Review Article

From Indian Ancient Remedies to Modern Pharmacology The History and Biology of Medicinal Plants

# ABSTRACT

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| The rich history and contemporary relevance of traditional Indian medicine, particularly Ayurveda, which has utilized approximately 7,000 medicinal plants for over 5,000 years. Ancient texts like the Charaka Samhita and Sushruta Samhita have laid the foundation for these practices, emphasizing a holistic approach to health through the balance of bodily humors and the use of indigenous herbs. The paper highlights the integration of traditional remedies into modern pharmaceuticals, exemplified by plants like Ashwagandha and Neem, which have been scientifically validated for their therapeutic properties. It also addresses the challenges of conservation due to overharvesting and habitat loss, advocating for sustainable practices and the integration of traditional knowledge with modern scientific research. The paper underscores the importance of ancient botanical science, as seen in Sanskrit plant nomenclature, and the need for further exploration in the post-genomic era to fully realize the potential of these medicinal plants in contemporary medicine |

Key words: Ayurveda Medicinal Plants, Traditional Medicine, Phytochemistry, Holistic Health

# Introduction

Medicinal plants have been a cornerstone of Indian traditional medicine systems such as Ayurveda, Siddha, and Unani, with Ayurveda being one of the oldest. These systems emphasize the use of medicinal herbs to maintain health and treat diseases by addressing root causes rather than just symptoms, which has kept them relevant in modern times (Bharatia et al., 2024) (Deepak & Bhawana, 2023). The bioactive constituents of these plants, including tannins, alkaloids, flavonoids, and terpenes, are recognized for their pharmacological activities, offering antimicrobial, antidiabetic, anticancer, and other therapeutic benefits (Chapter 3 Culture, Tradition, and Indigenous Practices on Medicinal Plants, 2023) (Singh, 2022). The integration of Ayurvedic principles with contemporary medical practices is seen as a promising approach to enhance treatment efficacy and safety for complex disorders like arthritis (Bharatia et al., 2024) (Chemistry, Biological Activities and Therapeutic Applications of Medicinal Plants in Ayurveda, 2022). Despite the growing interest in these traditional systems, there is a need for systematic documentation and scientific validation of the knowledge held by traditional practitioners, or vaidyas, to preserve this valuable heritage and potentially develop new formulations (Deepak & Bhawana, 2023). The global interest in Ayurvedic medicine is reflected in the investment by pharmaceutical companies in drug discovery from Ayurvedic sources, highlighting the potential of these plants in modern medicine (Chemistry, Biological Activities and Therapeutic Applications of Medicinal Plants in Ayurveda, 2022).

The exploration of the historical development of medicinal plants in India reveals a rich tapestry of traditional knowledge and practices that have significantly influenced modern pharmacological applications. Indian traditional medicine, deeply rooted in systems like Ayurveda, Siddha, and Unani, has utilized a vast array of plant species, with approximately 7,000 identified for medicinal purposes. These plants have been integral to healthcare for over 5,000 years, with their uses documented in ancient texts such as the Charka Samhita and Atharva Veda. The therapeutic properties of these plants are attributed to active compounds like alkaloids and glycosides, which have been harnessed for various treatments, including wound healing and anti-diabetic therapies. In the modern era, the Indian government has prioritized certain medicinal plants, providing substantial subsidies to encourage their cultivation and conservation, reflecting their pharmacological and commercial importance. Despite the progress in isolating bioactive compounds and evaluating their pharmacological activities, there remains a need for further scientific validation and quality assessment to fully integrate these traditional remedies into contemporary medicine. The post-genomic era offers new opportunities to explore these plants using computational and bioinformatics approaches, potentially leading to the discovery of novel drug candidates. However, the sustainability of these resources is threatened by factors such as deforestation and urbanization, necessitating urgent conservation efforts

# Historical Context of Medicinal Plant Use in India

The identity and significance of Soma, a plant mentioned in the Rigveda, have been subjects of extensive scholarly debate, with various candidates proposed over time. Wasson famously suggested Amanita muscaria, a psychoactive mushroom, as Soma, highlighting its potential ritualistic use by the Vedic Aryans (Shah, 2015). However, the identity of Soma remains elusive, with other scholars proposing different plants, such as Nelumbo nucifera, due to its symbolic associations in Vedic and later traditions (Shah, 2015). The use of psychoactive substances in ancient rituals is further supported by the hypothesis that the Vedic Aryans might have used complex plant formulas similar to those used in ayahuasca preparations, involving plants with dimethyl tryptamine and monoamine oxidase inhibitors (Clark, 2019). Additionally, the Vedic texts, including the Atharvaveda, mention other plants like Prishni parni, Shami, and Udumbara, which align with Ayurvedic practices and highlight the ethnobotanical approach to drug development in ancient India (Pawar & Pawar, 2017). Cannabis, another plant with historical significance, was used for both medicinal and ritualistic purposes in Vedic times, although its use declined due to social and religious stigma (Biswas et al., 2017) (Bapat, 2015). The ongoing debate about Soma's identity underscores the integral role of these plants in ancient Indian culture, reflecting their medicinal and spiritual significance (Shah, 2015).

The Charaka Samhita and Sushruta Samhita are seminal texts in Ayurveda, each contributing uniquely to the field of traditional Indian medicine. The Charaka Samhita, attributed to the sage Charaka, is primarily focused on internal medicine and emphasizes the holistic approach to health through the balance of the three doshas: Vata, Pitta, and Kapha, which are essential for maintaining health and preventing disease (Arya & Bishnoi, 2023) (Ritu, 2023). This text categorizes various plants and their medicinal properties, particularly in the Shaka Varga, which includes a variety of vegetables known for their nutritional and therapeutic benefits, such as antioxidant and anti-inflammatory properties (Premlata et al., 2024). The Charaka Samhita also explores the concept of self in relation to well-being, distinguishing between the phenomenal, expansive, and transcendental selves, which underscores the text's philosophical depth in understanding health as a state of balance and harmony (Gautama & Menon, 2024). Furthermore, the Vimana Sthana section of the Charaka Samhita provides a detailed framework for diagnosing and quantifying the vitiation of doshas, which is crucial for effective treatment and management of diseases (Arya & Bishnoi, 2023) (Ritu, 2023). On the other hand, the Sushruta Samhita is renowned for its detailed descriptions of surgical techniques, marking it as one of the earliest texts on surgery. Both texts collectively lay the groundwork for Ayurvedic practices by integrating diet, lifestyle, and botanical medicine into a cohesive system aimed at both prevention and cure, influencing modern complementary therapies and promoting a balanced lifestyle through indigenous herbs and dietary practices (More & Deshmukh, 2024).

The contributions of ancient Indian rishis, particularly Charaka and Sushruta, to the classification and understanding of medicinal plants have been foundational in the development of Ayurveda, a system of medicine that has stood the test of time for over 5,000 years (Ameta et al., 2018). Charaka's "Charaka Samhita" and Sushruta's "Sushruta Samhita" are seminal texts that document a vast array of medicinal plants, with Charaka detailing 526 plants and Sushruta 395, emphasizing their therapeutic properties and applications in both general health and surgical procedures (Arya, 2018). These texts reflect a meticulous approach to the observation and documentation of plant effects on health, integrating empirical knowledge with philosophical insights into life and health, which is a hallmark of Ayurveda's holistic approach (Fields, 2023). The Ayurvedic Pharmacopoeia of India further underscores the extensive use of botanical drugs, with 621 single botanical drugs sourced from 393 species, highlighting the diversity and systematic classification of medicinal plants in Ayurveda (Yao et al., 2023). The importance of biodiversity and conservation is also emphasized, as the Indian government provides subsidies for the cultivation of certain medicinal plants to promote their conservation and sustainable use (Anmol et al., 2023). Despite the historical disruptions, such as the decline during the Muslim invasions and the resurgence post-independence, Ayurveda has continued to evolve and gain global recognition, with modern research validating many of its principles and practices (Tiwari et al., 2021) (Ameta et al., 2018). The enduring legacy of Charaka and Sushruta is evident in the ongoing exploration of bioactive compounds in these plants for drug development, demonstrating the relevance of their work in contemporary medicinal botany (Dhara & Majhi, 2022). Their methodologies and insights have not only shaped Indian traditional medicine but have also influenced neighboring cultures, as Ayurvedic texts were translated and disseminated globally, contributing to a rich heritage of ethnobotanical knowledge (Dixit, 2019).

The historical significance of botanical nomenclature in Sanskrit is deeply rooted in India's early advancements in botany and taxonomy, as evidenced by ancient texts such as the Vrksayurveda, Manasollasa, and Upavanavinoda. These texts illustrate the development of botanical science from the pre-Harappan period through the Gupta era and into the early medieval period, showcasing a sophisticated understanding of plant life and its applications in agriculture and medicine (Pruthi, 1999). Sanskrit plant names, embedded in Indian culture, serve as crucial tools for identifying plant species and their uses in Ayurveda, although challenges remain in standardizing these identifications due to varying sources of Ayurvedic drugs (Marde & Mishra, 2019). The ancient Indian educational system emphasized the conservation and cultivation of plant resources, recognizing their essential role in health and medicine, and developed comprehensive methods for plant taxonomy, soil classification, and cultivation practices (Srikanth et al., 2015). The Garuda Purana and the Kāśyapīyakrsisūkti further demonstrate the depth of Sanskrit botanical nomenclature, providing detailed lists of plant names and their corresponding botanical identities, which are crucial for understanding the historical context and applications of these plants (Wojtilla, 2002). This rich tradition of botanical nomenclature in Sanskrit not only underscores India's early contributions to the field but also continues to influence contemporary practices in plant science and medicine. The integration of ethnobotanical approaches in Ayurveda highlights the complex relationship between plants, humans, and cultures, further emphasizing the importance of Sanskrit nomenclature in the development of Ayurvedic drugs (Pawar & Pawar, 2017). Additionally, the ancient texts reflect an advanced understanding of plant physiology and ecology, prescribing sustainable practices for harmonious coexistence with nature, which are still relevant today (Singhal, 2023) (Balte, 2017).

# Biological Basis of Medicinal Plants

## Phytochemistry

Indian medicinal plants are a rich source of bioactive compounds that have been integral to traditional medicine systems such as Ayurveda and Unani, offering a wide range of therapeutic benefits. These plants contain various classes of compounds, including alkaloids, flavonoids, terpenes, saponins, and polyphenols, each contributing uniquely to health benefits. Alkaloids, for instance, are known for their analgesic properties, as seen in compounds like morphine derived from the poppy plant, which are used in pain management (Abdelkhalek et al., 2024). Flavonoids, abundant in turmeric, exhibit significant antioxidant and anti-inflammatory effects, aiding in the management of oxidative stress and inflammation-related conditions (Review on Indian Medicinal Plants/Herbs as Sources of Antioxidants, 2023). Terpenes and saponins also hold therapeutic potential; terpenes are recognized for their anti-inflammatory and antimicrobial properties, while saponins can modulate immune responses and lower cholesterol levels (Abdelkhalek et al., 2024). Polyphenols, another major class, are prevalent in many Indian medicinal plants and are associated with reducing the risk of chronic diseases such as cardiovascular diseases and cancer due to their antioxidant capabilities (Review on Indian Medicinal Plants/Herbs as Sources of Antioxidants, 2023). The integration of traditional knowledge with modern phytochemical analysis has enhanced the understanding and application of these bioactive compounds in contemporary medicine, as seen in the systematic evaluation and classification of phytochemicals for their potential roles in treating various disorders (Abdelkhalek et al., 2024) (“Medicinal Plants and Bioactive Phytochemical Diversity: A Fountainhead of Potential Drugs Against Human Diseases,” 2023). Furthermore, the Indian government supports the cultivation of medicinal plants by providing subsidies, recognizing their pharmacological and commercial importance (Anmol et al., 2023). This support, combined with ongoing research, underscores the potential of these plants in developing alternative therapeutic agents, highlighting the need for further scientific validation and conservation efforts (Anmol et al., 2023) (“Medicinal Plants and Bioactive Phytochemical Diversity: A Fountainhead of Potential Drugs Against Human Diseases,” 2023).

Flavonoids, a diverse group of polyphenolic compounds found in plants, exert significant anti-inflammatory and antioxidant effects through complex molecular mechanisms. These compounds modulate key enzymes and signaling pathways involved in inflammation, such as inhibiting the metabolism of arachidonic acid and the activity of cyclo-oxygenase (COX) and lipo-oxygenase (LOX), which are crucial in the inflammatory response (Pisoschi et al., 2023). Additionally, flavonoids impact transcription factors like NF-κB, which play a pivotal role in cytokine production and inflammation, thereby reducing the expression of pro-inflammatory cytokines (Pisoschi et al., 2023) (Yi, 2023). Their antioxidant activity is attributed to their ability to scavenge reactive oxygen species (ROS), chelate transition metals, and activate antioxidant enzymes, which helps in reducing oxidative stress and preventing lipid peroxidation (Kang & Kim, 2023) (Fontana et al., 2022). Molecular dynamics simulations have shown that flavonoids can incorporate into lipid bilayer membranes, influencing their permeability and stability, which is essential for their biological activity (Vimalavathini et al., 2024). This interaction with lipid membranes is crucial for their antioxidant function, as it helps prevent lipid peroxidation (Fontana et al., 2022). Furthermore, flavonoids have been shown to inhibit both canonical and non-canonical inflammasomes, such as caspase-11, which are involved in inflammatory responses and diseases (Yi, 2023). The therapeutic effects of flavonoids are also influenced by their pharmacokinetics, including bioavailability and biotransformation, which depend on their chemical structure and administration route (Nakamura, 2023). Despite their poor absorption, flavonoid metabolites and their effects on intestinal bacterial fermentation contribute to their health benefits (Nakamura, 2023). The anti-inflammatory and antioxidant actions of flavonoids are mediated through a network of molecular interactions that involve enzyme inhibition, modulation of signaling pathways, and membrane interactions, highlighting their potential in therapeutic applications (Vimalavathini et al., 2024) (Chiriapkin et al., 2023) (Rakha et al., 2022). Table 1 comprises overview of bioactive compounds found in Indian medicinal plants, their mechanisms of action, and therapeutic effects.

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| **Compound Class** | **Example Plant** | **Mechanism of Action** | **Therapeutic Effect** |
| **Alkaloids** | Poppy (*Papaver somniferum*) | Analgesic via opioid receptor binding | Pain management (Abdelkhalek et al., 2024) |
| **Flavonoids** | Turmeric (*Curcuma longa*) | Inhibit NF-κB, scavenge ROS, reduce caspase-11 by 40% | Anti-inflammatory, antioxidant (Yi, 2023) |
| **Terpenes** | Neem (*Azadirachta indica*) | Disrupt microbial cell membranes | Antimicrobial (Yadav et al., 2024) |
| **Saponins** | Ginseng (*Panax ginseng*) | Modulate immune response, lower cholesterol | Immunomodulatory (Abdelkhalek et al., 2024) |
| **Polyphenols** | Green Tea (*Camellia sinensis*) | Reduce oxidative stress, inhibit lipid peroxidation | Anticancer, cardiovascular protection (Review on Indian Medicinal Plants, 2023) |

 Table 1: Bioactive Compounds in Indian Medicinal Plants and Their Therapeutic Effects

## Traditional vs. Modern Pharmacology

The traditional use of plants for medicinal purposes has been increasingly validated by modern research, highlighting the enduring relevance of herbal medicine. Abroma augusta, for instance, has been traditionally utilized in Ayurvedic and homeopathic medicine for managing diabetes and gynecological disorders, and recent studies have confirmed its antimicrobial properties, particularly against Gram-positive bacteria and fungi like Candida albicans, suggesting its potential for broader pharmaceutical applications (Jha et al., 2024). Similarly, Celastrus paniculatus is renowned for its memory-enhancing and neuropharmacological effects, with modern research supporting its nootropic and therapeutic potential for brain-related disorders (Singh, 2022). The resurgence of interest in traditional medicine is partly due to the limitations of modern pharmaceuticals in addressing complex diseases such as cancer and autoimmune disorders, prompting a renewed focus on the rich biomedical information embedded in traditional practices (Practice and Re-Emergence of Herbal Medicine, 2023). This is further exemplified by Ocimum sanctum (Tulsi), traditionally used for respiratory issues, which is now being investigated for its antimicrobial properties, highlighting its potential in combating modern pathogens (Patibandla et al., 2024). The integration of traditional knowledge with modern scientific validation is crucial, as it underscores the importance of developing effective and holistic medical solutions. This synthesis is facilitated by advanced technologies like genomics and synthetic biology, which help unravel the complex interactions of bioactive compounds within these plants (Jha et al., 2024) (Izah et al., 2023). Moreover, Ayurveda, a traditional Indian system of medicine, offers a holistic approach to managing conditions like diabetes and female reproductive health issues, emphasizing the interconnectedness of mind, body, and spirit, and advocating for personalized treatment plans based on individual constitution (Prasad, 2023) (Kanchan & Prathima, 2023). The integration of traditional and modern medicine is further supported by collaborative efforts between traditional healers, scientists, and healthcare professionals, aiming to preserve and enhance the therapeutic potential of medicinal plants (Jha et al., 2024) (Rao et al., 2023). This approach not only validates the efficacy of traditional remedies but also addresses contemporary health challenges, promoting a comprehensive healthcare solution that bridges ancient wisdom with modern scientific understanding (Jha et al., 2024) (Practice and Re-Emergence of Herbal Medicine, 2023).

Ashwagandha (Withania somnifera) and Neem (Azadirachta indica) exemplify the successful integration of traditional remedies into modern pharmaceuticals, highlighting the synergy between ancient knowledge and contemporary science. Ashwagandha, a cornerstone of Ayurvedic medicine for over 3,000 years, is renowned for its adaptogenic properties, which help the body resist various stressors. Modern research has validated its efficacy in treating a range of health issues, including heart conditions, metabolic disorders, and hepatic diseases, through advanced extraction techniques like ultrasonic-assisted extraction and high-performance liquid chromatography that isolate its bioactive compounds (Jain et al., 2024) (Kuśmierska et al., 2024). These compounds, such as withanolides, exhibit neuroprotective, anti-inflammatory, and immunomodulatory effects, making Ashwagandha a promising candidate for addressing stress-related disorders and enhancing overall well-being (Kuśmierska et al., 2024) (Singha et al., 2024). Furthermore, Ashwagandha's phytochemicals, including phenols and flavonoids, vary significantly across different plant varieties, influencing its pharmacological activities (Singh et al., 2024). Neem, on the other hand, has been utilized in traditional Indian medicine for its extensive antimicrobial properties, containing over 400 compounds like azadirachtin and nimbidin, which exhibit antibacterial, antifungal, and antiviral activities (Yadav et al., 2024). Neem's versatility extends beyond medicine to agriculture, where it serves as a natural pesticide and potential alternative to antibiotics (Yadav et al., 2024). The historical significance of both plants is well-documented in ancient Indian medical literature, underscoring their importance across various traditional medicinal systems (Ziaesaeidi, 2023). The scientific validation of Ashwagandha and Neem's therapeutic properties not only bridges the gap between ancient practices and modern healthcare solutions but also paves the way for the development of effective pharmaceuticals that harness the benefits of these traditional remedies (Yadav et al., 2024) (Jain et al., 2024) (Ziaesaeidi, 2023). Table 2 comprises the Summary of key medicinal plants used in Indian traditional medicine systems, their traditional applications, bioactive compounds, and modern scientific validations.

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| **Plant Name** | **Traditional System** | **Traditional Use** | **Bioactive Compounds** | **Modern Validation** |
| **Ashwagandha** (*Withania somnifera*) | Ayurveda | Stress relief, adaptogenic | Withanolides, flavonoids | Neuroprotective, anti-inflammatory (Jain et al., 2024) |
| **Neem** (*Azadirachta indica*) | Ayurveda, Unani | Antimicrobial, skin disorders | Azadirachtin, nimbidin | Antibacterial, antifungal (Yadav et al., 2024) |
| **Tulsi** (*Ocimum sanctum*) | Ayurveda | Respiratory issues, immune support | Eugenol, ursolic acid | Antimicrobial against *S. aureus* (Patibandla et al., 2024) |
| **Turmeric** (*Curcuma longa*) | Ayurveda, Siddha | Anti-inflammatory, wound healing | Curcumin | Anticancer, hepatoprotective (Newton, 2024) |

 Table 2: Key Medicinal Plants in Indian Traditional Medicine Systems

# Cultural Significance and Traditional Practices

Indigenous knowledge systems in India, particularly in the utilization of local flora for medicinal purposes, are deeply rooted in the cultural and ecological diversity of the region. In North-East India, the Scheduled Tribe communities rely on a rich biodiversity of 236 medicinal plants for their traditional healthcare systems, which not only address health needs but also hold potential for socio-economic upliftment through the herbal drug sector (Kumar et al., 2023) (Chakraborty, 2020). This region, characterized by its unique biodiversity and cultural diversity, is home to over 145 significant tribal communities who depend on traditional healers and methods such as maceration, decoction, and infusion to prepare medicinal herbs (Kumar et al., 2023). Similarly, in the northern regions of Jammu and Kashmir, four ethnic groups utilize 109 plant species, predominantly from the Asteraceae family, for treating various ailments, with herbs being the most common form used. The Bakerwal, Gujjar, and Pahadi groups show a higher similarity in plant use, while the Kashmiri group exhibits distinct preferences, highlighting cultural specificity in plant utilization (S., 2022). In the Sundarban mangrove forest region, tribal communities employ a variety of plants to treat conditions such as cuts, wounds, digestive disorders, and blood pressure, demonstrating the continued relevance of traditional medicine despite the rise of modern medical practices (Sen & Bhakat, 2020). In Haryana's Morni Hills and Raipur Rani, local populations use medicinal plants to address common health issues and more complex conditions like cancer and gynecological disorders, underscoring the importance of traditional knowledge in these regions (Dhiman et al., 2020). Ethnopharmacology plays a crucial role in bridging traditional wisdom with modern health systems, as seen in initiatives like AYUSH Aahar that promote holistic health approaches (Patra et al., 2019). The documentation and scientific validation of traditional knowledge are essential to prevent knowledge erosion and to develop curative pharmaceutical products (Shivani et al., 2022) (Bhattacharyya & Bhattacharya, 2016). Collectively, these studies illustrate the rich tapestry of indigenous medicinal plant use across India, shaped by regional biodiversity and cultural heritage, and emphasize the need for conservation and integration of traditional knowledge into modern healthcare systems (Murtem & Chaudhry, 2016).

The Siddha system of medicine, deeply rooted in Tamil Nadu, is one of the oldest traditional medical systems in India, predating even Ayurveda, and is characterized by its holistic approach to health care, emphasizing prevention over cure (Gannewar & Tiwari, 2023) (Nithya & Thangaraju, 2022). This system, attributed to the Siddhars, ancient spiritual saints, incorporates a wide range of treatments using herbal, mineral, and animal-derived substances, often in the form of herbomineral formulations known for their efficacy and longer shelf life (Devi et al., 2019). Siddha medicine is not only used for human ailments but has also been integrated into veterinary practices in regions like Pattukottai, Tamil Nadu, showcasing its versatility (Gannewar & Tiwari, 2023). The practice of Siddha medicine extends to various domains, including dentistry, where practitioners in Chennai utilize specific herbs and metals for treating oral diseases, highlighting the system's adaptability and comprehensive nature (Ramamurthy et al., 2022). In contrast, the tribal communities of Madhya Pradesh, such as the Bhil tribe, rely on indigenous knowledge and locally available medicinal plants for healthcare, often preferring traditional healers due to cultural alignment and accessibility issues (V., 2023). These communities face challenges like limited resources and lack of formal recognition, underscoring the need for intellectual property rights protection and benefit-sharing models to safeguard their traditional knowledge (V., 2023). The diversity of traditional medicine practices across India, from the Siddha system in Tamil Nadu to the ethnomedical practices of tribal communities in Madhya Pradesh, reflects a rich tapestry of cultural heritage and indigenous knowledge, each adapted to local ecological and cultural contexts (V., 2023) (Sundaram et al., 2019). This diversity underscores the importance of preserving and integrating these practices into the broader healthcare system, ensuring their sustainability and continued contribution to public health (V., 2023).

Traditional healing rituals involving medicinal plants are deeply embedded in cultural practices across various regions, reflecting a rich tapestry of historical and spiritual significance. In Sonamukhi Block, West Bengal, India, traditional healers utilize a diverse array of medicinal plants to create herbal medications, underscoring the importance of preserving indigenous knowledge for healthcare integration. This practice is part of a broader tradition in West Bengal, where a meta-analysis identified 377 plant species used for treating 126 ailments, with leaves being the most commonly used part (“Species Richness and Folk Therapeutic Uses of Ethnomedicinal Plants in West Bengal, India – A Meta-Analysis,” 2022). The reliance on traditional medicine is significant, with about 80% of the world's population, particularly in developing countries, depending on such practices due to their accessibility and lower cost compared to conventional medicine (Jana et al., 2021). In India, the historical use of medicinal plants is well-documented in ancient texts like the Vedas, illustrating a longstanding link between spirituality and plant conservation (Garg et al., 2021). Similarly, on Marajó Island, Brazil, ritualistic plants are integral to religious ceremonies such as Umbanda and Candomblé, where they are believed to aid in energetic and physical restoration, highlighting the intersection of pharmacological effects and spiritual beliefs. This reflects a global pattern where medicinal and aromatic plants (MAPs) have been used for centuries not only for their therapeutic properties but also for their cultural and spiritual significance, as seen in ancient civilizations like Mesopotamia and Egypt (Singh et al., 2024). In Western Ukraine, the revival of plant-based rituals among Orthodox Hutsuls and Greek Catholics involves using wild and cultivated plants in religious festivals, reflecting a resurgence of traditional ecological knowledge post-socialism. In Kanagarian Tiku, Indonesia, traditional ceremonies across Minangkabau, Java, and Nias tribes incorporate 44 plant species, with leaves being the most commonly used part, demonstrating the cultural continuity of plant use in rites of passage such as marriage and birth. These diverse practices highlight the universal role of medicinal plants in cultural rituals, serving both healing and spiritual functions across different societies. The integration of traditional knowledge with modern medicine is crucial for the sustainable use of these resources, as emphasized by the need for conservation and documentation efforts to prevent the loss of valuable indigenous knowledge (S., 2022) (Exploring Important Herbs, Shrubs, and Trees for Their Traditional Knowledge, Chemical Derivatives, and Potential Benefits, 2022).

Cultural beliefs play a pivotal role in the acceptance and use of herbal remedies across various regions, particularly in Africa and Asia. In countries like Nigeria and Ghana, herbal medicine is deeply entrenched in indigenous knowledge systems, often perceived as effective due to its holistic approach, which integrates physical and spiritual healing methods such as divination and incantations (Ogidi & Emaikwu, 2023) (Chaitanya et al., 2021). Despite the rise of modern medicine, the use of herbal remedies remains prevalent, driven by cultural norms and the belief in their efficacy, as seen in the treatment of conditions like malaria in Ghana (Asafo-Agyei et al., 2019). In Ethiopia, cultural perceptions, alongside socio-demographic factors such as age, gender, and education, significantly influence the use of medicinal plants among ethnic groups like the Gedeo, Oromo, and Sidama (James et al., 2019). Similarly, in rural Ghana, pregnant women frequently resort to herbal remedies due to cultural norms and health beliefs that emphasize personal health management and holistic healing (Peprah et al., 2019). The integration of traditional medicine into formal healthcare systems faces challenges, primarily due to poor collaboration between traditional and biomedical practitioners (Essandoh et al., 2023). In China, the use of Traditional Chinese Medicine (TCM) is heavily influenced by cultural values and emotional factors, with trust in healthcare personnel and policy endorsement playing crucial roles in shaping public attitudes (Anywar et al., 2021). In Indonesia, cultural beliefs and trust significantly impact consumer behavior towards herbal medicines (Anywar et al., 2021). These studies collectively highlight the profound impact of cultural beliefs on the acceptance and use of herbal remedies, suggesting that any efforts to integrate these practices into formal healthcare systems must consider these cultural dimensions to ensure effective and culturally sensitive healthcare delivery (“Determinants and Efficacy of Herbal Medicine Use among Pregnant Women in the Asante Akim North District, Ghana,” 2022) (Amoateng et al., 2018).

# Contemporary Applications and Research

Recent research underscores the potential of Indian herbal medicines in treating various health conditions, including cancer and liver disorders, by leveraging their therapeutic benefits and safety profiles. Traditional Indian herbal medicines, particularly those used in Ayurveda, have been subjected to modern scientific scrutiny to assess their efficacy. For instance, Withania somnifera (ashwagandha) and Curcuma longa (turmeric) have shown promising anti-cancer properties, with bioactive compounds like withaferin A and curcumin demonstrating significant anti-cancer activity in pre-clinical studies involving brain tumor cells (Newton, 2024). These findings are supported by the exploration of herbal medicines in cancer treatment, where phytocompounds have been recognized for their ability to induce apoptosis and inhibit cancer progression, offering a complementary approach to conventional therapies that often have severe side effects (Sunita & Kumar, 2023) (“Uncovering the Anticancer Potential of Phytomedicine and Polyherbal’s Synergism against Cancer – A Review,” 2022). In the realm of liver disorders, Ayurvedic and other traditional herbal medicines have been extensively studied for their hepatoprotective properties. Plants such as Silybum marianum and Phyllanthus amarus have demonstrated antioxidant and anti-inflammatory capabilities, providing protection against liver damage, particularly in the context of chemotherapy-induced hepatotoxicity (Babu et al., 2024). Furthermore, the role of herbal medicines in managing oxidative stress-related liver diseases, such as nonalcoholic fatty liver disease (NAFLD), highlights their potential in improving liver health by modulating lipid metabolism and inflammation (Park et al., 2022). Despite these promising findings, the need for rigorous clinical trials remains critical to ensure the reproducibility and safety of these herbal treatments in modern medical practice (Kwon et al., 2022). The integration of traditional knowledge with modern drug discovery methods continues to open new avenues for developing effective herbal-based therapies (qizi, 2022).

Technological advancements in pharmacognosy have significantly enhanced the isolation and study of active compounds from plants, primarily through innovations in extraction, chromatography, and molecular biology. Modern extraction techniques such as microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), and supercritical fluid extraction (SFE) have improved the efficiency and selectivity of isolating bioactive compounds from plant materials, offering higher yields and reduced processing times compared to traditional methods like maceration and Soxhlet extraction (Mondal et al., 2024) (Pratapsingh et al., 2023) (Jibhkate et al., 2023). These methods are complemented by chromatographic techniques, including high-performance liquid chromatography (HPLC) and gas chromatography (GC), which are pivotal in the separation and quantification of these compounds, providing precise analytical capabilities (Mondal et al., 2024) (Exploring Approaches for Investigating Phytochemistry: Methods and Techniques, 2023). Additionally, spectroscopic methods such as nuclear magnetic resonance (NMR) spectroscopy and mass spectrometry (MS) are crucial for the structural elucidation of phytochemicals, offering detailed insights into their molecular frameworks (Mondal et al., 2024) (Exploring Approaches for Investigating Phytochemistry: Methods and Techniques, 2023). The integration of computational techniques, including molecular docking, quantitative structure-activity relationship (QSAR) modeling, and machine learning, further aids in predicting the bioactivity of phytochemicals and their interactions with biological targets, streamlining the drug discovery process (Chihomvu et al., 2024). These advancements not only facilitate the identification and characterization of plant-derived compounds but also enhance our understanding of their pharmacokinetics and pharmacodynamics, thereby expanding their therapeutic applications (P et al., 2024) (Chaachouay & Zidane, 2024). Collectively, these technological innovations are transforming the field of pharmacognosy, enabling more efficient and comprehensive exploration of plant-based bioactive compounds for potential drug development (Ahmed & Jamil, 2024) (Shridhar & Kumar, 2023). The synergy between traditional knowledge and modern scientific techniques underscores the potential of plant-derived compounds in addressing global health challenges and improving patient outcomes (Ahmed & Jamil, 2024) (Chaachouay & Zidane, 2024)

The sustainability of medicinal plants in India is under significant threat due to overharvesting, habitat loss, and biodiversity threats, necessitating urgent conservation efforts. The increasing global demand for medicinal plants, driven by their therapeutic benefits, has led to unsustainable harvesting practices that endanger these vital resources and the ecosystems they inhabit. Overharvesting, particularly of slow-growing or region-specific species, poses significant extinction risks, as seen in the case of the endangered Himalayan herb Trillium govanianum, which is overharvested for its rhizome (Patil et al., 2024) (Gautam et al., 2023). Habitat loss due to land use changes, pollution, and invasive species further exacerbates the decline in plant populations, impacting biodiversity and ecological balance (Behera & Bhadra, 2024) (Shukla, 2023). India's rich biodiversity and traditional knowledge systems are at risk, highlighting the need for a comprehensive approach that integrates traditional wisdom with modern scientific research and conservation strategies (Sejabaledi, 2024) (“Current Status of Ethonopharmacology of Medicinal Plants in India: A Comprehensive Analysis,” 2023). Sustainable cultivation practices, such as promoting the use of plant parts other than roots or rhizomes, can alleviate pressure on wild populations and support biodiversity (Patil et al., 2024) (Gautam et al., 2023). Collaborative efforts involving conservation scientists, policymakers, local communities, and industry stakeholders are essential to develop and implement effective conservation and sustainable utilization strategies (Willy et al., 2023) (Conservation and Sustainable Management of Wild Medicinal and Aromatic Plant Species, 2023). These efforts align with global sustainability goals and are crucial for preserving India's medicinal plant heritage and ensuring the continued availability of these resources for future generations (“Conservation and Sustainable Use of Medicinal Plants,” 2023). The integration of indigenous knowledge, such as taboos and societal limitations on harvesting, with modern conservation techniques like in situ and ex situ conservation, offers a multipronged approach to safeguarding these resources (Sejabaledi, 2024) (“Conservation of Threatened Medicinal Plants – A Futuristic Approach,” 2023). By addressing these challenges and capitalizing on opportunities, it is possible to safeguard the rich biodiversity of medicinal plants and preserve their invaluable contributions to human health (Shukla, 2023).



Figure 1: Flowchart of Integrating Traditional Plant Knowledge into Modern Medicine

Integrating traditional knowledge with modern science offers a promising avenue for developing effective herbal products that respect both scientific rigor and cultural heritage. Ethnopharmacology serves as a crucial bridge in this integration, combining anthropology, pharmacology, and botany to harness the therapeutic potential of medicinal plants and traditional treatments. This approach is exemplified by initiatives like AYUSH Aahar in India, which emphasize holistic health approaches by reigniting interest in traditional dietary practices (“Bridging Traditional Wisdom with Modern Health: Exploring Ethnopharmacology and Ayush Aahar,” 2024). The synergy between traditional and modern medicine can enhance patient outcomes by leveraging the complementary strengths of both systems, fostering collaboration, mutual respect, and knowledge exchange among traditional healers, healthcare practitioners, and researchers (Kustiyati et al., 2024). This collaboration is particularly beneficial in underserved communities where traditional healers play a crucial role in health promotion and addressing psychosocial needs (Dean, 2024).

 Furthermore, the development of biogenic phytonanoparticles through green chemistry techniques exemplifies how traditional herbal knowledge can be augmented with modern scientific methods to create innovative, sustainable healthcare solutions (Puri et al., 2023). In India, the rich biodiversity and traditional knowledge of medicinal plants underscore the importance of collaborative research and regulatory frameworks to ensure the quality and safety of herbal products (“Current Status of Ethonopharmacology of Medicinal Plants in India: A Comprehensive Analysis,” 2023). This comprehensive approach not only enhances the efficacy and safety of herbal products but also ensures the conservation of cultural heritage and biodiversity, ultimately contributing to global health advancements (Goyal & Chauhan, 2024) (Singh et al., 2024). The integration of traditional and modern medicine, therefore, represents a holistic healthcare paradigm that can address contemporary health challenges while preserving invaluable traditional knowledge (Jha et al., 2024). Figure 1illustrate the flowchart illustrating the process of integrating traditional plant knowledge into modern medicine, from identification to product development.

# Conclusion

Indian traditional medicine has demonstrated remarkable longevity and sophistication in utilizing approximately 7,000 medicinal plants over 5,000 years, with ancient sages like Charaka and Sushruta. These plants, containing crucial bioactive compounds such as alkaloids, flavonoids, terpenes, and saponins, have been employed for various therapeutic purposes, with their efficacy increasingly validated by modern scientific methods including chromatography, spectroscopy, and computational analysis. While traditional knowledge, preserved through detailed botanical nomenclature in ancient texts, continues to influence contemporary research and drug development, particularly in areas like inflammation, diabetes, and cancer treatment, the field faces significant challenges including species identification (exemplified by the ongoing debate about Soma's identity), conservation threats from deforestation and urbanization, and the need for further clinical validation. Despite these challenges, the integration of traditional knowledge with modern scientific approaches, coupled with sustainable conservation practices, presents promising opportunities for developing effective medical solutions, particularly in addressing antimicrobial resistance through synergy-based botanical preparations.

Future research in the field of medicinal plants and herbal medicine should prioritize the exploration of lesser-known plants, particularly those used in traditional medicine systems such as Ayurveda, Unani, and Siddha, as these systems have historically utilized a wide array of plant species with potential therapeutic benefits that remain under-researched (Shamim et al., 2024) (Hapsari, 2023). The integration of biotechnology into medicinal plant research has opened new avenues for discovering novel therapeutic compounds by enabling precise manipulation and optimization of plant-derived compounds, thus enhancing their efficacy and safety profiles (P et al., 2024). This biotechnological approach also supports sustainable practices by reducing reliance on wild harvesting, which is crucial for conserving plant biodiversity (Unraveling Medicinal Plant Chemical Diversity for Novel Drug Discovery Through Biotechnological Interventions, 2023). Investigating the synergistic effects of plant compounds is another promising area, as these interactions can significantly enhance the efficacy of herbal treatments. Synergistic effects have been observed in both pharmaceutical applications and ecological interactions, suggesting a broader potential for these interactions in drug development (Siddiqui et al., 2023) (Nasim et al., 2022). Botanical hybrid preparations (BHP), which combine multiple herbs, have demonstrated superior efficacy compared to single-ingredient formulations, underscoring the importance of understanding molecular interactions and network pharmacology to optimize these combinations (Kapoor et al., 2023). Addressing antimicrobial resistance through synergy-based extracts of medicinal plants could provide new avenues for developing effective antimicrobials, as many plants possess antibacterial, anti-inflammatory, and antidiabetic properties that influence modern medicine (Shamim et al., 2024) (Hapsari, 2023). Overall, future research should systematically study these synergistic effects and explore the vast phytochemical diversity of lesser-known plants to uncover new therapeutic possibilities and enhance the efficacy of existing herbal remedies (Saad, 2024) (Motti, 2022).

# Declarations

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

ETHICAL APPROVAL

It is not applicable.

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