Biocultural dimensions of endangered medicinal flora: Community knowledge, gender roles, and governance in the Pakistani Himalayas

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Research

Abstract

Background: The mountain communities of the Pakistani Himalayas possess rich ethnobotanical traditions centered around high-value medicinal plants such as *Trillium govanianum* Wall. ex D. Don, *Dactylorhiza hatagirea* (D. Don) Soo, *Aconitum heterophyllum* Wall. ex Royle, and *Podophyllum hexandrum* Royle. These species play vital roles in local health care, livelihoods, and cultural identity. Despite this significance, systematic documentation is limited, posing risks to both traditional ecological knowledge (TEK) and biodiversity conservation.

Methods: From May 2024 to June 2025, an ethnobotanical survey was conducted across 24 mountain villages in Azad Jammu and Kashmir (Neelum, Leepa, and Hattian) and Khyber Pakhtunkhwa (Kaghan, Siran, and Galliat), at altitudes of 2,000-3,300 m. Using purposive and snowball sampling, A total of 120 respondents were engaged, including 98 household respondents and 22 key informants (10 forestry officers and 12 herbal traders) interviews were completed. Field observations and gender-segregated focus groups provided complementary insights into plant use, harvesting practices, and trade. Voucher

specimens were authenticated at the Pakistan Museum of Natural History. Data were analyzed thematically for TEK, gender, and governance dynamics, alongside quantitative summaries of market dependence.

Results: Community governance structures revealed extensive reliance on TEK for species identification, collection timing, and sustainable use. However, weak institutional enforcement and rising market demand threaten traditional management systems.

Conclusions: Integrating indigenous knowledge and women's participation into formal conservation and livelihood policies is essential for safeguarding both cultural resilience and Himalayan biodiversity.

Keywords: Ethnobotany; Traditional Ecological Knowledge (TEK); *Trillium govanianum; Dactylorhiza hatagirea; Aconitum heterophyllum; Podophyllum hexandrum;* Gender roles; Community governance; Biocultural conservation; Pakistani Himalayas

Background

The mountain communities of the Pakistani Himalayas sustain a rich ethnobotanical tradition centered on endangered medicinal flora, including *Trillium govanianum*, *Dactylorhiza hatagirea*, *Aconitum heterophyllum* and *Podophyllum hexandrum*. These species form part of an intricate biocultural complex where livelihoods, gendered labor, and local belief systems intersect. *T. govanianum*, commonly known as "**teen patra/nag chatri**," is among the most valuable Himalayan medicinal species. Its rhizomes are used in pharmaceutical formulations addressing reproductive health, inflammation, and hormonal balance (Khan *et al.* 2020, Verma *et al*. 2021, Hussain *et al*. 2023). The plant's slow growth rate and limited distribution make it ecologically vulnerable but commercially lucrative. The extraction of *T. govanianum* is deeply embedded in local livelihood structures, providing seasonal income during periods of agricultural inactivity (Sher *et al*. 2022). *D. hatagirea*, locally known as "**salam panja**," is a terrestrial orchid valued for its tuberous roots, which are used as an aphrodisiac, tonic, and restorative in traditional medicine (Gai *et al*. 2020, Shrivastava & Jain 2023). Containing bioactive compounds such as alkaloids, glycosides, and mucilage, it thrives in alpine meadows of the Western Himalayas but faces severe population decline due to overharvesting and habitat degradation (Kala 2015, Parajuli *et al.* 2025). Conservation measures, including in-situ protection and cultivation in controlled nurseries, have been proposed to ensure its sustainable use (Noor *et al.* 2024)

Likewise, *A. heterophyllum*, commonly known as "**patris**," is one of the most significant medicinal plants used in Unani and Ayurvedic systems (Bhat *et al*. 2015). Its roots are utilized for treating fever, diarrhea, and respiratory ailments due to the presence of diterpenoid alkaloids like atisine. Despite its therapeutic importance, *A. heterophyllum* is categorized as endangered because of excessive collection and limited natural regeneration. Ethnobotanical surveys indicate that local communities rely on this species for household remedies and income generation, highlighting the need for regulated harvesting and cultivation initiatives (Leão *et al*. 2017, Wani *et al*. 2021). Similarly *P.hexandrum*, also known as the Himalayan mayapple, locally known as " **bankakri**", is an important medicinal herb found in temperate and alpine zones of the Himalayas. Its rhizomes yield podophyllotoxin, a lignan used as a precursor for anticancer drugs like etoposide and teniposide (, Jin *et al.* 2022). In local practices, it is used to treat constipation, skin diseases, and warts. Overexploitation for pharmaceutical industries and loss of habitat have placed *P. hexandrum* under the endangered category (Kumar *et al*. 2020). Community-based cultivation and seed propagation efforts are suggested to ensure its conservation and economic utilization (Panday *et al.* 2013, Khanum & Ahmed 2019, Ahmed & Dhiman 2022).

Research found that households in regions of Himalayas like Uttarakhand, mid-western Nepal region and even Chitral region of Pakistan earned more than 50% of their seasonal income through medicinal plant collection (Joshi & Joshil*.* 2014, Phondani *et al.* 2016, Timmermann & Smith-Hall 2020, Shafi *et al.* 2025). Gender roles are critical while men often handle collection and transport, women contribute significantly to cleaning, drying, sorting, and packaging. Similar gendered labor dynamics have been documented across the Himalayan NTFP sector (Howard 2003, Sati 2013, Masoodi & Sundriyal 2020).

Income diversification and market participation remain constrained by lack of institutional support. Many collectors are unaware of market trends or government permit requirements, creating dependency on traders. This dependence limits local bargaining power and perpetuates cycles of poverty and resource depletion (Satyal *et al.* 2017, Bussmann *et al*. 2018).

Forestry departments and biodiversity agencies face persistent institutional challenges in regulating wild plant extraction. In Pakistan, the overlap between provincial and federal jurisdictions complicates management responsibilities. Identified

governance weaknesses include ambiguous institutional mandates and inadequate enforcement funding. Inconsistent monitoring, corruption, and poor coordination among departments further erode the effectiveness of policies. The absence of centralized digital databases further prevents long-term population tracking of threatened species (Aftab & Hickey 2010, ; Satyal *et al*. 2017, Gyeltshen *et al.* 2021, Imran 2025).

In contrast, co-management frameworks involving local communities have shown success in Nepal and Bhutan (Sharma *et al.* 2020, Gyeltshen *et al*. 2021) reported that community-based forest user groups in Nepal improved compliance with sustainable harvest practices while enhancing income security. Implementing similar participatory models in Pakistan could balance conservation and livelihood needs.

Traditional ecological knowledge (TEK) plays a vital role in conservation and sustainable harvesting. In Himalayan communities, plant knowledge is typically transmitted intergenerationally, with elder women acting as key custodians (Liu *et al*. 2023, Nosheen *et al*. 2024). Howard (2003) emphasized that women's ethnobotanical expertise globally underpins the continuity of traditional resource management systems. Documentation and integration of TEK into formal conservation policies remain inadequate. Strengthening these knowledge systems through participatory conservation education could enhance both cultural preservation and biodiversity management (Gyeltshen *et al.* 2021).

Despite growing attention to pharmacological potential of each of these herbs, there is limited empirical research addressing its socio-economic and institutional dimensions in Pakistan. Existing studies have largely focused on distribution ecology, overlooking trade structures, gendered labor, and governance inefficiencies (Ferrari & Khan 2018, Shafi *et al.* 2025).

Conceptual framework

This study is situated within a biocultural conservation framework, which conceptualizes medicinal plants as components of coupled social-ecological systems in which biodiversity, cultural knowledge, livelihoods, and institutions are deeply interlinked. From this perspective, conservation outcomes cannot be understood solely through ecological vulnerability, but must be examined in relation to social organization, knowledge systems, and governance structures.

The study further draws on gendered knowledge systems, recognizing that access to ecological knowledge, resource use, and benefit sharing is structured by gender relations, with women often serving as primary custodians of traditional ecological knowledge (TEK) while remaining marginalized in formal decision-making processes (Howard 2003, Nosheen *et al.* 2024). In parallel, common-pool resource governance theory provides a lens to examine medicinal plants as shared resources managed through overlapping informal norms and formal regulations, where weak institutions and market pressures can undermine sustainability. Integrating these perspectives allows the study to analytically explore how traditional knowledge, gender relations, and governance arrangements jointly shape medicinal plant use and conservation in the Pakistani Himalayas.

Despite increasing attention to the pharmacological potential of Himalayan medicinal plants, empirical research addressing their socio-economic and institutional dimensions in Pakistan remains limited. Existing studies have largely focused on distribution ecology, with insufficient attention to trade structures, gendered labor, and governance inefficiencies (Ferrari & Khan 2018, Shafi *et al.* 2025).

In light of the ecological vulnerability of high-value medicinal plants and the socio-economic dependence of Himalayan communities on their extraction, this study addresses the following research questions:

(1) How is traditional ecological knowledge (TEK) related to the identification, harvesting practices, and cultural significance of *Trillium govanianum*, *Dactylorhiza hatagirea*, *Aconitum heterophyllum*, and *Podophyllum hexandrum* in the Pakistani Himalayas?
(2) What roles do gendered divisions of labor play in knowledge transmission, extraction, processing, and commercialization of these medicinal species?
(3) To what extent do households depend economically on the seasonal collection of endangered medicinal plants, and how is this dependence shaped by market structures and access to institutional support?
(4) What institutional and governance constraints affect sustainable harvesting and conservation, and how do these interact with existing community-based norms and informal management practices?

This study contributes by empirically examining the interlinkages between economic reliance, governance challenges, and conservation dynamics through structured household surveys, institutional interviews, and field observations. The findings aim to inform policy interventions that integrate local livelihoods within biodiversity conservation frameworks

Materials and Methods

Study Area

The study was conducted between May 2024 and June 2025 in the western Himalayan region of Pakistan, encompassing selected areas of Azad Jammu and Kashmir (AJK) and Khyber Pakhtunkhwa (KP). Geographically, the region extends from 33° to 36° N latitude and 73° to 75° E longitude, with elevations ranging from 2,000 to 3,300 m above sea level. The area experiences a moist temperate climate, characterized by cold winters and mild summers, with mean annual temperatures ranging from 10 °C to 18 °C and annual precipitation exceeding 1,500 mm. The total study area covers approximately 14,646 km², supporting a population of about 0.05 million people, within a broader regional context of 83,900 km² inhabited by nearly 10 million individuals (Encyclopaedia Britannica 2025) . The landscape is dominated by moist temperate forests, terraced agricultural systems, and community-managed forest resources, which together form the foundation of local livelihoods and biocultural traditions.

The biocultural study was carried out across 24 villages situated in six major valleys Neelum, Leepa, and Hattian in AJK, and Kaghan, Siran, and Galliat in KP (Fig. 1, Table 1). Villages were selected to represent the ecological and cultural diversity of the western Himalayas, including differences in altitude, forest types, and traditional livelihood practices. Selection prioritized communities actively engaged in medicinal plant use to ensure coverage of local knowledge and practice. These valleys represent the ecological and cultural diversity of the Pakistani Himalayas, where indigenous communities maintain deep-rooted knowledge of medicinal flora, shaped by gender roles, community governance, and traditional ecological practices.

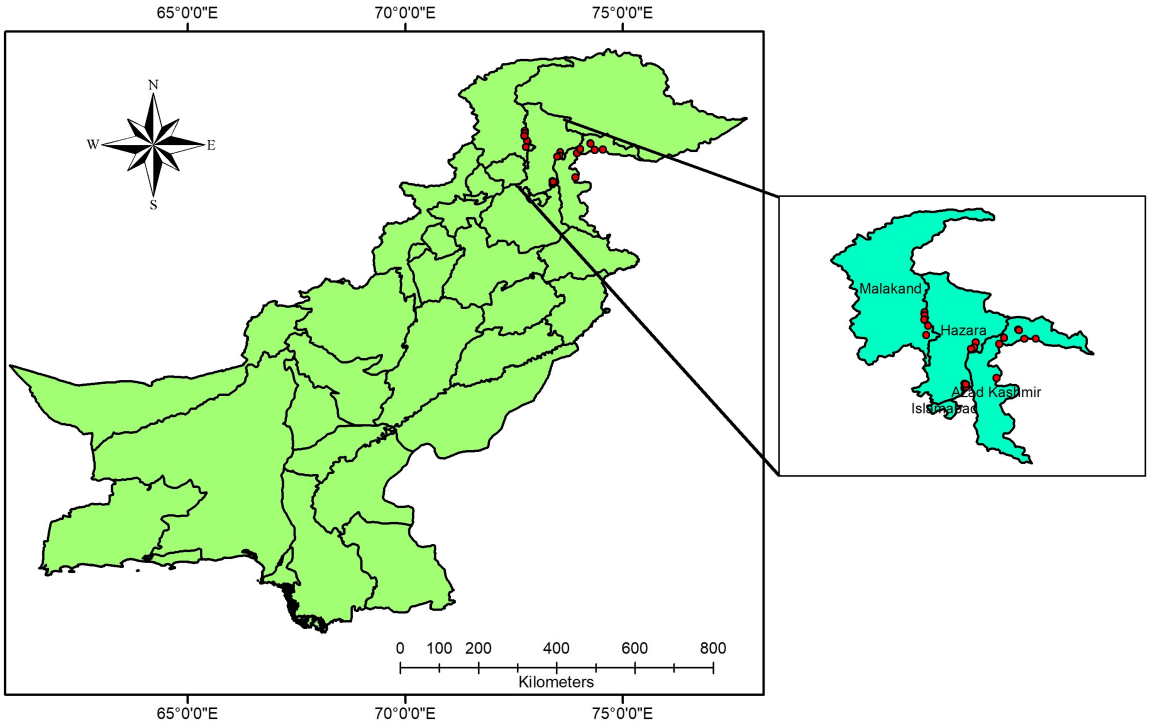

Figure 1 . Map of Pakistan showing the study region (Western Himalayas) and the specific sampling sites (inset).

Ethnographic Methods

A total of 120 respondents were engaged, including 98 community members (42 women, 56 men) and 22 key informants (10 forestry, 12 herbal traders) through semi-structured interviews using purposive and snowball sampling. This combination of purposive and snowball sampling allowed targeting of knowledgeable community members while also capturing additional key informants recommended by participants, ensuring comprehensive documentation of ethnobotanical knowledge, gender-specific roles, and governance practices. Questions addressed local names, uses, collection seasons, trade, and

conservation perceptions (Annex I). The guide included key sections on: (i) demographic and household information, (ii) dependence on medicinal plants and NTFPs, (iii) traditional knowledge and harvesting practices, (iv) institutional and market dynamics, and (v) perceptions and conservation awareness. Open-ended questions were included to capture additional qualitative insights. Focus groups were also held separately for women and men to understand gendered labor divisions. Field observations documented plant collection, drying, and sale processes.

Ethical approval: The research was conducted under institutional guidelines of the Pakistan Museum of Natural History and adhered to the International Society of Ethnobiology Code of Ethics. Prior informed consent, written or verbal was obtained from all participants. Access to biological resources, including the collection of plant specimens, was conducted with proper permission and in compliance with the Nagoya Protocol on Access and Benefit Sharing and relevant national regulations. Benefit-sharing was ensured through deposition of voucher specimens in the PMNH Herbarium (accession numbers PMNH-47160 to PMNH-475069) and dissemination of study findings to the local communities.

Table 1. Geographic coverage, demographic characteristics, and respondent distribution of the study sites.

Region	**Districts and Valleys**	**No. of Villages**	**Total Area (km²)**	**Total Population**	**Male respondent**	**Female respondent**	**No. of Respondents**
Azad Jammu and Kashmir	Neelum, Leepa,	12	6,255	26,930	18	16	34
Khyber Pakhtunkhwa	Kaghan, Siran, Galliat	12	8,391.8	24,550	37	27	64
Additional Consultations	Forestry Officers	-	-	-	15	07	22
Total	**24 villages + 22 key**	**24**	**14,646.8**	**51,480**			**120**

Voucher Specimens

Voucher specimens for four main species were collected and deposited in the PMNH Herbarium under accession numbers (PMNH-47160 to PMNH-475069), identified by Dr Rizwana Khanum.

Data Analysis

Thematic coding was employed to analyze qualitative data on traditional ecological knowledge (TEK), gender roles, and governance structures following Braun and Clarke (2006), Creswell *et al.* 2018 and Guest *et al*. (2012). Quantitative data, including household income and market values, were summarized using descriptive statistics. Gender-based differences in labor roles (plant identification, collection, processing, and marketing) and access to direct monetary benefits were assessed using chi-square tests of independence applied to household-level participation data (N = 98). Statistical significance was evaluated at $p < 0.05$.

The ethnomedicinal importance of each species was evaluated using the Relative Frequency of Citation (RFC) from community respondents only (N=98, excluding 22 key informants) to reflect local cultural knowledge, (Vitalini *et al.* 2013).

Results

All tables and findings presented in this section (Tables 2-5) are derived exclusively from primary data collected during fieldwork conducted in 24 villages and through key informant interviews between May 2024 and June 2025.

Cultural Knowledge and Species Recognition

Results from this study indicate that ethnobotanical knowledge of endangered medicinal plants in the surveyed communities was primarily transmitted through oral and intergenerational pathways Among the four local species *T.govanianum* "teen-patra" reported by respondents for healing and postpartum recovery rituals; *D. hatagirea* "salam panja" for tonic and aphrodisiac purposes,; *A. heterophyllum* "patris" serves as a common fever remedy; and *P. hexandrum* "bankakri" is believed to provide protection against snakebites. Recognition of these plants depends heavily on morphological and ecological cues such as the 'three-leaf shadow' of Trillium or the 'split-hand root' of *Dactylorhiza* (Supplementary File 1).

Gendered Labor and Knowledge Transmission

Gender-segregated interviews and focus group discussions revealed clear divisions of labor in medicinal plant collection and processing. Women were the primary participants in plant identification (80%) and post-harvest processing activities such as drying and cleaning (90%). Collection activities were shared, with women accounting for 60% and men 40% of participation. In contrast, marketing and sale were predominantly managed by men (85%), who interacted directly with traders and brokers.

Knowledge sources differed by activity. Plant identification knowledge was mainly acquired from elder female relatives, while collection skills were learned jointly by men and women during field activities. These patterns are summarized in Table 2.
Further proportional participation by activity, chi-square tests conducted on household-level data (Supplementary File 1) indicated a significant association between gender and labor roles in plant identification, post-harvest processing, and marketing ($p < 0.01$), while collection activities showed no significant gender bias ($p > 0.05$).

Table 2 Gendered distribution of labor roles in medicinal plant identification, collection, processing, and marketing (n = 98 households, Chi-square test (χ^2) indicates association between gender and participation; percentages are shown in parentheses) .

Activity	**Knowledge Source**	**Women n (%)**	**Men n(%)**	**χ^2 (p-value)**
Plant	Elder female relatives	78 (80%)	20 (20%)	p < 0.01*
Collection	Learned jointly by man	59 (60%)	39 (40%)	p = ns
Drying and	Domestic task	88 (90%)	10 (10%)	p < 0.001*
Marketing	Traders and brokers	15 (15%)	83 (85%)	p < 0.001*

χ^2 = Chi-square statistic; p-value indicates significance of association between gender and participation.
*p < 0.05 indicates statistically significant association.
ns = not significant

Economic Dependence on Extraction

Interviews with 98 households revealed that 85 percent relied on seasonal harvesting of these four herbs and associated species for supplemental income. Reported earnings ranged from PKR 15,000 to PKR 55,000 per household per season, with informal market prices averaging PKR 6,800 per kilogram. Household dependence on medicinal plant income accounted for roughly 32 percent of annual revenue.

Processing largely occurred at the household level (82 percent), reflecting limited access to cooperative processing or drying facilities. Despite significant female involvement over 60 percent of collection, drying, and cleaning tasks only 10 percent of women reported receiving direct monetary compensation. A chi-square test indicated a significant gender-based disparity in access to cash income from medicinal plant sales, with men significantly more likely than women to receive direct payment (χ^2, $p < 0.001$).

Table 3. . Household-level economic dependence on medicinal plant extraction and gendered access to income (n = 98 households) (Percentages indicate proportion of households; p-value from chi-square test shows gender disparity in receipt of direct payment).

Variable	**Observation/Value**
Total households interviewed	98
Households dependent on plant income	83 (85%)
Seasonal income range per household	PKR 15,000 - 55,000
Average market price (per kg)	PKR 6,800
Contribution to annual household income	32%
Women involved in extraction tasks	60% of households (digging, drying, cleaning)
Women receiving direct payment	10%
Knowledge transmission method	70% via elder female relatives
Plant processed at household level	82%
Gender difference in receipt of payment	**p < 0.001***

χ^2 = Chi-square statistic; *p-value indicates significance of gender disparity in receiving payment.

Institutional and Customary Governance

Institutional constraints were documented based on key informant interviews and administrative records across surveyed districts and collection zones. Formal permitting remains weak, with lack of formal communication channels in 75 % of localities. Forestry officers acknowledged overlapping mandates and limited enforcement. Nonetheless, local informal norms such as prohibiting harvest before flowering or avoiding total rhizome extraction demonstrate ecological sensitivity. Community elders act as mediators in disputes over collection rights.

Table 4. Institutional and governance constraints affecting medicinal plant conservation in the study area.

Issue Category	**Observed Challenge**
Permit issuance	75% of collection zones lacked permits in 2024
Staffing	Inadequate forest staff in >60% of surveyed districts
Budgetary resources	Delayed or absent operational funds for monitoring
Legal enforcement	Weak penalty system and limited mobility of officers
Inter-agency coordination	Ambiguity between provincial and federal roles
Community engagement	No formal communication channels in 80% of localities
Data management	Absence of species-level extraction records

Percentages indicate the proportion of districts or localities experiencing each challenge

Biocultural significance analysis

Relative Frequency of Citation (RFC) analysis indicated that *Trillium govanianum* "**teen patra"** has the highest RFC value (0.82), followed by *Dactylorhiza hatagirea* "**salam panja"** with an RFC value of 0.71, *Aconitum heterophyllum* "**patris"** with an RFC value of 0.64, and *Podophyllum hexandrum* "**bankakri"** with the lowest RFC value (0.45). RFC values reflect the proportion of respondents citing each species during household surveys and key informant interviews.

Table 5. Relative Frequency of Citation (RFC) and market value of key medicinal plant species (n = 98). (Relative Frequency of Citation (RFC) proportion of respondents citing each species; FC = number of respondents citing the species; mean market price is in PKR per kilogram).

Species	**Local Name**	**No. of Citations (FC)**	**RFC Value**	**Mean Market Price (PKR/kg)**
Trillium govanianum	**teen-patra**	80	0.82	6,800
Dactylorhiza hatagirea	**salam panja**	70	0.71	7,200
Aconitum heterophyllum	**patris**	63	0.64	5,900
Podophyllum hexandrum	**bankakri**	44	0.45	6,300

RFC significance was assessed using chi-square tests in Table 2 to examine gendered participation in species use.

Discussion

The findings from this study underscore the biocultural dimensions of medicinal plant use in the Pakistani Himalayas, where traditional ecological knowledge (TEK), gendered labor roles, and governance structures intersect in shaping the sustainable use and conservation of endangered medicinal flora. Our primary data demonstrate that TEK, gendered labor roles, and local governance intersect to shape the sustainable use and conservation of endangered medicinal plants in the Pakistani Himalayas. The communities in Azad Jammu and Kashmir (AJK) and Khyber Pakhtunkhwa (KP) demonstrate a rich ethnobotanical tradition, with species such *as Trillium govanianum* "**teen patra"**, *Dactylorhiza hatagirea* "**salam panja"**, *Aconitum heterophyllum* "**patris"**, and *Podophyllum hexandrum* "**bankakri"** playing a crucial role in both cultural identity and economic resilience (Khan et al. 2020, Verma *et al*. 2021). The household survey results that *Trillium govanianum* (RFC = 0.82) and *Dactylorhiza hatagirea* (RFC = 0.71) were the most frequently cited species by respondents (Table 5), reflecting their high cultural prominence and continued economic importance in these communities. TEK serves as an adaptive management system, finely tuned to ecological cues and passed down intergenerationally, primarily through elder women, who are the key custodians of this knowledge (Liu *et al*. 2023, Nosheen *et al.* 2024). Survey and focus group results (Table 2), indicate that women carried out of 80% of plant identification and 90% of post-harvest processing tasks, highlighting their central role in maintaining TEK. These patterns extend beyond the Pakistani Himalayas and reflect globally observed dynamics in ethnobotanical systems, where gender-differentiated knowledge and labor underpin the use and conservation

of medicinal plants. Across mountain and indigenous landscapes worldwide, women are consistently recognized as primary custodians of household healthcare knowledge and biodiversity management (Chamara *et al*. 2021, Mondal *et al.* 2025), yet remain structurally marginalized from formal decision-making and benefit-sharing mechanisms. Framing these findings within international debates on biocultural conservation highlights the need to recognize traditional ecological knowledge not only as a cultural asset, but as a governance-relevant system critical for sustainable resource management. Such perspectives align with global discussions under the Convention on Biological Diversity and the Nagoya Protocol, which emphasize equitable access-and-benefit-sharing and the inclusion of knowledge holders in conservation planning (Da Costa *et al*. 2021, Gomes *et al.* 2024, Mata *et al*. 2024). Taken together, these findings position the Pakistani Himalayas as a representative case within global biocultural conservation debates, demonstrating how gendered knowledge systems, livelihood dependence, and institutional arrangements jointly influence conservation outcomes across mountain and indigenous landscapes worldwide.

However, while women hold the most refined knowledge about these plants, they remain excluded from market decisions and resource management roles, reflecting persistent failures in the implementation of Access and Benefit-Sharing (ABS) mechanisms and resulting in significant economic inequities. Household survey data (Table 3) indicate that while 85% of households depended on medicinal plant income, only 10% of women involved in extraction received direct payment, illustrating a significant gender-based disparity (χ^2, $p < 0.001$). These patterns in the Himalayas are consistent with findings from neighboring regions where women contribute significantly (over 60%) to tasks such as plant collection, drying, and cleaning, yet only a small percentage (15%) receive direct monetary compensation for their labor (Ahmad & Habib 2014, Shinwari *et al.* 2017, Ganie *et al*. 2019, Kumar 2022), underscoring the importance of integrating equity into conservation frameworks. Such lucrative returns from medicinal plant trade have incentivized unsustainable harvesting practices, often occurring outside regulatory oversight. These dynamics have also been observed in transboundary markets in Nepal and India, where commercial demand has outpaced ecological recovery (Thapa *et al*. 2021, Chauhan *et al.* 2018).

At the global policy level, similar tensions between conservation, commercialization, and equity have been widely debated in relation to biocultural conservation and ABS governance framework. Building on these global debates, at the national level, Pakistan's export of over 10,650 tons of medicinal and aromatic plants, valued at US$ 9.81 million, underscores both the economic significance and ecological vulnerability of wild flora in high-altitude ecosystems already stressed by land-use changes and climate instability (Khanum *et al*. 2013, Aili *et al.* 2017, Riaz *et al*. 2022). Institutional interviews highlighted severe regulatory gaps, with 75% of mapped collection zones operating without formal permits in 2024. Key informant interviews and administrative records (Table 4) revealed additional challenges included inadequate staffing (>60% of districts), weak legal enforcement, absence of species-level extraction records, and limited community engagement (no formal communication channels in 75% of localities), underscoring the need for participatory governance mechanisms as indicated by recent studies (Kometa *et al*. 2026). Forest officials cited limited budgets, jurisdictional overlaps, and a lack of technical training as key barriers to enforcement issues widely documented in other decentralized forest governance systems (Aftab & Hickey 2010, Khan *et al*. 2020, Ji *et al*. 2024).

Community members reported minimal consultation, limited awareness of legal harvesting frameworks, and a disconnect between regulatory authorities and local realities. These findings align with broader critiques of top-down conservation approaches in low- and middle-income countries which often fail due to insufficient stakeholder inclusion and institutional misalignment (Khan 2018, Trotter *et al*. 2022). Such patterns mirror challenges reported across the Global South, reinforcing the relevance of this case study to international discussions on inclusive conservation governance, gender equity, and socially just ABS implementation. Taken together, the findings point to a triple challenge: ecological sensitivity, institutional fragmentation, and economic vulnerability. Blanket bans or exclusionary conservation strategies are unlikely to succeed in this context. Without addressing the financial reliance of rural populations on high-value species, enforcement efforts may simply drive harvesting further underground. The exclusion of women from benefit-sharing and decision-making structures further weakens community engagement and undermines long-term sustainability (Bayeh 2016, De Ridder *et al.* 2023, Rahmania *et al*. 2025.

This research supports growing calls for integrated, multiscalar conservation strategies in Himalaya's regions (Molho *et al*. 2020, Eriksen *et al*. 2021). Combining climate projections with field-based socio-economic data allows for more precise and socially responsive policy recommendations (Landreau *et al*. 2021). In mountain systems where ecological and economic systems are tightly interlinked, static protectionist approaches must evolve into adaptive, participatory frameworks (Palau & & Claramunt-López 2024). Future interventions should prioritize the restoration of climatically stable habitats, formalize sustainable harvest schemes, and strengthen co-management models with clear roles for women and marginalized groups

(Shah *et al*. 2013, Nosheen *et al.* 2024). Doing so would help reconcile biodiversity goals with rural development imperatives, ensuring that conservation is not only ecologically sound but also socially just and economically viable (Chaigneau *et al*. 2019, Wang *et al*. 2024).

Conclusion

The endangered medicinal flora of the Pakistani Himalayas, including species such as *Trillium govanianum, Dactylorhiza hatagirea, Aconitum heterophyllum, and Podophyllum hexandrum*, underscores the deep interconnection between biocultural knowledge, gender roles, and governance. These species are not only vital for local medicinal use but are embedded in the cultural practices and livelihoods of mountain communities. Protecting these plants requires strengthening local governance systems, empowering women as knowledge custodians, and integrating traditional ecological knowledge (TEK) into formal conservation policies. A biocultural conservation framework, which acknowledges the role of community knowledge and gendered labor dynamics, offers a pathway for more participatory, equitable, and sustainable resource management in these fragile mountain ecosystems, ensuring the long-term survival of both the species and the cultures that depend on them.

Declarations

Ethics approval: Formal institutional ethical approval was not required; however, the study adhered to PMNH guidelines and the International Society of Ethnobiology Code of Ethics, as it did not involve clinical procedures or vulnerable populations. However, the research adhered to established ethical standards for ethnobotanical studies. Prior informed consent was obtained verbally from all participants, with the aims of the study clearly explained to them. Participation was voluntary, and all data collected were treated with confidentiality and respect for local cultural norms and customs. While women were allowed to contribute and their data was quoted, their images were not collected or used due to local cultural norms and sensitivities.

Consent for publication: Not applicable

Data Availability

Anonymized interview data and associated photographs are available from the Pakistan Museum of Natural History upon request for non-commercial research.

Funding: part of research was funded through MBZ species conservation fund.

Conflict of interest statement: We declare that we have no conflict of interest.

Author contributions

Rizwana Khanum conceptualized the study, led the methodology, supervised the project, and contributed to writing the original draft and review. Ayesha Noor contributed to data curation, formal analysis, and writing. Amir Hussain was responsible for data curation, field data collection. Rasheed Hussain, Sardar Akrum, Sidra Qayum, Rizwan Ahmed Kazmi, Sardar Farhad Ali, Shehryar Khan, and Muhammad Hanif facilitated data collection in the field, supported in concerned forest villages, and assisted with data interpretation. Syed Munir and Sabih ul Hassan contributed to the methodology and data collection in the field

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