RESEARCH PAPER

Integrating Medicinal Botany and Ethnobotany: From Traditional Knowledge to Modern Healthcare Applications

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Abstract

Introduction: Medicinal plants remain central to primary healthcare, and the traditional knowledge (TK) of Indigenous and local communities is a key starting point for discovering plant-based therapies, yet medicinal botany and ethnobotany are often pursued separately. This disconnection has also left much traditional knowledge unscientifically validated, while increasing threats to the loss of intergenerational transmission and habitat loss of the plants on which it relies. This review thus explores the possibilities of scientific validation, technological innovation and policy and conservation to collectively transform TK into safe, scientifically validated, and sustainable healthcare. **Methods:** This narrative review synthesized 139 peer-reviewed and supporting sources, mainly published between 2021 and 2026, retrieved from Web of Science, PubMed and Google Scholar; classical Indian and Himalayan medical systems were drawn from recent secondary literature. **Results:** Ethnobotany directs researchers to species already trusted by communities, while medicinal botany validates them through phytochemical, pharmacological and clinical studies, as illustrated by artemisinin, vincristine, reserpine, metformin and paclitaxel. Genomics, metabolomics, artificial intelligence, digital ethnobotany, advanced extraction and novel drug-delivery systems are improving plant identification, standardization and therapeutic application. Persistent challenges include inconsistent documentation methods, habitat loss and unsustainable harvesting, gaps in traditional-knowledge protection and access-and-benefit-sharing, unreliable authentication, and limited clinical, dosing and safety data. **Discussion:** Scientific validation, technological innovation, and policy and conservation are functionally interdependent and should jointly inform research design. Integrating traditional knowledge with modern science, supported by DNA-based authentication, artificial intelligence-assisted prediction, community participation and equitable benefit-sharing, offers a foundation for safe, effective and sustainable plant-based therapies while recognizing knowledge holders and conserving biodiversity.

Keywords: Ethnobotany; Medicinal botany; Traditional knowledge; Phytochemistry; Drug discovery

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Introduction

Humans have used medicinal plants for hundreds of years and continue to use them in traditional and contemporary healthcare. Some 80% of the world population depends on herbal medicine for their primary healthcare needs, reflecting a long-standing medicinal history in China, India, and some nations in Africa (Latif & Nawaz, 2025). Some traditional and modern medications are also produced from plants (Nasim et al., 2022). Medicinal plants are very important because of the natural substances they contain, which have therapeutic power and can cure various illnesses. Plants have provided useful therapeutic compounds such as morphine, quinine, reserpine, colchicine, paclitaxel (Taxol), and digitalis, which have made a major contribution to modern medicine (Chaachouay & Zidane, 2024). The increasing popularity of plant-based medicines has prompted scientific studies on medicinal plants to encompass phytochemistry, pharmacology, biotechnology, and ethnobotany (Anmol et al., 2024). These are combined fields of research that contribute to the improvement of knowledge about medicinal plants and to the sustainable, effective, and safe use of them for future generations (Liu & Chen, 2024). Pharmacovigilance plays an important role in monitoring and ensuring the safety of herbal medicines (Singh et al., 2025; Sethi et al., 2025).

Traditional knowledge (TK) broadly refers to the accumulated understanding, practices, and beliefs that indigenous and local communities have developed over generations about the use of plants and other natural resources for health, nutrition, and daily life. It is generally passed down orally or through direct practice rather than through formal scientific documentation (Aremu et al., 2024). Such knowledge is of considerable importance to healthcare and to medicinal-plant research, as in many developing countries it continues to meet a substantial share of the population's primary healthcare needs where access to formal medicine is limited (World Health Organization [WHO], 2013). It also provides a starting point for pharmacological validation and drug discovery (Patwardhan & Aswar, 2025). Recognizing and safeguarding this knowledge is therefore important not only for cultural heritage but also for advancing evidence-based, plant-derived therapeutics (Alum, 2024).

Medicinal botany (medical botany) is the study and use of plants in relation to medicine and human health, including their medicinal properties and applications in biomedicine. The field also involves the evaluation of traditional botanical remedies as potential sources of therapeutic

agents (National Library of Medicine, 2004). It involves the collection of botanical, phytochemical, and pharmacological data, which is crucial to the identification of active chemicals of medicinal plants responsible for their therapeutic effects (Das et al., 2023; Singh et al., 2023). Medicinal plants can be tested for their efficacy, safety and purity and their traditional applications can be correlated with modern medicine and used for the production of useful drugs from natural sources. With the progress of plant science, evaluation of medicinal plants has transitioned from reliance on morphological research and empirical information to qualitative and quantitative phytochemical studies (Nagori et al., 2025). Today, molecular technologies for the detection of adulteration and for verification, such as DNA barcoding, are in combination with chromatographic and spectroscopic techniques such as high-performance thin-layer chromatography (HPTLC), high-performance liquid chromatography/ultra-high-performance liquid chromatography (HPLC/UHPLC), gas chromatography–mass spectrometry (GC–MS), and liquid chromatography–mass spectrometry (LC–MS) (Lindenmaier et al., 2025). The metabolomics techniques (nuclear magnetic resonance [NMR], LC–MS and GC–MS) combined with the chemometric approaches (principal component analysis [PCA] and partial least squares discriminant analysis [PLS-DA]) might help to do qualitative and quantitative analysis of the chemical profile of a plant, in an effort to monitor the chemical differences from one batch to another and to optimize them. Areas of investigation include using machine learning and artificial intelligence (AI) tools to identify metabolites, authenticate plant material, and predict pharmacological activity (Alum et al., 2025). This is a shift from using experience to evidence that is standardized and validated in a laboratory environment, and this is the direction of medicinal plant research today. Ethnobotany deals with human involvement with plants, whereas medicinal botany is looking for evidence mainly through scientific tests. Ethnobotany also refers to indigenous knowledge of forest resources utilized for medicinal, food, cultural, and spiritual purposes and how that information is learned and handed down from one generation to the next (Aremu et al., 2024).

Medicinal botany and ethnobotany are complementary in the use of TK in health systems, as ethnobotany contributes to the conservation of natural diversity and the promotion of the effective use of medicinal plants (Aremu et al., 2024). Two related fields are medicinal botany and ethnobotany, however they are not integrated well (Silveira & Boylan, 2023). Ethnobotanical research is primarily based on documentation of TK without proper phytochemical and pharmacological confirmation (Duche-Pérez et al., 2025). This gap restricts the integration of indigenous knowledge into evidence-based health care systems and

demonstrates the need for more scientific evidence and assimilation of traditional medicine in health policies (WHO, 2013). A strategy to bridge this gap is reverse pharmacology. In this approach, researchers start with the traditional use of a plant and move backward to confirm it pharmacologically (Patwardhan & Aswar, 2025), rather than starting with random lab screening. Thus, ethnobotanical knowledge is a first filter to direct phytochemical and medicinal research toward species already trusted by generations of societies.

Ethnobotany has recently been linked with phytochemistry, pharmacology and new technologies. In this context, Silveira and Boylan (2023) address the interdisciplinary link between ethnobotany and phytochemistry/pharmacology, and both Tan et al. (2025) and Chele et al. (2025) emphasize computational, omics and analytical methods in the research of medicinal plants. This review builds on these developments and combines the steps from traditional use to pharmacological validation with genomics, AI, digital ethnobotany and policy and conservation concerns such as the Nagoya Protocol, the Traditional Knowledge Digital Library (TKDL) and benefit-sharing (Fig. 1).

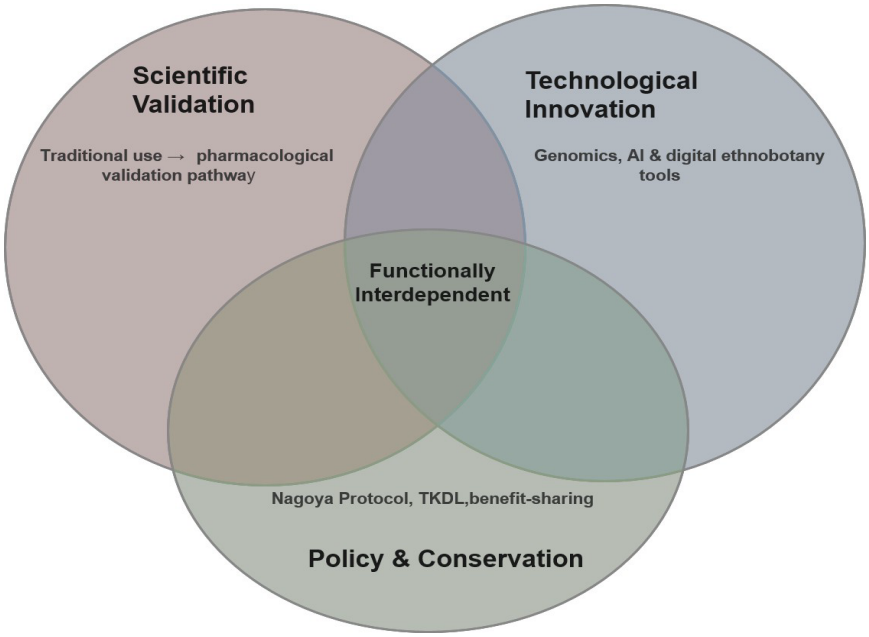

Fig. 1. Integrated Framework for Scientific Validation, Technological Innovation, and Policy & Conservation in Ethnobotany

Review Methodology

This review adopted a narrative-synthesis approach to combine the information on ethnobotany, medicinal botany, phytochemistry, pharmacology, biotechnology, and modern healthcare. Included were peer-reviewed scientific and review articles in English, largely from 2021 to 2026 with more focus on more recent studies, supplemented by a smaller number of

classical and historical sources (dating as far back as the late 19th century) needed to trace the historical development of ethnobotany and medicinal botany. Keywords such as ethnobotany, medicinal plants, TK, phytochemistry, pharmacological activity, and drug discovery were used to search the literature through Web of Science, PubMed and Google Scholar (Fig. 2). Articles were included if they were peer-reviewed, published in English primarily between 2021 and 2026, and directly addressed the intersection of ethnobotanical/TK with phytochemical, pharmacological, or technological validation; articles focused solely on unrelated plant biology, agriculture, or non-medicinal uses were excluded. References to classical and traditional medical systems such as Charaka Samhita, Sushruta Samhita, and Amchi/Tibetan medicinal literature were drawn from recent peer-reviewed secondary sources discussing these systems (Kour et al., 2026), rather than from direct examination of the original texts. A total of 139 sources were finally synthesized in this review, with the majority (~80%) published between 2021 and 2026. The selected literature was thoroughly reviewed, categorized, and critically synthesized based on the review's major themes. Reference lists of selected articles were also searched for more relevant publication. The findings were synthesized to present an integrated understanding of the role of medicinal botany and ethnobotany in modern healthcare.

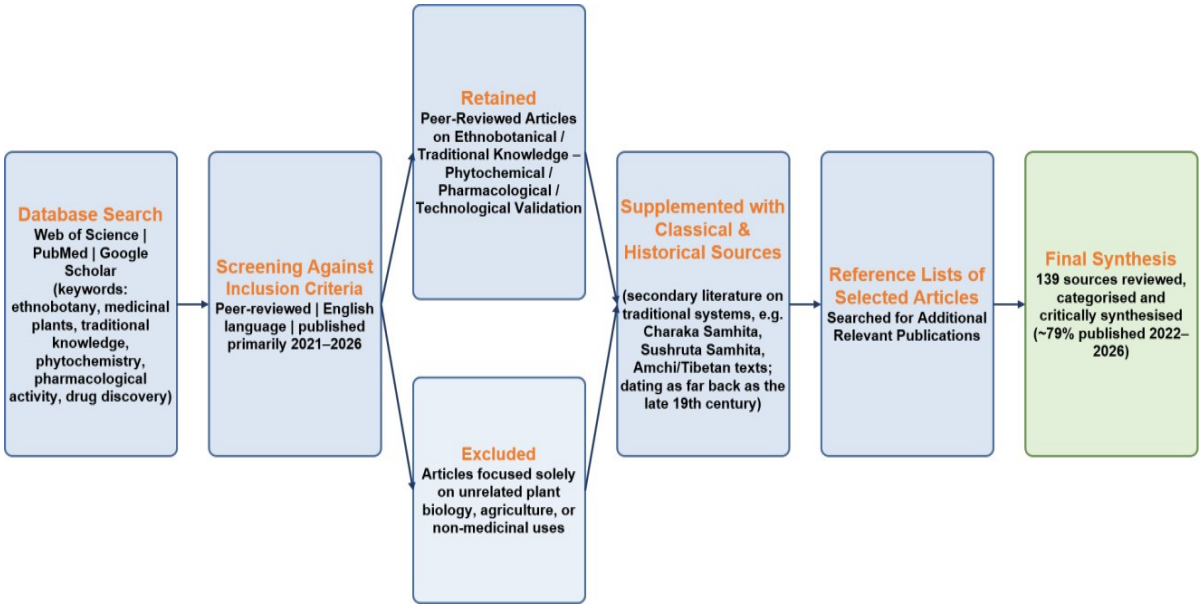

Fig. 2. Literature search and selection process followed in this review

Foundations of Ethnobotany and Medicinal Botany

Ethnobotany: Systems of Traditional Knowledge

The relationship between humans and plants goes back far into human history. Communities acquired and maintained knowledge of plants through generations of direct experiences, cultural practices and oral communication (Ouma, 2022). The continuity of such knowledge

depends on its transmission from one generation to the next. According to Lima Mota et al. (2023), in one Amazon river community, seniors are still teaching plant knowledge to younger family members, mostly when someone becomes sick or when people spend time with family. This transmission is more and more inconsistent. Milani et al. (2025) researched a school in Italy and found that children today knew considerably fewer indigenous plants than their grandparents did, so they had students interview their ancestors to help preserve the information alive. If this teaching continues, it becomes real medicine – plants used by families and traditional healers to treat common diseases. These healers and knowledge-holders are the ones who still hold this knowledge, and it is thanks to their efforts and contributions that it is still known. They should be fairly recognized and not used for the profit of others. That is why ethnobotany is important. Ethnobotany is the discipline that studies the interaction between plants and people and records and maintains it adequately (Alum, 2024). Ayurveda, one of the oldest medical systems, over three thousand years old, views body, mind and spirit to be intertwined, drawing on plant medicines from ancient writings like the Charaka and Sushruta Samhita, with the use of modern instruments such as TKDL and the Indian Medicinal Plants, Phytochemistry and Therapeutics database (IMPPAT). Amchi (Sowa-Rigpa), a medico-spiritual practice practiced in the mountains, especially in Ladakh, Tibet and Himachal Pradesh, uses hardy mountain herbs in medicines for respiratory, digestive and altitude-related problems. Tibetan medicine is based on Ayurveda, Amchi and Buddhist thinking. It uses medicines, nutrition and lifestyle to treat long term and inflammatory disease. Even today, 60–70% of the rural population in these regions still depend on such plant-based treatment, indicating the necessity for proper study and preservation of this expertise (Kour et al., 2026).

Historical Development of Medicinal Botany and Ethnobotany in India

In India, ethnobotany and medicinal botanical practices evolved from traditional to scientific studies based on the understanding of plants. The uses of plants in ancient medicine have been recorded in the Atharvaveda, a book that details plants and other natural substances identified for their medicinal properties (Prasad, 2000). The classical Ayurvedic medicine tradition has accumulated a vast body of knowledge on medicinal plants going back from 1500 BCE to 1900 CE, including plant identification, pharmacology and pharmacy in over 200 texts (Thomas et al., 2020). Indian traditional medicinal knowledge also includes Siddha medicine, Unani medicine, and various folk medicines (Ravishankar & Shukla, 2007; Mukherjee et al., 2017). The Hortus Malabaricus, the first published record in 1678, gave an important account of the medicinal plants of the Indian subcontinent and the ethnobotanical knowledge of Malabar

(Manilal, 1984). The traditional use of medicinal plants in culture and their development into structured knowledge systems is also reflected in history (Bauer-Petrovska, 2012; Ford, 1994). Ethnobotany was established as a field of study focusing on the relationship of plants and people with Harshberger's 1896 book (Harshberger, 1896). Ethnobotanical studies in India have become more organized and frequent since the 1950s, especially with native and rural groups (Jain, 1994; Rahman et al., 2019; Parul, 2022). In the 20th century, research on medicinal plants started to correlate TK with pharmacognosy, phytochemistry, pharmacology and natural-product drug development, such as on Indian medicinal plants like *Phyllanthus emblica* (Mukherjee et al., 2007; Mirunalini & Krishnaveni, 2010). Later, computational methods were used to predict and screen for the biological activity of natural products used in Ayurvedic medicine (Polur et al., 2011). The volume of ethnobotanical publications and number of new themes began to grow significantly in India in the 2000s (Pathak & Bharati, 2020) and the trend continued in the 2020s (Ranavagol, 2025). There is a growing amount of research focusing on standardization and quality control of Indian medicinal plants (Kaundal & Kumar, 2025); incorporation of in silico tools with TK; or phytochemical and pharmacological studies of traditional species of special interest, including *Azadirachta indica* (Debnath et al., 2025). So, Indian ethnobotany has now gradually shifted from documentation to evidence based and multi-disciplinary medicinal plant research (Fig. 3).

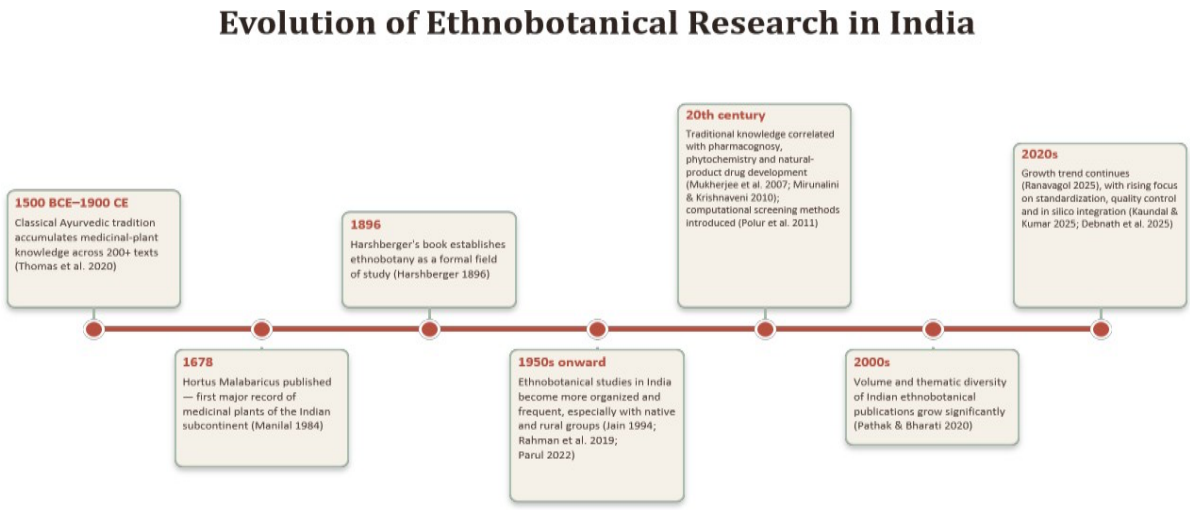

Fig. 3. A timeline of knowledge, from classical Ayurveda to modern integrative science

Medicinal Botany: The Scientific and Pharmacognostic Basis

Medicinal botany is the study of plants with reference to their chemical elements and to their therapeutic effects. In the process, the first step is to correctly identify the plant by its morphology, anatomy and sometimes its genetic material. In the absence of this information

additional authentication cannot be done (Neelam et al., 2025). Herbs often include multiple active constituents, not just one, so that the quality profile needs to be developed for consistency (Noviana et al., 2022), which can be achieved through chemical fingerprinting for standardization and testing of traditional formulations. Different sections of the same plant material (e.g. roots) contain substances which are now recognized to have anti-inflammatory and anti-cancer qualities, explaining the historical usage of these plants by healers (Stompor-Gorący, 2023). This whole process is exemplified by safflower, a traditional treatment used for generations and now recognized for its antioxidant and hepatoprotective effects (Bai et al., 2025). The primary goal here is to convert ancient knowledge into knowledge that is acknowledged and respected in the discipline of modern medicine (Neelam et al., 2025).

Link between Ethnobotany and Medicinal Botany

In fact, ethnobotany and medicinal botany are closely connected, even though they approach medicinal plants from different angles. Based on long-term human use ethnobotany aims to direct researchers to plants of interest although this information is not necessarily scientifically based (Chele et al., 2025). Then comes medicinal botany, which tests whether the plant has medicinal characteristics and what it does in the laboratory and in animals (Tan et al., 2025). For example, turmeric (*Curcuma longa*) is a kitchen spice used widely and has been used traditionally to treat diabetes, wounds, and swelling; however, a recent animal study found that the active constituents in turmeric actually work to lower blood glucose in diabetic mice, accelerate wound healing, and reduce paw swelling (Islam et al., 2024). Also, neem (*Azadirachta indica*), a plant with anti-fever and anti-infection properties used in South Asian countries since ancient times, was tested in mice with cerebral malaria and it significantly reduced the parasitic level and brain damage (Rahmah et al., 2024). In this way, tradition raises the question, science provides the answer, and together they turn old plant wisdom into medicine, a pathway summarized in Fig. 4.

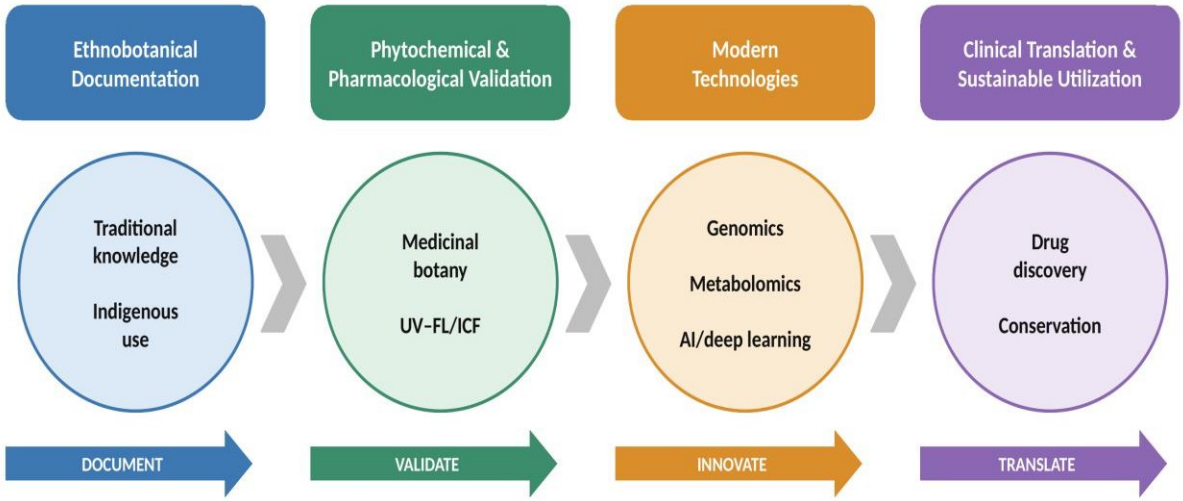

Fig. 4. From Traditional Knowledge to Sustainable Healthcare.
UV, use value; FL, fidelity level; ICF, informant consensus factor; AI, artificial intelligence.

Traditional and Indigenous Knowledge Systems in the Use of Medicinal Plants

Traditional and indigenous knowledge is an important source of information about medicinal plants, their identification, preparation and therapeutic usage. This is essentially passed down from generation to generation and assists in the ethnobotanical studies and scientific exploration of medicinal herbs (Aremu et al., 2024). Indigenous people and saint communities of Chitrakoot, native people of Chhota Bhangal, and ethnic communities of Himachal Pradesh continue to retain and apply TK of medicinal plants in their local healthcare practices (Pandey et al., 2026; Thakur et al., 2024; Thakur et al., 2025). But when communities modernize and this knowledge is not passed on, it risks extinction. The knowledge being transferred can be thoroughly documented and responsibly combined with modern research on medicinal botany, maintaining the knowledge while scientifically verifying traditional treatment utilizing plants (Alum, 2024). Ethnobotany can help to discover and assess medicinal plants and can also help in conserving biodiversity and preserving the TK and practices of local populations (Chhetri et al., 2025).

Traditional Knowledge to Modern Healthcare

Selection of Plant Based on Traditional Claims

TK has been used not only locally, but also to identify several medicinally important plants. Artemisinin is a case in point, as it was discovered in traditional Chinese medicine and has also been researched extensively, such as its possible anticancer activity (Feng et al., 2025). Metformin may also be derived from *Galega officinalis*, a plant that has been used in folk medicine in Europe to help treat symptoms of diabetes; metformin then became a principal

therapy for diabetes in modern times (Bailey, 2024). A similar pattern is seen with vincristine and vinblastine, two anticancer alkaloids that were identified while researchers investigated folk claims that the Madagascar periwinkle plant (*Catharanthus roseus*) could treat diabetes, and which remain important in the treatment of cancers such as leukemia today (Mendonce et al., 2025). All this indicates that the use of TK does not have to be opposed to modern medicine; indeed, in the case of reserpine, the discovery of an antihypertensive agent from the Ayurvedic medicinal plant *Rauvolfia serpentina* (Sarpagandha), the evolution of anti-hypertensive therapy was crucial (Anupama, 2025). Instead, it can serve as a culturally formed knowledge bank to aid in the identification of biologically active resources and provide leads to current drug discovery and therapeutic development.

Today, people recognize the role traditional plant knowledge can play in healing. This has resulted in the growth of phytochemical research and the development of plant-based medicine candidates and herbal formulations (Anmol et al., 2024). Quantitative ethnobotanical indices such as informant consensus factor (ICF), importance value index (IVI), and the Index of Cultural Relevance help identify and rank plants that are culturally important, widely used, and environmentally significant (Shyam et al., 2025). Indices like IVI, percentage respondent knowledge index (PRKI), ICF, and the fidelity level (Akhtar et al., 2025) may also aid in the further identification of bioactive compounds and in pharmacological confirmation. They do so by ranking medicinal plants according to therapeutic consensus and ethnobotanical importance. Balkrishna et al. (2024) noted that combining quantitative ethnobotanical approaches with traditional Ayurvedic textual knowledge can help resolve the botanical identity of a medicinal plant recorded as more than one species, so that scientific validation can then be focused on the correct species. Ethnobotanical data from the Western Ghats indicate a vast and as-yet-unconfirmed collection of medicinal plants. This underscores the importance of TK in selecting species for screening pharmacological effects and bioactive chemicals (Janardhana & Nekrakalaya, 2025). Integrating ethnobotanical knowledge with multi-omics, mass spectrometry, and computational approaches enables the identification and analysis of the most relevant plant chemicals in a faster, more accurate manner. This can help people find new drugs (Chele et al., 2025).

In metabolomics, mass spectrometry, NMR and computational methods can be used in an effort to discover new metabolites with different structures, relate the chemical properties of metabolites to their biological activity and facilitate labeling of metabolites. This accelerates the discovery of new natural products while reducing redundant effort spent re-examining

already known chemicals (Deleray et al., 2025). The selection of plants, the extraction, the chromatographic separation and the spectroscopic examination are all needed to find and isolate bioactive secondary metabolites. New technologies could solve these problems of structure diversity and compound instability (Assouguem et al., 2025). Therapeutic metabolites biosynthesis pathways and geographical distribution can be studied by genomics and multi-omics approaches. Comparative genomics, systems biology, and enzyme engineering can help make these substances and use them in a sustainable way (Xue et al., 2026). More recently, AI has been applied directly to this isolation-and-optimization stage: AI models can combine diverse biological data sources to identify the components involved in biosynthesis, model metabolic networks, and optimize extraction and isolation parameters for bioactive compounds, representing a recent, AI-based advance in the isolation of active constituents from medicinal plants (Chen et al., 2026).

Phytochemistry and Pharmacological Validation of Medicinal Plants

Medicinal plants are a source of many bioactive compounds such as flavonoids, terpenoids, alkaloids, phenolics, glycosides, essential oils and polysaccharides that possess antioxidant, anti-inflammatory, antimicrobial, anticancer, neuroprotective, cardioprotective and antidiabetic properties (Riaz et al., 2023). Modern analytical and computational technologies are able to better identify and understand these chemicals and how they work (Chihomvu et al., 2024). But the phytochemical profile of a plant is not constant and the quantity and type of phytochemicals produced by a plant are dependent on several variables, including altitude, temperature, light, ultraviolet exposure, water availability and soil quality (Pant et al., 2021; Jangpangi et al., 2025). This variation along with variations of extraction method makes proper phytochemical analysis and quality control essential involving collection of plant, extraction, screening and phytochemicals identification by thin-layer chromatography (TLC), HPLC, GC–MS, LC–MS and NMR etc (Savickiene & Raudone, 2024; Latif & Nawaz, 2025; Swaminathan et al., 2024). The chemicals are then approved for usage once safety and efficacy are established by in silico, in vitro, in vivo and clinical investigations (Intharuksa et al., 2024; Gudavalli et al., 2024). This scientific confirmation links TK with contemporary facts (Hernández et al., 2022), validating why many plants have been traditionally used for generations (Table 1). For instance, *Vitex trifolia* has terpenoids and flavonoids that validate its traditional usage in respiratory and inflammatory ailments (Mottaghipisheh et al., 2024). Similarly, artemisinin from *Artemisia annua* is an established antimalarial medicine, while curcumin, *Ginkgo biloba* and *Hypericum perforatum* have been investigated for their potential therapeutic effects on

inflammation, cognitive function and depression, respectively **(**Etaware et al., 2025; Jafari et al., 2024; Wieland et al., 2026; Kalbermatten & Saller, 2025). Some of the remedies are also being tested in clinical trials – *Achyrocline satureioides* for respiratory infections and some herbal formulations for wound healing (Bastos et al., 2025; Ahmed et al., 2025). Jingyin Granules and Reduning Injection showed promising results during coronavirus disease 2019 (COVID-19) (Latarissa et al., 2024). However, there are some limitations like limited clinical evidence, poor standardization, unclear dosing, toxicity, and herb–drug interactions (Al-Farsi & Nunes, 2026; Sartori et al., 2025) indicating the need for future research to include TK with modern laboratory and computational methods.

Table 1. Selected medicinal plants illustrating the link between traditional use, bioactive compounds, and pharmacological evidence

Plant species	Family	Part used	Traditional/ethnomedicinal use	Key bioactive compounds	Pharmacological evidence	Source
Artemisia annua L.	Asteraceae	Leaves/aerial parts	Traditionally used for fever and febrile illnesses.	Artemisinin; artemisinic acid; flavonoids	Artemisinin derivatives form the basis of artemisinin-based antimalarial medicines; crude plant preparations should not be equated with standardized ACT therapy.	WHO, 2023
Catharanthus roseus (L.) G.Don	Apocynaceae	Leaves/aerial parts	Traditional use in several medicinal systems, including for diabetes and other ailments.	Vincristine; vinblastine; catharanthine; vindoline	Vincristine and vinblastine are established anticancer alkaloids developed from the plant.	Kumar, Singh, et al., 2022
Salix alba L.	Salicaceae	Bark	Traditional use of willow bark for pain, fever and inflammatory complaints.	Salicin; salicylates; phenolic glycosides	Willow salicylates contributed to the development of modern salicylate analgesics; this should be distinguished from aspirin itself.	Tawfeek et al., 2021; Desborough & Keeling, 2017

Plant species	Family	Part used	Traditional/ethnomedicinal use	Key bioactive compounds	Pharmacological evidence	Source
Curcuma longa L.	Zingiberaceae	Rhizome	Traditional use for inflammatory conditions, digestive complaints and wounds.	Curcumin; demethoxycurcumin; bisdemethoxycurcumin	Experimental studies support anti-inflammatory, wound-healing and antidiabetic activities of curcuminoids; evidence varies by indication.	Islam et al., 2024
Zingiber officinale Roscoe	Zingiberaceae	Rhizome	Traditional use for nausea, vomiting and digestive complaints.	Gingerols; shogaols; zingerone	Clinical and experimental evidence supports antiemetic activity in several settings.	Ernst & Pittler, 2000
Centella asiatica (L.) Urb.	Apiaceae	Leaves/aerial parts	Traditional use for wounds, skin disorders, cognitive complaints and inflammatory conditions.	Asiaticoside; madecassoside; asiatic acid	Preclinical and clinical literature reports wound-healing, neuroprotective and other activities; evidence varies by indication.	Hein et al., 2025

Plant species	Family	Part used	Traditional/ethnomedicinal use	Key bioactive compounds	Pharmacological evidence	Source
Azadirachta indica A.Juss.	Meliaceae	Leaves	Traditional use for skin disorders, fever, infections and other ailments.	Azadirachtin; nimbin; nimbolide; quercetin	Preclinical studies report antimicrobial, anti-inflammatory and antimalarial-related activities; these should not be interpreted as established human therapy for all indications.	Rahmah et al., 2024
Berberis vulgaris L.	Berberidaceae	Root/stem bark/fruit	Traditional use for gastrointestinal, hepatic and inflammatory complaints.	Berberine; berbamine; palmatine	Experimental and clinical literature supports several pharmacological activities of berberine-containing preparations; evidence varies by indication.	Imenshahidi & Hosseinzadeh, 2019
Terminalia chebula Retz.	Combretaceae	Fruit	Traditional use for gastrointestinal disorders, constipation and other conditions.	Chebulagic acid; chebulinic acid; gallic acid; ellagic acid	Preclinical literature reports antioxidant, anti-inflammatory, antimicrobial and gastrointestinal-related activities; further clinical validation is needed for many indications.	Wang et al., 2024

Plant species	Family	Part used	Traditional/ethnomedicinal use	Key bioactive compounds	Pharmacological evidence	Source
Salvia miltiorrhiza Bunge	Lamiaceae	Root	Traditional use in cardiovascular and circulatory disorders.	Tanshinones; salvianolic acids	Extensive pharmacological and clinical literature concerns cardiovascular and cerebrovascular applications, with evidence varying by preparation and indication.	Su et al., 2015
Withania somnifera (L.) Dunal	Solanaceae	Root	Traditional Ayurvedic use as a rasayana and for weakness, stress and related complaints.	Withanolides; withaferin A; sitoindosides	Human and preclinical studies have investigated stress, anxiety, cognition and other outcomes; evidence is indication-specific.	Tandon & Yadav, 2020; Arumugam et al., 2024
Andrographis paniculata (Burm.f.) Nees	Acanthaceae	Leaves/aerial parts	Traditional use for fever, respiratory and digestive complaints.	Andrographolide; neoandrographolide	Clinical and experimental studies support activity in some respiratory and inflammatory indications; evidence differs among preparations.	Kumar et al., 2021

Plant species	Family	Part used	Traditional/ethnomedicinal use	Key bioactive compounds	Pharmacological evidence	Source
Nigella sativa L.	Ranunculaceae	Seeds	Traditional use for respiratory, digestive and inflammatory complaints.	Thymoquinone; nigellidine; nigellicine	Preclinical and clinical studies report immunomodulatory, anti-inflammatory and metabolic effects; clinical evidence remains indication-specific.	Gholamnezhad et al., 2016
Foeniculum vulgare Mill.	Apiaceae	Fruit	Traditional use for digestive complaints, flatulence and menstrual-related symptoms.	Anethole; fenchone; estragole	Pharmacological literature supports digestive, antimicrobial, antioxidant and spasmolytic activities; clinical evidence varies by use.	Badgujar et al., 2014
Ginkgo biloba L.	Ginkgoaceae	Leaves	Traditional and modern herbal use for cognitive and circulatory complaints.	Ginkgolides; bilobalide; flavonol glycosides	Standardized *Ginkgo biloba* extracts have been clinically investigated for cognitive and vascular outcomes; findings vary according to indication and extract.	Wieland et al., 2026

Plant species	Family	Part used	Traditional/ethnomedicinal use	Key bioactive compounds	Pharmacological evidence	Source
Asparagus racemosus Willd.	Asparagaceae	Root	Traditional Ayurvedic use for female reproductive health, lactation and gastrointestinal complaints.	Shatavarins; steroidal saponins; racemosol	Preclinical and emerging clinical evidence has investigated lactation, reproductive health and other traditional-use-related activities; evidence strength varies by indication.	Singh, 2016; Banerjee et al., 2025
Pistacia atlantica Desf.	Anacardiaceae	Gum/resin, fruit and other parts	Traditional use for stomach disorders, renal disorders, wounds and cough.	Terpenoids; phenolics; flavonoids; fatty acids	Pharmacological studies report antioxidant, anti-inflammatory and metabolic activities; clinical investigation has also been reported for P. atlantica gum.	Mahjoub et al., 2018
Rauvolfia serpentina (L.) Benth. ex Kurz	Apocynaceae	Root	Traditional use for hypertension, high blood pressure, snakebite, fever and other ailments.	Reserpine; ajmaline; ajmalicine; other indole alkaloids	Clinical evidence exists for Rauvolfia preparations and alkaloids, particularly in cardiovascular/CNS and antihypertensive contexts.	Kumar, Kumari, et al., 2022

Plant species	Family	Part used	Traditional/ethnomedicinal use	Key bioactive compounds	Pharmacological evidence	Source
Papaver somniferum L.	Papaveraceae	Latex/capsule	Long-standing traditional medicinal use for pain, cough and other ailments.	Morphine; codeine; thebaine; papaverine	Morphine and related alkaloids are established pharmaceutical agents; other reported plant activities should be interpreted according to their evidence level.	Butnariu et al., 2022
Camptotheca acuminata Decne.	Nyssaceae	Bark/wood and other tissues	Traditional Chinese medicinal use; subsequently investigated as a source of anticancer compounds.	Camptothecin and related camptothecin alkaloids	Camptothecin provided the lead for topoisomerase-I-targeting anticancer drugs, including topotecan and irinotecan.	Martino et al., 2017
Cinchona spp.	Rubiaceae	Bark	Traditional use of Cinchona bark for intermittent fevers.	Quinine; quinidine; cinchonine; cinchonidine	Cinchona bark and quinine have a documented history of antimalarial use; quinine became an established antimalarial drug.	Gachelin et al., 2017

Plant species	Family	Part used	Traditional/ethnomedicinal use	Key bioactive compounds	Pharmacological evidence	Source
Podophyllum peltatum L.	Berberidaceae	Rhizome/root and resin	Traditional medicinal use for warts, skin conditions and other ailments.	Podophyllotoxin; related lignans	*Podophyllotoxin from* Podophyllum *species provided the basis for semisynthetic anticancer derivatives such as etoposide and teniposide; the crude plant material/podophyllin is toxic and should not be equated with these standardized drugs.*	Singh & Agrawal, 2024

Abbreviations: ACT, artemisinin-based combination therapy; CNS, central nervous system.

Current Technological Approaches for the Improvement of Ethnobotanical Research The progress in genetics, biotechnology and metabolomics provides novel insights into the generation of active compounds of medicinal plants. Biosynthetic pathways have been elucidated by studying disease-resistance reactions, and specific genes and enzymes have been identified that are involved in the biosynthesis of phytochemicals (Wang et al., 2024; Saito, 2025). These compounds can be produced more efficiently and sustainably using newer biotechnological tools like clustered regularly interspaced short palindromic repeats/CRISPR-associated protein 9 (CRISPR/Cas9), metabolic engineering, tissue culture and hairy-root culture (Zaman & Park, 2026). Metabolomics using tools such as LC–MS, GC–MS and NMR may also help in discovering bioactive compounds and mapping out biosynthetic pathways, which, together with genomic information would lead to a better understanding of genes involved in metabolite production (Rai et al., 2025; Saito, 2025). The genomics–metabolomics pipeline is gaining new layers as AI and deep learning enter the sector. Currently, AI solutions in chemoinformatics can predict the structure of new potentially active compounds and their interaction with biological targets. These solutions include machine-learning-based models, molecular docking, virtual screening, and absorption, distribution, metabolism, excretion and toxicity (ADMET) properties prediction. They allow researchers to prioritize promising leads and avoid expensive in-vitro experiments (Gangwal et al., 2026). Also, deep-learning models are employed for the identification of plant species by recognizing images, being of help for both medication development and biodiversity conservation (Mulugeta et al., 2024). Multi-omics integration, which includes genomes, transcriptomics, proteomics and metabolomics and connects genes with metabolites and biosynthetic pathways not accessible to single-omics techniques, further supports this picture (Wang et al., 2024). There are, however, caveats, since models trained on extremely diverse data are likely to be more accurate for well-described, common species than for rare plants that are underrepresented within the training data (Algemayel et al., 2026).

Ethnobotany has progressed from traditional plant-use documentation toward knowledge-guided natural-product discovery, supported by improved analytical and computational approaches; several important drugs, including Taxol, vinblastine, quinine and artemisinin**,** have roots in traditional medicine. Advances in genomics, transcriptomics, proteomics, metabolomics and phenomics, combined with computational tools, now enable high-throughput screening and more precise characterization of plant-derived natural products (Chele et al., 2025). More recently, deep-learning methods have been applied to medicinal-

plant leaf identification, with one 2025 model achieving 98.90% test accuracy, demonstrating the potential of AI for automated plant identification (Gautam et al., 2025).

In addition to these laboratory breakthroughs, digital instruments are also increasingly important for maintaining traditional plant knowledge, much of which is still passed down orally and at risk of disappearing. Ethnobotanical knowledge can increasingly be documented, stored, mapped and accessed through digital databases, mobile applications, geographic information systems (GIS) and web-based platforms (Banisetti & Kosuri, 2023; Barroso da Silva, 2026; Saran & Singh, 2025). An example is the Traditional Knowledge Digital Library (TKDL), which systematically documents traditional information, correlates it with modern research and helps to prevent biopiracy (Sattigeri et al., 2025). Standardized databases and digital records also help pass this information to future generations and assist conservation efforts (Duche-Pérez et al., 2025).

Beyond its role in molecular authentication of medicinal plants, DNA barcoding can be used to detect adulteration and substitution in herbal medicines. Advanced approaches such as multilocus barcoding, metabarcoding, mini-barcoding, and barcoding high-resolution melting (Bar-HRM) can be applied to processed medicinal plant materials and combined with morphological, chromatographic, and spectrometric methods for complementary botanical and chemical quality control (Nazar et al., 2025; Aswin et al., 2026). Following authentication and chemical characterization, bioinformatic analysis can integrate chemical, gene, disease, and drug–target information to prioritize bioactive molecules and explore their potential multi-target actions and mechanisms, supporting the identification of therapeutic candidates from medicinal plants (Maciejewska-Turska et al., 2025). At the molecular level, integrating genomics, transcriptomics, and metabolomics data with molecular networking, reaction-pair analysis, and gene expression patterns through multi-omics approaches can enhance the discovery of plant biosynthetic pathways (Reinhardt et al., 2025). AI techniques can be used to combine diverse biological data sources, identify components involved in the biosynthesis of valuable compounds, model metabolic networks, and optimize cultivation and extraction parameters (Chen et al., 2026). For natural product research, AI technologies are used in molecular representation, binding prediction, drug repurposing, retrosynthesis, and generative optimization, and multi-omics technologies are used to study plant traits, biosynthesis, regulatory mechanisms, and quality control (Wang et al., 2026). In ethnopharmacology, machine learning, deep learning, natural language processing (NLP), molecular docking, and bioactivity prediction are applied to analyze ethnobotanical information and assist in natural

product research (Suryawanshi et al., 2026). At the delivery stage, nanotechnology can address the problems of phytochemicals' poor solubility, low bioavailability, and rapid degradation by using sustained and targeted delivery systems based on polymeric, lipid, and protein nanoparticles (Beygi et al., 2025). The therapeutic potential of ethnomedicinal plants rests not only on the identification of bioactive chemicals but also on how efficiently they can be isolated, stabilized and delivered into the body. Modern extraction methodologies and sophisticated chromatographic techniques have increased the purity, yield and consistency of phytochemical isolation (Fonmboh et al., 2020). Methods such as supercritical-fluid extraction and microwave-assisted extraction have improved the recovery and preservation of essential bioactive ingredients (Hein et al., 2025). Common problems such as poor solubility and low bioavailability are addressed by exploring newer formulation strategies: Phytosomal formulations enhance absorption by coupling plant compounds with phospholipids (Kamireddy et al., 2024), and vesicular drug-delivery systems improve stability, permeability and controlled, targeted release (Lukhele et al., 2023). Nanotechnology-based carriers and omics-guided discovery and predictive computational techniques further enhance the bioavailability and therapeutic targeting of these drugs (Latif & Nawaz, 2025). These modern technological approaches to ethnobotanical research and drug discovery are summarized in Fig. 5.

Recent AI Applications in Ethnobotanical Documentation

Ethnobotanical documentation has increasingly moved from conventional field records toward digital databases and computational approaches. In India, the Online Structural and Analytics based Database for Herbs of India (OSADHI) integrates TK, geographical distribution, phytochemical information, and chemoinformatics for 6,959 medicinal plant species, while machine-learning models have been applied to predict phytochemical activities (Kiewhuo et al., 2023). More recently, AI applications have expanded to medicinal-plant identification, integration of ethnobotanical and phytochemical datasets, and computational prediction of bioactive compounds, with particular relevance to Himalayan medicinal-plant research (Kour et al., 2026). AI is also being applied in ethnopharmacology through data mining, molecular docking, bioactivity prediction, and natural-product research (Suryawanshi et al., 2026), while other recent work highlights AI's potential for structuring, preserving, and analysing ethnomedicinal knowledge through computer vision and machine-learning approaches (Azeez et al., 2026). Beyond South Asia, a broader wave of digital methods through data mining, molecular docking, bioactivity prediction, and natural-product research has reshaped

ethnobiological fieldwork more generally: mobile data collection platforms, participatory mapping tools, biodiversity cataloguing systems, and remote sensing have expanded researchers' capacity to document and analyse biocultural knowledge, though this digitalization also raises methodological and ethical questions around data governance and community participation (Barroso da Silva, 2026). These advances are not without risks: the use of AI in scientific writing may introduce fictitious content and unverifiable references into ethnobotanical literature, underscoring the need for critical appraisal and source verification (Kalle & Sõukand, 2026).

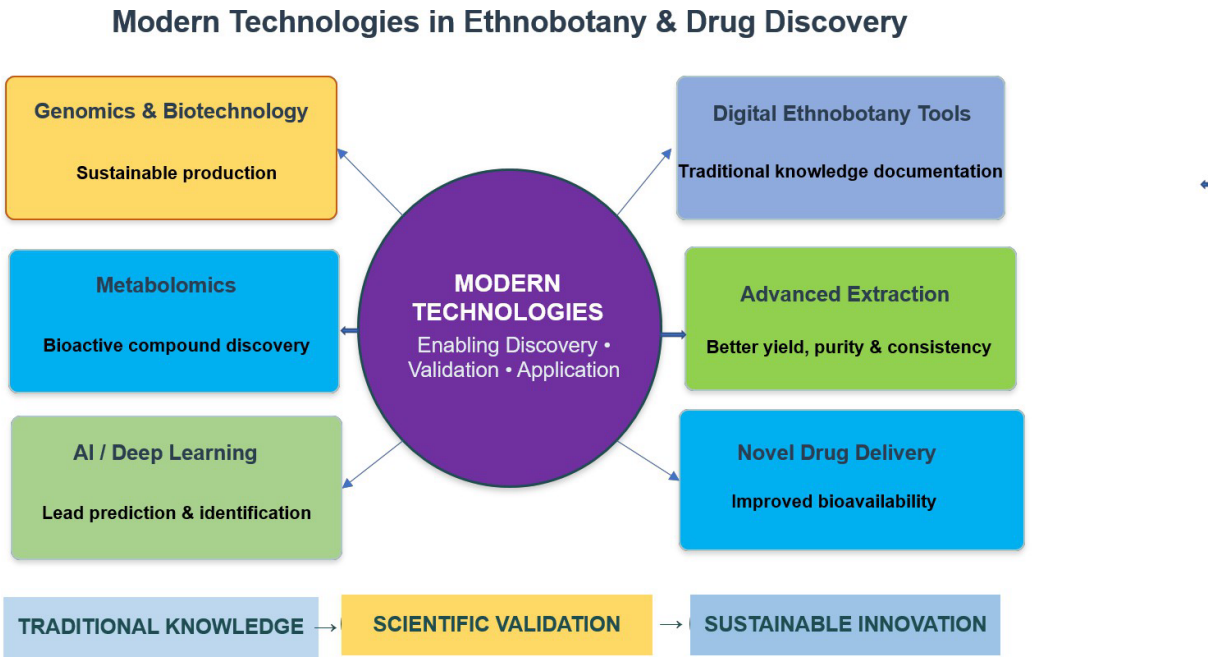

Fig. 5. From traditional knowledge to scientific validation and sustainable innovation

Challenges and Future Directions

Challenges in Ethnobotanical Research and Traditional Knowledge Integration

The main challenges and the corresponding future directions are summarized in Fig. 6.

Variation in documentation, sampling and data-processing methods limits comparability across ethnobotanical studies (Febriyanti et al., 2026).

Habitat degradation, environmental changes and unsustainable harvesting threaten medicinal-plant resources and may contribute to variation in phytochemical profiles (Mykhailenko et al., 2025; Pant et al., 2021; Jangpangi et al., 2025).

Gaps in TK protection and access-and-benefit-sharing implementation remain important challenges in ethnobotanical research (Mishra, 2025; Park & Park, 2025; Bajpai & Dixit, 2025).

Reliance on morphological identification and basic bioassays can limit reliable authentication and reproducibility of medicinal-plant research (Nazar et al., 2025).

Limited clinical evidence, standardization, dosing information and safety data constrain the translation of TK into evidence-based healthcare (Al-Farsi & Nunes, 2026; Sartori et al., 2025).

Future Directions

Develop standardized and reproducible frameworks for ethnobotanical documentation and data processing.

Promote sustainable harvesting, conservation and community-based cultivation of medicinal plants.

Strengthen recognition of knowledge holders and transparent, institutionalized access-and-benefit-sharing mechanisms.

Integrate DNA-based authentication with complementary botanical, chromatographic and spectrometric approaches.

Integrate ethnobotanical evidence with phytochemical, pharmacological, clinical and computational approaches for rigorous validation.

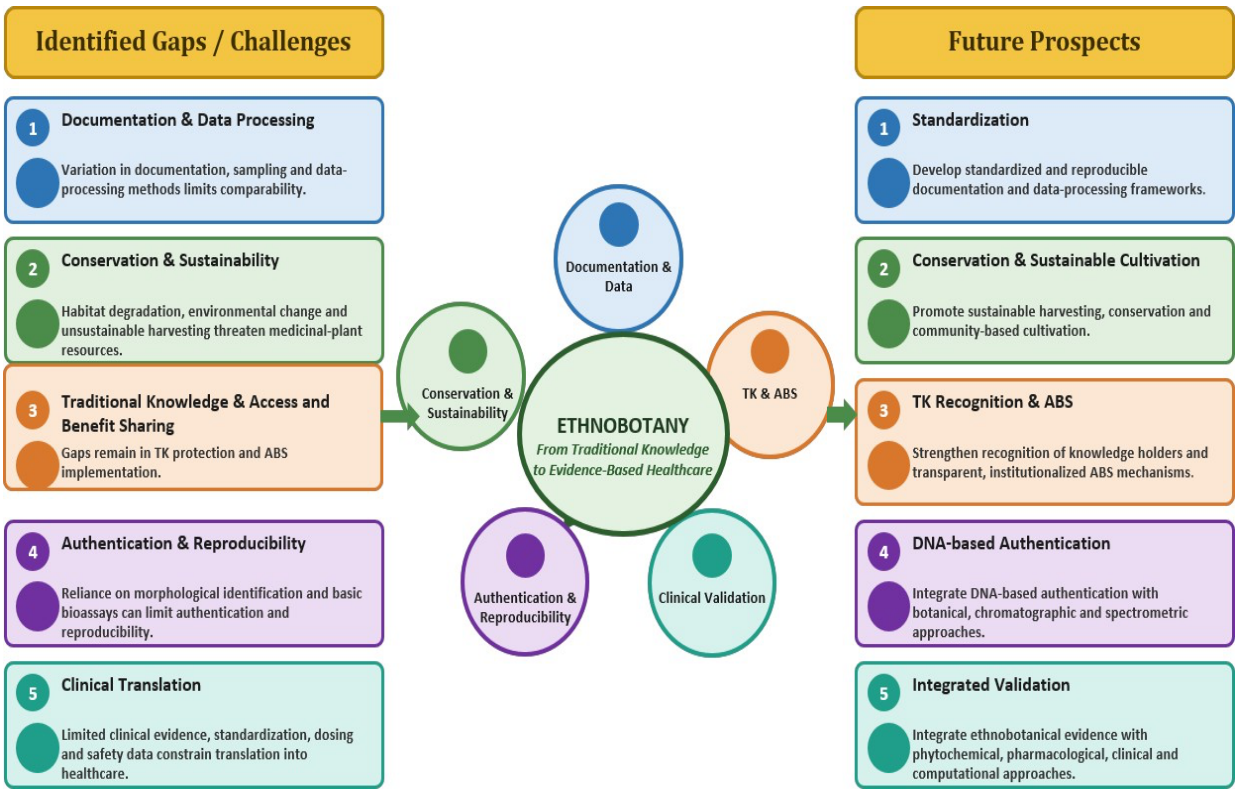

Fig. 6. Challenges in ethnobotanical research and traditional knowledge integration, with corresponding future directions.
ABS, access and benefit-sharing; TK, traditional knowledge.

Conclusion

This review has shown that scientific validation, technological innovation, and policy/conservation are functionally interdependent, and this should inform future research design. TK remains a vital resource for primary healthcare and drug discovery, and integrating it with phytochemical analysis, molecular identification, and clinical trials can support the development of safe, effective, evidence-based plant medicines (Gerner et al., 2025; Shimrah et al., 2026; Kiflie et al., 2024; Manisha et al., 2025). Realizing this potential, however, depends on national and international legislation that enables the interdisciplinary collaboration, conservation, and equitable benefit-sharing outlined above (Gerner et al., 2025). Systematic documentation of undocumented medicinal plants and re-validation of TK will therefore be essential, not only to advance healthcare innovation, but also to safeguard biodiversity and ensure the responsible use of plant medicinal resources for future generations.

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Author's contributions

The authors confirm contributions to the paper as follows:

Poonam Thakur: Investigation, Resources, Data curation, Visualization, Writing – original draft, Writing – review & editing. Priyanka Sharma: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing. Gulshan Kumar: Visualization, Validation, Writing – review & editing.

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Data availability

No new data were generated in this study. The data in the tables were compiled from published studies cited in the References.

Conflict of interest

The authors declare no conflict of interest.

References

Ahmed, L. A., Hussain, A., Barbhuiya, P. A., Zaman, S., Laskar, A. M., Pathak, M. P., Dutta, P. P., & Sen, S. (2025). Herbal medicine for the management of wounds: A systematic review of clinical studies. *Infectious Disorders - Drug Targets*, *25*(5), Article e18715265320593. https://doi.org/10.2174/0118715265320593241007095952

Akhtar, S., Naithani, S., Thapliyal, A., & Bachheti, A. (2025). The importance value index of medicinal plants traditionally used by local and tribal communities of Chenab Valley of Jammu and Kashmir, India. *Ethnobotany Research and Applications*, *30*, 1–16. https://doi.org/10.32859/era.30.56.1-16

Al-Farsi, H., & Nunes, S. (2026). Herbal drug development: From traditional knowledge to modern application. *Journal of Dravyaguna and Bhaishajya Vigyan*, *3*(1), 15–18. https://doi.org/10.33545/dravyaguna.2026.v3.i1.a.29

Algemayel, C., Abou Jaoude, D., Talhouk, S. N., Issa, I., & Ghassibe, C. (2026). Advances in machine learning models for plant species identification: A scoping review. *Ecological Informatics*, *93*, Article 103464. https://doi.org/10.1016/j.ecoinf.2025.103464

Alum, E. U. (2024). The role of indigenous knowledge in advancing the therapeutic use of medicinal plants: Challenges and opportunities. *Plant Signaling & Behavior*, *19*(1), Article 2439255. https://doi.org/10.1080/15592324.2024.2439255

Alum, E. U., Manjula, V. S., Uti, D. E., Echegu, D. A., Ugwu, O. P.-C., Egba, S. I., & Agu, P. C. (2025). Metabolomics-driven standardization of herbal medicine: Advances, applications, and sustainability considerations. *Natural Product Communications*, *20*(8), 1–16. https://doi.org/10.1177/1934578X251367650

Anmol, Aggarwal, G., Sharma, M., Singh, R., Shivani, Kumar, S. A., & Sharma, U. (2024). Ethnopharmacologically important highly subsidized Indian medicinal plants: Systematic review on their traditional uses, phytochemistry, pharmacology, quality control, conservation status and future prospective. *Journal of Ethnopharmacology*, *320*, Article 117385. https://doi.org/10.1016/j.jep.2023.117385

Anupama, Y. J. (2025). Historical milestones in the management of hypertension – The story of reserpine. *Indian Journal of Kidney Diseases*, *4*(3), 91–95. https://doi.org/10.4103/ijkd.ijkd_46_25

Aremu, A. O., Luo, B., & Mussarat, S. (2024). Medical ethnobotany. *BMC Complementary Medicine and Therapies*, *24*, Article 216. https://doi.org/10.1186/s12906-024-04515-0

Arumugam, V., Vijayakumar, V., Balakrishnan, A., Bhandari, R. B., Boopalan, D., Ponnurangam, R., Thirupathy, V. S., & Kuppusamy, M. (2024). Effects of Ashwagandha (*Withania somnifera*) on stress and anxiety: A systematic review and meta-analysis. *Explore, 20*(6), 103062. https://doi.org/10.1016/j.explore.2024.103062

Assouguem, A., Annemer, S., Kara, M., & Lazraq, A. (2025). Innovative approaches in the extraction, identification, and application of secondary metabolites from plants.

Phyton-International Journal of Experimental Botany, *94*(6), 1631–1668. https://doi.org/10.32604/phyton.2025.065750

Aswin, P. P., Shukla, S., & Dalal, J. (2026). Enhancing authentication: A review of DNA barcoding technique for detecting adulterants in Indian herbal medicines. *Microchemical Journal*, *220*, Article 116655. https://doi.org/10.1016/j.microc.2025.116655

Azeez, E. M., Adeleke, B. S., & Azeez, Z. A. (2026). Digitising disappearing knowledge: Artificial intelligence applications in the documentation and conservation of West African ethnomedicinal plant traditions. *International Journal of Research in Pharmacy and Allied Science*, *5*(6), 99–108. https://doi.org/10.71431/IJRPAS.2026.5608

Badgujar, S. B., Patel, V. V., & Bandivdekar, A. H. (2014). *Foeniculum vulgare* Mill.: A review of its botany, phytochemistry, pharmacology, contemporary application, and toxicology. *BioMed Research International, 2014*, 842674. https://doi.org/10.1155/2014/842674

Bai, H., Yang, J., & Wang, R. (2025). *Carthamus tinctorius* L.: A comprehensive review of its ethnomedicine, phytochemistry, pharmacology, and clinical applications. *Frontiers in Pharmacology, 16*, 1609299. https://doi.org/10.3389/fphar.2025.1609299

Bailey, C. J. (2024). Metformin: Therapeutic profile in the treatment of type 2 diabetes. *Diabetes, Obesity and Metabolism*, *26*(Suppl. 3), 3–19. https://doi.org/10.1111/dom.15663

Bajpai, S., & Dixit, R. (2025). The Nagoya Protocol and biodiversity conservation: Legal insights on access and benefit-sharing for medicinal and aromatic plant resources. *International Journal of Minor Fruits, Medicinal and Aromatic Plants*, *11*(1), 56–67. https://doi.org/10.53552/ijmfmap.11.1.2025.56-67

Balkrishna, A., Thakur, P., Singh, S., & Mishra, R. (2024). An ethnobotanical survey for the determination of informant consensus factor to demystify traditional herb Teliya-kanda in Indian medicinal system. *Indian Journal of Traditional Knowledge*, *23*(9), 898–907. https://doi.org/10.56042/ijtk.v23i9.13620

Banerjee, P., Das, A., Kumar, P., Chakraborty, S., & Jalan, K. (2025). An updated insight on the chemistry, ethnobotany, and health benefits of *Asparagus racemosus* (Shatavari): With a special emphasis on Shatavarin IV. *Journal of the American Nutrition Association, 44*(8), 681–692. https://doi.org/10.1080/27697061.2025.2496945

Banisetti, D. K., & Kosuri, N. P. (2023). Ethnobotanical research in the digital age: Harnessing technology for data collection and analysis. *International Journal of Indigenous Herbs and Drugs*, *8*(4), 1–6. https://doi.org/10.46956/ijihd.v8i4.466

Barroso da Silva, H. T. L. (2026). Digital technologies in ethnobiology and ethnoecology: Methodological opportunities, ethical challenges, and participatory implications. *Journal of Ethnobiology and Ethnomedicine*, *22*(1), Article 65. https://doi.org/10.1186/s13002-026-00889-2

Bastos, C. I. M., Dani, C., Cechinel, L. R., Neves, A. H. da S., Rasia, F. B., Lamers, M. L., Bianchi, S. E., Meirelles, G., Worm, P. V., Bassani, V. L., & Siqueira, I. R. (2025). Validation of a traditional medicine, *Achyrocline satureioides* infusion, for the improvement of mild respiratory infection symptoms: A randomized, placebo-controlled and open-label clinical trial. *Pharmaceuticals*, *18*(6), Article 861. https://doi.org/10.3390/ph18060861

Bauer-Petrovska, B. (2012). Historical review of medicinal plants' usage. *Pharmacognosy Reviews*, *6*(11), 1–5. https://doi.org/10.4103/0973-7847.95849

Beygi, M., Oroojalian, F., Karav, S., Kesharwani, P., & Sahebkar, A. (2025). Nano-phytoconstituents: Recent advances, regulatory insights, challenges, and future horizons. *Journal of Drug Delivery Science and Technology*, *108*, Article 106908. https://doi.org/10.1016/j.jddst.2025.106908

Butnariu, M., Quispe, C., Herrera-Bravo, J., Pentea, M., Sarac, I., Küşümler, A. S., Özçelik, B., Painuli, S., Semwal, P., Imran, M., Gondal, T. A., Emamzadeh-Yazdi, S., Lapava, N., Yousaf, Z., Kumar, M., Eid, A. H., Al-Dhaheri, Y., Suleria, H. A. R., Contreras, M. del M., . . . Cho, W. C. (2022). *Papaver plants: Current insights on phytochemical and nutritional composition along with biotechnological applications*. *Oxidative Medicine and Cellular Longevity, 2022*, 2041769. https://doi.org/10.1155/2022/2041769

Chaachouay, N., & Zidane, L. (2024). Plant-derived natural products: A source for drug discovery and development. *Drugs and Drug Candidates*, *3*(1), 184–207. https://doi.org/10.3390/ddc3010011

Chele, K. H., Piater, L. A., van der Hooft, J. J. J., & Tugizimana, F. (2025). Bridging ethnobotanical knowledge and multi-omics approaches for plant-derived natural product discovery. *Metabolites*, *15*(6), Article 362. https://doi.org/10.3390/metabo15060362

Chen, J., Cai, J., To Quyen Duong, H., Bunsupa, S., Han, R., & Tong, X. (2026). AI-driven integration and optimization of medicinal plant multi-omics metabolic networks. *Frontiers in Plant Science*, *17*, Article 1756809. https://doi.org/10.3389/fpls.2026.1756809

Chhetri, R., Bhutia, L. T., & Bose, B. (2025). An ethnobotanical insight into the healing traditions as strategies for forest conservation of indigenous ethnic communities in the West Sikkim district of the Sikkim Himalayas, India. *Trees, Forests and People*, *22*, Article 101058. https://doi.org/10.1016/j.tfp.2025.101058

Chihomvu, P., Ganesan, A., Gibbons, S., Woollard, K., & Hayes, M. (2024). Phytochemicals in drug discovery – A confluence of tradition and innovation. *International Journal of Molecular Sciences*, *25*(16), Article 8792. https://doi.org/10.3390/ijms25168792

Das, S., Singh, P. K., Ameeruddin, S., Kumar Bindhani, B., Obaidullah, W. J., Obaidullah, A. J., Mishra, S., & Mohapatra, R. K. (2023). Ethnomedicinal values of *Boerhaavia diffusa* L. as a panacea against multiple human ailments: A state-of-the-art review.

Frontiers in Chemistry, *11*, Article 1297300. https://doi.org/10.3389/fchem.2023.1297300

Debnath, S., Das, M., Mondal, S., Sarkar, B. K., & Babu, G. (2025). Neem (*Azadirachta indica* A. Juss): A multifaceted tree & an elixir in the traditional system of Indian medicine. *Discover Plants*, *2*, Article 156. https://doi.org/10.1007/s44372-025-00196-2

Deleray, V., Dorrestein, P. C., & Avalon, N. E. (2025). Molecules to medicine: Advances in metabolomics for natural product drug discovery. *Current Opinion in Biotechnology*, *96*, Article 103373. https://doi.org/10.1016/j.copbio.2025.103373

Desborough, M. J. R., & Keeling, D. M. (2017). The aspirin story—from willow to wonder drug. *British Journal of Haematology, 177*(5), 674–683. https://doi.org/10.1111/bjh.14520

Duche-Pérez, A., Gutiérrez Aguilar, O. A., Valero Quispe, J. L., Serruto Castillo, A., & Mamani Daza, L. J. (2025). Systematic review of ethnomedicinal knowledge: Documentation, evaluation, and conservation of medicinal plants and their therapeutic applications (Version 2). *F1000Research*, *13*, Article 1324. https://doi.org/10.12688/f1000research.157960.2

Ernst, E., & Pittler, M. H. (2000). Efficacy of ginger for nausea and vomiting: A systematic review of randomized clinical trials. *British Journal of Anaesthesia, 84*(3), 367–371. https://doi.org/10.1093/oxfordjournals.bja.a013442

Etaware, P. M., America, O., Egara, O. W., & Ekun, V. S. (2025). Herbal medicine: Scientific validation and future prospects. *International Journal of Pharmacy and Chemistry*, *11*(3), 67–75. https://doi.org/10.11648/j.ijpc.20251103.12

Febriyanti, R. M., Ramadhania, Z. M., Tjitraresmi, A., Indradi, R. B., Maisyarah, I. T., Maundu, P. M., Muhaimin, M., & Sujarwo, W. (2026). A systematic review of ethnobotanical study in Indonesia: Diversity and cultural patterns of medicinal plant use. *Journal of Ethnobiology and Ethnomedicine*, *22*, Article 42. https://doi.org/10.1186/s13002-026-00879-4

Feng, J., He, Y., Bai, T., You, Q., Zhu, H., Jia, C., Liu, B., & Li, S. (2025). Bibliometric and visualized analysis of artemisinin and its derivatives in cancer. *Drug Design, Development and Therapy*, *19*, 5517–5538. https://doi.org/10.2147/DDDT.S514219

Fonmboh, D. J., Abah, E. R., Fokunang, T. E., Herve, B., Teke, G. N., Rose, N. M., Borgia, N. N., Fokunang, L. B., Andrew, B. N., Kaba, N., Bathelemy, N., & Ntungwen, F. C. (2020). An overview of methods of extraction, isolation and characterization of natural medicinal plant products in improved traditional medicine research. *Asian Journal of Research in Medical and Pharmaceutical Sciences*, *9*(2), 31–57. https://doi.org/10.9734/ajrimps/2020/v9i230152

Ford, R. I. (1994). Ethnobotany: Historical diversity and synthesis. In R. I. Ford (Ed.), *The nature and status of ethnobotany* (2nd ed., pp. 33–50). Museum of Anthropology, University of Michigan.

Gachelin, G., Garner, P., Ferroni, E., Tröhler, U., & Chalmers, I. (2017). Evaluating *Cinchona* bark and quinine for treating and preventing malaria. *Journal of the Royal Society of Medicine, 110*(1), 31–40. https://doi.org/10.1177/0141076816681421

Gangwal, A., Ansari, M. U. M., Siddique, J., Sawale, S., Padmane, S., & Wadekar, R. (2026). Integrating artificial intelligence into drug discovery from medicinal plants: Current applications and infrastructural challenges. *Chemical Biology & Drug Design*, *108*(2), Article e70372. https://doi.org/10.1111/cbdd.70372

Gautam, V., Kaur, G., Ghantasala, G. S. P., Vidyullatha, P., Allabun, S., Othman, M., & Zheleznyak, A. (2025). A lightweight deep learning method for medicinal leaf image classification using feature fusion. *Scientific Reports*, *15*, Article 34417. https://doi.org/10.1038/s41598-025-17436-w

Gerner, I. R., Zerbe, S., & Säumel, I. (2025). Voices around the South Tyrolean herbal pharmacy – Exploring the stakeholder landscape and perspectives on medicinal plants as culturally salient species. *Journal of Ethnobiology*, *45*(3), 225–238. https://doi.org/10.1177/02780771251349282

Gholamnezhad, Z., Havakhah, S., & Boskabady, M. H. (2016). Preclinical and clinical effects of *Nigella sativa* and its constituent, thymoquinone: A review. *Journal of Ethnopharmacology, 190*, 372–386. https://doi.org/10.1016/j.jep.2016.06.061

Gudavalli, D., Pandey, K., Ede, V. G., Sable, D., Ghagare, A. S., & Kate, A. S. (2024). Phytochemistry and pharmacological activities of five species of *Bauhinia* genus: A review. *Fitoterapia*, *174*, Article 105830. https://doi.org/10.1016/j.fitote.2024.105830

Harshberger, J. W. (1896). The purposes of ethno-botany. *Botanical Gazette*, *21*(3), 146–154. https://doi.org/10.1086/327316

Hein, Z. M., Gopalakrishna, P. K., Kanuri, A. K., Thomas, W., Hussan, F., Naik, V. R., Shantakumari, N., Che Ramli, M. D., Mohd Moklas, M. A., Che Mohd Nassir, C. M. N., & Vishnumukkala, T. (2025). *Centella asiatica*: Advances in extraction technologies, phytochemistry, and therapeutic applications. *Life*, *15*(7), Article 1081. https://doi.org/10.3390/life15071081

Hernández, R. D., González, A. F., Suarez, B. B. G., & Guerra, I. R. (2022). Pharmacological studies as essential tools for the scientific validation of the traditional use of herbal drugs: Some considerations. In P. Chong Aguirre, M. Miranda Martínez, & P. Manzano Santana (Eds.), *Medicinal plants of Ecuador* (pp. 31–53). CRC Press. https://doi.org/10.1201/9781003173991-4

Imenshahidi, M., & Hosseinzadeh, H. (2019). Berberine and barberry (*Berberis vulgaris*): A clinical review. *Phytotherapy Research, 33*(3), 504–523. https://doi.org/10.1002/ptr.6252

Intharuksa, A., Kuljarusnont, S., Sasaki, Y., & Tungmunnithum, D. (2024). Flavonoids and other polyphenols: Bioactive molecules from traditional medicine recipes/medicinal plants and their potential for phytopharmaceutical and medical application. *Molecules*, *29*(23), Article 5760. https://doi.org/10.3390/molecules29235760

Islam, M. Z., Akter, J., Hossain, M. A., Islam, M. S., Islam, P., Goswami, C., Nguyen, H. T. T., & Miyamoto, A. (2024). Anti-inflammatory, wound healing, and anti-diabetic effects of pure active compounds present in the Ryudai gold variety of *Curcuma longa*. *Molecules*, *29*(12), Article 2795. https://doi.org/10.3390/molecules29122795

Jafari, A., Abbastabar, M., Alaghi, A., Heshmati, J., Crowe, F. L., & Sepidarkish, M. (2024). Curcumin on human health: A comprehensive systematic review and meta-analysis of 103 randomized controlled trials. *Phytotherapy Research*, *38*(12), 6048–6061. https://doi.org/10.1002/ptr.8340

Jain, S. K. (1994). Ethnobotany and research on medicinal plants in India. In D. J. Chadwick & J. Marsh (Eds.), *Ethnobotany and the search for new drugs* (Ciba Foundation Symposium 185, pp. 153–168). John Wiley & Sons. https://doi.org/10.1002/9780470514634.ch11

Janardhana, S. K., & Nekrakalaya, B. (2025). Ethnobotany to bioprospecting of medicinal plants from Western Ghats, India – A review. *Indian Journal of Traditional Knowledge*, *24*(1), 63–72. https://doi.org/10.56042/ijtk.v24i1.16335

Jangpangi, D., Patni, B., Chandola, V., & Chandra, S. (2025). Medicinal plants in a changing climate: Understanding the links between environmental stress and secondary metabolite synthesis. *Frontiers in Plant Science*, *16*, Article 1587337. https://doi.org/10.3389/fpls.2025.1587337

Kalbermatten, N., & Saller, R. (2025). St John's wort (*Hypericum perforatum*) fresh plant tincture for patients with mild to moderate depression: A prospective observational study. *Complementary Medicine Research*, *32*(5), 363–375. https://doi.org/10.1159/000547920

Kalle, R., & Sõukand, R. (2026). Time travel within the history of ethnobotany. *Plants*, *15*(3), Article 496. https://doi.org/10.3390/plants15030496

Kamireddy, S., Sangeetha, S., & Kosanam, S. (2024). Phytosomal drug delivery system: A detailed study. *Current Traditional Medicine*, *10*(4), Article e310523217507. https://doi.org/10.2174/2215083810666230531163053

Kaundal, R., & Kumar, D. (2025). Current demands for standardization of Indian medicinal plants: A critical review. *Medicine in Drug Discovery*, *27*, Article 100211. https://doi.org/10.1016/j.medidd.2025.100211

Kiewhuo, K., Gogoi, D., Mahanta, H. J., Rawal, R. K., Das, D., Vaikundamani, S., Jamir, E., & Sastry, G. N. (2023). OSADHI—An online structural and analytics based database for herbs of India. *Computational Biology and Chemistry*, *102*, Article 107799. https://doi.org/10.1016/j.compbiolchem.2022.107799

Kiflie, M. A., Sharma, D. P., Haile, M. A., & Srinivasagan, R. (2024). EfficientNet ensemble learning: Identifying Ethiopian medicinal plant species and traditional uses by integrating modern technology with ethnobotanical wisdom. *Computers*, *13*(2), Article 38. https://doi.org/10.3390/computers13020038

Kour, D., Kataria, A., Kumar, A., Bassi, A., Kaur, T., Gusain, M., Sheikh, I., Khan, S. S., Dutta, A., Kaur, S., Kour, H., Bajaj, P., & Alaneme, G. U. (2026). Synergizing ethnobotany and artificial intelligence: Exploring therapeutic frontier of Himalayan medicinal plants. *Environmental Sciences Europe*, *38*, Article 114. https://doi.org/10.1186/s12302-026-01395-8

Kumar, S., Kumari, D., & Singh, B. (2022). Genus *Rauvolfia*: A review of its ethnopharmacology, phytochemistry, quality control/quality assurance, pharmacological activities and clinical evidence. *Journal of Ethnopharmacology, 295*, 115327. https://doi.org/10.1016/j.jep.2022.115327

Kumar, S., Singh, B., & Bajpai, V. (2021). *Andrographis paniculata* (Burm.f.) Nees: Traditional uses, phytochemistry, pharmacological properties and quality control/quality assurance. *Journal of Ethnopharmacology*, *275*, 114054. https://doi.org/10.1016/j.jep.2021.114054

Kumar, S., Singh, B., & Singh, R. (2022). *Catharanthus roseus* (L.) G. Don: A review of its ethnobotany, phytochemistry, ethnopharmacology and toxicities. *Journal of Ethnopharmacology, 284*, 114647. https://doi.org/10.1016/j.jep.2021.114647

Latarissa, I. R., Meiliana, A., Sormin, I. P., Sugiono, E., Wathoni, N., Barliana, M. I., & Lestari, K. (2024). The efficacy of herbal medicines on the length of stay and negative conversion time/rate outcomes in patients with COVID-19: A systematic review. *Frontiers in Pharmacology*, *15*, Article 1383359. https://doi.org/10.3389/fphar.2024.1383359

Latif, R., & Nawaz, T. (2025). Medicinal plants and human health: A comprehensive review of bioactive compounds, therapeutic effects, and applications. *Phytochemistry Reviews*, *25*(3), 2299–2342. https://doi.org/10.1007/s11101-025-10194-7

Lima Mota, M. R., Lauer-Leite, I. D., & Novais, J. S. de. (2023). Intergenerational transmission of traditional ecological knowledge about medicinal plants in a riverine community of the Brazilian Amazon. *Polibotánica*, (56), 311–329. https://doi.org/10.18387/polibotanica.56.16

Lindenmaier, M. P., Bernart, M. W., & Brinckmann, J. A. (2025). Advanced methodologies for the quality control of herbal supplements and regulatory considerations. *Phytochemical Analysis*, *36*(8), 2417–2433. https://doi.org/10.1002/pca.70000

Liu, T., & Chen, X. (2024). Bioactive compounds from natural sources: Discovery, evaluation, and applications. *Molecules*, *29*(13), Article 3209. https://doi.org/10.3390/molecules29133209

Lukhele, B. S., Bassey, K., & Witika, B. A. (2023). The utilization of plant-material-loaded vesicular drug delivery systems in the management of pulmonary diseases. *Current Issues in Molecular Biology*, *45*(12), 9985–10017. https://doi.org/10.3390/cimb45120624

Maciejewska-Turska, M., Georgiev, M. I., Kai, G., & Sieniawska, E. (2025). Advances in bioinformatic methods for the acceleration of the drug discovery from nature. *Phytomedicine*, *139*, Article 156518. https://doi.org/10.1016/j.phymed.2025.156518

Mahjoub, F., Akhavan Rezayat, K., Yousefi, M., Mohebbi, M., & Salari, R. (2018). *Pistacia atlantica* Desf.: A review of its traditional uses, phytochemicals and pharmacology. *Journal of Medicine and Life, 11*(3), 180–186. https://doi.org/10.25122/jml-2017-0055

Manilal, K. S. (1984). Hortus Malabaricus and the ethnoiatrical knowledge of ancient Malabar. *Ancient Science of Life*, *4*(2), 96–99.

Manisha, M., Babu, R., Begam, A. M., Shakya Chahal, K., & Ashok Harale, A. (2025). Medicinal plants and traditional uses and modern applications. *Journal of Neonatal Surgery*, *14*(3), 162–175. https://doi.org/10.52783/jns.v14.2210

Martino, E., Della Volpe, S., Terribile, E., Benetti, E., Sakaj, M., Centamore, A., Sala, A., & Collina, S. (2017). The long story of camptothecin: From traditional medicine to drugs. *Bioorganic & Medicinal Chemistry Letters, 27*(4), 701–707. https://doi.org/10.1016/j.bmcl.2016.12.085

Mendonce, K. C., Palani, N., Rajadesingu, S., Radhakrishnan, K., Ayyar, M., & Priya, L. S. (2025). Pharmacological potential of bioactive compounds in *Catharanthus roseus* extract: A comprehensive review. *Toxicology Reports*, *15*, Article 102094. https://doi.org/10.1016/j.toxrep.2025.102094

Milani, F., Bottoni, M., Maiellaro, A., Crisci, A., Bruschi, P., Giuliani, C., & Fico, G. (2025). Counteracting traditional knowledge erosion: An ethnobotanical survey in Valle Imagna (Bergamo, Italy) to foster intergenerational transfer. *Plants*, *14*(22), Article 3477. https://doi.org/10.3390/plants14223477

Mirunalini, S., & Krishnaveni, M. (2010). Therapeutic potential of *Phyllanthus emblica* (amla): The Ayurvedic wonder. *Journal of Basic and Clinical Physiology and Pharmacology*, *21*(1), 93–105. https://doi.org/10.1515/JBCPP.2010.21.1.93

Mishra, P. (2025). The Biological Diversity (Amendment) Act 2023: A gateway to sustainable access? *Environmental Law Review*, *27*(1), 31–41. https://doi.org/10.1177/14614529251328784

Mottaghipisheh, J., Kamali, M., Doustimotlagh, A. H., Nowroozzadeh, M. H., Rasekh, F., Hashempur, M. H., & Iraji, A. (2024). A comprehensive review of ethnomedicinal approaches, phytochemical analysis, and pharmacological potential of *Vitex trifolia* L. *Frontiers in Pharmacology*, *15*, Article 1322083. https://doi.org/10.3389/fphar.2024.1322083

Mukherjee, P. K., Harwansh, R. K., Bahadur, S., Banerjee, S., Kar, A., Chanda, J., Biswas, S., Ahmmed, S. M., & Katiyar, C. K. (2017). Development of Ayurveda – Tradition to trend. *Journal of Ethnopharmacology*, *197*, 10–24. https://doi.org/10.1016/j.jep.2016.09.024

Mukherjee, P. K., Rai, S., Kumar, V., Mukherjee, K., Hylands, P. J., & Hider, R. C. (2007). Plants of Indian origin in drug discovery. *Expert Opinion on Drug Discovery*, *2*(5), 633–657. https://doi.org/10.1517/17460441.2.5.633

Mulugeta, A. K., Sharma, D. P., & Mesfin, A. H. (2024). Deep learning for medicinal plant species classification and recognition: A systematic review. *Frontiers in Plant Science*, *14*, Article 1286088. https://doi.org/10.3389/fpls.2023.1286088

Mykhailenko, O., Jalil, B., McGaw, L. J., Echeverría, J., Takubessi, M., & Heinrich, M. (2025). Climate change and the sustainable use of medicinal plants: A call for "new" research strategies. *Frontiers in Pharmacology*, *15*, Article 1496792. https://doi.org/10.3389/fphar.2024.1496792

Nagori, M., Rajput, D., Choudhary, G., & Khabiya, R. (2025). Qualitative and quantitative methods of phytochemical analysis. In U. E. Odoh, S. S. Gurav, & M. O. Chukwuma (Eds.), *Pharmacognosy and phytochemistry: Principles, techniques, and clinical applications* (pp. 143–166). Wiley. https://doi.org/10.1002/9781394203680.ch08

Nasim, N., Sandeep, I. S., & Mohanty, S. (2022). Plant-derived natural products for drug discovery: Current approaches and prospects. *Nucleus*, *65*, 399–411. https://doi.org/10.1007/s13237-022-00405-3

National Library of Medicine. (2004). *Medical botany*. In *Collection development guidelines of the National Library of Medicine*. National Center for Biotechnology Information. https://www.ncbi.nlm.nih.gov/books/NBK518761/

Nazar, N., Saxena, A., Sebastian, A., Slater, A., Sundaresan, V., & Sgamma, T. (2025). Integrating DNA barcoding within an orthogonal approach for herbal product authentication: A narrative review. *Phytochemical Analysis*, *36*(1), 7–29. https://doi.org/10.1002/pca.3466

Neelam, R., Maurya, R., Prakash, S., Shukla, S., & Shukla, A. (2025). A comprehensive review of pharmacognostic techniques for the identification and standardization of herbal drugs. *Journal of Drug Discovery and Health Sciences*, *2*(3), 26–32. https://doi.org/10.21590/jddhs.02.03.04

Noviana, E., Indrayanto, G., & Rohman, A. (2022). Advances in fingerprint analysis for standardization and quality control of herbal medicines. *Frontiers in Pharmacology*, *13*, Article 853023. https://doi.org/10.3389/fphar.2022.853023

Ouma, A. (2022). Intergenerational learning processes of traditional medicinal knowledge and socio-spatial transformation dynamics. *Frontiers in Sociology*, *7*, Article 661992. https://doi.org/10.3389/fsoc.2022.661992

Pandey, A. K., Bux, F., Sonkar, K., Roy, A., & Yadav, H. (2026). To document traditional ethnobotanical knowledge of medicinal plants used by indigenous and saint communities of Chitrakoot, India. *Journal of Ethnobiology and Ethnomedicine*, *22*, Article 80. https://doi.org/10.1186/s13002-026-00931-3

Pant, P., Pandey, S., & Dall'Acqua, S. (2021). The influence of environmental conditions on secondary metabolites in medicinal plants: A literature review. *Chemistry & Biodiversity*, *18*(11), Article e2100345. https://doi.org/10.1002/cbdv.202100345

Park, T. J., & Park, S. P. (2025). Legal and economic perspectives on fair and equitable benefit sharing in the Nagoya Protocol. *Conservation Biology*, *39*(2), Article e14410. https://doi.org/10.1111/cobi.14410

Parul. (2022). A review on past, present and future of ethnobotany in India. *Journal of Pharmaceutical Negative Results*, *13*(Special Issue 6), 1602–1606. https://doi.org/10.47750/pnr.2022.13.S06.212

Pathak, M., & Bharati, K. A. (2020). Mapping ethnobotany research in India. *Ethnobotany Research and Applications*, *20*, 1–12. https://doi.org/10.32859/era.20.49.1-12

Patwardhan, B., & Aswar, U. (2025). Harnessing the potential of ethnopharmacology for future medicines. *Journal of Ethnopharmacology*, *353*(Pt A), Article 120359. https://doi.org/10.1016/j.jep.2025.120359

Polur, H., Joshi, T., Workman, C. T., Lavekar, G., & Kouskoumvekaki, I. (2011). Back to the roots: Prediction of biologically active natural products from Ayurveda traditional medicine. *Molecular Informatics*, *30*(2–3), 181–187. https://doi.org/10.1002/minf.201000163

Prasad, P. V. (2000). Atharvaveda and its materia medica. *Bulletin of the Indian Institute of History of Medicine*, *30*(2), 83–92.

Rahmah, Z., Nirmala, K. C., Nashichuddin, A., Riskiyana, R., Milliana, A., Indriana, N., Astari, L. F., Ayudianti, P., & Kholil, M. (2024). Effect of neem leaf extract (*Azadirachta indica*) in reducing the degree of parasitemia and apoptosis in C57BL mice with cerebral malaria. *Veterinary World*, *17*(7), 1497–1503. https://doi.org/10.14202/vetworld.2024.1497-1503

Rahman, I. U., Afzal, A., Iqbal, Z., Ijaz, F., Ali, N., Shah, M., Ullah, S., & Bussmann, R. W. (2019). Historical perspectives of ethnobotany. *Clinics in Dermatology*, *37*(4), 382–388. https://doi.org/10.1016/j.clindermatol.2018.03.018

Rai, M., Dutta, M., Saito, K., & Rai, A. (2025). A deep dive into plant metabolomics: Milestones, technologies, and translational impact. *Plant Physiology*, *199*(4), Article kiaf408. https://doi.org/10.1093/plphys/kiaf408

Ranavagol, K. S. (2025). Scientometrics study on ethnobotanical research in India (2000–2024). *International Journal of Research in Library Science*, *11*(1), 198–213. https://doi.org/10.26761/IJRLS.11.1.2025.1843

Ravishankar, B., & Shukla, V. J. (2007). Indian systems of medicine: A brief profile. *African Journal of Traditional, Complementary and Alternative Medicines*, *4*(3), 319–337. https://doi.org/10.4314/ajtcam.v4i3.31226

Reinhardt, J. K., Craft, D., & Weng, J.-K. (2025). Toward an integrated omics approach for plant biosynthetic pathway discovery in the age of AI. *Trends in Biochemical Sciences*, *50*(4), 311–321. https://doi.org/10.1016/j.tibs.2025.02.001

Riaz, M., Khalid, R., Afzal, M., Anjum, F., Fatima, H., Zia, S., Rasool, G., Egbuna, C., Mtewa, A. G., Uche, C. Z., & Aslam, M. A. (2023). Phytobioactive compounds as therapeutic agents for human diseases: A review. *Food Science & Nutrition*, *11*, 2500–2529. https://doi.org/10.1002/fsn3.3308

Saito, K. (2025). Development of phytochemical genomics: From decoding metabolome to functional genomics and biotechnology of plant metabolism. *Proceedings of the Japan Academy, Series B: Physical and Biological Sciences*, *101*(8), 445–484. https://doi.org/10.2183/pjab.101.030

Saran, S., & Singh, P. (2025). Integrating geospatial technologies, artificial intelligence, and citizen science for ethnobotanical medicinal plants: Towards improved digital public health. *International Journal of Ayurveda Research*, *6*(4), 293–300. https://doi.org/10.4103/ijar.ijar_341_25

Sartori, D., Aronson, J. K., Brand, J. S., Gauffin, O., Hedfors Vidlin, S., Norén, G. N., & Onakpoya, I. J. (2025). Signals of adverse reactions to herbal medicines: Evidence and document analysis based on a scoping review. *Drug Safety*, *48*(12), 1339–1352. https://doi.org/10.1007/s40264-025-01580-3

Sattigeri, V. J., Kumar, A., Asthana, V., & Jain, A. (2025). Digitization of Indian traditional agricultural practices in the Traditional Knowledge Digital Library – Towards sustainability science. *Annals of Library and Information Studies*, *72*(4), 406–416. https://doi.org/10.56042/alis.v72i4.25672

Savickiene, N., & Raudone, L. (2024). Trends in plants phytochemistry and bioactivity analysis. *Plants*, *13*(22), Article 3173. https://doi.org/10.3390/plants13223173

Sethi, S. S., Bhardwaj, T., Sethi, S. K., Kaur, S., Rimpi, & Baldi, A. (2025). Advancing herbal medicine safety: The need for a global pharmacovigilance approach. *Naunyn-Schmiedeberg's Archives of Pharmacology*, *398*(10), 13499–13514. https://doi.org/10.1007/s00210-025-04066-2

Shimrah, T., Leisan, J., & Lungleng, P. (2026). Cultural consensus in medicinal plant use among the Tangkhul Naga of Northeast India. *Ethnobotany Research and Applications*, *33*, 1–11. https://doi.org/10.32859/era.33.36.1-11

Shyam, B. S., Tandiya, C., Bakshi, S., & Sharma, N. K. (2025). Factors determining ethnomedicinal plants choice in Pushparajgargh Tehsil of Madhya Pradesh, India: Ethnomedicinal plant choices. *Indian Journal of Traditional Knowledge*, *24*(6), 555–565. https://doi.org/10.56042/ijtk.v24i6.10529

Silveira, D., & Boylan, F. (2023). Medicinal plants: Advances in phytochemistry and ethnobotany. *Plants*, *12*(8), Article 1682. https://doi.org/10.3390/plants12081682

Singh, A., Singh, N., Singh, S., Srivastava, R. P., Singh, L., Verma, P. C., Devkota, H. P., Rahman, L. U., Kumar Rajak, B., Singh, A., & Saxena, G. (2023). The industrially important genus *Kaempferia*: An ethnopharmacological review. *Frontiers in Pharmacology*, *14*, Article 1099523. https://doi.org/10.3389/fphar.2023.1099523

Singh, K., Gupta, J. K., Chanchal, D. K., Shinde, M. G., Kumar, S., Jain, D., Almarhoon, Z. M., Alshahrani, A. M., Calina, D., Sharifi-Rad, J., & Tripathi, A. (2025). Natural products as drug leads: Exploring their potential in drug discovery and development. *Naunyn-Schmiedeberg's Archives of Pharmacology*, *398*(5), 4673–4687. https://doi.org/10.1007/s00210-024-03622-6

Singh, N., & Agrawal, P. (2024). A comprehensive review on the pharmacognostic and toxicological profile of *Podophyllum peltatum* (Bajiaolian). *Pharmacological Research - Modern Chinese Medicine, 10*, 100353. https://doi.org/10.1016/j.prmcm.2023.100353

Singh, R. (2016). *Asparagus racemosus*: A review on its phytochemical and therapeutic potential. *Natural Product Research, 30*(17), 1896–1908. https://doi.org/10.1080/14786419.2015.1092148

Stompor-Gorący, M. (2023). Pharmacological studies of medicinal potential phytochemicals in plant roots. *Pharmaceuticals*, *16*(11), Article 1520. https://doi.org/10.3390/ph16111520

Su, C.-Y., Ming, Q.-L., Rahman, K., Han, T., & Qin, L.-P. (2015). *Salvia miltiorrhiza*: Traditional medicinal uses, chemistry, and pharmacology. *Chinese Journal of Natural Medicines*, *13*(3), 163–182. https://doi.org/10.1016/S1875-5364(15)30002-9

Suryawanshi, R. M., Chaudhari, P. D., & Gilhotra, R. M. (2026). AI in ethnopharmacology, the pharmaceutical industry, and its applications. *Annales Pharmaceutiques Françaises*, *84*(2), 161–174. https://doi.org/10.1016/j.pharma.2025.11.011

Swaminathan, V., Manivannan, R., Suresh Kumar, G., Yuvaraj, G., Mukil, J., Subasri, S. V., Jagadeeswaran, P., & Mothilal, M. (2024). Collection, identification and qualitative phytochemical testing of medicinal plants. *International Journal of Pharmaceutical Sciences*, *2*(12), 3196–3217. https://doi.org/10.5281/zenodo.14562692

Tan, E. W., Low, L. H., Atanasov, A. G., & Goh, B. H. (2025). Bridging traditions and technology: The role of ethnopharmacology in shaping next-generation multidisciplinary researchers. *Pharmacology Research & Perspectives*, *13*(1), Article e70074. https://doi.org/10.1002/prp2.70074

Tandon, N., & Yadav, S. S. (2020). Safety and clinical effectiveness of *Withania somnifera* (Linn.) Dunal root in human ailments. *Journal of Ethnopharmacology, 255*, 112768. https://doi.org/10.1016/j.jep.2020.112768

Tawfeek, N., Mahmoud, M. F., Hamdan, D. I., Sobeh, M., Abdel-Naim, A. B., & Wink, M. (2021). Phytochemistry, pharmacology and medicinal uses of plants of the genus *Salix*: An updated review. *Frontiers in Pharmacology, 12*, 593856. https://doi.org/10.3389/fphar.2021.593856

Thakur, A., Kumari, R., Kumar, A., & Chaudhary, A. (2024). Quantitative ethnobotanical study of medicinal plants used by native people of selected areas of Chhota Bhangal, Himachal Pradesh. *Ethnobotany Research and Applications*, *28*, 1–29. https://doi.org/10.32859/era.28.46.1-29

Thakur, N., Kumar, N., Kumar, S., Sharma, A., Ahlawat, Y. K., Malik, A., & Ahmed, M. (2025). Ethnobiological survey on medicinal plants used by Gaddi and Gujjar tribes of riparian region of Beas River of Himachal Pradesh in North Western Himalayas, India. *Clinical Phytoscience, 11*, 4. https://doi.org/10.1186/s40816-024-00388-5

Thomas, V., Nair, S. N. V., Ved, D. K., & Shankar, D. (2020). Controversial identities of medicinal plants in classical literature of Ayurveda. *Journal of Ayurveda and Integrative Medicine*, *11*(4), 565–572. https://doi.org/10.1016/j.jaim.2019.09.003

Wang, B., Liu, Q., Zhao, W., Zhang, T., Zhang, D., Sutcharitchan, C., & Li, S. (2026). Revolutionizing drug discovery from natural products: The roles of artificial intelligence and multi-omics in accelerating innovation. *Acta Pharmaceutica Sinica B*, *16*(7), 4103–4127. https://doi.org/10.1016/j.apsb.2025.12.030

Wang, C., Zhang, H., Wang, X., Wang, X., Li, X., Li, C., Wang, Y., & Zhang, M. (2024). Comprehensive review on fruit of *Terminalia chebula*: Traditional uses, phytochemistry, pharmacology, toxicity, and pharmacokinetics. *Molecules*, *29*(23), Article 5547. https://doi.org/10.3390/molecules29235547

Wieland, L. S., Ludeman, E., Chi, Y., Feinberg, T. M., Chen, I.-H., Chen, K.-H., Zhu, Y., Wolverson, E., & Amri, H. (2026). *Ginkgo biloba* for cognitive impairment and dementia. *Cochrane Database of Systematic Reviews*, *2026*(2), Article CD013661. https://doi.org/10.1002/14651858.CD013661.pub2

World Health Organization. (2013). *WHO traditional medicine strategy: 2014–2023*. https://www.who.int/publications/i/item/9789241506096

World Health Organization. (2023). *WHO guidelines for malaria*. World Health Organization. https://www.who.int/publications/i/item/guidelines-for-malaria

Xue, J.-Y., Liu, S.-J., Wang, J., Huang, X.-C., Xu, Z.-C., Fang, X.-X., Li, Z., & Van de Peer, Y. (2026). Multi-omics roadmap to plant-derived medicines. *Engineering*. https://doi.org/10.1016/j.eng.2025.10.019

Zaman, W., & Park, S. (2026). Advances in functional genomics and biotechnology for enhancing therapeutic potential of medicinal plants. *International Journal of Molecular Sciences*, *27*(10), Article 4245. https://doi.org/10.3390/ijms27104245