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# Revival of Rare or Underutilized Ayurvedic Plants in Herbal Gardens: A Conservation Approach

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## Abstract

Ayurveda, a venerable traditional Indian medical system, relies heavily on a diverse array of medicinal plants. However, a significant portion of this botanical heritage, particularly rare and underutilized species, faces unprecedented threats from over-exploitation, habitat degradation, climate change, and the erosion of traditional knowledge. This report explores the critical role of herbal gardens as a multifaceted conservation strategy for these invaluable Ayurvedic plants. It delves into their function as vital centers for *ex-situ* conservation, germplasm preservation, and the development of advanced propagation techniques. Furthermore, the report examines how these gardens support *in-situ* conservation efforts, facilitate pharmacological research and drug discovery, and play a pivotal role in revitalizing traditional knowledge through community engagement. An analysis of existing policy frameworks, including initiatives by the National Medicinal Plants Board (NMPB) and the Botanical Survey of India (BSI), alongside international conventions like the Convention on Biological Diversity (CBD) and CITES, highlights the institutional support for these efforts. Case studies of successful conservation projects in India demonstrate the tangible impact of herbal gardens. Finally, the report addresses the persistent challenges, such as economic viability and market linkages, emphasizing future directions that integrate scientific innovation, ethical frameworks, and robust public-private partnerships to ensure the sustainable revival and utilization of India's rich Ayurvedic plant diversity.

## 1. Introduction

### 1.1. The Global Significance of Ayurvedic Medicinal Plants

Ayurveda, an ancient Indian system of medicine, boasts a profound heritage spanning over 3000 years, with a remarkable reliance on plant-based formulations, constituting more than 90% of its therapeutic preparations.[1] This deep-rooted tradition is not confined to India; globally, an estimated 80% to 99% of the world's population depends on indigenous healing systems and traditional medicines, underscoring the universal importance of medicinal plants for health and well-being.[1]

India, often celebrated as the 'Herbarium of the World', stands as one of the 17 mega-biodiversity nations, contributing significantly to global plant species diversity.[2] The nation's vast geographical expanse encompasses 15 agro-climatic zones and four of the world's 34 biodiversity hotspots—the Nicobar Islands, Western Ghats, North-Eastern rainforests, and the Himalayas—which collectively harbor approximately 45,000 plant species.[1] Of these, an impressive 15,000 species are recognized for their medicinal properties, with 7,000 to 7,500 herbal species actively utilized by various communities across the country to treat a myriad of diseases.[1] This immense botanical wealth forms the fundamental backbone of Ayurvedic practices, providing the raw materials for its intricate formulations.

Beyond their direct therapeutic applications in traditional medicine, medicinal plants hold immense significance in modern drug discovery. At least 25% of contemporary pharmaceutical drugs are derived either directly or indirectly from plant compounds, highlighting their indispensable contribution to global healthcare.[4] The continued exploration of plant-based remedies offers promising avenues for novel drug development.[6] Furthermore, the collection and processing of medicinal plants represent a vital source of livelihood for millions, particularly the poor and under-employed in rural and tribal communities across India, contributing at least 35 million workdays annually.[7] The profound global dependency on botanical resources is evident in these interconnected facets. The decline of Ayurvedic plants, therefore, is not merely a regional or cultural issue but a global health and economic concern. The potential loss of these plants impacts not only traditional healthcare systems but also limits future drug discovery and exacerbates livelihood insecurity for millions. The designation of India as the "Herbarium of the World" underscores a global responsibility for the conservation of its unparalleled plant wealth.

### 1.2. Defining Rare, Endangered, and Underutilized Ayurvedic Flora

To effectively address the conservation of Ayurvedic plants, it is crucial to delineate the categories of species facing distinct levels of threat or neglect.

**Rare and Endangered Plants:** A species is broadly considered "threatened" or "endangered" when it faces a high risk of global extinction, characterized by a rapid decline in population or critically low numbers.[8] The International Union for Conservation of Nature (IUCN) provides a globally recognized framework for classifying species based on their extinction risk. Within this framework, "endangered" (EN) species are those facing a very high risk of extinction in the wild, positioned between "vulnerable" (VU) and "critically endangered" (CR).[8] "Rare" species, while having small populations, are not yet classified as endangered or vulnerable, indicating a need for proactive monitoring.[10] The IUCN Red List employs a comprehensive system of nine categories to classify extinction risk: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), and Not Evaluated (NE).[9] These classifications are determined by rigorous criteria, including observed or projected population decline, geographic range size and fragmentation, small population size, and very restricted distribution.[9] For instance, the Astavarga group, comprising eight rare and threatened species like Kakoli, Kshirkakoli, Jeevak, and Meda, found predominantly in the Himalayan region, exemplifies such endangered Ayurvedic flora.[12]

**Underutilized Plants:** These are domesticated plant species that, while used for food, medicine, trading, or cultural practices within local communities, have not been widely commodified or extensively studied as part of mainstream agriculture or scientific inquiry.[5] They are often referred to by various terms such as minor, orphan, underused, local, traditional, alternative, minor, niche, or underdeveloped crops.[13]

The characteristics of underutilized crops include a strong linkage with the cultural heritage of their places of origin, often poorly documented distribution, biology, cultivation, and uses, and adaptation to specific agroecological niches and marginal lands.[13] They typically suffer from weak or absent formal seed supply systems and are primarily used in traditional, localized production systems with minimal external inputs.[13] Despite often possessing high nutritional value and/or significant medicinal properties, these plants receive little attention from research, extension services, policy and decision-makers, and consumers.[13]

The distinction between these categories reveals a critical aspect of vulnerability and neglect. Underutilized species, while not necessarily "endangered" in the immediate sense, are susceptible to becoming so due to a lack of mainstream attention, poor documentation, and the absence of formal conservation efforts. Their underutilization in scientific inquiry and development means their full potential—be it nutritional, medicinal,

or genetic resistance—remains largely untapped, leading to genetic erosion.[13] This situation necessitates a proactive conservation approach for underutilized species, anticipating future threats rather than merely reacting to current endangerment. A contributing factor to their neglect is the perception of these plants as "famine food" or "poor people's food," a consequence of agricultural modernization.[13] This societal perception creates a cultural barrier that hinders their broader adoption and commercialization, even when they demonstrate significant nutritional or medicinal value. This cultural bias perpetuates their under-researched status and limited support, making their conservation and revival more challenging than simply demonstrating their biological benefits.

### 1.3. The Urgent Need for Conservation in the Face of Biodiversity Loss

The current rate of global plant species loss is alarming, with estimates indicating extinction rates 100 to 1000 times above the natural background rate.[2] This translates into a dire prediction: the potential loss of at least one major drug discovery every two years, impacting future pharmaceutical innovations.[2] India, despite its rich biodiversity, is particularly vulnerable. Out of its vast medicinal plant wealth, approximately 15,000 species are threatened with extinction due to relentless overharvesting and extensive habitat destruction, with a concerning 20% of wild resources already nearing exhaustion.[2] The gravity of this situation is further underscored by national and international assessments: the Indian Red Data Book lists 256 medicinal plants as endangered, and the IUCN Red List includes 560 Indian plant species, with 247 falling into the threatened category.[10]

The increasing global demand for herbal products, fueled by a growing consumer preference for natural remedies, exerts immense pressure on natural plant resources, leading to overproduction and rapid depletion.[2] This scarcity has severe consequences, often resulting in the substitution or adulteration of original plant sources in the supply chain.[2] Such practices compromise the quality, safety, and efficacy of Ayurvedic drugs and formulations, eroding consumer trust and potentially leading to adverse health outcomes.[2]

The economic and health ramifications of this biodiversity loss are profound. The data clearly indicate that the disappearance of species is not merely an ecological crisis but a direct threat to public health and the pharmaceutical industry, both traditional and modern. The economic incentive to over-exploit these valuable resources, without adequate regulation or sustainable practices, creates a negative feedback loop. The very resource being capitalized upon is simultaneously being destroyed, leading to market instability and a decline in the perceived reliability of herbal products due to adulteration. This situation underscores the urgent need for a fundamental paradigm shift from exploitative harvesting to systematic, sustainable cultivation and conservation practices.

## 2. Threats to Ayurvedic Plant Diversity in India

The rich tapestry of Ayurvedic plant diversity in India faces a complex web of threats, primarily driven by human activities and environmental changes. Understanding these pressures is paramount to developing effective conservation strategies.

### 2.1. Anthropogenic Pressures: Over-exploitation and Habitat Degradation

Over-exploitation stands out as a primary and immediate concern, fueled by the escalating global demand for herbal remedies.[4] The deep-rooted traditions of Ayurvedic and Unani medicines in India, coupled with a surging international market for herbal products, place immense pressure on wild medicinal plant populations.[21] Unregulated harvesting practices, particularly those that involve uprooting entire plants rather than selective collection of leaves or fruits, exacerbate this threat significantly. Such methods disrupt the natural regeneration capacity of the plants, posing severe long-term risks to their survival.[21]

Numerous Ayurvedic plants have been severely impacted by this unsustainable demand. The Astavarga group, comprising eight rare and threatened species such as Kakoli, Kshirkakoli, Jeevak, Meda, Mahameda, Rishbhak, Ridhhi, and Vridhii, predominantly found in the Himalayan region, are highly valued in Ayurveda and are under considerable threat.[12] Other prominent examples of overharvested species include Jatamansi (*Nardostachys grandiflora*), Kutki (*Picrorhiza kurrooa*), Red Sanders (*Pterocarpus santalinus*), Snakeroot (*Rauvolfia serpentina*), and Himalayan Yew (*Taxus wallichiana*).[7]

*Commiphora wightii*, commonly known as Guggul, is another critically endangered species primarily due to the high demand for its resin, which is extensively used in Ayurvedic medicine.[22] Similarly,

*Saussurea lappa* is explicitly listed among the critically endangered and heavily exploited medicinal plants.[10] The current market dynamics create a vicious cycle: increased demand, often driven by a renewed faith in herbal medicine [18], leads to unsustainable harvesting practices that deplete the very resource. This pursuit of short-term economic gain undermines the long-term viability of both the plant species and the traditional medicine systems that depend on them. The problem is further compounded by the inherent biological characteristics of many valuable species, such as slow growth rates and low population densities, which make them particularly vulnerable to over-harvesting.[18]

Concurrently, habitat loss represents another critical anthropogenic pressure. The relentless expansion of human activities, including widespread deforestation, land degradation, rapid urbanization, agricultural expansion, and infrastructure development, directly encroaches upon the natural habitats of medicinal plants.[4] This destruction disrupts the delicate ecological balances that support these plant species, endangering not only the plants themselves but also the rich biodiversity dependent on these ecosystems. This impact is particularly severe for narrowly distributed and endemic species, whose limited geographical range makes them highly vulnerable to even localized habitat destruction.[26]

### 2.2. Environmental Challenges: Climate Change and its Ecological Impacts

Climate change poses a significant and escalating threat to Ayurvedic plant diversity, manifesting through altered rainfall patterns, increased ambient temperatures, elevated atmospheric CO2 levels, and detrimental changes in soil properties.[1] These environmental shifts directly disrupt the specific habitats essential for the optimal growth of medicinal plants, leading to reduced growth rates and, critically, diminished medicinal activity due to changes in their phytochemical composition.[1]

A particularly concerning consequence of climate change is the occurrence of phenological shifts, where plants exhibit altered timing of life cycle events such as earlier flowering and fruiting.[1] These shifts can create severe mismatches between plants and their co-evolved insect pollinators, threatening the populations of both the plants and their essential pollinators.[1] Such disruptions directly impede reproductive success, which is a fundamental determinant of species sustainability.[19] The varied climatic zones across India, ranging from tropical in the south to temperate and alpine in the Himalayan north, are particularly susceptible to these changes, which can instigate divergence in the phytochemical composition of plant species, potentially altering their therapeutic properties.[1] This implies that climate change does not merely threaten the

*existence* of medicinal plants but also their *efficacy*. Alterations in environmental conditions could change the concentration or profile of active compounds within these plants, potentially rendering traditional preparations less effective or even introducing unforeseen safety concerns. This adds a critical layer of complexity to conservation efforts, necessitating not just the preservation of species but also the monitoring of their biochemical integrity and adaptation to changing environmental conditions.

### 2.3. Erosion of Traditional Knowledge and its Consequences

The traditional knowledge (TK) systems intrinsically linked with medicinal plants are undergoing rapid disappearance, posing a profound threat to Ayurvedic heritage.[25] This erosion is primarily attributed to the oral tradition of knowledge transfer, which is vulnerable in the absence of systematic written documentation.[25] Contemporary trends indicate a diminishing interest among younger generations in traditional practices, often perceived as outdated or economically unviable.[20] Compounding this, traditional knowledge holders frequently experience a lack of respect and appreciation for their invaluable wisdom.[29]

Broader societal shifts, including accelerated urbanization, globalization, rapid technological advancements, and increased migration from rural to urban areas, further contribute to the loss of ethnobotanical knowledge.[28] As natural forests degrade and specific plant species become unavailable for use by local communities, the traditional methods of sustainable collection and preparation, which are often highly nuanced and localized, are also progressively lost.[4] The perceived low income derived from traditional healing practices, coupled with the increasing accessibility and preference for modern medical facilities that often promise faster effects, further deters the younger generation from pursuing and preserving this ancestral knowledge.[30]

This situation reveals a critical co-extinction phenomenon: as plant species disappear from their natural habitats, the intricate knowledge of their uses, cultivation methods, and sustainable harvesting practices also vanishes. Conversely, the erosion of traditional knowledge means that even if a plant is conserved *ex-situ*, the practical understanding required for its effective preparation and application, which is often culturally embedded and orally transmitted, may be irrevocably lost. This highlights that conservation efforts must extend beyond mere botanical preservation to encompass a biocultural approach, ensuring the safeguarding of both the plant species and the invaluable human wisdom associated with them.

### 2.4. Socio-economic Factors: Commercialization, Lack of Regulation, and Biopiracy

The increasing commercialization of medicinal plant resources, while offering potential economic benefits and livelihoods, simultaneously introduces complex issues related to equitable access and benefit-sharing.[4] The commercial focus of private nurseries, which often prioritize decorative or high-profit conventional crops over medicinal plants, further contributes to the neglect and underutilization of many valuable Ayurvedic species.[26]

A significant systemic challenge within the medicinal plant industry is the pervasive lack of comprehensive regulation.[21] This regulatory vacuum often leads to unsustainable harvesting practices, widespread adulteration of herbal products, and inadequate quality control measures throughout the supply chain.[21] The absence of stringent guidelines and effective enforcement mechanisms makes it exceedingly difficult to conserve endangered species effectively and maintain the integrity of herbal medicines.[21]

Furthermore, biopiracy represents a substantial threat, wherein foreign entities exploit India's rich biodiversity and traditional knowledge for commercial profit without obtaining proper consent or providing fair compensation to the original custodians.[21] This exploitative practice not only deprives India of its natural resources and intellectual heritage but also exacerbates the threats to rare and endangered plant species by incentivizing their unsustainable extraction.[21] The paradox here is striking: the very economic potential of these plants, if left unregulated and ethically unguided, becomes a primary driver of their destruction and the dispossession of traditional communities from their ancestral heritage. This fundamental flaw in the market system necessitates urgent rectification through the establishment of robust regulatory frameworks, strong intellectual property protection, and equitable benefit-sharing mechanisms to ensure that economic development aligns with conservation objectives and social justice.

**Table 1: Select Rare and Endangered Ayurvedic Plants in India and their IUCN Conservation Status**

| Botanical Name (Common/Ayurvedic Name) | IUCN Red List Status | Key Traditional Uses/Medicinal Value | Region of Occurrence/Endemism | References |
|---|---|---|---|---|
| *Lilium polyphyllum* (Kakoli) | Rare/Threatened | Jeevaniya, Brhnayiya, Vayasthapan, bronchial asthma | Himalayan region (India, Pakistan, Nepal, China, Tibet, Afghanistan) | [5] |
| *Crepidium acuminatum* (Jeevak) | Rare/Threatened | Jeevaniya, Brhnayiya, Vayasthapan | Himalayan region (India, Cambodia, China, SE Asia) | [12] |
| *Malaxis muscifera* (Rishbhak) | Rare/Threatened | Jeevaniya, Brhnayiya, Vayasthapan | Himalayan region (India, Afghanistan, Bhutan, Nepal, China, Pakistan) | [12] |
| *Habenaria intermedia* (Meda) | Rare/Threatened | Jeevaniya, Brhnayiya, Vayasthapan | Temperate Himalaya (Kashmir to Sikkim, Uttarakhand, Himachal Pradesh) | [12] |
| *Habenaria edgeworthii* (Ridhhi) | Rare/Threatened | Jeevaniya, Brhnayiya, Vayasthapan | Himachal Pradesh, Uttarakhand to NW Himalaya (Nepal, Pakistan) | [12] |

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|---|---|---|---|---|
| *Nardostachys grandiflora* (Jatamansi) | Endangered | Fits, heart palpitations, constipation, regulate menstruation and digestion | China, Bhutan, India, Nepal | [7] |
| *Picrorhiza kurrooa* (Kutki) | Endangered | Antibiotic, liver ailments | India, Pakistan | [7] |
| *Pterocarpus santalinus* (Red Sanders) | Endangered (Globally) | Diabetes, anti-inflammatory, red dye | India (Eastern Ghats) | [7] |
| *Rauvolfia serpentina* (Snakeroot/Sarpagandha) | Critically Endangered | Central nervous disorders (anxiety, maniacal behavior) | Bangladesh, Bhutan, China, Indonesia, India, Lao PDR, Malaysia, Myanmar, Nepal, Sri Lanka, Thailand, Viet Nam | [3] |
| *Taxus wallichiana* (Himalayan Yew) | Vulnerable | Sedative, aphrodisiac, respiratory diseases, snake bites | Afghanistan, Bhutan, China, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Viet Nam | [7] |
| *Commiphora wightii* (Guggul) | Critically Endangered | Arthritis, obesity, cholesterol-related disorders | Arid regions of India (Rajasthan, Gujarat, Maharashtra) | [3] |

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|---|---|---|---|---|
| *Saussurea lappa* (Kuth) | Critically Endangered | Medicinal uses (often for aromatic properties) | India (Himalayan region) | 10 |
| *Acorus calamus* (Sweet Flag/Bach) | Endangered | Flatulent colic, atonic dyspepsia, ulcers | Throughout India | 68 |
| *Chlorophytum borivilianum* | Critically Endangered | Medicinal uses (often for vitality, aphrodisiac) | India | 3 |
| *Oroxylum indicum* | Vulnerable | Medicinal uses | Throughout India | 3 |
| *Ginkgo biloba* | Endangered | Medicinal uses | India | 3 |
| *Tinospora cordifolia* (Giloy) | Endangered | Adaptogenic, immune enhancer, liver health | Throughout India | 10 |
| *Bacopa monnieri* (Brahmi) | Endangered | Cognitive enhancement, memory, anxiety | Throughout India | 10 |
| *Glycyrrhiza glabra* (Licorice) | Endangered | Heartburn, indigestion, ulcers | Throughout India | 10 |
| *Gymnema sylvestre* | Vulnerable | Medicinal uses | Throughout India | 10 |
| *Holostemma ada-kodien* | Near Threatened | Medicinal uses | Throughout India | 10 |

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|---|---|---|---|---|
| *Celastrus paniculatus* (Malakangini) | Near Threatened | Muscle cramps, backache, osteoarthritis, hair care | Throughout India | [10] |
| *Aegle marmelos* (Bael) | Vulnerable | Dysentery, diabetes, coolant, gut health | Throughout India | [3] |
| *Asparagus racemosus* (Shatavari) | Medicinal uses | Infertility, libido, uterine health, lactation | Throughout India | [56] |
| *Withania somnifera* (Ashwagandha) | Medicinal uses | Stress tolerance, immunity, joint pains, skin health | Throughout India | [31] |

### 3. Herbal Gardens: A Cornerstone of Ayurvedic Plant Conservation

Herbal gardens represent a critical and multifaceted approach to the conservation and revival of Ayurvedic medicinal plants. Their roles extend beyond mere cultivation, encompassing *ex-situ* and *in-situ* conservation, advanced propagation, scientific research, and the vital preservation of traditional knowledge.

#### 3.1. Ex-situ Conservation Strategies and Germplasm Preservation

Herbal gardens serve as indispensable centers for *ex-situ* conservation, a strategy focused on propagating and multiplying medicinal and aromatic plants outside their natural habitats to ensure their long-term survival.[34] This approach is particularly crucial for rare and endangered species that face immediate and severe threats in their wild environments.[35] By providing a controlled environment, these gardens act as a safe haven, mitigating the pressures of habitat destruction and over-exploitation that imperil wild populations.[39]

A significant function of these gardens is the conservation of the genetic material, or germplasm, of medicinal plants. This involves the systematic collection and preservation of seeds, tissue samples, and plant cuttings, which are then stored in specialized seed banks or through advanced cryopreservation facilities.[39] Such meticulously preserved genetic material is invaluable for future breeding programs aimed at increasing population sizes, for reintroduction efforts to restore species to their native habitats, and for ongoing research into plant genetics and evolution.[39] The National Medicinal Plants Board (NMPB) in India actively supports these efforts through its Central Sector Scheme for Conservation, Development and Sustainable Management of Medicinal Plants. This scheme promotes the establishment of various types of herbal gardens, including Home Herbal Gardens (HHG), School Herbal Gardens (SHG), and larger Institutional/Public Herbal Gardens,

thereby decentralizing and broadening conservation efforts across the country.[42]

Herbal gardens, therefore, function as dynamic, accessible living gene banks and biodiversity sanctuaries. Beyond simply cultivating plants, they offer a more visible and interactive form of *ex-situ* conservation compared to traditional seed banks, which are often less accessible to the public. This dual role of genetic preservation and public engagement makes them powerful tools for both scientific conservation and fostering broader public appreciation and understanding of botanical diversity.

### 3.2. Supporting In-situ Conservation and Ecosystem Resilience

While primarily focused on *ex-situ* conservation, herbal gardens play a complementary and indirect role in supporting *in-situ* conservation efforts. By providing a cultivated source for medicinal plants, they effectively reduce the pressure on wild populations, thereby mitigating the need for destructive wild harvesting and allowing natural habitats to recover and regenerate.[46] This strategy is vital for species like Jatamansi and Kutki, which are heavily collected from the wild.[7]

The NMPB's Central Sector Scheme explicitly integrates and supports *in-situ* conservation through the establishment of Medicinal Plants Conservation and Development Areas (MPCDA).[43] The Foundation for Revitalisation of Local Health Traditions (FRLHT) has been a key implementer of this strategy, establishing 30 such MPCAs across 13 states, encompassing over 10,935 hectares, specifically to conserve medicinal plant flora within their natural habitats.[4] These

*in-situ* efforts involve a range of ecological management practices, including fire protection measures, implementation of soil and moisture conservation techniques, systematic removal of invasive weeds, and rehabilitation of degraded or bare areas.[16] The Medicinal Plants Conservation Centre (MPCC) in Pune, part of the extensive FRLHT network, has seen its legally recognized MPCAs inspire similar replication efforts in other states, demonstrating the effectiveness of this integrated approach.[47] The interplay between

*ex-situ* conservation in herbal gardens and *in-situ* conservation in protected areas is crucial. Herbal gardens, by providing cultivated sources, create a necessary buffer for wild populations, affording them the space and time to regenerate naturally. This integrated approach, combining controlled cultivation with direct habitat protection, is essential for holistic biodiversity management and ensuring long-term ecological resilience of medicinal plant species.

### 3.3. Advanced Propagation and Cultivation Techniques

Herbal gardens are dynamic centers for the application and development of diverse propagation methods, ranging from time-honored traditional techniques to cutting-edge biotechnological innovations. Traditional methods commonly employed include growing plants from seed, taking stem cuttings, and propagation through division and layering.[48] These practices are often shared and refined through networks of gardeners and nurseries.[48]

Crucially, these gardens also serve as sites for developing and applying modern biotechnological methods, such as tissue culture, also known as micropropagation.[36] Tissue culture allows for the rapid reproduction of a large number of uniform plants from a small piece of plant material (e.g., leaf, bud, stem), while meticulously maintaining their genetic integrity.[49] This technique is particularly valuable for conserving native or endangered species, especially those that exhibit slow growth rates, poor seed viability, or other challenges with conventional propagation methods.[46] For medium to long-term conservation, specialized techniques like slow-growing media and cryopreservation are employed within tissue culture laboratories associated with herbal gardens.[49]

Successful cultivation within herbal gardens necessitates careful site selection, considering factors such as optimal soil quality, consistent water availability, and efficient transport connections for both incoming materials and outgoing plant products.[34] Practical cultivation practices, including thorough bed preparation, enrichment of soil with organic manure (e.g., vermicompost, farmyard manure), maintaining proper spacing between plants, and ensuring adequate irrigation, are fundamental for promoting optimal plant growth and health.[50] The integration of ancient wisdom with cutting-edge science represents a significant evolution in conservation practice. Traditional knowledge provides the foundational understanding of plant uses and their growth habits, while biotechnology offers powerful solutions to overcome biological limitations. This synergy is vital for the effective, efficient, and scalable revival of Ayurvedic plant species.

### 3.4. Facilitating Research, Drug Discovery, and Pharmacological Screening

Herbal gardens serve as living laboratories, providing indispensable plant resources for a broad spectrum of scientific inquiry, including botanical research, pharmacology, and ethnobotany.[35] These gardens offer a unique environment where scientifically established information on both traditional and modern uses of medicinal plants can be gathered and disseminated, thereby supporting the burgeoning field of pharmacognosy—the study of medicines derived from natural sources.[35]

A significant contribution of herbal gardens lies in their role in drug discovery. They provide authenticated plant materials, which are essential for rigorous phytochemical analysis and pharmacological screening.[6] Researchers can systematically isolate and characterize the bioactive compounds responsible for the plants' therapeutic properties, elucidating their mechanisms of action and potential applications.[6] The availability of plant materials with documented genetic origins from germplasm facilities, often integrated within or closely linked to herbal gardens, is increasingly a fundamental requirement for conducting high-quality, reproducible natural product research.[40] This also aids in the crucial task of developing robust screening methods to identify and prevent the adulteration of commercial herbal products, thereby ensuring product integrity and consumer safety.[40]

Herbal gardens thus act as critical interfaces where traditional claims about medicinal plant efficacy can be rigorously validated through modern scientific methods. By providing authenticated samples and enabling systematic research, they contribute significantly to the standardization of herbal medicines, which in turn enhances their acceptance in mainstream healthcare systems. This scientific validation also plays a vital role in combating issues like adulteration, ultimately increasing consumer trust and the overall market value of Ayurvedic products.

### 3.5. Revitalizing Traditional Knowledge and Community Engagement

Herbal gardens are instrumental in the revitalization of traditional knowledge (TK) by serving as dynamic spaces for cultural preservation and intergenerational knowledge transmission.[29] They play a crucial role in fostering a sense of cultural identity and cohesion within communities by integrating indigenous healing practices and promoting the cultivation and use of native plants with medicinal properties.[37]

Educational programs, workshops, seminars, and training sessions organized within these gardens are highly effective in creating awareness among diverse stakeholders, including farmers, students, naturalists, and the general public, about the importance of medicinal plants and their traditional uses.[35] This direct engagement helps to actively combat the erosion of traditional knowledge, which is often caused by a perceived lack of interest among younger generations and insufficient documentation.[20]

Community involvement is recognized as a cornerstone of successful and sustainable conservation efforts.[16] Initiatives such as the Medicinal Plants Conservation Centre (MPCC) in Pune actively engage local

communities, including tribal populations, in conservation activities. This collaborative approach provides significant opportunities for direct participation, income generation through value-adding processes (e.g., primary processing, storage of medicinal plants), and improved access to essential plants for healthcare within these communities.[16] This demonstrates that linking conservation to livelihood incentives can profoundly motivate communities towards sustainable utilization practices.[16]

Furthermore, the implementation of robust documentation protocols for medicinal plant collections is crucial for preserving the associated traditional knowledge. These protocols involve meticulously recording detailed information on species, their locality, traditional uses, and cultivation practices. The adoption of international standards, such as the FAO/Bioversity multi-crop passport descriptors, ensures that this invaluable knowledge is systematically captured and made accessible for future generations and research.[54] This approach extends beyond mere plant conservation; it emphasizes the preservation of

*biocultural heritage*. By involving local and indigenous communities not just as beneficiaries but as active participants and knowledge holders, herbal gardens empower them to become true stewards of their traditional practices and plant resources. This creates a more resilient and culturally appropriate conservation model, ensuring that traditional knowledge is not just documented but actively practiced, transmitted, and valued.

**Table 2: Examples of Underutilized Ayurvedic Plants and their Traditional Medicinal Uses**

| Botanical Name (Common/Ayurvedic Name) | Traditional Medicinal Uses/Benefits | Current Status/Reason for Underutilization | References |
|---|---|---|---|
| *Alternanthera sessilis* (Sessile joyweed) | Fever, diarrhoea, anaemia, liver diseases | Neglected/underval ued minor crop, low production and sale | [5] |
| *Sesbania grandiflora* (Vegetable hummingbird) | Headache, fever, congestion, sore throat | Neglected/underval ued minor crop, low production and sale | [5] |
| *Nymphaea spp.* (Water lily) | Diabetes, liver and urinary disorders, menstruation problems | Neglected/underval ued minor crop, low production and sale | [5] |
| *Portulaca oleracea* (Purslane) | Osteoporosis, psoriasis; rich in β-carotene, folic acid, Vitamin C, essential fatty acids | Neglected/underval ued minor crop, low production and sale | [5] |

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|---|---|---|---|
| *Talinum triangulare* (Water leaf) | Diuretic, gastrointestinal disorders, high blood pressure, anemia | Neglected/undervalued minor crop, low production and sale | 5 |
| *Ipomoea aquatica* (Water spinach) | Piles, nosebleeds, high blood pressure | Neglected/undervalued minor crop, low production and sale | 5 |
| *Sauropus androgynus* (Chekurmanis) | High nutritive value, rich in protein, minerals, vitamins A, B, C, antioxidants | Neglected/undervalued minor crop, low production and sale | 5 |
| *Solanum torvum* (Turkey berry) | Fever, wounds, tooth decay, reproductive problems, hypertension | Neglected/undervalued minor crop, low production and sale | 5 |
| *Vigna umbelata* (Rice bean) | Multipurpose legume, rich in vitamins and proteins | Neglected/undervalued minor crop, low production and sale | 5 |
| *Dendrocalamus strictus* (Male bamboo) | Therapy for cold, cough, fever | Neglected/undervalued minor crop, low production and sale | 5 |
| *Abutilon indicum* (Country Mallow/Kanghi) | Nervine tonic, joint disorders, increases strength | Poor documentation, traditional use in localized areas | 68 |
| *Argyreia speciosa* (Elephant Creeper/Vridhadaru) | Diabetes, skin diseases, wounds | Poor documentation, traditional use in localized areas | 72 |

| | | | |
|---|---|---|---|
| *Alangium salvifolium* (Ankol) | Snakebite, scorpion bite, dog bite (traditional use) | Poor documentation, traditional use in localized areas | [72] |
| *Amomum subulatum* (Greater Cardamom/Badi Elaichi) | Bronchitis, asthma, appetizer, digestant | Poor documentation, traditional use in localized areas | [72] |
| *Achyranthes aspera* (Prickly chaff flower/Chirchita) | Indigestion, cough, asthma, liver health | Poor documentation, traditional use in localized areas | [5] |
| *Boerhaavia diffusa* (Spreading Hogweed/Punarnava) | Anemia, liver diseases, wounds, kidney health | Poor documentation, traditional use in localized areas | [68] |
| *Cyperus rotundus* (Nut Grass/Nagarmotha) | Fever, diabetes, solar dermatitis | Poor documentation, traditional use in localized areas | [72] |
| *Desmodium gangetium* (Shal Leafed Bush/Shalparni) | Analgesic, anti-inflammatory | Poor documentation, traditional use in localized areas | [72] |
| *Alhagi camelorum* (Camel Thorn/Yavasa) | Rheumatism, vomiting, stomachache, constipation | Poor documentation, traditional use in localized areas | [72] |
| *Anacyclus pyrethrum* (Pellitory/Akarkara) | Toothache, dryness of mouth/throat, catarrh, loss of libido | Poor documentation, traditional use in localized areas | [72] |
| *Butea monosperma* (Flame of | Complexion of skin, worm infestations, | Poor documentation, | [72] |

| | | | |
|---|---|---|---|
| Forest/Palasha) | roundworm | traditional use in localized areas | |
| *Abrus precatorius* (Rosary Pea/Ratti) | Joint pains, fungal skin infections, alopecia | Poor documentation, traditional use in localized areas | 5 |
| *Albizia lebbeck* (Siris Tree/Shirish) | Bronchial asthma, detoxification | Poor documentation, traditional use in localized areas | 68 |
| *Cassia fistula* (Indian Laburnum/Amaltas) | Mild laxative, ulcers, wounds | Poor documentation, traditional use in localized areas | 72 |
| *Clerodendron serratum* (Bharangi) | Common cold, chronic sinusitis, allergic rhinitis | Poor documentation, traditional use in localized areas | 72 |
| *Alstonia scholaris* (Dita/Chitvan) | Skin ulcers, fever, increasing lactation | Poor documentation, traditional use in localized areas | 72 |
| *Cissampelos pareira* (Velvet Leaf Tree/Patha) | Ulcers, sinuses, skin diseases, poisonous bites | Poor documentation, traditional use in localized areas | 72 |
| *Cassia angustifolia* (Indian Senna/Senna) | Laxative, constipation, irritable bowel syndrome, weight loss | Poor documentation, traditional use in localized areas | 68 |
| *Areca catechu* (Areca Nut/Supari) | Obesity, hyperlipidaemia, diabetes, irregular | Poor documentation, traditional use in | 72 |

| | | | |
|---|---|---|---|
| | menstruation | localized areas | |
| *Barleria prionitis* (Vajradanti) | Strengthens teeth, fever, catarrh | Poor documentation, traditional use in localized areas | [68] |

**Table 3: Key Contributions of Herbal Gardens to Medicinal Plant Conservation and Research**

| Category of Contribution | Specific Contribution | Brief Description/Mechanism | References |
|---|---|---|---|
| **Conservation** | Ex-situ Gene Pool Preservation | Cultivation and maintenance of rare, endangered, and threatened species outside natural habitats, preserving genetic material through seeds, tissue culture, and cryopreservation. | [34] |
| | Resource Augmentation | Propagation of high-demand species to reduce pressure on wild populations, allowing natural regeneration. | [43] |
| | Biodiversity Enhancement | Introduction of diverse medicinal plant species, contributing to local ecosystem health and richness. | [38] |
| **Research & Development** | Living Laboratories for Study | Provide authenticated plant | [6] |

| | | | |
|---|---|---|---|
| | | materials for botanical, ethnobotanical, and pharmacological research. | |
| | Drug Discovery & Screening | Facilitate phytochemical analysis, isolation of bioactive compounds, and pharmacological screening for new drug leads. | 6 |
| | Propagation Technique Development | Research and refine traditional and modern (e.g., tissue culture) propagation methods for difficult-to-grow species. | 36 |
| | Quality Control & Authentication | Provide authenticated plant samples for developing screening methods to identify adulterants in commercial products. | 40 |
| **Education & Awareness** | Public Awareness & Sensitization | Create and spread knowledge about medicinal plants, their traditional uses, and the importance of biodiversity among students, farmers, and the general public. | 35 |

| | | | |
|---|---|---|---|
| | Traditional Knowledge Transmission | Serve as spaces for intergenerational learning and cultural preservation, fostering respect for indigenous healing practices. | [29] |
| | Skill Development & Training | Offer training programs in horticulture, agriculture, botany, and conservation for various stakeholders. | [16] |
| **Socio-Economic Benefits** | Livelihood Generation | Support farmers and local communities through cultivation, value addition, and direct market linkages, providing economic returns. | [16] |
| | Entrepreneurship Development | Promote opportunities for rural youth in organic cultivation and value-added products from medicinal plants. | [74] |
| | Recovery of Marginal Lands | Utilize degraded or unfertile lands for medicinal plant cultivation, enhancing productivity and ecological restoration. | [35] |

## 4. Policy Frameworks and Institutional Initiatives in India

India's commitment to conserving its rich Ayurvedic plant heritage is underpinned by a robust framework of national policies and institutional initiatives, complemented by adherence to international conventions.

### 4.1. Role of the National Medicinal Plants Board (NMPB) and Ministry of AYUSH

The National Medicinal Plants Board (NMPB), established on November 24, 2000, under the Ministry of AYUSH (Ayurveda, Yoga & Naturopathy, Unani, Siddha & Homoeopathy), serves as the central nodal agency for promoting the medicinal plant sector in India.[42] Its comprehensive mandate encompasses coordination among various ministries and organizations, policy support, and the implementation of programs for the overall growth of medicinal plants, covering conservation, cultivation, trade, and export.[56]

The NMPB is a primary driver of conservation efforts through its "Central Sector Scheme for Conservation, Development and Sustainable Management of Medicinal Plants".[42] This scheme provides project-based support for a wide array of activities, including both

*in-situ* conservation through Medicinal Plants Conservation and Development Areas (MPCDA) and *ex-situ* conservation via the establishment of various types of herbal gardens—Home Herbal Gardens (HHG), School Herbal Gardens (SHG), and Institutional/Public Herbal Gardens.[43] The scheme also supports resource augmentation, research and development (R&D), and extensive Information, Education, and Communication (IEC) activities, including the establishment of nurseries.[43] Under this scheme, the NMPB has supported a substantial number of projects, including 1,498 projects across the country, leading to the conservation and augmentation of over 103,026 hectares of land, the establishment of 24,000 herbal gardens, and support to 1,175 Joint Forest Management Committees (JFMCs).[43]

Complementing this, the National Ayush Mission (NAM), a centrally sponsored scheme, further promotes the cultivation of medicinal plants by providing financial assistance and subsidies to farmers. Subsidies range from 30% to 75% of the cultivation cost for 140 prioritized medicinal plant species, with a strong focus on ensuring quality planting material and supporting post-harvest management.[43] The NMPB, through its seven Regional Cum Facilitation Centres (RCFCs), provides both financial and technical assistance to farmers and other stakeholders for the development of quality planting material.[43]

Key initiatives launched by the NMPB demonstrate its proactive approach. The "e-Charak" online portal and mobile application facilitate trading and information exchange among various stakeholders in the medicinal plants sector.[44] Global Ayush Innovation and Investment Summits are organized to foster buyer-seller interactions and facilitate Memorandum of Understandings (MoUs), involving thousands of farmers and generating significant economic value.[56] Species-specific awareness campaigns, such as "Ayush Aapke Dwaar" for sapling distribution (including Ashwagandha, Bael, Kalmegh, Tulsi, Giloe, Shatavari, Amla, Kutki, Jatamansi, Aloe vera, Brahmi, Stevia, Tejpatta, Ashoka, Guggulu, Sarpagandha) and "Shatavari – For Better Health," highlight a targeted approach to popularize and promote the cultivation and awareness of important Ayurvedic plants.[56]

The governmental role in these initiatives acts as a crucial catalyst for establishing sustainable supply chains. By actively supporting cultivation, conservation, trade, and even post-harvest management, the NMPB and Ministry of AYUSH are formalizing and incentivizing sustainable practices within the medicinal plant sector.[43] This strategic shift from unregulated wild collection towards a more structured, cultivated approach is fundamental for ensuring long-term sustainability and maintaining the quality and authenticity of Ayurvedic products.

### 4.2. Contributions of the Botanical Survey of India (BSI)

The Botanical Survey of India (BSI), established in 1890 under the Ministry of Environment, Forest and Climate Change, is a premier governmental research institution with a foundational role in the research and conservation of India's vast plant wealth.[60] BSI's mandate extends to the comprehensive study of flora, including endangered species, and the collection and maintenance of germplasm and gene banks for threatened and vulnerable plant species.[60] It is also a key contributor to taxonomic research, which is essential for accurate identification and classification of plant species.[60] Historically, botanical gardens under the East India Company, such as the Saharanpoor botanical garden (dating back to before 1750), were acquired by 1817 specifically for growing medicinal plants, laying early groundwork for BSI's future role.[60]

BSI's core objectives, expanded significantly after its reorganization in 1954, include conducting intensive floristic surveys, inventorying endemic, rare, and threatened plant species, and developing effective conservation strategies.[61] A crucial aspect of its work involves establishing and maintaining botanical gardens for

*ex-situ* conservation, providing a safety net for species facing threats in the wild.[61] BSI also conducts pharmacognostic studies on economically important species and those listed under international agreements like CITES or national legislation such as Schedule VI of the Indian Wildlife (Protection) Act, 1972.[61] Furthermore, BSI contributes to capacity building in plant taxonomy through various courses and conducts environmental impact assessments.[61] The institution publishes "Plant Discoveries," an annual bilingual publication providing authentic information on India's plant wealth, and "Nelumbo," a peer-reviewed journal focused on plant taxonomy and sciences.[60]

The work of BSI underscores that effective conservation is fundamentally built upon comprehensive scientific understanding and meticulous documentation. Without accurate identification, detailed distribution data, and robust taxonomic research, targeted conservation efforts are virtually impossible. BSI's role as a national repository of plant knowledge provides the essential scientific bedrock upon which all other conservation and sustainable utilization strategies for Ayurvedic plants are developed and implemented.

### 4.3. International Conventions: CBD and CITES in the Indian Context

India's conservation efforts for Ayurvedic plants are also framed within its commitments to international environmental agreements, notably the Convention on Biological Diversity (CBD) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

The Convention on Biological Diversity (CBD), to which India is a Party, is a legally binding international treaty established in 1992.[62] Its three overarching goals are the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from genetic resources.[62] The CBD's framework, including the Strategic Plan for Biodiversity 2011-2020 and its associated Aichi Biodiversity Targets, guides India's national biodiversity strategies and action plans (NBSAPs).[62] The Convention explicitly recognizes that the conservation of biodiversity is "a common concern of humankind" and an integral part of the development process.[63] It also provides guidance based on the precautionary principle, advocating for action to prevent biodiversity loss even in the absence of full scientific certainty.[62]

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is another crucial international agreement that regulates international trade in threatened species to ensure it is sustainable and does not jeopardize their survival.[7] In the Indian context, the Wildlife (Protection) Act, 1972, specifically lists six plants of Indian origin in CITES appendices under Schedule VI, thereby prohibiting their collection or trade from forest land.[64] Globally, 27 medicinal plant species are included in CITES Appendices

due to conservation concerns arising from international trade, with

*Saussurea costus* (Kuth) notably listed in Appendix I, indicating the highest level of protection.[24] Furthermore, entire genera, such as

*Aquilaria* spp. (Agarwood), *Hoodia* spp., and *Rhodiola* spp., are listed in Appendix II due to their overuse in the medicinal plant trade, signifying that over 1,000 medicinal plant species could be subject to CITES protection if traded internationally.[24]

Despite these comprehensive international and national legal frameworks, a significant challenge persists in the effective implementation and enforcement of control measures on the ground. Reports indicate that, despite existing regulations, wild populations of many medicinal plants continue to decline due to poor implementation of collection and trade controls.[7] This highlights a critical gap between international policy commitments and effective local enforcement. The limited impact of these frameworks points to the need for strengthening institutional capacity, increasing awareness among local communities involved in collection, and improving traceability within the supply chain to ensure that conservation policies are translated into tangible, on-the-ground sustainable practices.

### 4.4. Intellectual Property Rights and Measures Against Biopiracy

India has proactively developed a robust legal framework to combat biopiracy and safeguard its traditional knowledge (TK) and biological resources, particularly those related to Ayurvedic plants.[32] A cornerstone of this framework is the Traditional Knowledge Digital Library (TKDL), a groundbreaking initiative that functions as a prior art database.[32] The TKDL systematically documents India's traditional knowledge, including Ayurvedic formulations and uses, by translating and structuring ancient texts into international patent classifications, making it accessible to patent offices worldwide under non-disclosure agreements.[32]

The TKDL has been remarkably instrumental in challenging and successfully revoking numerous patent applications filed by foreign entities on traditional Indian knowledge. Notable successes include the challenges against patents on Turmeric, Neem (*Azadirachta indica*), and Ashwagandha (*Withania somnifera*), where the TKDL provided irrefutable proof of existing prior art, thereby nullifying claims of novelty.[32] This proactive approach not only protects India's intellectual heritage but also sets a global precedent for recognizing and respecting indigenous intellectual property rights.

Complementary legislation further strengthens this protective shield. The Biological Diversity Act (2002) regulates access to India's biological resources and ensures the fair and equitable sharing of benefits arising from their utilization.[32] The Patents Act (1970, amended 2005) explicitly prevents the patenting of traditional knowledge without significant scientific modification and mandates the disclosure of the source and geographical origin of any biological material used in an invention.[33] Additionally, the Geographical Indications (GI) of Goods (Registration and Protection) Act (1999) protects local products and ensures economic benefits for the communities that have developed traditional practices.[33] The Protection of Plant Varieties and Farmers' Rights Act (PPV&FRA, 2001) acknowledges the role of traditional farmers in preserving plant diversity and ensures they are fairly compensated for the commercial use of their varieties, allowing for the registration of traditional plant varieties to prevent biopiracy.[33]

The TKDL, in particular, represents a paradigm shift from reactive legal battles to a proactive defense of traditional knowledge. Its success in revoking patents not only safeguards India's heritage but also establishes a global benchmark for respecting indigenous intellectual property. This mechanism is crucial for ensuring that the benefits derived from rare and underutilized Ayurvedic plants are shared equitably, thereby creating a powerful incentive for their conservation by the communities who have traditionally nurtured and preserved

this invaluable knowledge.

### 5. Case Studies: Successful Revival and Conservation Efforts

Across India, various botanical and herbal gardens, alongside community-led initiatives, demonstrate tangible successes in the revival and conservation of rare and underutilized Ayurvedic plants. These case studies highlight diverse approaches and the significant impact of dedicated efforts.

#### 5.1. Notable Indian Botanical and Herbal Gardens

**Botanic Garden of Indian Republic (BGIR), Noida:** Established in 2002, the BGIR has emerged as a crucial nodal center for conservation research and environmental education.[65] This garden has successfully introduced and acclimatized numerous plant species from diverse phytogeographical regions across India for conservation and germplasm preservation. Many of these introduced species have adapted well to the alien environmental conditions and are now consistently producing viable fruits and seeds throughout the year.[65] A particularly notable achievement is the successful preservation of

*Hildegardia populifolia*, a critically endangered species. With only 18 known trees remaining in the wild, the BGIR proudly maintains a collection of more than 15 individuals, underscoring its vital role as a living sanctuary for highly threatened flora.[66]

**Dr. Sushila Tiwari Herbal Garden, Rishikesh, Uttarakhand:** This herbal garden is a significant site for *ex-situ* conservation, housing approximately 126 plant species, encompassing trees, shrubs, herbs, climbers, and grasses.[3] Its collection includes critically endangered species such as

*Chlorophytum borivilianum*, and endangered species like *Oroxylum indicum*, *Ginkgo biloba*, *Commiphora wightii*, *Rauvolfia serpentina*, and *Strychnos lucida*.[3] The garden plays a crucial role in providing high-quality planting materials and actively promoting the utility of medicinal plants among various stakeholders, thereby contributing to both conservation and awareness.[38]

**Government Degree College (GDC) Kanda Herbal Garden, Uttarakhand:** This garden exemplifies the role of educational institutions in conservation. It focuses on creating awareness, educating students and local farmers about the importance of medicinal plants, and promoting their cultivation as a means of crop diversification and enhancing economic returns.[50] The GDC Kanda garden has successfully planted a variety of medicinal and aromatic plants, including Ashwagandha, Artemisia, Lemongrass, Aloe Vera, Brahmi, Lavender, and Peppermint, all suited to the local climatic conditions.[50] Future plans include the introduction of endemic and rare/endangered species for

*in-situ* conservation within the garden's managed areas.[50]

**Medicinal Plants Conservation Centre (MPCC), Pune, Maharashtra:** Initiated in 1999 by the Foundation for Revitalisation of Local Health Traditions (FRLHT), the MPCC employs a highly effective collaborative approach, engaging local communities, the State Forest Department, and non-governmental organizations.[47] It operates an extensive network of 13 Medicinal Plant Conservation Areas (MPCAs) across Maharashtra, collectively conserving approximately 1,500 varieties of medicinal plants, including 76 species identified as endangered.[47] The MPCC has pioneered

*ex-situ* conservation by actively encouraging local farmers to conduct trials for cultivating locale-specific medicinal plants, thereby reducing pressure on wild populations.[47]

**Chandigarh Botanical Garden & Nature Park:** This garden showcases a broad spectrum of medicinal

plants, with extensive plantings of trees, shrubs, herbs, and climbers. Its collection includes many well-known Ayurvedic plants such as *Abrus precatorius*, *Acorus calamus*, *Adhatoda vasica*, *Aloe barbedensis*, *Asparagus racemosus*, *Bacopa monnieri*, *Boerhavia diffusa*, *Centella asiatica*, *Curcuma longa*, *Glycyrrhiza glabra*, *Gymnema sylvestre*, *Ocimum sanctum*, *Rauvolfia serpentina*, *Tinospora cordifolia*, and *Withania Somnifera*.[68] The diversity of species cultivated here demonstrates a comprehensive approach to botanical preservation and public education.

The success stories from these multiple gardens across different regions of India highlight a crucial aspect of effective conservation: the adaptability and effectiveness of herbal gardens within diverse agro-climatic zones. This decentralized approach, often involving local communities and educational institutions, suggests that conservation efforts are most impactful when they are tailored to specific regional ecological and socio-cultural contexts, thereby enhancing the overall resilience of the national conservation strategy.

### 5.2. Community-Led Conservation Models and Their Impact

Community involvement is recognized as an indispensable element for the long-term sustainability of medicinal plant conservation efforts.[16] In the Sechu Tuan Nalla Wildlife Sanctuary in the western Himalayas, local communities, known as Praja, have implemented an exemplary model of self-regulated conservation.[69] These communities actively monitor illegal activities and regulate the harvesting of highly prized, endangered medicinal herbs such as

*Fritillaria cirrhosa* (locally known as Jangli lahsun or Kakoli), which is a key component of Ayurvedic formulations like Astavarga and Chyavanprash.[12] A critical aspect of their traditional practice is ensuring that harvesting occurs only after the plant has set and dispersed its seeds, thereby allowing for sufficient natural regeneration for the following year.[69] This demonstrates an inherent understanding of sustainable resource management embedded within indigenous knowledge systems.

The FRLHT-coordinated Medicinal Plant Conservation Area (MPCA) program further illustrates the power of community engagement. This program actively involves local tribal communities, such as the "Soligas" in the Billigiri Rangan Hills, through comprehensive awareness programs and specialized training sessions.[16] This direct involvement is crucial not only for revitalizing local health traditions but also for ensuring the sustainable use of medicinal plants by those who have historically relied upon them.[16]

A significant innovation within these community-led models has been the establishment of Model Production Units (MPUs). These units involve tribal communities in the entire value chain—from collecting and primary processing to value-adding and marketing herbal products.[16] This approach provides gainful employment and enables communities to secure better prices for their products, directly linking conservation efforts to tangible livelihood incentives.[16] This demonstrates that integrating financial benefits with conservation objectives can powerfully motivate communities towards adopting and maintaining sustainable utilization practices, creating a symbiotic relationship between ecological preservation and economic well-being. The explicit focus on indigenous knowledge as a foundation for sustainable harvesting, as seen with

*Fritillaria cirrhosa*, highlights that traditional ecological knowledge often contains inherent sustainable practices that predate modern conservation science. Integrating these time-tested, community-led methods, such as rotational harvesting and respecting plant reproductive cycles, is not merely about social equity but represents a scientifically sound approach to ensuring the long-term viability of wild medicinal plant populations.

### 5.3. Species-Specific Revival Successes

Targeted interventions focusing on critically important or highly threatened species have yielded promising results in their revival and conservation.

**Astavarga Group:** This group of eight rare and threatened species, including Kakoli, Kshirkakoli, Jeevak, Meda, Mahameda, Rishbhak, Ridhhi, and Vridhii, are found predominantly in the Himalayan region and hold immense medicinal value in Ayurveda.[12] Efforts to revive these species often involve advanced propagation techniques like tissue culture and dedicated

*ex-situ* cultivation in specialized herbal gardens. Their inclusion in conservation programs underscores their foundational importance to Ayurvedic formulations.

***Commiphora wightii* (Guggul):** Listed as Critically Endangered by the IUCN (2014), Guggul is highly valued in Ayurveda for its resin, which is used to treat conditions such as arthritis, obesity, and cholesterol-related disorders.[22] Conservation initiatives for Guggul focus on implementing sustainable harvesting practices, proper management, and systematic cultivation to ensure its long-term availability.[22] Its presence in collections like the Dr. Sushila Tiwari Herbal Garden indicates active *ex-situ* conservation efforts for this vital species.[38]

***Rauvolfia serpentina* (Snakeroot/Sarpagandha):** Classified as Critically Endangered [70], the roots of *Rauvolfia serpentina* have been used for centuries in India for various central nervous disorders, including anxiety states and maniacal behavior.[7] This species is actively conserved in *ex-situ* collections, being found among the endangered plants in the Dr. Sushila Tiwari Herbal Garden [38] and the Chandigarh Botanical Garden [68], demonstrating dedicated efforts for its revival.

***Picrorhiza kurrooa* (Kutki):** Native to India and Pakistan, the rhizomes of Kutki are widely utilized in Ayurvedic and Unani traditional medicines as an antibiotic and for treating liver ailments.[7] It is consistently listed among endangered medicinal plants.[10] The National Medicinal Plants Board (NMPB) has included Kutki in its year-long sapling distribution campaigns, promoting its cultivation and broader awareness.[56]

***Pterocarpus santalinus* (Red Sanders):** This species is globally endangered [70], and its heartwood is valued in traditional medicine for treating diabetes and reducing inflammation.[7]

***Acorus calamus* (Sweet Flag/Bach):** Listed as Endangered [70],

*Acorus calamus* is traditionally used for conditions such as flatulent colic, atonic dyspepsia, and ulcers.[72] It is successfully cultivated in botanical gardens like the Chandigarh Botanical Garden, contributing to its *ex-situ* conservation.[68]

***Santalum album* (Sandalwood):** This highly valued medicinal plant is also listed as Endangered [70], necessitating focused conservation efforts. The NMPB's strategic focus on species-specific campaigns for plants such as Shatavari, Amla, Moringa, Giloe, and Ashwagandha [59] exemplifies a targeted approach to popularize and promote the cultivation and awareness of these important Ayurvedic plants. This strategic prioritization of individual species, particularly those with high medicinal value or critical conservation status, allows for concentrated resources and tailored propagation and conservation methods, significantly increasing the likelihood of successful revival for species that are foundational to Ayurvedic medicine or face imminent extinction.

## 6. Challenges and Future Directions for Sustainable Revival

Despite the significant progress in conserving rare and underutilized Ayurvedic plants through herbal gardens and policy initiatives, several challenges persist. Addressing these will be crucial for ensuring the long-term sustainability of these vital botanical resources.

### 6.1. Addressing Economic Viability and Market Linkages

A primary challenge in promoting the widespread cultivation of medicinal plants is ensuring their economic viability for farmers.[3] The growth periods for some medicinal plants can be extended, making them less profitable compared to other conventional cash crops, which often yields higher and faster returns.[4] This economic disparity often deters farmers from investing in medicinal plant cultivation, even when there is a demand for the raw materials.[3]

To overcome this, there is a critical need to develop and promote cultivation practices that are economically feasible for farmers, coupled with reliable and direct market linkages.[57] This involves increasing consumer awareness about the nutritional and medicinal value of underutilized species, which can be achieved through targeted awareness campaigns.[73] Furthermore, developing value-added products from these plants can significantly improve economic returns for cultivators, making the endeavor more attractive.[57] For instance, the domestication and commercial cultivation of wild edible plants offer substantial potential for stable yields and the conservation of agro-ecosystems, presenting exciting market opportunities for small-scale farms.[73] Understanding consumer perception and preferences is also vital for developing robust commercialization strategies.[73] The National Ayush Mission (NAM) providing subsidies for cultivation is a positive step, but its success hinges on ensuring that the returns from medicinal plants are competitive with other agricultural crops.[43] Establishing direct market linkages between forest-based collector communities and the user industry can also reduce wastage and improve economic returns for primary collectors.[57]

### 6.2. Enhancing Research and Documentation

While herbal gardens contribute significantly to research, there remain gaps in comprehensive studies, particularly concerning the full chemical characterization and pharmacological validation of many underutilized species.[14] There is a need for systematic frameworks to ensure sustainable practices in sourcing and to address critical research and development needs in the phytopharmaceutical industry.[19]

Improving data management and documentation protocols for medicinal plant collections is paramount. This includes meticulous recording of accession information (institution, accession number, collector, date, species, locality, georeferenced coordinates, ownership, permits, population data) and environmental conditions (light, moisture, soil, slope).[54] Documentation should extend to treatment at facilities, covering germination tests, propagation details, soil media, horticultural steps, growth to maturity, flowering, and seed set.[55] Crucially, experimental protocols, including both successful and unsuccessful attempts in tissue culture or cryopreservation, must be carefully noted, as even failures provide valuable information for future practitioners.[55] Adopting international standards, such as the FAO/Bioversity multi-crop passport descriptors, can ensure data compatibility and facilitate global information exchange.[55] The decline of traditional knowledge due to lack of documentation and disinterest from younger generations [25] underscores the urgency of these efforts. Comprehensive documentation, including ethnobotanical insights, is essential for future drug discovery and informing global conservation policies.[76]

### 6.3. Strengthening Policy Implementation and Funding

Despite robust policy frameworks and institutional initiatives by bodies like the NMPB and Ministry of AYUSH, challenges in effective implementation and enforcement persist.[7] The lack of comprehensive

regulation in the medicinal plant industry often leads to unsustainable harvesting and quality control issues.[21]

Strengthening policy implementation requires increased financial support for conservation programs and the development of herbal gardens.[74] While the NMPB provides project-based support for various types of herbal gardens and subsidies for cultivation [43], the scale of the challenge necessitates broader funding mechanisms. Exploring new frontiers of funding, including corporate social responsibility (CSR) funds, can significantly bolster these initiatives.[77] Public-private partnerships (PPPs) offer a promising avenue, bringing together the efficiency and flexibility of the private sector with the accountability and long-term perspective of the public sector.[78] These partnerships can minimize transaction costs, coordinate efforts, and facilitate technology transfer to farmers, thereby promoting higher productivity and efficiency in the medicinal plant sector.[78] The NMPB has indicated openness to proposals from multinational companies for herbal garden development, provided they align with guidelines.[45] Such collaborations can provide critical resources for infrastructure development, training, and market access, ensuring the sustainable development of the sector.

### 6.4. Fostering Holistic Conservation Approaches

The complex interplay of threats to Ayurvedic plant diversity—including climate change, over-exploitation, habitat loss, and the erosion of traditional knowledge—necessitates a holistic and integrated conservation approach.[1] A narrow focus on single threats or isolated conservation methods will be insufficient.

A comprehensive understanding of ecological functions, sustainable practices, and socio-economic dynamics is crucial.[19] The concept of ecosystem services, which evaluates the diverse benefits derived from nature beyond purely economic or environmental trade-offs, offers a valuable framework.[19] By aligning research strategies with sustainability goals and focusing on how medicinal plant conservation contributes to broader ecosystem resilience, a more integrated approach can be achieved.[19] This involves addressing the four key determinants of a species' sustainability: habitat and habitat loss, reproductive success, climate change impacts, and bio-economy (uses).[19] International conventions like the CBD emphasize the sustainable use of biodiversity components and fair benefit sharing.[62] However, the gap between policy and implementation, as observed with CITES controls [7], highlights the need for stronger local enforcement and community-led conservation actions, such as fixing harvest limits and implementing self-regulated rotational harvesting.[79] Ensuring that economic development aligns with conservation objectives is paramount, preventing the paradox where the economic value of plants drives their destruction.[21]

### 6.5. Integrating Traditional Knowledge with Modern Science

The future of Ayurvedic plant conservation lies in a robust integration of traditional ecological knowledge (TEK) with modern scientific innovation. While ethnobotanical studies document traditional uses, there remains a critical need for further research to scientifically validate the efficacy and safety of many traditional remedies.[76]

Future research directions should prioritize collaborative research efforts that bring together traditional healers, ethnobotanists, pharmacologists, and conservation biologists.[76] This synergy can lead to the identification of new bioactive compounds, the development of sustainable harvesting protocols based on indigenous practices, and the refinement of cultivation techniques for rare species.[76] Ethical frameworks are essential to ensure that the benefits arising from the utilization of traditional knowledge are shared fairly and equitably with the communities who have preserved this knowledge for generations, thereby preventing biopiracy and fostering trust.[32] Documentation studies are particularly needed to support epidemiological surveys and future drug discovery efforts from biodiversity.[76] Ethnopharmacological studies on traditional methods of preparation can also discourage over-exploitation and enhance local community resilience, culture, and ownership of medicinal technology.[76] This comprehensive integration ensures that conservation

efforts are not only scientifically sound but also culturally appropriate and socially just, securing the long-term viability of Ayurvedic plant resources for global health.

## 7. Conclusion

The revival and conservation of rare and underutilized Ayurvedic plants are imperative for safeguarding India's rich botanical heritage, sustaining traditional medicine systems, and contributing to global health and economic well-being. These invaluable plant resources face severe threats from over-exploitation, habitat destruction, the pervasive impacts of climate change, and the alarming erosion of traditional knowledge. The current rate of species loss jeopardizes not only biodiversity but also the potential for future drug discoveries and the livelihoods of countless communities.

Herbal gardens emerge as a cornerstone of this multifaceted conservation approach. They function as critical *ex-situ* repositories, meticulously preserving the genetic diversity of threatened species through germplasm banks and advanced propagation techniques like tissue culture. Simultaneously, by providing cultivated sources, they indirectly alleviate pressure on wild populations, thereby supporting *in-situ* conservation efforts and promoting ecosystem resilience. These gardens are also vital living laboratories, facilitating rigorous scientific research, pharmacological screening, and the validation of traditional medicinal claims, bridging the gap between ancient wisdom and modern science. Crucially, herbal gardens serve as dynamic centers for revitalizing traditional knowledge, fostering intergenerational learning, and empowering local communities as active stewards of their biocultural heritage.

India's policy landscape, spearheaded by the National Medicinal Plants Board (NMPB) and the Ministry of AYUSH, provides substantial institutional support through comprehensive schemes, financial incentives for cultivation, and initiatives aimed at market development and awareness. The foundational work of the Botanical Survey of India (BSI) in documentation and taxonomic research underpins these efforts. Furthermore, India's adherence to international conventions like the CBD and CITES, coupled with robust intellectual property protection mechanisms such as the Traditional Knowledge Digital Library (TKDL), demonstrates a strong commitment to combating biopiracy and ensuring equitable benefit-sharing.

Despite these commendable efforts, challenges persist, particularly concerning the economic viability of medicinal plant cultivation for farmers, the need for more comprehensive research and documentation, and the effective implementation of policies on the ground. The future of sustainable revival hinges on addressing these challenges through an integrated approach. This necessitates strengthening market linkages, promoting value-added products, enhancing scientific research with a focus on phytochemical integrity, ensuring robust funding through diverse channels including public-private partnerships, and fostering truly holistic conservation strategies that embrace the concept of ecosystem services. Ultimately, the successful revival of rare and underutilized Ayurvedic plants depends on a synergistic integration of traditional knowledge with modern scientific innovation, guided by ethical frameworks and empowered community engagement, ensuring that these vital botanical treasures continue to enrich human health and ecological balance for generations to come.

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