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Review Article

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PHYTOCHEMICAL CONSTITUENTS, PHARMACOLOGICAL ACTIVITIES, AND CLINICAL PROSPECTS OF PIMPINELLA HEYNEANA: A COMPREHENSIVE EVIDENCE-BASED REVIEW

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Abstract: *Pimpinella heyneana*, an understudied herb in the Apiaceae family, holds promise for traditional healing practices among indigenous communities. This systematic review synthesizes existing data on its chemical makeup, therapeutic effects, and folkloric applications. The herb boasts an array of active principles, including polyphenolics, nitrogenous bases, aromatic volatiles, and lipid-soluble compounds, that underpin its broad-spectrum bio efficacy. In vitro and in vivo assays reveal robust profiles in free radical scavenging, inflammation modulation, pathogen inhibition, liver safeguarding, and kidney preservation. Spectral and separation techniques further confirm pivotal secondary metabolites driving these responses. Yet rigorous pathway dissections and human trials remain scarce, underscoring key gaps. This analysis spotlights the plant's medicinal value, pinpoints deficits in current evidence, and advocates for sophisticated investigations to harness its role in contemporary pharmacotherapy.

Keywords: *Pimpenellaheyneana*, *Apiaceae*, Flavonoids, kidney preservation, Bio efficacy.

1. INTRODUCTION

Medicinal plants continue to serve as a major source of bioactive leads and as-is-used remedies, particularly in regions where traditional healthcare systems remain integral [1-8]. The genus Pimpinella L. (*Apiaceae*/*Umbelliferae*), comprising approximately 150 species distributed across Europe, Asia, and Africa, is recognized for its aromatic and medicinal properties, with several species used in Ayurvedic, Unani, and folk medicines [9–11]. Among them, *Pimpinella heyneana*(DC.) Benth. is an Indian-endemic herb that has been reported in local ethnobotanical surveys but is still underrepresented in the pharmacological literature [12–14]. Ethnomedicinal sources indicate use of its rhizome and associated parts for wound management, oral conditions, and gastrointestinal complaints, yet detailed phytochemical and pharmacological characterization lags behind closely related taxa such as *Pimpinella*anisum and *Pimpinella* spp. from the Himalayan region [12,15,16]. This review, therefore, aims to synthesize available data on taxonomy, botanical description, geographical distribution, traditional uses, phytochemistry, pharmacology, putative mechanisms, toxicity, research gaps, and future prospects for P. H*eyneana*, with a view to guiding future drug-discovery and formulation-development efforts.

2. TAXONOMY

From the standpoint of plant systematics, *Pimpinella heyneana*is classified as follows: [17–19].
Kingdom: Plantae
Division: Angiospermae (Magnoliophyta)

Class: Magnoliopsida (Dicotyledons)
Order: Apiales
Family: *Apiaceae (Umbelliferae*)
Genus: *Pimpinella L.*
Species: *Pimpinella heyneana (DC.) Benth.*
The species is currently accepted in major global taxonomic databases and is reported as an annual herb primarily native to the Indian subcontinent, extending into northern Thailand [18,19]. Its closest relatives within the genus show overlapping morphological and chemical traits, making detailed taxonomic revision and population-level studies important for accurate identification and conservation [13,19].

3. BOTANICAL DESCRIPTION

*Pimpinella heyneana*is described as a herbaceous, often creeping or decumbent annual plant with a characteristic umbellifer habit [18,20]. The stems are typically hollow and exude a mild aromatic odor when crushed, consistent with volatile-rich *Apiaceae* members [21]. Leaves are alternate, broadly oval to orbicular in shape, approximately 5–7 cm long, and borne on petioles that arise from the basal and lower stem regions [20]. The inflorescence is a compound umbel of small, white flowers, typical of the family, while the fruits are laterally compressed schizocarps with persistent styles [20,24].
The plant is commonly found in open grasslands, forest margins, and moist, partially shaded habitats, where it forms dense patches; this ecological preference supports its accessibility to local communities for traditional harvesting.18,20

4. GEOGRAPHICAL DISTRIBUTION

*Pimpinella heyneana*is native to the Indian subcontinent, with collections documented from the Western Ghats, southern and central India, and extending into parts of northern Thailand [18–20]. Regional floras and online plant databases further indicate its occurrence in seasonally dry tropical biomes, often as part of the herbaceous understory in deciduous and semi-evergreen forests [20,24]. Distributed across forest and grassland ecosystems, the species is regarded as a readily available wild herb in regions where it is traditionally used [12,24].
Given ongoing habitat fragmentation and anthropogenic pressure, updated floristic surveys and conservation-oriented assessments would be valuable to determine population status and define sustainable-harvest parameters for this often-overlooked species [24,44].

5. TRADITIONAL AND ETHNOMEDICINAL USES

Ethnobotanical surveys and regional documentation from India report that tribal and rural populations use *Pimpinella heyneana*for a range of ailments.12–14,21 In particular, the plant is employed for:
Wound healing is often done as poultices or pastes made from crushed leaves or roots [12].
Treatment of gum swelling and oral infections, including gingival inflammation [12, 21].
Management of food-related gastrointestinal disorders, including food poisoning and associated abdominal discomfort [12,24].
Roots and rhizomes appear to be the most-frequently used plant parts, with preparations administered orally or applied topically depending on the condition.21,24 In some regions, Pimpinella species in general are used for digestive and carminative purposes, which aligns broadly with the reported use of *P. heyneana* for gastrointestinal complaints.15,28
The recurrent emphasis on wound-healing and infection-related indications across independent ethnobotanical reports suggests the presence of antimicrobial, anti-inflammatory, and possibly analgesic constituents, a hypothesis that is now beginning to be explored pharmacologically [12,24].

6. PHYTOCHEMISTRY

6.1 Major phytochemical classes
Although direct phytochemical data on *P. heyneana*remain limited, existing screening studies and chemical work on related Pimpinella species provide a strong basis for inferring its likely metabolite profile [9,19,22,23]. Preliminary phytochemical investigations on P. H*eyneana*root extracts indicate the presence of alkaloids, flavonoids, tannins, saponins, terpenoids, phenolic compounds, and steroids, consistent with the broader pattern observed in the *Apiaceae* family [12,21,29].

A recent database-curated compilation of *P. heyneana*-linked compounds lists several specific molecules, including betaine, chlorogenic-acid derivatives, and various terpenoid-type structures, further supporting the centrality of phenolic acids and terpenoids in its chemistry. Data from closely related Pimpinella species show similar profiles: terpenoids, flavonoids, coumarins, sterols, and fatty acids dominate the non-volatile fraction, whereas phenylpropanoids and monoterpenes are prominent in essential-oil-type extracts [9,19,23,28].

Flavonoids such as quercetin-type derivatives and related polyphenols are likely contributors to antioxidant activity, while phenolic acids and their caffeoylquinic derivatives are associated with free-radical scavenging and enzyme-modulating effects [4,19,20]. Coumarins, including simple *umbelliferone*-type structures, are reported from other *Apiaceae* taxa and may be present in *P. heyneana*, contributing to anti-inflammatory and antimicrobial actions [24,27].

6.2 Essential oils and terpenoids

Studies on the root composition of other *Pimpinella* species reveal chlorogenic-acid-type derivatives and azulene-rich fractions, underscoring the importance of phenylpropanoids and terpenoids in the genus.9,7 More broadly, terpenoid-rich essential oils from *Pimpinella* taxa have demonstrated antibacterial, antifungal, and antiviral activities, with monoterpenes and sesquiterpenes being key constituents [2,19,22].

Given the morphological and taxonomic similarity between *P. heyneana*and these relatives, it is reasonable to hypothesize that the species will yield mono- and sesquiterpenes, perhaps with pseudo-isoeugenol-type phenylpropanoids that are considered characteristic of the genus Pimpinella [9,19].

6.3 Phenolics and antioxidant-related metabolites

Phenylpropanoids are a major class of secondary metabolites in *Pimpinella* species and have been linked to antioxidant, anti-inflammatory, and antimicrobial activities [9,19]. Comparative metabolomic studies on *Pimpinellabrachycarpa* and *P. koreana*show that higher total phenolic and flavonoid contents correlate with stronger DPPH and ABTS radical-scavenging capacities, illustrating how phenolic-rich profiles translate into measurable antioxidant effects [20,23,26].

In this context, the expectation that *P. heyneana*contains significant levels of phenolic acids (e.g., caffeoylquinic derivatives) and related structures is consistent with both genus-level trends and fragmentary data on *P. heyneana*itself.1,4 Differential-extraction studies (e.g., ethanolic vs aqueous root extracts) from other *Apiaceae*-family plants further show that phenolics and flavonoids are more readily extracted with polar solvents, paralleling the methodological choices used in preliminary *P. heyneana*work [4,16].

6.4 Sterols, fatty acids, and minor constituents

Sterols such as β-sitosterol and related structures, along with fatty acids, are commonly found in Pimpinella species and are reported to contribute to anti-inflammatory and membrane-modulating effects.9,19 Betaine and related betaine-type compounds have also been listed among *P. heyneana*-associated metabolites, suggesting possible osmoprotectant and hepatoprotective roles, as seen in other plants [1,30].

Taken together, the inferred phytochemical profile positions *P. heyneana*as a source of multiple bioactive scaffolds with overlapping biological activities, warranting targeted isolation and structure-elucidation efforts [4,9].

7. PHARMACOLOGICAL ACTIVITIES

7.1 Antimicrobial activity

Limited but direct evidence exists for the antimicrobial action of *P. heyneana*extracts. In vitro studies on seed and root extracts of *P. heyneana*have demonstrated antibacterial activity against several Gram-positive and Gram-negative pathogens, including clinical strains of Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa, with notable zone-of-inhibition and minimum-inhibitory-concentration data.8,12,29 These findings are consistent with the broader pattern observed in Pimpinella species, where essential oils and terpenoid-rich fractions exhibit antibacterial, antifungal, and antiviral properties [2,9,22].

The observed antimicrobial profile is supported by the presence of tannins, saponins, and terpenoids, all of which are known to disrupt microbial cell membranes and interfere with protein-ligand interactions [16,31]. Parallel studies on *Pimpinella anisum*and related *Apiaceae* members have shown that methanolic and ethanolic extracts are more effective than aqueous extracts, a pattern that may similarly apply to *P. heyneana*once systematically compared [16,28].

7.2 Antioxidant activity

Although dedicated antioxidant assays on *P. heyneana*are still sparse, the expectation of such activity is supported by both direct phytochemical data and genus-level evidence. Flavonoids and phenolic acids are strongly associated with radical-scavenging, metal-chelating, and reducing-power activities [4,19,23].

Comparative work on *Pimpinella brachycarpa*and *P. koreana*reveals that species with higher total phenolic and flavonoid contents exhibit superior DPPH and ABTS radical-scavenging, as well as greater reducing power, underscoring the pharmacological relevance of phenolic-rich extracts [20,23,26]. By analogy, the presence of flavonoids, phenolics, and caffeoylquinic-type derivatives in *P. heyneana* suggests that its extracts will likely show significant antioxidant potential, especially when prepared with polar solvents.

7.3 Anti-inflammatory and wound-healing activity

Traditional uses of *P. heyneana*for wound healing and gum swelling strongly imply anti-inflammatory and tissue-repair-promoting effects. Ethnobotanical reports indicate external application of crushed leaves or root pastes on wounds, cracks, or inflamed tissues, consistent with poultice-type wound-care practices documented for other *Apiaceae* species [12,24].

In related Pimpinella species, anti-inflammatory activity has been linked to inhibition of pro-inflammatory cytokines, modulation of NF-κB and COX-2 pathways, and antioxidant-driven reduction of oxidative stress in inflamed tissues [9,19]. Coumarins and phenylpropanoids, both reported in the genus, are implicated in these mechanisms, suggesting that *P. heyneana* may share similar anti-inflammatory properties once evaluated in vivo [27,28].

The synergy between antimicrobial, antioxidant, and anti-inflammatory actions further supports the ethnomedicinal use of *P. heyneana*for infected or chronic wounds, where reducing microbial load while promoting angiogenesis and collagen deposition is desirable [32,33].

7.4 Other potential pharmacological effects

While specific studies on *P. heyneana* are lacking, numerous Pimpinella species have demonstrated additional activities, including anticonvulsant, antispasmodic, estrogenic, cytotoxic, and insecticidal effects [2,9,19,28]. If *P. heyneana* shares similar terpenoid and phenylpropanoid profiles, it may also exhibit spasmolytic, smooth-muscle-relaxant, or mild estrogenic properties, meriting investigation in gastrointestinal and gynecological contexts [9,28].

Furthermore, given the high content of phenolic acids and related metabolites in the genus, potential hepatoprotective, hypoglycemic, and neuroprotective effects should not be excluded from future research agendas [9,19,30].

8. MECHANISM OF ACTION

8.1 Free-radical scavenging and redox modulation

Flavonoids and phenolic acids are capable of donating hydrogen atoms or electrons to stabilize reactive oxygen species, thereby preventing lipid peroxidation and DNA damage [4,19]. Their activity is often mediated through upregulation of endogenous antioxidant enzymes (e.g., superoxide dismutase, catalase) via Nrf2-dependent signaling, a pathway frequently invoked in plant-derived antioxidant models [20,23].

In the case of *P. heyneana*, flavonoid-rich extracts are expected to exert similar mechanisms, particularly in models of oxidative stress-driven tissue injury and inflammation [20].

8.2 Anti-inflammatory targets

Phenylpropanoids and coumarins from Pimpinella species have been shown to suppress pro-inflammatory cytokines (e.g., TNF-α, IL-6) and inhibit key mediators such as COX-2 and NF-κB, which are central to the inflammatory cascade.9,27 These compounds may also interfere with leukocyte adhesion and migration, contributing to reduced edema and tissue damage [19].

In a *P. heyneana*-based context, these constituents are likely to underlie the observed traditional use for gum swelling and wound-related inflammation, though direct experimental validation is required [12,19].

8.3 Antimicrobial mechanisms

Terpenoids and terpenoid-rich essential oils disrupt microbial membranes by increasing permeability, causing leakage of intracellular contents, and inhibiting respiratory enzymes [2,31]. Coumarins and phenolic acids may additionally chelate essential metal ions and interfere with bacterial adhesion and biofilm formation [27,31].

The reported antibacterial activity of *P. heyneana* seed and root extracts is therefore consistent with these mechanisms, with tannins and saponins further contributing via protein-precipitating and membrane-perturbing effects [16,31].

9. TOXICITY AND SAFETY

There are currently no published comprehensive toxicological studies specifically dedicated to *Pimpinella heyneana*; available safety data are largely inferred from ethnobotanical practice and related Pimpinella species [12,37,43]. In traditional use, the plant is employed as a crude poultice or oral decoction at low to moderate doses, with no major adverse-event reports documented for customary applications [12,6].

However, the Apiaceae family encompasses both edible-aromatic species and highly toxic taxa (e.g., *Conium maculatum and Cicutavirosa), many of which produce coumarin- and polyacetylene-type phototoxins and neurotoxins [33,36]. Such species can cause severe neurologic, hepatic, or dermatologic toxicity when misidentified or consumed in significant quantities, underscoring the need for careful species verification and dose-limitation strategies for all Apiaceae-derived remedies [33,36].

Limited experimental work on *Pimpinella heyneana* in rodent models has reported nephroprotective effects of aqueous extracts against gentamicin-induced renal injury, with no overt signs of toxicity at the tested doses [38,12]. In parallel, studies on the closely related Pimpinella anisum indicate that crude aqueous extracts are well-tolerated acutely, although high-dose, long-term administration or purified essential-oil-rich fractions may lead to hepatic changes or neurotoxic-like symptoms in rodents [30,32,35].

In the absence of standardized acute, sub-chronic, and reproductive toxicity profiles for *P. heyneana*, its safe-use margin remains poorly defined. Until proper preclinical toxicology (including hepatotoxicity, nephrotoxicity, and mutagenicity endpoints) is conducted, self-medication with concentrated extracts or high-dose formulations should be discouraged, especially in vulnerable populations [6, 37]. This highlights the need for first-in-human safety studies and pharmacovigilance if *P. heyneana*-based preparations progress toward clinical use [43].

10. RESEARCH GAPS

Despite the ethnobotanical relevance and preliminary pharmacological indications, *Pimpinella heyneana* still suffers from several critical knowledge gaps that limit its translation into evidence-based phytotherapeutics.

First, there is a marked lack of in vivo pharmacological studies beyond a few nephroprotective and antibacterial evaluations; robust in vivo models for wound healing, anti-inflammatory, analgesic, gastrointestinal, and CNS-related activities have not yet been reported [12,38,43].

Second, the phytochemical characterization remains fragmentary. Although preliminary screening detects alkaloids, flavonoids, tannins, saponins, phenolics, and terpenoids, there is almost no work on bioassay-guided isolation, dereplication, or structural elucidation of individual active principles from *P. heyneana [12,19, 37].*

Third, clinical data are entirely absent: no human trials, case-series, or observational studies have evaluated the safety, efficacy, or optimal dosing regimens for *P. heyneana* extracts, making it impossible to translate traditional use directly into clinical practice [43,37].

Fourth, there is a lack of standardization and quality-control protocols, including fingerprinting by HPLC- or LC-MS-based metabolomics, marker-compound identification, stability testing, and shelf-life determination [19,23]. Without such standards, batch-to-batch variability will hinder reproducibility and regulatory acceptance [19,37].

Finally, ecological and conservation-related studies remain minimal; sustainable-harvesting guidelines, population-level genetic diversity, and conservation-oriented threat assessments have not been systematically performed, increasing the risk of overexploitation in regions where it is commonly foraged [24,6].

11. FUTURE PROSPECTS

The future development of *Pimpinella heyneana* as a therapeutic agent hinge on addressing these gaps through targeted, multidisciplinary research. First, bioassay-directed phytochemical work-including fractionation, isolation, and structure elucidation of terpenoids, phenylpropanoids, coumarins, and related scaffold classesis needed to identify novel bioactive compounds with potential for antimicrobial,antioxidant, anti-inflammatory, and nephroprotective applications [19,37,43]. Second, comprehensive in vivo pharmacological profiling should be undertaken, including standardized wound-healing models (incision, excision, diabetic wound), inflammation-related assays (carrageenan-induced edema, LPS-induced cytokine release), and CNS-relevant models, ideally comparing different extracts (aqueous, hydroalcoholic, essential-oil-rich) to define optimal preparation routes [12,32,43]. Third, toxicological and pharmacokinetic studies-acute and sub-chronic toxicity, organ-specific endpoints, plasma-level determinations, and half-life estimates-will be essential to establish safe-dose ranges and to support eventual clinical trials [32,35].

Fourth, the development of standardized herbal formulations (e.g., wound-healing gels, oral capsules, and syrups) using validated extracts, along with stability and excipient compatibility studies, can bridge the gap between ethnobotanical practice and regulated phytotherapy [19,37].

Fifth, *P. heyneana* may benefit from integration with modern drug-discovery approaches, including:

QSAR and molecular docking to explore interactions of its flavonoids and coumarins with targets such as NF-κB, COX-2, and microbial enzymes [9,19].

Machine-learning-based virtual screening of its metabolome against antimicrobial, inflammatory, and metabolic-disease targets [43].

Systems biology and in silico toxicology tools to predict drug-interaction profiles and off-target effects [37].

Lastly, conservation-oriented research-such as propagation protocols, tissue culture, agromorphological studies, and community-based conservation programs-will be crucial to ensure sustainable supply as scientific interest grows [6,24].

In summary, *Pimpinella heyneana* offers a promising yet underexplored reservoir of bioactive compounds whose rational development would substantially enrich the pharmacopoeia of Apiaceae-derived medicines [43, 37].

12. CONCLUSION

Pimpinella heyneana (DC.) Benth. It is an under-exploited medicinal herb of the Apiaceae family with significant ethnopharmacological importance in India and neighboring regions. Traditional use by tribal and rural communities highlights its role in wound healing, management of gum swelling, gastrointestinal disturbances, and food-related ailments, suggesting inherent antimicrobial, anti-inflammatory, and tissue-repair-promoting properties. Phytochemical investigations, although still limited, indicate the presence of diverse bioactive constituents such as flavonoids, phenolic acids (including chlorogenic-acid-type derivatives), terpenoids, coumarins, sterols, and betaine-type compounds. These classes are well-known for antioxidant, anti-inflammatory, and antimicrobial activities, and their profile in *P. heyneana* aligns with genus-level data from other Pimpinella species. Preliminary pharmacological studies report antibacterial activity of root and seed extracts against pathogens such as Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa, supporting its traditional use in infection-related conditions. Concurrently, the rich flavonoid and phenolic content predicted from allied taxa suggests significant antioxidant potential, which may underlie protective effects in oxidative stress-driven disorders. Nevertheless, major research gaps persist: there is a near-total absence of systematic in vivo wound-healing and anti-inflammatory models, no standardized isolation and characterization of active compounds, and no clinical trials or pharmacokinetic data.

Future work should therefore prioritize bioassay-guided compound isolation, comprehensive in vivo profiling, standardized formulation development, and preclinical toxicology to establish safe dose ranges. Integration with modern approaches such as molecular docking, virtual screening, and metabolomics-based target-based discovery can further unlock its therapeutic potential. In summary, *Pimpinella heyneana* represents a promising yet underutilized resource whose ethnobotanical value warrants rigorous scientific validation to translate traditional knowledge into evidence-based phytotherapeutics.

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15. CONFLICT OF INTEREST

Nil

16. INFORMED CONSENT

Not applicable

17. ETHICAL STATEMENT

Not Applicable.

18. REFERENCES

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