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Vanishing Botanicals: Medicinal Plant Depletion Threatens the Ayurvedic Industry

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A B S T R A C T

The Ayurvedic industry, deeply rooted in the use of medicinal plants, plays a vital role in providing holistic healthcare and contributing significantly to the economy, particularly in India. However, it currently faces critical challenges due to the rapid depletion of essential medicinal plant resources. Unsustainable harvesting practices, driven by increasing global demand, lead to overexploitation of wild plant populations, often without regard for regeneration. Habitat destruction caused by deforestation, agricultural expansion, and urbanization further exacerbates the decline in medicinal plant diversity. Additionally, the impacts of climate change - such as altered rainfall patterns and temperature fluctuations -threaten the growth and phytochemical properties of many species. Insufficient regulation, lack of systematic documentation, and poor implementation of conservation guidelines worsen the situation. The depletion of medicinal plants affects the availability of raw materials, compromises product quality, leads to the use of substitutes or adulterants, and undermines the therapeutic efficacy and safety of Ayurvedic formulations. This review analyzes the key causes and implications of medicinal plant depletion, highlighting sustainable cultivation practices, conservation strategies, policy measures, and technological innovations as urgent solutions to secure the future of the Ayurvedic industry.

Keywords: Medicinal plant depletion, Ayurvedic industry, Sustainable conservation, Traditional knowledge erosion, Phytochemical standardization

1. Introduction

Ayurveda, one of the world's oldest systems of traditional medicine, has long relied on the therapeutic properties of medicinal plants to promote holistic health and well-being. As a major component of India's healthcare system and economy, the Ayurvedic industry supports millions of livelihoods through the cultivation, collection, and processing of herbal medicines. However, increasing global demand for herbal products, combined with unsustainable harvesting practices, habitat destruction, and climate change, has led to a significant decline in the availability of key medicinal plants. Most of the Species are becoming increasingly scarce, threatening the supply chain for classical Ayurvedic formulations like Kashayam, Choornam and Arishtam. The situation is further worsened by inadequate regulatory frameworks and the lack of comprehensive documentation, which hampers efforts to monitor and manage plant populations effectively.

The Ayurvedic industry is a significant contributor to both national health care and the economy, generating substantial employment in cultivation, collection, processing, and manufacturing of herbal medicines (Ved & Goraya, 2007). Medicinal plants are the cornerstone of Ayurvedic formulations, with classical preparations such as Kashayam, Arishtam, and Choornam relying almost entirely on plant-based raw materials (Kunle et al., 2012). Globally, the herbal medicine market has grown rapidly, estimated to reach USD 129.1 billion by 2023, which places immense pressure on natural resources (WHO, 2013). Despite their economic and therapeutic importance, the indiscriminate and unsustainable harvesting of medicinal plants has emerged as a critical issue (Chandra et al., 2017).

Overexploitation of wild populations, driven by high market demand, leads to the depletion of slow-growing and endangered species such as *Rauwolfia serpentina, Saussurea costus, Podophyllum hexandrum, Taxus wallichiana, Nardostachys jatamansi, Aconitum heterophyllum, Swertia chirata, Coptis teeta* etc. Habitat destruction due to deforestation, urbanization, and agricultural expansion further contributes to the loss of biodiversity (Ved & Goraya, 2007). Climate change also disrupts plant growth patterns, affecting phytochemical profiles essential for therapeutic efficacy (Patwardhan et al., 2015).

Moreover, the lack of systematic documentation and poor regulatory implementation exacerbates the situation, making sustainable management of medicinal plants difficult (Rajasekaran & Amalraj, 2017). This depletion threatens the availability of raw materials for Ayurvedic products, compromises quality, leads to adulteration, and undermines the traditional knowledge system that has been preserved for centuries (Pushpangadan et al., 2005).

Effective conservation strategies, sustainable cultivation practices, and policy interventions are urgently needed to protect medicinal plant resources (Kala, 2005). Integration of scientific innovations such as phytochemical standardization and biotechnology can further reduce dependency on wild plants (Joshi et al., 2016).

Without urgent action to implement sustainable cultivation, conservation strategies, and modern technological solutions, the long-term sustainability of the Ayurvedic industry and its rich traditional knowledge system remains at serious risk. This review explores the primary causes of medicinal plant depletion, its impact on the Ayurvedic industry, and strategies for sustainable management and conservation.

2. Major Causes of Medicinal Plant Depletion

2.1 Overexploitation of Wild Resources

Medicinal plants are frequently harvested directly from their natural habitats without adherence to sustainable management practices (Chen et al., 2016; Fajinmi et al., 2023)., leading to overexploitation and rapid depletion of wild populations. Rauwolfia serpentina, used for its antihypertensive and sedative properties, has faced overharvesting to the extent that it is now listed as a threatened species under CITES (Ved & Goraya, 2007). Similarly, Saussurea costus, valued for its root in traditional formulations and perfumes, has experienced dramatic population declines in the Himalayan region due to indiscriminate collection practices (Kala, 2005, Mykhailenko et al., 2025).

Often, collectors uproot the entire plant, ignoring the possibility of harvesting renewable parts like leaves or bark, which could allow the plant to regenerate naturally. This unsustainable practice not only diminishes the individual species but also disrupts the overall ecological balance by affecting pollinators, soil fertility, and habitat integrity (Chandra et al., 2017, Howes et al., 2020).

In addition, the open and unregulated market trade of wild-collected medicinal plants encourages overexploitation. Lack of awareness and economic dependency on plant collection among local communities further drive the unsustainable harvesting trend (Rajasekaran & Amalraj, 2017, Dalir et al., 2025). Without effective regulatory frameworks and enforcement, overharvesting continues to push many valuable medicinal plants toward extinction, threatening the future of the Ayurvedic industry and biodiversity.

2.2 Habitat Destruction

Large-scale deforestation, agricultural expansion, infrastructure development, and urbanization result in the destruction of natural habitats that support diverse medicinal plant species (Gusain et al., 2021). Biodiversity-rich areas like the Western Ghats and Himalayan regions are especially impacted, causing significant loss of plant diversity.

2.3 Climate Change Effects

Global climate change is emerging as a critical threat to medicinal plant resources (Mykhailenko et al., 2025). Changes in temperature, altered rainfall patterns, and increased frequency of extreme weather events such as droughts and floods significantly affect the growth, reproductive cycles, and natural distribution of medicinal plants. For example, many species in the Himalayan region, such as *Rauvolfia serpentina* and *Aconitum heterophyllum*, are highly sensitive to temperature and precipitation changes, which disrupt their germination and growth processes (Patwardhan et al., 2015).

Phytochemical properties of medicinal plants, which determine their therapeutic efficacy, are also influenced by climatic factors. Studies have shown that variations in temperature and rainfall can alter the concentration of bioactive compounds in plants like *Withania somnifera* (Ashwagandha) and *Hypericum perforatum* (St. John's Wort), reducing their medicinal potency (Chandra et al., 2017, Howes et al., 2020). Such variability poses challenges for quality control and standardization in the Ayurvedic industry.

Moreover, some species are unable to adapt to the rapidly changing climate, leading to reduced population sizes or localized extinction. For instance, *Saussurea costus*, an important source of medicinal compounds, is becoming increasingly rare due to shrinking suitable habitat zones caused by rising temperatures and soil degradation in the Himalayan belt (Kala, 2005). This not only threatens the ecological balance but also undermines the long-term availability of critical raw materials for the Ayurvedic industry.

2.4 Lack of Proper Regulation and Documentation

One of the critical factors contributing to the depletion of medicinal plants is the poor implementation of existing guidelines related to sustainable harvesting (Chen et al., 2016; Ssenku et al., 2022). Although the Government of India has established frameworks such as the Good Agricultural and Collection Practices (GACP) and the Biological Diversity Act (2002), enforcement remains weak in many regions (Ved & Goraya, 2007). Harvesters often continue to collect plants indiscriminately from the wild due to a lack of awareness, economic dependence, and absence of effective regulatory monitoring (Pushpangadan et al., 2005).

Furthermore, there is a significant gap in systematic documentation of medicinal plant populations. Most species lack accurate, up-to-date data regarding their abundance, geographical distribution, and ecological status (Rajasekaran & Amalraj, 2017). Without reliable population assessments, it is extremely difficult to determine sustainable harvesting limits or implement targeted conservation strategies. Species such as *Nardostachys jatamansi* and *Saussurea costus* are often collected without any monitoring of their regeneration rate, leading to local extinction in some areas (Kala, 2005).

The unregulated trade of wild-collected medicinal plants compounds the problem further. In many cases, market intermediaries exploit the lack of regulatory checks, facilitating the trade of endangered species without documentation or permits (Hamilton, 2004). This not only undermines conservation

efforts but also increases the risk of adulteration and reduced quality in Ayurvedic formulations. Comprehensive policies and their strict enforcement are urgently needed to address this regulatory gap and promote sustainable use of medicinal plant resources.

3. Threats to the Ayurvedic Industry

3.1 Raw Material Scarcity

The depletion of medicinal plants poses a direct and significant threat to the availability of raw materials essential for Ayurvedic formulations (Chen et al., 2016; Davis et al., 2024). Many classical Ayurvedic preparations, such as Kashayam, Arishtam, and Choornam, rely on specific plant species for their therapeutic properties. As wild populations decline due to unsustainable harvesting and habitat loss, manufacturers face chronic shortages of key ingredients. *Terminalia arjuna* (Arjuna), used for cardiovascular health, *Asparagus racemosus* (Shatavari), valued for its adaptogenic and reproductive health benefits, *Berberis aristata* (Indian Barberry), known for its antimicrobial and hepatoprotective properties, *Swertia chirata*, used for fever and digestive ailments, and *Coscinium fenestratum* (Tree turmeric), used for anti-diabetic and anti-inflammatory effects, are now increasingly threatened due to overexploitation and habitat degradation (Ved & Goraya, 2007; Kala, 2005). To address raw material shortages, some companies have resorted to using substitutes or synthetic analogs, which may not deliver the same therapeutic effect, thus compromising the authenticity and efficacy of Ayurvedic products (Pushpangadan et al., 2005). Small-scale manufacturers, in particular, struggle to bear the rising costs associated with scarce materials, threatening their survival in the competitive market (WHO, 2013).

3.2 Economic Impact

Scarcity of medicinal plants drives up the cost of raw materials, disproportionately affecting small-scale manufacturers and rural farmers involved in cultivation or collection. High-value species such as *Saussurea costus, Aconitum heterophyllum, Picrorhiza kurroa* essential for various Ayurvedic formulations, have seen price surges as their wild availability diminishes (Kala, 2005). The industry increasingly depends on imported raw materials from countries like Nepal, China, and Pakistan, adding to production costs and exposing manufacturers to supply chain disruptions (Kunle et al., 2012). This dependence on external sources reduces the global competitiveness of the Indian Ayurvedic industry, which traditionally emphasizes indigenous resources and practices. In many cases, unregulated trade enables intermediaries to profit, often at the expense of sustainability and fair economic returns to local collectors (Hamilton, 2004).

3.3 Loss of Product Quality and Therapeutic Efficacy

With the decline of authentic raw materials, manufacturers are often compelled to use plant substitutes or adulterated materials that do not meet the required pharmacological standards. For instance, *Withania somnifera* (Ashwagandha), known for its adaptogenic properties, is sometimes substituted with other low-potency species, resulting in reduced therapeutic outcomes (Chandra et al., 2017). Adulteration increases the risk of consumer health issues and regulatory non-compliance, thereby damaging the industry's reputation in global markets.

3.4 Erosion of Traditional Knowledge

Traditional knowledge surrounding the identification, collection, and preparation of medicinal plants has been orally transmitted across generations, particularly in indigenous and local communities of India especially in Kerala. This valuable body of knowledge includes not only the therapeutic uses of plants but also sustainable harvesting methods, seasonal collection practices, and preparation techniques that enhance efficacy. However, the disappearance of plant species due to overharvesting, habitat destruction, and climate change is causing an irreversible loss of this cultural and scientific heritage.

In Kerala, several important medicinal plants are increasingly threatened, contributing to the erosion of traditional knowledge. For example, *Terminalia arjuna*, used extensively in cardiac care, is becoming scarce, resulting in the loss of knowledge about its identification and preparation (Kala, 2005). *Asparagus racemosus* (Shatavari), valued for adaptogenic and reproductive health benefits, is declining, affecting local practitioners who use it for female health (Ved & Goraya, 2007). *Coscinium fenestratum* (Tree turmeric), known for antidiabetic and anti-inflammatory properties, faces population reduction in Kerala's forests, reducing access for traditional use (Pushpangadan et al., 2005). Similarly, *Phyllanthus emblica* (Amla), important for Rasayana formulations, and Piper longum (Pippali), used in respiratory and digestive preparations, are being overexploited (WHO, 2013).

As these species vanish, so does the intergenerational knowledge of their therapeutic properties, harvesting seasons, and synergistic formulations, which are central to the holistic practice of Ayurveda. Without urgent conservation efforts, this erosion threatens both the authenticity of Ayurvedic medicine and the cultural heritage of the region.

4. Strategies for Sustainable Use and Conservation

4.1 Cultivation of Medicinal Plants

Promoting the cultivation of high-demand medicinal plant species is one of the most effective strategies to reduce pressure on wild populations and ensure a sustainable supply of raw materials for the Ayurvedic industry (Fajinmi et al., 2023; Shukla et al., 2023). Cultivation enables better control over growth conditions, ensuring consistency in phytochemical content and quality of harvested materials. *Withania somnifera* (Ashwagandha) and *Centella asiatica* (Gotu Kola), both widely used in Ayurvedic formulations, are now increasingly cultivated under controlled agricultural practices to meet growing market demand (Ved & Goraya, 2007).

The implementation of Good Agricultural and Collection Practices (GACP) plays a critical role in maintaining the quality and traceability of medicinal plants. GACP guidelines emphasize proper site selection, soil health management, optimal harvesting time, and post-harvest handling, which contribute to improved yield, standardization, and sustainable production (Pushpangadan et al., 2005). Moreover, cultivation helps in preventing adulteration by minimizing the risk of contamination with similar but ineffective species.

In addition to large-scale commercial cultivation, small-scale farming of medicinal plants offers economic opportunities for rural farmers and reduces dependence on wild collection. Governments and organizations like the National Medicinal Plants Board (NMPB) support cultivation through financial incentives, training programs, and establishing model nurseries (Kala, 2005). Such initiatives encourage local communities to adopt sustainable agricultural practices, which not only conserve biodiversity but also improve livelihoods, ensuring long-term availability of high-quality raw materials for the Ayurvedic industry.

4.2 In-situ and Ex-situ Conservation

In-situ conservation refers to the preservation of medicinal plants within their natural habitats, allowing species to grow and evolve in the ecosystems where they have adapted over centuries. This approach plays a critical role in maintaining ecological balance and supporting the continued interaction between plants, pollinators, and soil microorganisms. One effective in-situ strategy is the establishment of Medicinal Plant Conservation Areas (MPCAs), where natural populations of endangered and rare species are protected from overharvesting and habitat destruction. The Government of India has designated several MPCAs in biodiversity-rich regions such as the Western Ghats and the Himalayan belt to conserve species like *Nardostachys jatamansi* and *Saussurea costus* (Kala, 2005).

Ex-situ conservation complements in-situ efforts by preserving medicinal plant species outside their natural habitats. Seed banks, tissue culture laboratories, and botanical gardens are essential for safeguarding genetic diversity and enabling the propagation of rare and threatened species under controlled conditions. The Central Institute of Medicinal and Aromatic Plants (CIMAP), for instance, operates extensive seed banks and in-vitro propagation facilities to conserve germplasm of critical medicinal species and supply high-quality planting material for cultivation (Patwardhan et al., 2015). Tissue culture techniques allow rapid multiplication of elite plant lines with desired phytochemical profiles, reducing the need to harvest wild plants (Petelka et al., 2022; Howes et al., 2020).

Together, in-situ and ex-situ conservation strategies form a robust framework for the sustainable management of medicinal plant resources. While in-situ conservation protects natural biodiversity and supports ecosystem services, ex-situ methods ensure the long-term survival of species threatened by habitat loss or climate change. Integrated conservation approaches help maintain ecological resilience, support research, and ensure the sustainable supply of high-quality raw materials for the Ayurvedic industry (Chandra et al., 2017).

4.3 Sustainable Harvesting Techniques

Sustainable harvesting techniques play a crucial role in conserving medicinal plant populations while allowing their continued use in Ayurvedic formulations. One of the most important approaches is rotational harvesting, where different areas of a habitat are harvested in a planned sequence, allowing previously harvested sites sufficient time to regenerate. This reduces the continuous strain on a single population and helps maintain ecological balance. For example, local communities in the Western Ghats practice rotational harvesting of Centella asiatica and Phyllanthus amarus under community-based management schemes, which promotes natural regeneration and long-term availability (Kala, 2005).

Another important technique is the selective collection of renewable parts such as leaves, fruits, flowers, or bark, rather than uprooting the whole plant. Harvesting only parts of the plant ensures that the plant remains alive and continues to grow, reproducing naturally in the ecosystem. For instance, sustainable harvesting protocols for *Saraca asoca*, used in menstrual disorders, recommend collecting only a portion of the bark while leaving enough to allow the plant to survive and heal (Ved & Goraya, 2007). Adopt the "30% rule": harvest no more than 30% of a plant population in a given area to ensure regeneration.

In addition to harvesting techniques, the implementation of seasonal restrictions and quota systems can prevent overharvesting during vulnerable growth or reproductive periods. Government regulations and permit systems help ensure that only a sustainable number of plants are harvested annually, especially for endangered species like *Saussurea costus* and *Aconitum heterophyllum* (Rajasekaran & Amalraj, 2017). Training programs organized by National Medicinal Plants Board and NGOs educate harvesters about ecological impacts, proper collection methods, and the importance of sustainability.

These efforts are vital in promoting long-term conservation, improving the quality of raw materials, and securing livelihoods for local communities involved in plant collection.

4.4 Regulatory Framework and Monitoring

Implementation of existing regulatory policies such as the Biological Diversity Act (2002) and guidelines from the NMPB plays a pivotal role in ensuring sustainable collection, use, and trade of medicinal plants. The Biological Diversity Act provides a legal framework to regulate the collection of biological resources, promote sustainable use, and protect traditional knowledge associated with medicinal plants (Pushpangadan et al., 2005). The NMPB issues specific guidelines on Good Agricultural and Collection Practices (GACP), emphasizing sustainable harvesting methods, documentation, and traceability of raw materials (Ved & Goraya, 2007).

Periodic assessments, audits of supply chains, and monitoring of wild plant populations are essential for effective policy enforcement. Scientific surveys and population studies help track the health and regeneration status of critical species like *Nardostachys jatamansi* and *Saussurea costus* (Kala, 2005). Furthermore, the use of digital platforms and Geographic Information Systems (GIS) for real-time monitoring supports efficient data collection and informed decision-making (Rajasekaran & Amalraj, 2017). These measures ensure accountability, minimize illegal trade, and help in designing targeted conservation strategies.

4.5 Community Participation and Benefit-Sharing

Empowering local communities is a fundamental strategy in the sustainable management of medicinal plant resources. Educating collectors about sustainable harvesting techniques and the ecological importance of medicinal plants helps build awareness and promotes responsible practices (Patwardhan et al., 2015). Additionally, economic incentives and structured benefit-sharing mechanisms provide a direct financial interest in conservation efforts. Community-based conservation, awareness programs, and benefit-sharing mechanisms support sustainable harvesting and provide economic incentives (Gusain et al., 2021; Dalir et al., 2025).

Community-managed conservation projects in the Western Ghats encourage local collectors to adhere to sustainable harvesting quotas in exchange for guaranteed market access and fair prices (Kala, 2005). Benefit-sharing policies not only secure livelihoods but also motivate communities to engage in conservation activities such as cultivation of high-value species and protection of natural habitats. These participatory models create a win-win situation by reducing pressure on wild populations while improving the socio-economic well-being of rural populations (Pushpangadan et al., 2005).

4.6 Scientific and Technological Innovations

Scientific and technological advances are helping to reduce dependence on wild-harvested plant materials while ensuring the availability of high-quality bioactive compounds for Ayurvedic formulations. Phytochemical standardization techniques focus on isolating and quantifying active ingredients, enabling manufacturers to use smaller quantities of raw material without compromising efficacy (Kunle et al., 2012). This reduces the volume of plant material required and encourages the use of cultivated, standardized crops.

Additionally, biotechnology approaches such as cell suspension cultures and synthetic biology provide alternative sources of important phytoconstituents. For instance, tissue culture techniques enable the mass propagation of elite plant varieties under controlled laboratory conditions, preserving desired genetic and phytochemical traits (Patwardhan et al., 2015). Synthetic biology allows for the production of specific bioactive compounds in vitro, eliminating the need to harvest wild plants altogether (Chandra et al., 2017). These innovations not only reduce ecological pressure on natural populations but also contribute to the scalability, reproducibility, and safety of Ayurvedic medicines.

5. Conclusion

The depletion of medicinal plants poses an existential threat to the Ayurvedic industry, which fundamentally depends on plant-based raw materials for its therapeutic formulations. Unsustainable harvesting practices, habitat destruction, climate change, and insufficient regulatory enforcement have accelerated the decline of key species of ayurvedic products. This depletion leads to raw material scarcity, rising production costs, reduced product quality, and the gradual erosion of traditional knowledge, severely undermining the industry's economic viability and global credibility. Addressing this complex challenge requires urgent and coordinated actions by policymakers, industry stakeholders, researchers, and local communities. Promoting the cultivation of high-demand species under Good Agricultural and Collection Practices (GACP) helps reduce dependency on wild resources, ensuring standardized quality and traceability of raw materials. In-situ and ex-situ conservation strategies, such as establishing Medicinal Plant Conservation Areas (MPCAs), seed banks, and tissue culture labs, are vital for safeguarding genetic diversity and regenerating endangered species. Regulatory frameworks must be strengthened, and periodic monitoring of plant populations and supply chains must be enforced. Community participation supported by benefit-sharing models motivates sustainable practices while securing livelihoods. Scientific innovations, including phytochemical standardization and biotechnological production of active compounds, further reduce pressure on wild populations. Integrating these strategies with traditional knowledge will ensure the sustainable use of medicinal plants, securing the future of Ayurveda and its continued contribution to global health care.

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