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PHYTOCHEMICAL INVESTIGATION AND ETHNOPHARMACOLOGICAL EVALUATION OF SOME ETHNOMEDICINAL PLANTS OF RAJASTHAN

Aditi Pareek, Manal Khan and Aparna Pareek*

Department of Botany
University of Rajasthan (Rajasthan), India

**Corresponding author*: aparna992000@yahoo.com

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Abstract: Tribal and local communities have traditionally utilized ethnomedicinal plants and associated knowledge to manage various diseases. Rajasthan, with its unique agroclimatic zones, plant diversity, and flora, constitutes a significant storehouse of ethnomedical knowledge and possesses several plants of reasonable phytochemical and pharmacological interest. In the present article, selected ethnomedicinal plants from Rajasthan with their predominant phytochemicals, ethnomedicinal practices, and documented pharmacological activity are reviewed. Most of the documented traditional plants contain active medicinal compounds such as alkaloids, flavonoids, tannins, phenolics, terpenoids, saponins, and phytosterols at good concentrations. Phytochemical characterization and conventional or eco-friendly extraction processes have generated sufficient knowledge of the composition of plants. Due to the lack of traditional knowledge, plants need to be scientifically explored and documented rigorously. Also, traditional application practices need validation through phytochemical and pharmacological investigation in collaboration with phytochemical studies in finding bioactive compounds. This article emphasizes the potential use of some medicinal plants from the state in ethnomedicinal studies and exploration research in ethnopharmacology.

Keywords: Bioactive compounds, Eco-friendly, Ethnomedicinal plants, Phytochemical analysis, Rajasthan.

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INTRODUCTION

Medicinal plants are a rich source of potential drugs due to their phytochemical constituents. According to the World Health Organization (WHO), almost 80% of the global population receives their primary medical care from medicinal plants. Plants that are used by local people for the treatment of various ailments are ethnomedicinal plants (Rao, 2021; Jafri and Mishra, 2022). In the Northeast Region (NER) of India, around 130 major ethnic groups and over 300 subgroups employ a variety of ethnomedicinal plants on a regular basis to treat wounds (Barbhuiya *et al.,* 2026). The significance of maintaining traditional knowledge of important ethnomedicinal plants in the Ganga River watershed region is highlighted in the study conducted by Balkrishna *et al*. (2025). However, despite extensive ethnomedicinal practices across India, regions like Rajasthan remain comparatively underexplored.

A number of modern medicines currently sold in industrialized nations are plant-based or derived from plants, while traditional ethnomedicinal biota

continue to serve in various health care practices of rural and tribal people (Prakash and Verma, 2021). Rajasthan has a rich diversity of ethnomedicinal plants, most of which are still unexplored (Pareek, 2017; Sharma and Pareek, 2021). In the Alwar district of Rajasthan, India, a sacred grove known as Bherunath Ji Bani emphasizes rich plant biodiversity and it has been determined that the sacred groves are home to a large variety of medicinal plants (Suman and Meena, 2025). Jhunjhunu district, situated in the Shekhawati region of Rajasthan, is an important place for researching indigenous medicinal plants and their ethno-medicinal importance. Commonly found indigenous medicinal plants in this region are *Azadirachta indica* (neem), *Aloe vera*, *Calotropis procera*, *Prosopis cineraria*, and *Withania somnifera*. These plants are traditionally used for curing several ailments, including digestive problems, skin infections, respiratory disorders, and inflammatory diseases (Arya *et al.,* 2017; Mishra and Dhaka, 2026). Therefore, there is an urgent need to include scientific advancement in this field. It is desirable to understand the chemical components of plants since this knowledge would aid in the production of complicated chemical substances that can be used in drug formulations. Phytochemical investigation of ethnomedicinal and ethnoveterinary plants is an important area of research that aims to identify the bioactive compounds that contribute to the medicinal properties of plants (Mishra and Dhaka, 2026).

Phytochemicals are naturally found plant substances, mainly being secondary metabolites, which confer plants with medical efficacy. The most important and widely studied phytochemicals responsible for pharmacological effects, such as polyphenols and phenolic compounds, have been used for qualitative analysis and quantitative analysis. The character-ization of individual bioactive compounds in plant phytochemistry is necessary for identification of purity; to detect food adulteration, quality assessment, quality control, antimicrobial and antifungal activities, antiviral activities, antioxidative potential, anticancer and anti-inflammatory properties (Sharma and Pareek, 2021).

SELECTED ETHNOMEDICINAL PLANTS OF RAJASTHAN

In India, the traditional practices are significantly used, especially in arid and semi-arid zones like the region of Rajasthan. The plants mentioned, along with their traditional use in arid regions, have been studied. Bioactive constituents from such zones and the industrial uses of plant resources are also being studied (Anmol *et al.,* 2023). Traditional medicine is being explored for other alternative therapeutic systems but in-depth analysis of the phytochemical and phytopharmacological profiles of most of the ethnomedicinal plants from Rajasthan is limited. They need to be explored and evaluated for identification and quantization of their bioactive chemical constituents (Balkrishna *et al.,* 2025).

Previous ethnobotanical surveys have documented numerous plant species used traditionally for oral, gastrointestinal, respiratory, dermatological, nasal, inflammatory, allegry and other health conditions. Selected Rajasthan-specific ethnomedicinal plants, together with their common traditional uses, major reported phytochemicals, and pharmacological activities, are summarized in Table 1. The selection represents evidence-supported examples based on different plant families and therapeutic application of Rajasthan's ethnobotanical flora (Sharma and Pareek, 2021; Aggarwal, 2025). The species presented in Tables 1-3 were selected based on documented ethnomedicinal use in Rajasthan together with the availability of phytochemical, analytical and/or experimental pharmacological evidence.

The phytochemicals of different medicinal plants in Rajasthan have exhibited significant phytochemical profiles and associated biological activities. Ethnomedicinal plants used for gastrointestinal diseases in south Rajasthan exhibited antimicrobial activity, and the phytochemistry, antimicrobial activity, antioxidant properties, and anthelmintic properties were identified for *Balanites aegyptiaca* in the semi-arid regions of Rajasthan (Meena *et al.,* 2025; Balkrishna *et al.,* 2025). Phytochemical screening showed the presence of phenolics, flavonoids, alkaloids and saponins in the twenty ethnomedicinal plants from North-eastern states of India, and their antibacterial activity shown against *E. coli, S. Aureus,* and *Klebsiella pneumoniae* is varied as per the species (Barbhuiya *et al.,* 2026). Phytochemical investigation of the plants *Fagonia schweinfurthii* from Western Rajasthan revealed the presence of alkaloids, saponins, flavonoids, phenolics and so on in various parts of the plants (Pratap *et al.,* 2024). It was also observed that phytochemistry varies with respect to the solvent used in extract preparations. Many medicinal plants which are already used in the indigenous system of medicine of Rajasthan have been reported with varied indications, and even varied plant parts have been utilized for the treatment of ailments (Table 2).

Table 1: Selected ethnomedicinal plants of Rajasthan.

S. No.	Plant species	Family	Vernacular name	Plant part used	Ethnomedicinal use in Rajasthan	Major reported phytochemicals	Reported pharmacological activities	References
1.	*Abrus precatorius* L.	Fabaceae	Chirmi, Ratti	Leaves	Used for blisters and wounds, leaves are chewed or applied as paste	Alkaloids, flavonoids, saponins, terpenoids	Antitumor, anti-microbial, antioxidant	Bhakta and Das, 2020
2.	*Acacia nilotica* (L.) Delile	Fabaceae	Babul, Babool	Bark, twigs	Used for oral hygiene, gingivitis, wounds and ulcers	Tannins, flavonoids, phenolics, alkaloids	Antimicrobial, anti-inflammatory, antioxidant	Rather *et al*., 2015; Meena *et al*., 2025
3.	*Azadirachta indica* A. Juss.	Meliaceae	Neem	Twigs, leaves, bark	Twigs used for cleaning teeth and massaging gums; leaves used for various ailments	Limonoid, flavonoids, tannins, terpenoids	Antimicrobial, anti-inflammatory, antioxidant	Sangeeta and Dhaka, 2018
4.	*Balanites aegyptiaca* (L.) Delile	Zygophyllaceae	Hingot, Hingota	Fruit, seed, branches	Used traditionally for gastrointestinal disorders and oral hygiene	Saponins, flavonoids, phenolics, tannins, alkaloids	Antioxidant, antimicrobial, anthelmintic	Khan *et al*., 2025a
5.	*Butea monosperma* (Lam.) Taub.	Fabaceae	Palas, Dhauk	Seed, stem	Used traditionally for respiratory ailments and wounds	Flavonoid, phenolics, tannins, alkaloids	Anti-inflammatory, antimicrobial, antioxidant	Jain and Dubey, 2023
6.	*Calotropis procera*	Apocynaceae	Aak, Akdo	Latex, leaves	Used traditionally for wounds, skin ailments and other local remedies	Cardiac glycosides, flavonoids, terpenoids	Anti-inflammatory, antimicrobial, analgesic	Vimala and Chaudhary, 2023
7.	*Citrullus colocynthis* (L.) Schrad.	Cucurbitaceae	Tumba	Root	Root preparations used traditionally for dental ailments	Cucurbitacins, flavonoids, alka-loids, phenolics	Anti-inflammatory, antimicrobial, analgesic	Meena and Rao, 2010
8.	*Jatropha gossypifolia*	Euphorbiaceae	Ratanjoti	Young stem, leaves	Young stems used as tooth brushes for bleeding gums and gum boils	Flavonoid, alkaloids, terpenoids, phenolics	Antimicrobial, anti-inflammatory, wound healing, and anticancer properties L.	Saini, 2024
9.	*Salvadora oleoides* Decne.	Salvadoraceae	Jal, Pilu	Roots, tender twigs	Roots and tender twigs used as chewing sticks for dental ailments	Flavonoid, phenolics, terpenoids, sterols	Antimicrobial, antioxidant, anti-inflammatory	Saini, 2024
10.	*Tephrosia purpurea* (L.) Pers.	Fabaceae	Bansa	Tender shoots	Tender shoots used for cleaning teeth and maintaining oral hygiene	Flavonoid, rotenoids, phenolics, terpenoids	Antioxidant, anti-inflammatory, antimicrobial	Bairwa *et al*., 2022
11.	*Ziziphus nummularia* (Burm.f.) Wight & Arn	Rhamnaceae	Jharber	Leaves, roots, bark	Traditionally used for gastrointestinal and skin-related ailments	Flavonoid, saponins, tannins, phenolics	Antidiarrheal, antimicrobial, anti-inflammatory	Dudi *et al*., 2020

COMMON PHYTOCHEMICALS IN ETHNOMEDICINAL PLANTS

The term phytochemical denotes varied secondary metabolites in plants that participate in plant defense, respond to environmental cues and mediate interactions with other species. Their biological impact depends on the compound itself, plant species and part, extraction solvent, dose and model; thus, detection alone does not imply its therapeutic efficacy. Table 2 summarizes the use and traditional use of some of the ethnomedicinal plants of Rajasthan while Table 3 mentions that it's identified phytochemicals, extractants used for extraction, along with the analytical tools applied for qualitative and quantitative investigation of plant parts, and finally, the biologically determined activity of each plant.

1. Alkaloids and nitrogen-containing compounds: Alkaloids comprise a broad range of structurally disparate nitrogen-containing compounds, which demonstrate a diverse spectrum of biological activities. Several ethnomedicinal plants of Rajasthan including *Tinospora cordifolia, Datura innoxia, Indigofera tinctoria* and *Fagonia schweinfurthii,* have been reported to have alkaloids in them (Pareek and Soni, 2023). Various compounds, including the alkaloids, have been identified in *F. schweinfurthii* samples from western Rajasthan, in addition to the presence of flavonoids, saponins and phenolics, depending on the extraction technique used (Pratap *et al.,* 2024). Alkaloids identified in *T. cordifolia,* such as jatrorrhizine, berberine, magnoflorine and palmatine,

Table 2: Ethnomedicinal uses and plant parts of selected medicinal plants reported from Rajasthan.

S. No.	Plant Name	Family	Vernacular name	Traditional ethno-medicinal use	Plant part used	Reference
1.	*Aloe vera* (L.) Burm.f.	Liliaceae	Gawarpatha	Indigestion	Leaves	Meena and Rao, 2010
2.	*Caesalpinia bonduc* (L.) Roxb.	Caesalpiniaceae	Kantkaranj	Piles, ulcers	Seeds	Jain *et al*., 2011
3.	*Datura innoxia* Mill.	Solanaceae	Dhatura	Purulent wounds	Leaves	Khan *et al*., 2025b
4.	*Euphorbia neriifolia* L.	Euphorbiaceae	Thor	Scorpion stings	Latex	Kumari and Jain, 2018
5.	*Ficus rumphii* Bl.	Moraceae	Pipli	Asthma, vomiting; anthelmintic	Leaves, bark, roots	Yadav and Singh, 2025
6.	*Indigofera tinctoria* L.	Fabaceae	Neel	Laxative, expectorant, anthelmintic, piles, asthma, leukoderma, heart disorders	Leaves	Shreya *et al*., 2023
7.	*Medicago sativa* L.	Fabaceae	Rizka	Anti-inflammatory	Leaves	Rani *et al*., 2023
8.	*Soymida febrifuga* (Roxb.) A. Juss.	Meliaceae	Rohini	Gastrointestinal disorders	Bark	Rathore and Amarawat, 2020
9.	*Sesamum indicum* L.	Pedaliaceae	Til	Hepatoprotection, inflammation, cancer	Seeds	Dudi and Singh, 2024
10.	*Tinospora cordifolia* (Willd.) Miers	Menispermaceae	Neemgiloy	Rheumatism, jaundice, urinary disorders	Leaves, roots	Pareek and Soni, 2023
11.	*Tribulus terrestris* L.	Zygophyllaceae	Gokhru	Aphrodisiac, blood purification, diuretic	Roots, fruits	Limboo *et al*., 2026
12.	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Rhamnaceae	Jharber	Cough, cold, skin disorders; astringent	Fruits, leaves	Dudi *et al*., 2020

have been characterized for various other effects like antibacterial activity, anti-inflammatory effects, and antioxidant activity in preclinical or *in vitro* studies, but are no proved efficacy against various clinical conditions. Besides pharmacological attributes, the safety profile of several alkaloids is of concern, particularly for tropane alkaloids present in *Datura innoxia*, due to their powerful influence on the nervous system (Maheshwari *et al.,* 2024; Khan *et al.,* 2025b). Alkaloids, therefore, must be seen as evidence of a chemical complexity that characterizes many ethnomedicinal species rather than as proof for therapeutic efficacy. The available studies for selected alkaloids are summarized in Table 3.

2. Phenolics, Flavonoids and Tannins: Several phenolics, especially flavonoids, have been obtained from the medicinal plants that are usually show antioxidant as well as antimicrobial activities. Along with other contents *namely* phenolics and flavonoids, alkaloids and saponins were also found from the leaves of *F. schweinfurthii* and the composition of these changes depends on the solvents used for extraction (Pratap *et al.,* 2024). It has been explored that the phenolics lignans (such as sesamin, sesamolin, and sesamol) isolated from the *Sesamum indicum* seed possess antioxidant activity and also an anti-inflammatory effect. The activity of flavonoids is different for various compounds and systems. Thus, any anticancer, antibacterial or antiviral action should only apply to certain compounds and experimental systems. The protein-binding and metal-chelating activity of tannins seems to be responsible for antioxidant or antimicrobial effects, although they might influence the bioavailability of other nutrients and processes at larger concentrations. Thus, dose-dependent activity and safety should be checked for tannin-rich extracts (Balkrishna *et al.,* 2025).

3. Saponins and phytosterols: The saponins are amphiphilic glycosides can react with the membranes of living tissues, and sapogenins are present in many other medicinal plants from Rajasthan like *F. schweinfurthii, Ziziphus nummularia* etc (Pratap *et al.,* 2024). The antimicrobial and anti-inflammatory activities of saponins show variability and cannot be directly generalized to human use. In general, crude extracts of any plants contain several classes of phytochemicals; hence these activities are usually considered not due to saponins. Phytosterols like β-sitosterol and stigmasterol are also widely distributed and used. Although, the pharmacological properties of β-sitosterol regarding lipid metabolism and several others have been explored, it was also detected in *Soymida febrifuga*. However, all results are obtained with isolated compounds or by dietary methods may be applied to the respective crude extracts and/or ethnomedicinal applications.

4. Terpenoids and related compounds: Terepenoids include mono-, sesqui-, di-, and triterpenoids as well as steroiodals are known to present in number of ethnomedicinal plants. The terpenoidic or steroiodal content from the flowers of *T. cordifolia*, stem of *Euphorbia neriifolia,* aerial parts of *Z. nummularia* and

fruits of *Tribulus terrestrisas* determined through different chromatographic and spectral methods have been documented, to have antioxidants, anti-inflammatory and antimicrobial activity, respectively (Pratap *et al.,* 2024). The evidence for the individual terpenoid involves *in vitro* and preclinical research and thus in order to interpret the reported anticancer / antiviral / anti-malarial activities they are subject to the specific compound and model (Limboo *et al.,* 2026). Hence, chemical content may be altered according to the plant material and extraction conditions.

5. Linking phytochemical composition with ethnomedicinal use: The relationship between the phytochemical constituents and the traditional applications of Rajasthan plants should be regarded as generating research hypotheses rather than as supporting clinical efficacy. Chemical and biological evidences for *S. indicum, T. cordifolia, T. terrestris, Z. nummularia* and *Aloe vera* varied from qualitative screening to GC-MS and HPLC and LC-MS in terms of chemical and varied from chemical tests to cellular, animal model studies as tabulated in Table 3 (Dudi and Singh, 2024; Limboo *et al.,* 2026).

The extraction conditions such as the solvent, the plant part used, the herb to solvent ratio and the quantity of extraction, can influence the percentage of recovered phytochemical and thus modify the activity in experimented tests (Pareek, 2017; Pratap *et al.,* 2024). Furthermore, when crude extracts are applied, effects that might be observed would only be based on the synergistic interaction of several compounds rather than each of it. Rajasthan native ethno-medicinal plants could possess numerous components that could be therapeutically useful, but in fact up to now, few and more or less restricted results are based on actual clinical experiences while most are experimental/ computational and lack information on therapeutic success (Saini, 2024; Balkrishna *et al.,* 2025). Toxicity, bioavailability, pharmacokinetics, dose and interactions with drugs also must be explored before their effects on humans can be investigated. However, phytochemical analysis can provide some interesting clues for the scientific evaluation of traditional usage of these plants.

Table 3: Phytochemical and Pharmacological evidence of selected Ethnomedicinal Plants.

S. No.	Plant	Plant part / extract	Major phytochemicals	Analytical method	Quantitative/ analytical findings	Biological evidence	References
1.	*Aloe vera*	Leaves/gel	Anthraquinones, polysaccharides, phenolics	HPLC/LC-MS	Major anthraquinones and polysaccharides reported	Antioxidant, antimicrobial and anti-inflammatory effects	Pandey *et al*., 2016
2.	*Caesalpinia bonduc*	Seeds; methanol extract	Flavonoids, terpenoids, fatty acids	GC-MS	27 phytochemicals identified	Hepatoprotective activity *in vivo*; antimicrobial activity *in vitro*	Naz *et al*., 2021
3.	*Datura innoxia*	Leaves; solvent extracts	Tropane alkaloids, flavonoids, phenolics	Phytochemical screening	Major phytochemical classes detected	Preliminary evidence	Baradwal and Begum, 2023
4.	*Euphorbia neriifolia*	Latex/leaves; organic extracts	Terpenoids, steroids, phenolics	GC-MS/LC-MS	Multiple constituents reported	Antimicrobial, anti-inflammatory and cytotoxic effects	Persaud *et al*., 2025
5.	*Fagonia schweinfurthii*	Aerial parts; different solvents	Alkaloids, flavonoids, saponins, tannins	Phytochemical screening	Composition varied with extraction solvent	Biological activity	Joshi and Jain, 2021
6.	*Indigofera tinctoria*	Leaves; ethanol extract	Flavonoids,phenolics, terpenoids, fatty acids	GC-MS	26 compounds identified	Compound activities cited in GC-MS study	Mishra *et al*., 2020
7.	*Soymida febrifuga*	Bark; methanol/ethyl acetate/acetone extracts	Lupeol, β-sitosterol, catechin, epicatechin	HPTLC	Lupeol, β-sitosterol, catechin, epicatechin	*In-vitro* antioxidant activity (DPPH and ORAC)	Gadhvi *et al*., 2026
8.	*Sesamum indicum*	Seeds; oil/ organic extracts	Sesamin, sesamolin, sesamol, phenolics	HPLC/HPTLC/GC-MS	Sesamin and sesamolin quantitatively determined	Antioxidant and other biological effects	Mikropoulou *et al*., 2019
9.	*Tinospora cordifolia*	Leaves/ stems; aqueous/organic extracts	Berberine, palmatine, magnoflorine, cological evidence jatrorrhizine, diterpenoids	HPLC/LC-MS/GC-MS	Individual alkaloids quantitatively determined in extracts	Mainly in-vitro/ preclinical pharma-	Bajpai *et al*., 2015
10.	*Tribulus terrestris*	Leaves; water/ methanol/ethyl acetate extracts	Steroidal saponins, flavonoids, phenolics	HPLC-MS/MS	27, 75 and 51 compounds identified in different extracts	Antioxidant and enzyme-inhibitory activity *in vitro*	Uysal *et al.*, 2023
11.	*Ziziphus nummularia*	Leaves; n-hexane/ 70% ethanol	Terpenoids, fatty acids, phytosterols, flavonoids	GC-MS	105 phytoconstituents identified in n-hexane extract and 56 in 70% ethanol extract	Antioxidant/anti-microbial effects reported in experimental studies	Sonia and Singh, 2019

EXTRACTION METHODS

The phytochemical extraction is influenced by the plant matrix, target compounds, solvent polarity, temperature, extraction time, and solvent-to-solid ratio. The conventional methods are maceration, percolation, infusion, decoction and Soxhlet extraction, which are still largely adopted due to ease and cost-efficiency, while may take more solvent consuming, longer time or have heat effects. The infusion and decoction are particularly valuable for preparing aqueous traditional formulations and recovering a narrow spectrum of polarized constituents, while Soxhlet extraction can obtain comprehensive extraction, but thermally unstable compounds may degrade (Cao *et al.,* 2025).

Modern methods can improve mass transfer, as well as the speed of extraction, for example, UAE, MAE, SFE and ASE. Ultrasound-assisted extraction (UAE) can help break up cells with minimal solvent, and it provides efficient extraction with very low energy usage, and also uses less solvent. The rapid heating involved in microwave-assisted extraction (MAE) offers rapid speed. (Supercritical fluid extraction) SFE, particularly using CO_2, could save conventional organic solvents, and extracts non-polar ingredients, while it needs a set of high-pressure equipment and is more costly (Zhang *et al.,* 2018). A similar technique for faster extraction using heated solvent at high pressure can also be employed, which is accelerated solvent extraction (ASE) (Hlatshwayo *et al.,* 2025). Consequently, environment benefits and economical aspects derived from these techniques will be evaluated by the toxicity, the energy inputs, the operating conditions, the recovering processes, the costs and a scale-up methodology. The selection of extraction method is also important, as different approaches offer distinct advantages and limitations depending on the target phytochemicals and the intended application (Table 4).

Extraction efficiency and phytochemical content are affected by both pre-extraction and extraction parameters. Among pre-extraction factors, plant species, part and place of harvest, harvest time, particle size, drying process and water content are the most significant ones. Solvent polarity, pH, temperature, extraction time, solvent-to-solid ratio, and method of extraction affect the recovery, selectivity, as well as thermo- and photolabile components' stability during the extraction processes (Cao *et al.,* 2025) It is thus advisable that an extraction condition should be chosen regarding the chemical nature of the target compound and the target use rather than just for maximum extraction amount (Table 4; Fig. 1).

Chemical profiling using chromatographic and spectrophotographic analyses (GC-MS, LC-MS, HPTLC and HPLC), which enables identification, fingerprinting and quantification of the phyto-constituents. All these analytical methodologies allow identification and establishment of the chemical profiles, and determination of compounds to be used in further research/ investigation. However, chemical identification alone does not establish pharmacological efficacy; biological relevance must be demonstrated using appropriate experimental models. Therefore, the extraction performance should be evaluated by several criteria such as recovery of target compounds, chemical stability, reproducibility, biological activity, solvent requirement, cost and scalability (Zhang *et al.,* 2018).

RESEARCH GAPS AND FUTURE DIRECTIONS

Although, ethnomedicinal plants used in Rajasthan are well documented, the scientific evidence is not uniform due to studies based solely on ethnobotanical claims, preliminary phytochemical analysis, and *in vitro* biological assessment. A significant gap in research has been due to a lack of interaction between ethnobotanical exploration and systematized phytochemical characterization and mechanism-centred pharmacological investigation. The bioactive compounds, mechanisms of action, optimal doses, absorption, metabolism, clinical safety, and therapeutic efficacy of many species remain inadequately established. These constraints, along with dissimilarities in the plants examined, methods of extraction and experimental parameters, undermine their reproducibility and comparability (Limboo *et al.,* 2026).

Future research should focus on authentically identified plant materials, systematic extraction process, development of efficient analytical tools, such as HPLC, LC-MS/MS and GC-MS as well as bioassay guided fractionation and isolation of active constituents. A promising species selected based on *in vitro* screening must be subjected to mechanistic and toxicology study, pharmacokinetic and adequate animal studies before making therapeutic claims. Moreover, integration of metabolomics, chemometrics and computational methods to complement experimental work would help in early detection and identification of active phytochemicals. Besidse these works, documentation of indigenous knowledge system, ethical collection and harvesting practices, conservation of species and fair benefit-sharing would be emphasized. In the context of ethnomedicine research of Rajasthan, thus the work would need to shift from documentation towards reproducible, practicable, validated and translation-oriented ethnopharmacology (Pareek *et al.,* 2023).

Table 4: Safety and Toxicity of selected Ethnomedicinal Plants.

S. No.	Method	Main advantage	Major limitation / suitable use	References
1.	Maceration/percolation	Simple; low equipment requirement	Time- and solvent-intensive	Cao *et al.*, 2025
2.	Infusion/decoction	Simple; relevant to traditional preparations thermolabile compounds	Heat may degrade	Zhang *et al.*, 2018
3.	Soxhlet	Exhaustive extraction	Prolonged heating and solvent use	Cao *et al.*, 2025
4.	UAE	Faster mass transfer; reduced extraction time	Requires optimization	Cao *et al.*, 2025
5.	MAE	Rapid and efficient extraction	Excessive heating; solvent-dependent environmental impact	Zhang *et al.*, 2018
6.	SFE	Low organic-solvent use; selective	Expensive, high-pressure equipment	Zhang *et al.*, 2018
7.	ASE	Rapid extraction; reduced solvent/ time	Specialized equipment	Hlatshwayo *et al.*, 2025

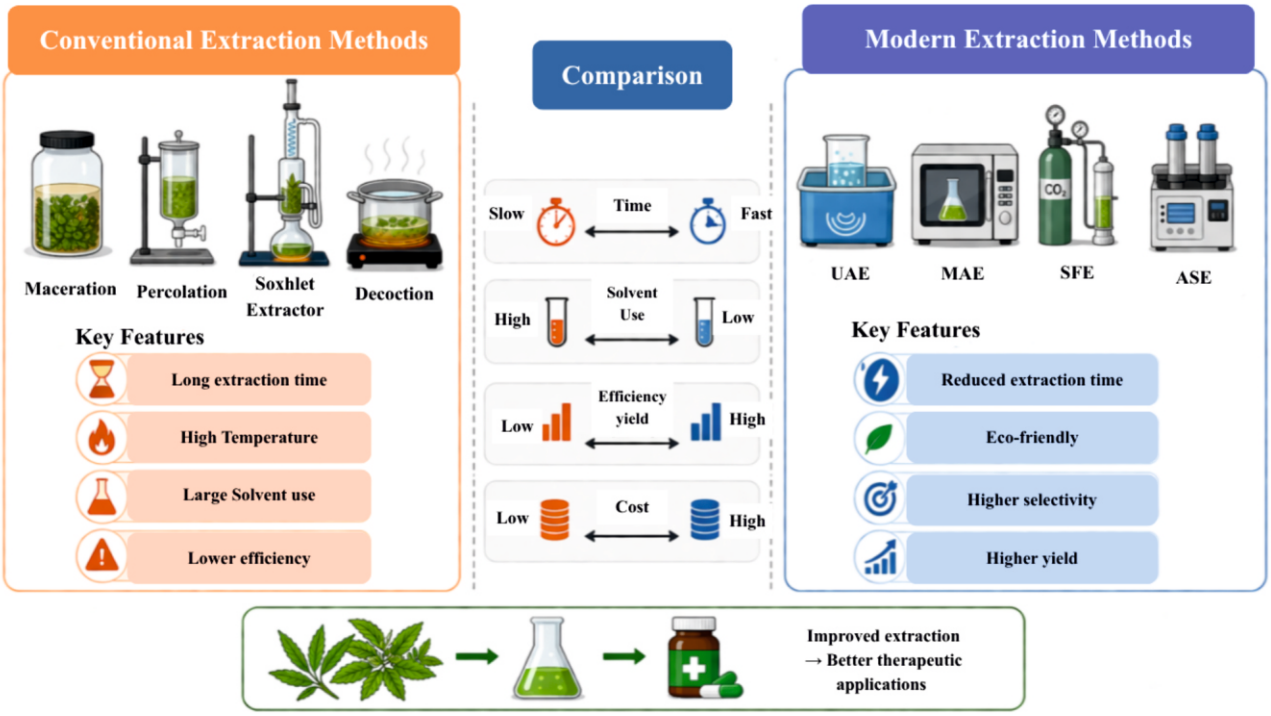

Fig. 1: Comparative assessment of conventional and modern extraction methods.

CONCLUSIONS

Rajasthan's ethnomedicinal plants have a rich store of diverse bioactive phytochemicals like alkaloids, flavonoids, phenolics, terpenoids, tannins, saponins and phytosterols, but with largely uneven support for all of the traditional claims by basic phytochemical or *in vitro* analysis, and a lack of comprehensive study of individual compounds characterization, mechanism of action, toxicity, pharmacokinetics and their efficacy in vivo. Thus, future research needs to be encouraged on poorly studied species by using authenticated plants, standardized extract methods, the latest analytical instrumentation and bioassay-guided isolation, and guided by mechanistic and *in vivo* validation. Also, careful documentation and conservation of traditional Rajasthan knowledge ought to proceed alongside laboratory investigations. Therefore, future research directions in ethno-pharmacology would move from observational to standardized, and *in vivo*-proven, and practicable, translational clinical ethnopharmacology, with responsible and rationalized use of ethno-medicinal resources of Rajasthan.

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