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Research Article

CHARACTERIZATION AND ESTIMATION OF PHYTOCHEMICAL CONSTITUENTS IN TRADITIONAL INDIAN MEDICINAL FLORA

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ABSTRACT

Indian medicinal plants are rich sources of bioactive phytochemicals with therapeutic relevance in modern drug development. This study aims to characterize and quantify major phytochemical constituents from selected medicinal plants traditionally used in Ayurveda and Siddha systems. Standard extraction procedures using methanol, ethanol, and aqueous solvents were optimized. Qualitative phytochemical screening was conducted for alkaloids, flavonoids, tannins, terpenoids, saponins, phenols, and glycosides. Quantitative estimation of key metabolites, including total phenolic content (TPC), total flavonoid content (TFC), and alkaloid concentration, was performed using Folin-Ciocalteu, aluminum chloride, and Harborne methods, respectively. Further characterization using FTIR, UV–Vis spectrophotometry, and HPLC revealed significant variation in metabolite profiles among plant species. The results confirm the presence of diverse secondary metabolites with strong medicinal potential. These findings provide a scientific basis for the therapeutic value of Indian medicinal plants and their possible applications in herbal formulations and pharmaceutical industries.

Keywords: Phytochemical characterization, Indian medicinal plants, Secondary metabolites, HPLC.

INTRODUCTION

India is one of the world's richest centers of medicinal plant biodiversity and has a long history of traditional medicine systems such as Ayurveda, Siddha, Unani, and folk medicine. Plants contain structurally diverse phytochemicals, including alkaloids, phenols, flavonoids, saponins, and terpenoids, which contribute to therapeutic properties such as anti-inflammatory, antioxidant, antimicrobial, anticancer, and antidiabetic effects. Despite the widespread use of medicinal plants, scientific validation and phytochemical characterization remain incomplete for many species. Phytochemical screening and quantitative estimation help identify bioactive molecules and support standardization of herbal formulations. Modern analytical tools such as FTIR, HPLC, GC–MS, and UV–Vis spectrophotometry enhance the accuracy and reliability of plant metabolite profiling. This study focuses on the systematic extraction, detection, and quantification of phytochemicals in selected Indian medicinal plants to strengthen their evidence-based medicinal value. Phytochemical analysis of medicinal plants has long played a crucial role in understanding their therapeutic potential. Foundational methodologies described in classical works have provided the basis for qualitative and quantitative evaluation of plant bioactive compounds (Harborne, 1998; Kokate *et al*., 2010). These early frameworks continue to guide modern phytochemical and pharmacognostical investigations across Indian medicinal flora. Recent studies have focused extensively on profiling key groups of secondary metabolites such as phenolics, flavonoids, alkaloids, and terpenoids. For example, mass spectrometric analyses have highlighted the diverse chemical landscape of medicinal plant species and their relevance to traditional therapeutic applications (Yathiender *et al*., 2023; Anil *et*

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al., 2019). Comprehensive phytochemical profiling across Indian plants has similarly identified multiple bioactive constituents with significant pharmacological potential (Mulay & Karle, 2020).

Integration of classical screening with advanced analytical techniques has further enhanced phytochemical discovery. GC–MS–based studies, such as those on *Ocimum sanctum*, have confirmed the presence of compounds associated with antioxidant and anti-inflammatory properties (Srivastava *et al*., 2021; Prema *et al*., 2022). Reviews on Indian ethnomedicinal phytochemicals have emphasized the potential of secondary metabolites as leads for drug discovery and therapeutic development (Fatima *et al*., 2021). The expansion of phytochemical databases—most notably IMPPAT 2.0—has also enabled systematic, bioinformatics-driven exploration of medicinal plant constituents (Mohanraj *et al*., 2023), strengthening data accessibility for drug-development pipelines.

Experimental validations continue to demonstrate the pharmacological relevance of Indian plants. Studies assessing antioxidant capacity and bioactive content have reported substantial phytochemical richness (Rajurkar & Hande, 2011; Saveetha *et al*., 2021). Preliminary screening of various species has confirmed the consistent presence of alkaloids, flavonoids, saponins, and related metabolites that support their traditional medicinal use (Doss, 2009). Detailed spectroscopic and chromatographic characterizations further contribute to structural and functional understanding of plant metabolites. Comparative analyses of species such as *Acalypha indica* and *Euphorbia hirta* using physico-chemical and spectroscopic approaches have highlighted the value of integrated methodologies in phytochemical research (M & Sharma, 2023). Quantitative phytochemical studies combined with antibacterial and drug-likeness assessments have also helped identify compounds of medicinal relevance in various Indian plants (Chakrabarty *et al*., 2024; Ghosh *et al*., 2020).

Targeted screening of specific plant species has deepened insights into their phytochemical and pharmacological properties. For instance, extensive phytochemical evaluation of *Adenanthera pavonina* leaves has revealed significant antioxidant potential alongside diverse phyto-constituents (Krishnaveni *et al*., 2022). Investigations on *Meliosma simplicifolia* have similarly demonstrated notable antioxidant and antibacterial activities (Pavithra & Sekar, 2021). Multiple medicinal plants, including *Acorus calamus* and *Solanum trilobatum*, have been shown to contain a wide range of secondary metabolites through qualitative screening (Mohan *et al*., n.d.). High-performance thin-layer chromatography (HPTLC) fingerprinting has also emerged as a robust method for establishing reproducible chemical profiles, as demonstrated in studies on *Leucas* species (Geethika & Sunojkumar, 2017), supporting both quality control and pharmacological exploration. Additionally, environmental and health-related studies underscore the broader importance of phytochemical research in understanding biological interactions and toxicity (Mahalakshmi *et al*., 2025).

MATERIALS AND METHODS

Medicinal plants such as *Ocimum sanctum*, *Azadirachta indica*, *Phyllanthus amarus*, and *Withania somnifera* were collected from authenticated botanical gardens and verified by a taxonomist, following widely accepted phytochemical collection standards (Mulay & Karle, 2020; Rajurkar & Hande, 2011). The collected leaves, stems, and roots were washed thoroughly, shade-dried for 72 hours, powdered, and stored in airtight containers to prevent degradation of thermolabile constituents, a practice commonly recommended in phytochemical studies (Saveetha *et al*., 2021). Extraction was performed using methanol, ethanol, and water through Soxhlet and maceration techniques, aligning with methodologies widely employed for traditional Indian medicinal plants (Yathiender *et al*., 2023). Qualitative phytochemical screening included tests for alkaloids, flavonoids, phenols, tannins, terpenoids, saponins, and glycosides, consistent with standard protocols adopted in phytochemical research (Srivastava *et al*., 2012; Pavithra & Sekar, 2021). Quantitative estimations comprised Total Phenolic Content (TPC) using the Folin–Ciocalteu reagent, Total Flavonoid Content (TFC) using the aluminum chloride method, alkaloid estimation following the Harborne procedure, and tannin quantification through the Folin–Denis method, all of which are commonly utilized in phytochemical evaluation of medicinal plants (phytochemical screening of Indian traditional medicinal plants: A review, 2020). Advanced analytical tools were incorporated to validate and characterize phytochemical constituents. FTIR spectroscopy (4000–400 cm^{-1}) was employed to identify functional groups associated with phenolics, flavonoids, and terpenoids, while UV–Vis spectroscopy (200–800 nm) was used to track characteristic absorption peaks of major bioactive molecules, supporting earlier analytical findings on Indian botanicals (Srivastava *et al*., 2021). HPLC profiling enabled detection of biomarker compounds such as quercetin, gallic acid, rutin, catechin, and berberine under validated chromatographic conditions—a technique reinforced by recent studies focusing on therapeutic plant metabolites and their biomedical relevance (Nafisa Farheen *et al*., 2025; Sindhuja *et al*., 2025). The broader significance of such phytochemical characterization is also noted in reviews emphasizing medicinal plant applications in pharmacology, biotechnology, and environmental research (Ramya *et al*., 2025; Swetha *et al*., 2025; Thangasubha *et al*., 2025; Vijay Krishnan *et al*., 2025).

RESULTS AND DISCUSSION

The selected Indian medicinal plants exhibited rich phytochemical profiles with significant levels of bioactive compounds, consistent with earlier reports on Indian ethnomedicines (Fatima *et al*., 2021). Methanol was identified as the most effective solvent for extracting diverse secondary metabolites, which aligns with findings from comparative phytochemical extractions (Mulay & Karle, 2020). FTIR and UV–Vis analyses confirmed the dominance of functional groups associated with antioxidant and anti-inflammatory activities, supporting spectroscopic assessments reported in previous studies (M & Sharma, 2023). HPLC results revealed high concentrations of quercetin and gallic acid, corroborating phytochemical fingerprinting documented in Leucas species and other medicinal plants (Geethika & Sunojkumar, 2017). Qualitative screening showed abundant flavonoids, tannins, phenols, alkaloids, and terpenoids, especially in methanolic extracts, which is in agreement with established phytochemical procedures described by Harborne (1998) and Kokate *et al*. (2010). Quantitatively, TPC ranged from 40–210 mg GAE/g extract, while TFC varied between 25–150 mg QE/g extract, values similar to those reported for other traditional Indian herbs (Ghosh *et al*., 2020). Alkaloid content ranged from 0.8–5.5%, consistent with earlier investigations on therapeutic plant species (Krishnaveni *et al*., 2022). FTIR spectra revealed characteristic O–H, C=C, C=O, N–H, and C–O–C stretches corresponding to phenols, flavonoids, terpenoids, alkaloids, and glycosides, as also noted in prior phytochemical and spectroscopic evaluations (Mohan *et al*., n.d.). UV–Vis peaks between 270–350 nm further supported the presence of phenolic and flavonoid compounds, in line with findings from comparative medicinal plant analyses (Mahalakshmi *et al*., 2025). HPLC chromatograms confirmed major components such as quercetin (12.4 min), gallic acid (6.8 min), rutin (10.2 min), and berberine (15.6 min), echoing compound-specific data from phytochemical databases like IMPPAT 2.0 (Mohanraj *et al*., 2023). Overall, the results validate traditional medicinal uses and highlight the therapeutic potential of these herbs, reinforcing insights from recent medicinal plant reviews (Nafisa Farheen *et al*., 2025; Pavithra & Sekar, 2021).

CONCLUSION

This study successfully identified, characterized, and quantified essential phytochemicals present in selected Indian medicinal plants. The high levels of flavonoids, phenols, alkaloids, and tannins reflect strong therapeutic potential, supporting their traditional applications in Ayurveda and herbal medicine. The combination of qualitative screening, quantitative assays, FTIR, UV–Vis, and HPLC provides baseline data for standardizing herbal formulations and strengthens the scientific basis for their pharmacological relevance. Future research should focus on GC–MS profiling for volatile metabolite identification, isolation and purification of dominant phytocompounds, and detailed in vitro antioxidant and antimicrobial assays. In vivo toxicity studies are essential to establish safety. Standardized herbal formulations may be developed based on the identified bioactive markers. Advanced approaches such as AI-based chemometric modeling and comparative evaluation of wild versus cultivated plant species can further enhance the scientific understanding and therapeutic utilization of these medicinal herbs.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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