Terpinolene	Monoterpene hydrocarbon	1.1-2.7	Aerial parts	GC/MS	Isolated compound	sedative	37,39

* The abundances were taken from various studies and are not directly comparable because of the differences in the specimen, source, botanical materials, extraction processes, and analytical conditions.

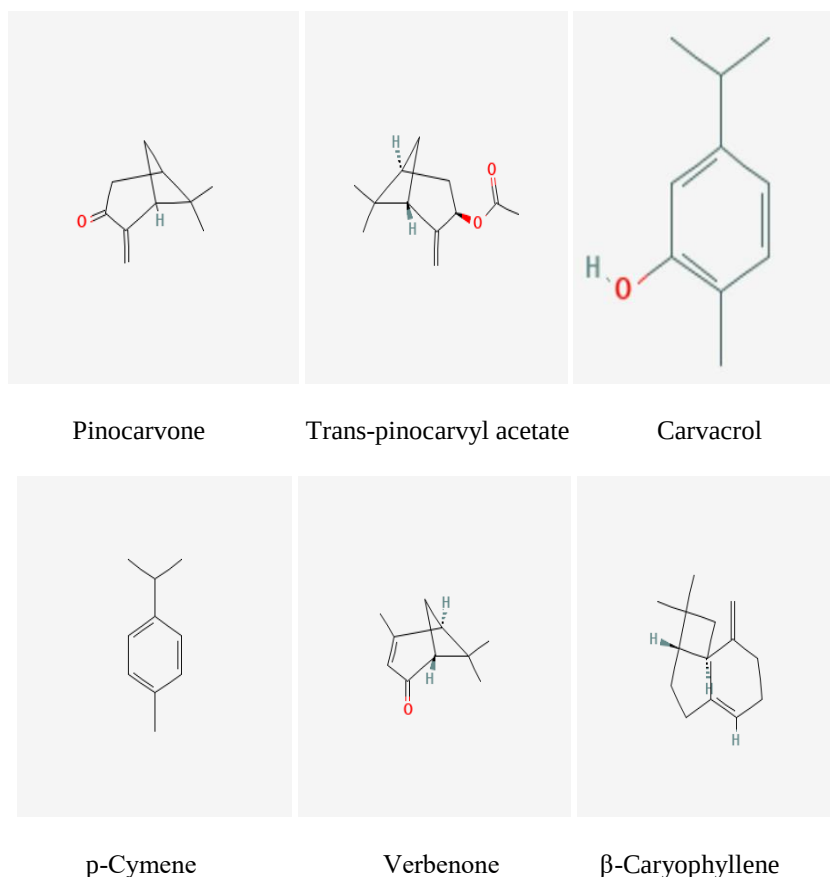


FIGURE 3. - Selected compounds reported in essential oils of *Lallemantia royleana* [18-21,23,24]

7. DISCUSSION

The essential oil of *Lallemantia royleana* is marked by the existence of diverse bioactive volatile components, as compiled in Table 2. As a whole, these molecules confer a diverse spectrum of pharmacological effects, implying that the essential oil serves as a valuable naturally occurring source of medicinal agents. Some compounds in the essential oil of *Lallemantia royleana* (e.g., pinocarvone, trans-pinocarvyl acetate, p-cymene, carvacrol, verbenone, and β -Caryophyllene) were discussed individually in the current review. The compounds highlighted in this review were chosen according to their recurrent detection in published phytochemical research of *L. royleana* essential oil and their documented pharmacological significance. Priority was given to chemicals supported by the present literature to deliver a comprehensive overview of the biological importance of the volatile oil. It should be emphasized that, for most discussed compounds, the present findings are originated from research on the isolated chemicals rather than analysis of volatile oils incorporating these compounds. Therefore, the documented biological effects should be considered cautiously and should not be assigned solely to the whole essential oil. The biological effects documented for these components include antioxidant, anti-inflammatory, antimicrobial, expectorant, sedative, and anticancer effects, which may together playing a part in the medicinal importance associated with the herbs [38]. In addition, the present researches are diverse concerning experimental approach, including in vitro analysis, in vivo studies, and a small number of researches of the whole essential oil. This methodological heterogeneity restricts cross-study comparison of pharmacological activities and precludes definitive conclusions regarding the pharmacological effectiveness of *L. royleana* volatile oil. Collectively, the present evidence encourages the pharmacological efficacy of many chemicals detected in *L. royleana* volatile oil. Nevertheless, properly-designed research examining the whole essential oil using standardized experimental protocols are needed before firm conclusions can be made regarding its effectiveness, mode of action, and safety profile. Collectively, the wide range of pharmacological effects related with the volatile oil of *L. royleana* reveal the cooperative functions of its volatile components. Instead of acting individually, these compounds may exhibit cooperative effects that increase the whole biological actions of the volatile oil. However, synergistic associations have not been definitively demonstrated and need direct experimental analysis. Furthermore, extra in vivo experiments and clinical trials are necessary to confirm these pharmacological actions and determine the therapeutic efficacy and safety profile of the volatile oil for therapeutic uses.

8. LIMITATIONS AND SAFETY CONSIDERATIONS

The present research on *Lallemantia royleana* volatile oil is majorly depends on phytochemical profiling, in vitro assessments, and restricted non-clinical analysis. Therefore, the pharmacological properties documented for single chemicals should not be specifically inferred to the whole volatile oil. Variability in plant source, volatile oil constituents, and experimental approaches further restrict cross-studies comparison. Safety profile for *L. royleana* essential oil is still inadequate. Extensive data related to toxicity, sensitization likelihood, safety warnings, reproductive health safety, pharmacokinetic characters, and botanical-medicine interactions are not yet established. Safety profile assays regarding species-specific of the whole volatile oil are also restricted or not available. More standardized examinations, incorporating toxicological, pharmacokinetic, in vivo, and clinical researches, are needed to verify its safety and therapeutic effectiveness.

9. CONCLUSION

Lallemantia royleana is considered a worthwhile source of biologically active terpenoids which is a major constituent of volatile oil. This oil is abundant in oxygenated monoterpenes such as trans-pinocarvyl acetate, pinocarvone, verbenone, and β -citral which may play a part in the plant biological activities. However, the present research is mainly originated from phytochemical investigation and analysis of pure chemical, while evaluation of the whole volatile oil still restricted. Accordingly, the pharmacological activities documented for single chemicals should not be directly ascribed to the complete volatile oil. The current findings still inadequate to verify therapeutic effectiveness, as most present research are supported by in vitro assessments and restricted preclinical analysis. Future researches should focus on the establishment of standardize criteria of plant materials and essential oil chemical profile, extensive toxicological assessment, evaluation of possible botanical–drug combined effects, pharmacokinetic analysis, and carefully-designed in vivo experiments followed by clinical studies to detect its safety profile and therapeutic effectiveness.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

REFERENCES

- [1] K. Karakoca, M. A. Ozusaglam, Y. S. Cakmak, and E. S. Karaman, "Antioxidative, antimicrobial and cytotoxic properties of *Isatis floribunda* Boiss. ex Bornm. extracts," *EXCLI J.*, vol. 12, pp. 150–157, 2013.
- [2] M. Abbas, T. Mehmood, A. Bashir, M. Zafar, and A. Afzal, "Economics of *Lallemantia royleana* (Tukham-e-Balangoo) production in the low intensity cropping zone of the Punjab, Pakistan," *Pak. J. Agric. Res.*, vol. 25, no. 2, pp. 12–14, 2012.
- [3] M. Q. Hayat, M. A. Khan, M. Ahmad, N. Shaheen, G. Yasmin, and S. Akhter, "Ethnotaxonomical approach in the identification of useful medicinal flora of Tehsil Pindigheb (District Attock), Pakistan," *Ethnobot. Res. Appl.*, vol. 6, pp. 35–62, 2008.
- [4] A. Ghannadi and B. Zolfaghari, "Compositional analysis of the essential oil of *Lallemantia royleana* (Benth. in Wall.) Benth. from Iran," *Flavour Fragrance J.*, vol. 18, no. 3, pp. 237–239, 2003.
- [5] J. F. Morton, "Mucilaginous plants and their uses in medicine," *J. Ethnopharmacol.*, vol. 29, no. 3, pp. 245–266, 1990.
- [6] S. M. A. Razavi, T. Mohammadi Moghaddam, and A. Mohammad Amini, "Physical-mechanical properties and chemical composition of Balangu seed," *Int. J. Food Eng.*, vol. 4, no. 5, 2008.
- [7] H. Samee, Z. X. Li, H. Lin, J. Khalid, and Y. C. Guo, "Anti-allergic effects of ethanol extracts from brown seaweeds," *J. Zhejiang Univ. Sci. B*, vol. 10, no. 2, pp. 147–153, 2009.
- [8] F. Naghibi, M. Mosaddegh, S. M. Motamed, and A. Ghorbani, "Labiatae family in folk medicine in Iran: From ethnobotany to pharmacology," *Iran. J. Pharm. Res.*, vol. 2, pp. 63–79, 2005.

- [9] S. Mahmood, M. Q. Hayat, A. Sadiq, S. Ishtiaq, S. Malik, and M. Ashraf, "Antibacterial activity of **Lallemantia royleana** (Benth.) indigenous to Pakistan," **Afr. J. Microbiol. Res.**, vol. 7, no. 31, pp. 4006–4009, 2013.
- [10] S. Mishra, A. Bhandari, N. Parvez, and P. K. Sharma, "Extraction of **Lallemantia royleana** seed mucilage as pharmaceutical excipient," **World J. Pharm. Res.**, vol. 4, no. 4, pp. 1578–1589, 2015.
- [11] M. S. Daneshmandi, R. T. Afshari, and R. S. Haghighi, "Identification of chemical and biochemical characteristics of balangu seeds (**Lallemantia royleana** Benth. in Wall.) under accelerated aging conditions," **Iran. J. Seed Sci. Technol.**, vol. 6, no. 1, pp. 23–37, 2017.
- [12] M. Bozorgi and M. Vazirian, "Antioxidant activity of **Lallemantia royleana** (Benth.) seed extract," **Trad. Integr. Med.**, 2016.
- [13] G. R. Amin, "Popular medicinal plants of Iran," **Iran. Res. Inst. Med. Plants**, vol. 2, no. 3, pp. 66–67, 2005.
- [14] Z. Xu and L. Chang, **Identification and Control of Common Weeds**, vol. 3. Dordrecht, The Netherlands: Springer Netherlands, 2017.
- [15] A. E. Al-Snafi, "Pharmacological and therapeutic effects of **Lallemantia royleana**: A review," **IOSR J. Pharm.**, vol. 9, no. 6, pp. 43–50, 2019.
- [16] A. Farahnaky, H. Askari, and M. Bakhtiyari, "Rheology of balangu Shirazi (**Lallemantia royleana**) seed gum: A high viscosity thickening agent," in **Gums & Stabilizers for the Food Industry 15**, P. A. Williams and G. O. Phillips, Eds. RSC Press, 2009, pp. 190–200.
- [17] A. Saleem, M. Waqar, A. Aslam, A. Mobeen, A. Tariq, and F. M. Ali, "Therapeutic role of **Lallemantia royleana** (Balangu seeds) and its pharmacological properties: An overview," **Sch. Bull.**, vol. 8, no. 9, pp. 283–287, 2022.
- [18] M. Nicoletti, F. Maggi, F. Papa, S. Vittori, L. Quassinti, M. Bramucci, et al., "In vitro biological activities of the essential oil from the 'resurrection plant' **Myrothamnus moschatus** (Baillon) Niedenzu endemic to Madagascar," **Nat. Prod. Res.**, vol. 26, no. 24, pp. 2291–2300, 2012.
- [19] J. B. Seibert, T. R. Amparo, L. R. D. Sousa, et al., "Easy obtainment and biological applicability of pinocarvyl acetate by encapsulating the **Microlicia graveolens** essential oil in oil-in-water nanoemulsions," **Pharmaceutics**, vol. 17, pp. 1–16, 2025.
- [20] M. Imran, M. Aslam, S. A. Alsagaby, F. Saeed, I. Ahmad, M. Afzaal, et al., "Therapeutic application of carvacrol: A comprehensive review," **Food Sci. Nutr.**, vol. 10, no. 11, pp. 3544–3561, 2022.
- [21] A. Balahbib et al., "Health benefits and pharmacological properties of **p*-cymene*," **Biomolecules**, vol. 11, no. 5, Art. no. 571, 2021.
- [22] A. Marchese, C. R. Arciola, R. Barbieri, et al., "Update on monoterpenes as antimicrobial agents: A particular focus on **p*-cymene*," **Molecules**, vol. 22, no. 8, Art. no. 947, 2017.
- [23] M. Tomić et al., "Individual stereoisomers of verbenol and verbenone express bioactive features," **J. Mol. Struct.**, vol. 1240, Art. no. 130566, 2021.
- [24] J. Gertsch, M. Leonti, S. Raduner, et al., " β -Caryophyllene is a dietary cannabinoid," **Proc. Natl. Acad. Sci. USA**, vol. 105, no. 26, pp. 9099–9104, 2008.
- [25] S. S. Dahham, Y. M. Tabana, M. A. Iqbal, et al., "The anticancer, antioxidant and antimicrobial properties of β -caryophyllene from the essential oil of **Aquilaria crassna**," **Molecules**, vol. 20, no. 7, pp. 11808–11829, 2015.
- [26] U. R. Juergens et al., "Anti-inflammatory activity of 1,8-cineol (eucalyptol) in bronchial asthma: A double-blind placebo-controlled trial," **Respir. Med.**, vol. 97, no. 3, pp. 250–256, 2003.
- [27] A. A. Saddiq and S. A. Khayat, "Chemical and antimicrobial studies of monoterpene: Citral," **Pestic. Biochem. Physiol.**, vol. 98, no. 1, pp. 89–93, 2010.
- [28] R. de Cássia da Silveira e Sá, L. N. Andrade, and D. P. de Sousa, "A review on anti-inflammatory activity of monoterpenes," **Molecules**, vol. 18, no. 1, pp. 1227–1254, 2013.
- [29] B. Salehi et al., "Therapeutic potential of α - and β -pinene: A miracle gift of nature," **Molecules**, vol. 24, no. 20, Art. no. 3664, 2019.
- [30] A. Nostro and T. Papalia, "Antimicrobial activity of carvacrol: Current progress and future perspectives," **Recent Pat. Anti-Infect. Drug Discov.**, vol. 7, no. 1, pp. 28–35, 2012.
- [31] J. C. Lopez-Romero, H. González-Ríos, A. Borges, and M. Simões, "Antibacterial effects and mode of action of selected essential oils components against **Escherichia coli** and **Staphylococcus aureus**," **Evid.-Based Complement. Altern. Med.**, vol. 2015, Art. no. 795435, 2015.
- [32] P. Karimian, G. Kavooosi, and Z. Amirghofran, "Anti-oxidative and anti-inflammatory effects of **Tagetes minuta** essential oil in activated macrophages," **Asian Pac. J. Trop. Biomed.**, vol. 4, no. 3, pp. 219–227, 2014.
- [33] H. S. R. Santana, F. O. de Carvalho, E. R. Silva, et al., "Anti-inflammatory activity of limonene in the prevention and control of injuries in the respiratory system: A systematic review," **Curr. Pharm. Des.**, vol. 26, no. 18, pp. 2182–2191, 2020.

- [34] A. C. Aprotosoie, M. Hăncianu, I. I. Costache, and A. Miron, "Linalool: A review on a key odorant molecule with valuable biological properties," **Flavour Fragrance J.**, vol. 29, no. 4, pp. 193–219, 2014.
- [35] D. F. Coêlho et al., "Cytotoxic and antioxidant properties of natural bioactive monoterpenes nerol, estragole, and 3,7-dimethyl-1-octanol," **Adv. Pharmacol. Pharm. Sci.**, vol. 2022, Art. no. 8002766, 2022.
- [36] Y. D. Guo, M. X. Zhang, Q. Y. Yu, L. L. Wang, Y. X. Han, T. L. Gao, et al., "Hyssopus cuspidatus* Boriss volatile extract (SXC): A dual-action antioxidant and antifungal agent targeting *Candida albicans* pathogenicity and vulvovaginal candidiasis via host oxidative stress modulation and fungal metabolic reprogramming," **Antioxidants**, vol. 14, no. 9, Art. no. 1046, 2025.
- [37] K. Ito and M. Ito, "The sedative effect of inhaled terpinolene in mice and its structure–activity relationships," **J. Nat. Med.**, vol. 67, no. 4, pp. 833–837, 2013.
- [38] K. H. C. Baser and G. Buchbauer, Eds., **Handbook of Essential Oils: Science, Technology, and Applications**. Boca Raton, FL, USA: CRC Press, 2009.
- [39] J. Sharifi-Rad, S. M. Hoseini-Alfatemi, M. Sharifi-Rad, and W. N. Setzer, "Chemical composition, antifungal and antibacterial activities of essential oil from *Lallemantia royleana* (Benth. in Wall.) Benth.," **J. Food Saf.**, vol. 35, no. 1, pp. 19–25, 2015.
- [40] A. R. Pulatova, T. K. Makhkamov, and R. K. Allaberdiev, "Biologically active compounds of *Lallemantia royleana* (Benth.) Benth. and their significance in modern medicine," **Multidiscip. J. Sci. Technol.**, vol. 5, no. 10, pp. 416–422, 2025.