



Sustainable management and utilisation of forest genetic resources- Impact of medicinal plant usage in India

Kalaiselvi R.^{1*}, Rekha R. Warriar²

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ABSTRACT: Forest genetic resources (FGR) are crucial for maintaining genetic diversity in trees, supporting ecosystem resilience, and enabling adaptation to environmental changes. This paper highlights FGR's ecological, economic and societal importance, from the point of medicinal plant usage, including biodiversity conservation and climate and economic contributions. Dynamic conservation of these resources ensures long-term ecosystem sustainability. Sustainable harvest as a conservation strategy is crucial for wild-harvested species and their habitats, primarily because it supports local economies and maintains ecological diversity. Sustainable yield practices ensure that extraction rates do not exceed regeneration capacities, and diversifying forest products can enhance economic viability. Non-destructive harvesting methods that benefit local communities can preserve species and ecosystem diversity. However, challenges arise due to a lack of data on plant distribution, genetic diversity and sustainable yields. Research on the conservation of medicinal plants lags behind global demand, and understanding the unique aspects of each species is essential for effective management. Engaging local communities in forest management and recognizing their rights is essential for sustainable practices. Documentation of traditional knowledge is a priority for India which abounds in such information. Initiatives like TKDL (Traditional Knowledge Digital Library) are in place but lacks specific laws, risking exploitation without benefiting traditional communities. National policies advocate for in-situ and ex-situ conservation and equitable benefit-sharing. Open access to resources often leads to overexploitation, and there is a need for legislative support for sustainable wild harvesting schemes. International agreements like CITES (Conservation on International Trade in Endangered Species of wild fauna and flora) and the CBD (Convention on Biological Diversity) provide frameworks for managing the harvest and trade of medicinal plants. Conservation strategies must include seed orchards and appropriate seed storage technologies to ensure the availability of quality planting material, addressing challenges posed by destructive harvesting practices and the scarcity of seeds. A three tier approach has been described for the sustainable cultivation of medicinal plants, while empowering communities to benefit from their cultivation and ensuring conservation efforts.

Key words: Local communities, Traditional knowledge, Three-tier approach, Dynamic conservation, Economic contributions.

INTRODUCTION

Forest genetic resources (FGR) are instrumental in maintaining the genetic diversity of trees within an evolutionary process and allowing generation turnover in the forest.^[1] This literature review aims to explore the definition and importance of FGR, integrating and synthesizing research findings to highlight their ecological, economic and societal significance.

Forest trees are highly significant due to their ecological, economic and societal importance.^[2] They play a crucial role in maintaining biodiversity, regulating climate and providing ecosystem services. Additionally, they contribute to the global economy through the production of timber, non-timber forest products, and various ecosystem services. In ecological terms, forest trees are unparalleled in their role in maintaining biodiversity

1. Senior Research Fellow *Corresponding author; Email: kalaibcbt@gmail.com.

2. Senior Principal Scientist, Institute of Forest Genetics and Tree Breeding, Indian Council of Forestry Research and Education, P.B. No. 1061, R.S. Puram P.O., Coimbatore-641002, India

and ecosystem functioning. Their genetic diversity allows them to adapt to changing environmental conditions, making them resilient to disturbances such as climate change and pests.^[2] Furthermore, forest trees are essential for carbon sequestration, soil conservation and the provision of habitat for numerous species.

From an economic perspective, forest genetic resources are valuable for the production of timber, pulp and non-timber forest products. The timber industry is a major contributor to the global economy, providing employment and raw materials for various industries. Non-timber forest products such as fruits, nuts and medicinal plants also contribute significantly to livelihoods and local economies. In societal terms, forests provide numerous cultural, recreational and aesthetic benefits. They are essential for indigenous and local communities, serving as a source of food, medicine and materials for traditional practices. Forests also play a crucial role in tourism and recreation, attracting visitors and generating income for local communities.

Dynamic conservation of FGR is essential for maintaining the genetic diversity of forest trees.^[1] This involves the implementation of strategies to ensure the evolutionary processes and generation turnover in forests. It encompasses the conservation and sustainable use of genetic resources to support the long-term resilience of forest ecosystems. The dynamic conservation of FGR is crucial for addressing current and future challenges such as climate change, habitat loss and invasive species. By maintaining genetic diversity, forest trees can adapt to changing environmental conditions and continue to provide ecosystem services. Furthermore, the conservation of FGR supports the sustainable management of forests, ensuring the continued availability of timber and non-timber forest products.

MEDICINAL PLANT DIVERSITY IN INDIA

India has a rich history and strong foundation in *Ayurveda*, the traditional herbal medical system, which has played a pivotal role in the prevention and treatment of human diseases for thousands of years.^[3] Plants have been used as traditional medicine across various civilizations and are known to possess phytochemical ingredients with medicinal value. This has led to a resurgence of interest in medicinal plants as potential sources for the development of new herbal drugs in the 21st century.^[3] The diversity of medicinal plants in India faces increasing threats from human activities, leading to habitat deterioration and loss, as well as the depletion of wild populations.^[4] The growing evidence of the effectiveness of many natural plant remedies is accelerating the extinction of numerous medicinal plant species due to relentless harvesting from the wild. Forecasts for global demand and trade in medicinal plants indicate a sharp rise in the coming years, signalling that reliance solely on natural sources is no longer sustainable. Domestication and cultivation present viable strategies for ensuring a consistent supply of medicinal plants in the long term.

The active compounds in these plants, mainly secondary metabolites like alkaloids, glycosides, coumarins, or steroids, are influenced not only by the plants' physiological processes but also by the ecological conditions they experience. The environmental factors shaping the production of these secondary metabolites ultimately affect the efficacy of derived medicinal drugs. While limited, experimental evidence supports the idea that secondary metabolite content and properties of medicinal plants vary depending on their habitats. In essence, the interplay between habit and habitat significantly impacts the quality of medicinal plants. Therefore, any efforts to enhance production or management practices must prioritize maintaining or improving quality. Medicinal plants often exhibit different behaviours when cultivated outside their

natural habitats or ecological ranges, underscoring the importance of comprehensively understanding their biological and ecological contexts in their natural habitats. This understanding is crucial for conservation biology and predicting their behaviour under artificial cultivation.

The pharmacological effects of medicinal plants have been considered promising for the future management of healthcare, and there is an increasing interest in exploring these plants as potential drug candidates.^[3] With India being a hotspot of biodiversity, the diversity of medicinal plants in the country presents significant potential for the development of herbal medicines. While existing research has provided valuable insights into the diversity and potential applications of medicinal plants in India, there are still knowledge gaps that warrant further investigation. Future research directions could include comprehensive surveys of medicinal plant species across different regions of India to enhance the documentation of their diversity and traditional uses. Additionally, studies focusing on the conservation and sustainable utilization of medicinal plant resources, particularly in urban areas, can contribute to the development of effective management strategies.

Sustainable management and utilization of FGR

India boasts a rich repository of valuable medicinal and aromatic plants, with an estimated 6,000–7,000 species among its 17,000–18,000 flowering plants. Indian Medicinal Plants Database maintained by the National Medicinal Plants Board (NMPB) and listed botanical names of 7,263 plants, with 2,052 found in Kerala alone (<https://www.medicinalplants.in/statewiselist/kerala>; <https://www.medicinalplants.in/>) Medicinal plants serve not only as raw materials for the healthcare industry but also as crucial income sources for rural and indigenous communities, particularly those residing near forests.

A nationwide study sponsored by NMPB, conducted by FRLHT (Foundation for Revitalisation of Local Health Traditions) during 2006-07, revealed that out of over 7,263 species, 960 medicinal plant species are extensively traded in India, with 178 species having an annual consumption exceeding 100 metric tons.^[5] Recent estimates suggest a consolidated commercial demand of herbal raw drugs for 2014-15 at 512,000 MT, with exports reaching 134,500 MT and domestic consumption at 195,000 MT. Rural households also utilize an estimated 167,500 MT of herbal raw drugs annually. Of the 1,178 medicinal plant species recorded in trade practices, 242 species are consumed in quantities exceeding 100 MT annually (www.nmpb.nic.in).

The studies indicate a growing demand for medicinal plants both domestically and internationally. To address this demand and mitigate the unsustainable harvest from the wild, cultivation of medicinal plants can be pursued as a livelihood activity with proper support systems. Kerala stands out as a significant hub for *ayurveda* and herbal manufacturing, boasting extensive networks of herbal medicine manufacturing units, with 986 registered units in 2005.^[6] Additionally, tribal and rural healers across India possess vast knowledge of medicinal plants and herbal formulations.

However, indiscriminate collection and unregulated trade of medicinal plants pose serious threats to their survival worldwide. Unsustainable harvesting and habitat destruction have led to the listing of numerous species in the Red Data Books of the Botanical Survey of India and the IUCN (International Union of Conservation of Nature). As per IUCN Red List of Threatened Species more than 12,000 plants on the Red List, with 8,447 listed as threatened (IUCN, 2007).^[7] According to IUCN, about 15,000 medicinal plant species may be threatened with extinction worldwide from overharvesting and habitat loss (ISSC-MAP, 2007).^[8] In response, the Government of India

has placed 29 threatened species of medicinal plants on the negative export list (GoI, 2000).^[9] Gauthami *et al.*^[10] reviewed the existing information and compiled an exhaustive list of 84 threatened medicinal plants of India represented in both IUCN (India region) and CAMP exercise (India region).

Industries relying on raw materials from plant collectors encounter issues like supply failures and material substitution. If traders cannot meet the demand for raw materials, the future of the ayurvedic industry could be jeopardized. Measures must be taken to address the escalating demand for medicinal plants.

Cultivation is often cited as a conservation strategy for medicinal plants to offer alternative supplies for species in high market demand. However, relatively few medicinal and aromatic plant species have been successfully cultivated worldwide, with most still being harvested from their natural habitats. Little attention has been paid to their selection and improvement for developing suitable varieties. While botanic gardens have made efforts in *ex situ* conservation, focusing primarily on interspecific diversity, intra-specific diversity preservation remains inadequate. The private sector holds most genetic material collections, with their diversity status largely unknown. Although propagation methods for threatened species have received more attention lately, efforts often lack an overarching understanding of how they contribute to conservation objectives.

MEDICINAL PLANTS IN TRADITIONAL HEALTHCARE SYSTEMS

India is known for its rich diversity of medicinal plants, which have been used for centuries in traditional medicine. Several studies have explored the diversity and richness of medicinal plant species in different regions of India, shedding light on the factors that influence this diversity. India is renowned for its rich diversity of medicinal plants, with numerous studies focusing on different aspects of this biodiversity.

The majority of plant species utilized in traditional or herbal medicine are gathered from the wild, a practice expected to persist. Presently, approximately 15,000 medicinal plant species are globally imperiled due to factors such as habitat loss, excessive harvesting, invasive species and pollution. The decline or scarcity of these plants poses not only conservation challenges but also threatens public health and livelihoods. A significant methodological hurdle in medicinal plant conservation lies in enhancing the management of wild populations. Preserving wild medicinal plants necessitates the conservation of their habitats, and successful conservation efforts (motivated by health, economic, or cultural factors) have the potential to benefit various other plant and animal species. Consequently, medicinal and aromatic plants represent a particularly crucial area of research globally.

In India, nearly 7,500 plants are recognized for their medicinal properties, utilized across various healthcare systems such as Ayurveda, Siddha, Unani and Homeopathy. The demand for medicinal plant-based raw materials for medicine production is steadily rising, posing a recent challenge. Unsustainable harvesting practices often lead to the loss of species, with counterfeit materials infiltrating the market. Globally, it is becoming increasingly apparent that 'Health for all' can be assured only by strengthening traditional systems of medicine. Traditional medicine, based largely on herbs, still supports the primary healthcare of more people worldwide than 'conventional' or western medicine. Traditional knowledge and practices associated with medicinal plants are not only culturally important but also hold scientific promise.

The traditional healthcare system, reliant on plant genetic resources, remains prevalent in developing nations, while accessibility to modern medicine is hindered by insufficient drug supplies, population growth and prohibitive treatment costs. The preservation and advancement of Indian healing

traditions hinge on the consistent availability of authentic, high-quality medicinal plants. Moreover, the annual demand for herbal drugs in India surged by 62% between 2005 and 2015^[5,11] leading to heightened demand for medicinal plants. This underscores the need for simultaneous efforts to expand cultivation areas and promote sustainable wild harvests of medicinal plants. Medicinal plants play pivotal roles in socio-economic and cultural contexts, particularly in rural communities' traditional healing practices. They also form an integral part of India's herbal drug-based health and wellness industry.

Traditional knowledge and practices associated with medicinal plants have been crucial in providing potential sources of therapeutic aids in health systems for both humans and animals. These practices have been handed down through generations and have been used to address various health concerns. The importance of Traditional Knowledge (TK) in various cultural expressions, including healthcare, remains paramount. India has initiated efforts like the Traditional Knowledge Digital Library (TKDL) to safeguard such knowledge, aiding patent offices in denying patents already mentioned in TKDL as Indian TK. However, much TK remains orally transmitted and undocumented, collected in People's Biodiversity Registers (PBRs). There is no specific law in India to protect TK, leading to initiatives to create electronic TK databases for conservation. Yet, these databases are often exploited commercially without adequately benefitting knowledge holders. Strong legislation is necessary to prevent misuse and ensure the social and economic well-being of traditional communities, thereby preserving, promoting and managing TK and cultural expressions. Thus, a policy document is essential for protecting traditional knowledge comprehensively.

More than 80% of the medicinal plants we consume are sourced from forests, with approximately 24% comprising trees and the

remainder consisting of herbs and shrubs, forming the bulk of our medicinal plant reservoir. While many claims suggest these plants are collected from cultivated sources, verifying such assertions for authenticity is challenging. Besides serving healthcare purposes, medicinal plants also serve as sources of income for rural and tribal communities, falling within the scope of Access and Benefit Sharing (ABS). Traditional knowledge associated with numerous medicinal plants remains undocumented and is orally transmitted across generations.

A significant disparity exists between the demand and supply of raw drugs, exacerbated by destructive resource extraction, particularly concerning the roots and bark of many plants. Interventions are needed, possibly through decentralized approaches like Biodiversity Management Committees (BMCs), where levies imposed on medicinal plants could be shared among collectors and traditional knowledge bearers.

Economic impact of medicinal plant trade

The economic impact of the trade of medicinal plants has been a subject of interest for researchers in various fields. India has emerged as a significant hub for traditional medicine, with 11.7% of the population reporting their most frequent source of care over the past 3 years as traditional medicine, and 19.0% reporting traditional medicine use in the previous 12 months. This reflects the holistic approach to healthcare that is prevalent in many traditional healing practices.

The use of traditional medicine is not without its challenges, as evidenced by the barriers faced by individuals in accessing hospitals and clinics. Ezeonu and Ejikeme^[12] identified communication issues, financial eligibility and long waiting times as common obstacles. This underscores the importance of understanding the cultural and practical considerations that influence the choice

between traditional and conventional healthcare options.

Humans also rely on the healing properties of various species within the same genera to alleviate physical ailments. For instance, numerous species of *Swertia* such as *Swertia chirayita*, *S. angustifolia*, and *S. cordata* are utilized in the treatment of malarial fever. Similarly, different species of *Berberis* including *B. aristata*, *B.*

asiatica, *B. lycium*, and *B. jaeschkeana* are sought after for their berberidine content, which is effective in curing specific eye diseases. It is worth noting that these species within the same genera possess varying proportions of chemical compounds, leading to a preference in their demand. Many medicinal plant species are used as remedy for more than one disease as indicated in Table 1.

Botanical Name	Hindi Name	Parts Used	No. of uses	Uses
<i>Aegle marmelos</i>	<i>Bel</i>	Fruit, bark	31	Dysentery, diarrhea, fever
<i>Bacopa monnieri</i>	<i>Brahmi</i>	Whole plant	20	Brain tonic, blood purifier, fever
<i>Ocimum tenuiflorum</i>	<i>Tulsi</i>	Seed, leaf	18	Fever, vomiting, liver complaints, blood purifier
<i>Phyllanthus emblica</i>	<i>Amlaa</i>	Fruit	29	Constipation, diabetes, tonic
<i>Withania somnifera</i>	<i>Ashwagandha</i>	Root, leaf	14	Eye complaints, asthma, cough
<i>Asparagus racemosus</i>	<i>Sataavari</i>	Root	22	Dysentery, cough, cut and wounds

Financial year	Export Value (USD Million)
2015 – 2016	308.39
2016 – 2017	330.18
2017 – 2018	456.12
2018 – 2019	446.13
2019 - 2020	428.08
2020 – 2021	539.87
2021 – 2022	612.10
2022 - 2023	628.25

(Source: Statista, India: value of ayurvedic and herbal products exports 2023).^[14]

India's herbal industry plays a crucial role in the country, providing livelihoods to various stakeholders such as farmers, herbalists and manufacturers. Additionally, it contributes significantly to India's exports, encompassing a wide range of products including raw herbs, extracts, essential oils and herbal formulations.^[15] This industry is in line with India's commitment to sustainable agriculture, promoting the cultivation of medicinal plants through environmentally friendly practices. Not only does it help preserve biodiversity, but it also uplifts marginalized communities. India is recognized globally as a

leader in ethical herbal trade, supporting sustainable agriculture and the cultivation of medicinal plants. With the growing global demand for holistic healthcare and natural remedies, India's herbal industry is poised for further expansion. It not only drives economic development but also aligns with the worldwide shift towards eco-friendly, non-toxic and culturally rich healthcare solutions. This secures India's economic future and reinforces its role as a guardian of its herbal heritage.

India's medicinal plants sector serves as both a treasure trove of traditional healing practices and a thriving economic force. Not only does it make a significant contribution to India's GDP, but it also meets the global demand for herbal remedies.^[16] Thanks to India's abundant biodiversity and centuries-old tradition of utilizing medicinal flora, the country has emerged as a global leader in the herbal medicine market. This sector encompasses a wide range of products, including herbal medicines, health supplements, cosmetics and nutraceuticals. As the preference for natural and sustainable healthcare solutions continues to rise

worldwide, the economic value of the medicinal plant trade has experienced exponential growth. Despite the setbacks caused by the COVID-19 pandemic in 2020, India's exports of ayurvedic and herbal products have generally been on an upward trajectory. In the fiscal year 2022-23, these products were exported at a value of US\$628.25 million (Table 2), representing a 2.6% increase from the previous year.^[17] Key export destinations for India include the United States, the United Arab Emirates, the United Kingdom, Germany, and Singapore. This growth can be attributed to the increasing awareness of the benefits of traditional medicine, rising disposable incomes and a growing demand for natural and organic products. The Indian government's proactive measures, such as providing financial support, organizing trade events, and initiating research and development projects, are expected to further boost the ayurvedic and herbal sector. With its rich heritage in *ayurveda* and abundant resources of medicinal plants, India is well-positioned to capitalize on this global growth trend.

Socio-economic significance of medicinal plant usage

The utilization of medicinal plants has been an important aspect of traditional healthcare systems across the globe. The socio-economic significance of medicinal plant usage has been the subject of numerous studies, aiming to understand the impact of various factors on the preservation and transmission of ethnobotanical knowledge, as well as the implications for local communities and economies. One significant finding in the existing literature is the impact of increased accessibility to health centers and improved transportation infrastructure on the loss of ethnobotanical knowledge. Singh et al.,^[18] highlighted that these developments contribute to the decline in traditional knowledge about medicinal plant usage, potentially leading to a decrease in the utilization of these plants for healthcare purposes. This suggests that as communities gain better access to modern

healthcare facilities, the reliance on traditional medicinal plants diminishes, impacting the socio-economic dynamics of local populations. Moreover, the knowledge and usage of medicinal plants are often passed down from one generation to another, with parents serving as the main source of information. This implies that the intergenerational transmission of ethnobotanical knowledge plays a crucial role in the continued usage of medicinal plants within communities. Understanding these dynamics is essential for comprehending the socio-economic implications of medicinal plant usage and the potential disruptions in traditional knowledge systems. In addition, Sabde et al.,^[16] also underscore the negative impact of enhanced accessibility to modern facilities on ethnobotanical knowledge. This further emphasizes the need to explore the complex interplay between socio-economic factors, healthcare infrastructure, and the preservation of traditional medicinal plant usage.

Emerging markets

The global medicinal plant sector is experiencing significant economic growth due to the increasing interest of multinational pharmaceutical companies and domestic manufacturers in herbal-based medicines. For instance, in 1997, Africa exported 3500 tons of *Prunus africana* (African plum) bark, generating \$220 million in revenue for the treatment of prostate disease. The market value of *Aloe vera*, used in burn treatment and skincare products, has also seen a tremendous increase. In countries like Nepal, Bhutan, and Bangladesh, thousands of tons of medicinal plants are collected annually from forests, contributing millions of dollars to the economy. India, a key player in regional trade, relies heavily on forest-based economy, with up to 40% of the state's economy coming from medicinal and aromatic plants (MAPs) and non-timber forest products (NTFPs). The country exports medicinal and aromatic plants worth US\$ 18–20 million, mostly in raw form, with India expected to be one of the top five countries

globally in terms of revenue growth. The pharmaceutical market in India has shown remarkable growth, increasing from a USD 6 billion market in 2005 to a USD 20 billion market in 2015 (Table 3).

Rank	Country	Market in USD		Absolute growth	% growth
		2005	2015		
1	USA	248	444	196	79
2	China	13	38	25	192
3	Japan	68	82	14	21
4	France	32	46	14	44
5	India	6	20	14	233
6	UK	19	32	13	68
7	Canada	13	25	12	92
8	Spain	14	25	11	79
9	Brazil	9	20	11	122
10	Mexico	10	19	9	90
11	Turkey	7	15	8	114
12	Germany	31	38	7	23
13	South Korea	8	15	7	88
14	Italy	20	25	5	25

(Source: IMS World Review, Mckinsey Pharma Model (Indian Pharmaceuticals 2015; IMS Health Information and Consulting Services India Pvt. Ltd))

The overexploitation and unsustainable harvesting practices of medicinal plants have raised concerns about their ecological impact. In particular, the demographic impacts of harvesting non-timber forest products (NTFP) have been the focus of increasing attention due to reports of potentially unsustainable harvest.^[19] The demographic impacts of harvesting NTFP highlight the need for comprehensive assessments of ecological differences between sites and the potential consequences of unsustainable harvest. Arya Vaidya Sala, Kottakkal, who researched elaborately on these aspects recommend various sustainable harvest practices especially for root harvests. For the leaf harvest, it should be repeated only thrice annually, while in the case of fruits, they should be collected only once a year.

ROLE OF COMMUNITY PARTICIPATION AND INDIGENOUS KNOWLEDGE IN FGR MANAGEMENT

The role of community participation in forest genetic resources (FGR) management is crucial

for the sustainable use and conservation of these resources. Baldeck et al.^[20] emphasize that soil resources and topography play a significant role in shaping local tree community structure in tropical forests, highlighting the importance of understanding the local ecological context in FGR management. Moreover, community participation in FGR management is essential in responding to biotic and abiotic factors, especially in the context of anthropogenic climate change.^[21] This underscores the importance of engaging local communities in sustainable practices to enhance the resilience of forest ecosystems. Furthermore, the management of tree genetic resources and the livelihoods of rural communities in the tropics is closely linked to non-timber forest products, smallholder agroforestry practices, and tree commodity crops.^[22] This suggests that community participation is integral in promoting sustainable practices that benefit both the local communities and the conservation of FGR. Additionally, the role of forest resources in local livelihoods has been demonstrated in various

ecosystems, such as the East Mau Forest Ecosystem in Kenya.^[23] This highlights the direct dependence of communities on forest resources, further emphasizing the need for their involvement in FGR management.

Community participation is essential in predicting the impacts of climate change on biodiversity, as it allows for the integration of local knowledge and practices into conservation efforts.^[24] This highlights the potential for community-based monitoring and adaptive management strategies in FGR conservation. Additionally, the involvement of local communities in forest soil phosphorus resources and fertilization can affect ectomycorrhizal community composition, beech P uptake efficiency, and photosynthesis, further demonstrating the interconnectedness between community participation and ecosystem processes.^[25] Community participation in cultural heritage management has been the subject of extensive research, comparing Chinese and international practices.^[26] While this research focuses on cultural heritage, the findings underscore the importance of understanding local community dynamics and engaging them in conservation and management efforts. This knowledge can be extended to FGR management, highlighting the need for culturally sensitive and inclusive approaches that involve local communities.

Collaborative Forest Management (CFM) systems have been present in India since ancient times. These systems encompass a wide range of practices, from the preservation of sacred groves where no extraction is permitted, to the management of community forests where various management techniques are employed. These systems can be found in states such as Orissa, Tripura, Gujarat, and Karnataka. Unfortunately, even sacred groves in many states have suffered severe degradation, although some still remain intact. For instance, in the Coorg District of Karnataka, numerous temple forests or sacred

groves are well-preserved,^[27] whereas in the Uttara Kannada District, many kan (small patches of evergreen forest) are in a degraded state. Similarly, in the North eastern States, numerous sacred groves face varying degrees of pressure.^[28]

In India, the concept of Community-based Natural Resource Management (CBNRM) has been put into practice through the implementation of Community Forest Management. CFM is an approach to managing natural resources that takes into consideration the human communities residing in or around these resources. In India, the Joint Forest Management program, which is a part of CFM, referred to as Participatory Forest Management (PFM) set guidelines in 1998, and the Vana Samrakshana Samithi (VSS) serve as the implementing body. The adoption of CBNRM greatly contributes to the enhancement of livelihoods through the management and conservation of natural resources.^[29,30]

Involving communities at all stages, from collection/cultivation to marketing, will ensure fair and equitable benefits. The communities also require to be empowered with post-harvesting techniques, marketing and certification. These three areas enhance the worth of the value chain, and the incentives directly reach the dependent community. Benefit-sharing is a very crucial area in the trade of natural resources. The National Biodiversity Authority of India has made it mandatory that for any benefit arising from the communities, either in the form of material or knowledge, a proportion of the returns would reach the community. Empowering the local dependent community on these issues would provide good economic benefits to them, thereby aiding in natural resources conservation.

Documentation of indigenous knowledge related to phenology of the species, distribution, climate and productivity, animal interaction, regeneration, propagation, cultural and spiritual relevance,

building local and species profile, medicinal values and traditional uses, harvesting patterns and processing. This principle helps the local people for documentation of traditional knowledge related to harvesting practices, ensuring customary rights of forest dwellers by involving them only without external labour forces, merging scientific information with traditional knowledge to develop good harvesting practices, and recognising the association between community and the resources. [26,27]

CHALLENGES AND CONSTRAINTS IN IMPLEMENTING SUSTAINABLE MANAGEMENT PRACTICES

The significance of sustainable harvest as a conservation strategy for wild-harvested species and their habitats is growing. This is primarily due to their crucial role in supporting local economies and their enduring value to harvesters. The underlying concept is that by practicing non-destructive harvesting methods and ensuring local benefits, we can preserve population, species, and ecosystem diversity. “The most important ingredient required to achieve a truly sustainable form of resource use is information”.^[31] Unfortunately, resource managers often face challenges due to the lack of data on wild resources, including plant distribution, genetic diversity, and sustainable yield.^[32] Research on the conservation and sustainable use of medicinal plants lags behind the global demand for this valuable resource. Understanding the unique ecological, socio-economic, health and cultural aspects of each species is essential for effective management.

The sustainable management of medicinal plants is essential for their conservation and long-term availability. However, there are several challenges and constraints associated with the implementation of sustainable management practices for medicinal plants. This literature review integrates and synthesizes the research findings to provide a comprehensive overview of these challenges

and constraints, while also highlighting knowledge gaps and suggesting potential future research directions.

It promotes the concept of sustainable yield, ensuring that the rate of timber and non-timber forest product extraction does not exceed the forest’s capacity to regenerate.^[33] Economic viability is enhanced by diversifying forest products and services. This includes developing markets for non-timber forest products, ecotourism, and ecosystem services such as carbon credits and water purification. Adding value to raw materials through local processing can also boost economic returns and local employment.^[34] Engaging local communities in forest management is a cornerstone of sustainable management. Recognizing and respecting the rights of indigenous peoples and local communities, including land tenure and access rights, is essential. Participatory approaches ensure that forest management practices meet the needs and aspirations of these communities.^[35] The National Forest Policy of 1988 and National Biodiversity Action Plan (NBAP) outline strategies for the conservation of biodiversity, including FGR. They stress the need for in-situ and ex-situ conservation measures, sustainable management practices, and equitable sharing of benefits arising from the use of genetic resources.

In many scenarios, the resource is available to everyone, rather than being subject to limited access or private ownership. As a result, commercial gatherers of medicinal plants resort to “mining” these resources instead of effectively managing them to sustain their livelihoods.^[36] The implementation of open access schemes for harvesting plant populations hinders rational and cautious utilization, making it challenging to adhere to quotas and closed seasons.

Lack of legislative and policy support for wild harvesting schemes: There is a lack of information on trade in MAP (medicinal and aromatic plant), with data being seldom collected or published

nationally. A significant portion of production and consumption occurs at subsistence levels, leading to an under estimation of the economic significance of these activities in government decision-making related to rural development, natural resource management planning, and budget allocations. As a result, national legislation and policies often lack the necessary frameworks to effectively and sustainably manage wild resources. Nevertheless, two recent international legislative developments have presented governments with valuable opportunities to address this issue. Including medicinal plant species in the Convention on International Trade of Endangered Species (CITES) and implementing the CBD (Convention on Biological Diversity) have paved the way for governments to develop legislation that controls and monitors the harvest and trade of medicinal plants. Furthermore, these developments emphasize the importance of considering medicinal plant conservation and sustainable use as a top priority when establishing protected areas.^[37]

Efforts in exploration, collection, diversity assessment, and conservation should align with the rationale for conserving medicinal plants' genetic resources for utilization. In this context, conserving and managing wild germplasm diversity, especially in medicinal trees, is crucial. Destructive harvesting practices, common in the industry, significantly threaten species survival and germplasm loss. Complementary conservation and use strategies for medicinal trees, including *ex situ* methods like field genebanks and seed storage, need to be designed. Appropriate seed storage technologies tailored to different species are necessary ensuring the quality of traded seeds and planting material.

The scarcity of seeds and planting stock poses a major challenge in medicinal tree cultivation. Ensuring ready availability of seeds and planting material is vital for large-scale planting initiatives, especially as these trees become increasingly rare

in their natural habitats. Establishing "seed orchards" could serve as a reliable source of quality seeds, safeguarding continuous supply amid ongoing forest tree harvests. A seed production system is one such technology which caters to supply of large quantity seed requirements for harvest/large scale planting. It could be a natural or an artificial (introduced) stand – the latter introduces maximum genetic diversity in stand. The SPS ensures a continuous supply of quality seeds (due to the specific composition of the stand) in addition to germplasm conservation. An SPS comprising different medicinal trees was established and handed over to the Vattaluki Tribal Society (VTS) in Attapadi. The tribals have been sensitized on the importance of the species which have been reintroduced into their land, and the need for conservation of the species through regular visits.^[38]

A novel strategy to encourage medicinal tree cultivation

Agroforestry systems integrating medicinal plant (MP) tree cultivation can provide multiple benefits including biodiversity conservation, improved soil health, and additional income streams for farmers. A three-tiered approach to encouraging MP tree cultivation within agroforestry systems is suggested here.

Canopy Layer:

a. High-Value Medicinal Trees: Select high-value MP tree species suitable for the canopy layer of agroforestry systems. These trees should have medicinal properties, high market demand, and be compatible with the local agro-climatic conditions. Examples include Neem (*Azadirachta indica*), Indian Gooseberry (*Emblica officinalis*), and Arjun tree (*Terminalia arjuna*).

b. Species Diversity: Promote species diversity within the canopy layer to mimic natural forest ecosystems and enhance ecological resilience. Mix MP trees with other valuable tree species such as fruit trees or timber species to maximize

the economic and ecological benefits of the agroforestry system.

c. Support Services: Provide technical support and training to farmers on proper tree selection, planting techniques, and management practices for the canopy layer. Encourage sustainable harvesting methods to ensure the long-term viability of MP tree populations.

Shrub Layer:

a. Medicinal Shrubs and Understory Plants: Introduce medicinal shrubs and understory plants beneath the canopy layer to enhance biodiversity and maximize land productivity. These may include species like Aloe (*Aloe vera*), and Turmeric (*Curcuma longa*), which have medicinal properties and can thrive in partial shade conditions.

b. Nitrogen Fixing Species: Incorporate nitrogen-fixing shrubs such as *Gliricidia sepium* or *Sesbania* spp. in the shrub layer to improve soil fertility and support the growth of MP trees and other crops in the agroforestry system.

c. Integrated Pest Management: Utilize shrubs with pest-repellent properties or attract beneficial insects to control pests and diseases in the agroforestry system, reducing the need for synthetic pesticides.

Ground Layer:

a. Medicinal Herbs and Ground Cover Plants: Cultivate medicinal herbs and ground cover plants in the understory to further enhance biodiversity, soil protection, and weed suppression. Examples include Holy Basil (*Ocimum tenuiflorum*), Brahmi (*Bacopa monnieri*), Gotu Kola (*Centella asiatica*), and Lemongrass (*Cymbopogon citratus*)

b. Crop Diversification: Integrate annual or perennial cash crops with medicinal herbs in the ground layer to diversify income sources and increase farm resilience. Rotate crops to optimize soil health and minimize disease pressure.

c. Water Management: Implement water conservation measures such as mulching, contour bunds, or rainwater harvesting structures to optimize water use efficiency and mitigate the impacts of climate variability on crop production.

By implementing this three-tiered agroforestry approach, farmers can harness the synergies between MP tree cultivation and other agricultural activities to improve livelihoods, conserve natural resources, and contribute to sustainable development. To encourage this strategy, government support, community involvement, and market incentives should be robust.

The government should establish supportive policies and regulations to promote the cultivation of medicinal plants. This may include incentives such as subsidies, tax breaks, and grants for farmers engaged in MP tree cultivation. Investments in research and development initiatives focused on identifying suitable MP tree species for cultivation in different regions, optimal cultivation practices, and efficient processing techniques needs to be enhanced. Extension services can disseminate this knowledge to farmers through training programs and workshops. Infrastructure for MP tree cultivation, including access to quality seeds and planting materials, irrigation facilities, and transportation networks to facilitate the distribution of medicinal plant products to markets is the need of the hour.

These initiatives can be successful only with the involvement of communities. Local communities need to be empowered with the knowledge and skills necessary for tree cultivation through training programs and awareness campaigns. They should be involved in all stages of cultivation, from planting to harvesting and processing. There is also an urgent need for the integration and incorporation of traditional knowledge systems related to MP tree cultivation practiced by indigenous and local communities. Respectful engagement with traditional healers and herbalists can enhance MP

cultivation efforts' sustainability and cultural relevance.

Value Addition such as processing, packaging, and branding of MP tree products to enhance their market competitiveness and value, development of niche markets for organic, sustainably sourced medicinal plant products, certification schemes and quality standards for MP tree products to ensure consumer safety and trust, certification programs for organic and sustainably harvested products can fetch premium prices in domestic and international markets and ensure quality assurance.

These efforts would create a sustainable environment for medicinal plant cultivation while empowering communities to benefit from their cultivation and conservation efforts.

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