Wild Edible and Medicinal Plants: A Case Study in Yagang and Gengu Villages, Darla Gewog, Chukha Bhutan for Community Perceptions, Gendered Roles, and Pathways for Sustainable Management.

Authors.

Karma Orong[1], Sangay Dorjee[2], Wangdi[3]

[1]Ugyen Wangchuck Institute for Forestry Research and Training, Bhutan

[23]Forest Resources Planning and Management Division, Bhutan

Karma Orong: https://orcid.org/0000-0002-8718-6121

Sangay Dorjee: https://orcid.org/0009-0004-9566-9133

Wangdi: https://orcid.org/0009-0007-7726-1742

Corresponding author: Sangay Dorjee; **Email:** sangayjee12@gmail.com

Abstract

Wild edible and medicinal plants (WEMPs) play a critical role in the livelihoods of forest-adjacent communities, yet integrated village-level evidence from Bhutan remains limited. This study examined WEMP diversity, household dependence, gendered roles, knowledge transmission, and perceived threats in Yagang and Gengu villages, Darla Gewog, Chhukha District. Data were collected through semi-structured interviews and field-based plant-use records, yielding 58 valid respondent records and 101 plant records. A total of 101 species were documented, including 48 medicinal-only, 38 edible-only, and 15 dual-use species. Household reliance on WEMPs was nearly universal (98.3%), primarily for medicine (96.5%), food (80.7%), and nutrition (80.7%), with minimal contribution to income (1.8%). Knowledge was predominantly transmitted through grandparents (98.2%), indicating strong intergenerational continuity. Gendered roles were differentiated, with men more frequently involved in plant collection and women in preparation and storage.Most respondents perceived a decline in WEMP populations (94.1%), attributing this to interrelated pressures such as cattle grazing, unsustainable harvesting, and land-use change. Despite this, there was strong support for domestication and integration of WEMPs into agroforestry systems. These findings are based on perception-driven data rather than direct ecological measurements and are specific to the two study villages. The results highlight the importance of localized,

gender-responsive, and agroforestry-based strategies to sustain WEMP systems while maintaining their ecological and socio-cultural functions.

Keywords: agroforestry, ethnobotany, gender roles, medicinal plants, wild edible plants

1. Introduction

Wild edible and medicinal plants (WEMPs) are integral to rural livelihood systems, contributing to nutrition, primary healthcare, cultural practices, and seasonal income (Howard, 2003; Turner et al., 2011; Leakey, 2012; Zehra et al., 2022). In forest-adjacent and agroforestry landscapes, WEMPs function as routine foods, household remedies, and safety nets during periods of shortage, illness, or market instability. Their role is therefore both ecological and social, linking biodiversity, household resilience, and indigenous knowledge systems. This multifunctional importance is increasingly recognized in global assessments, which highlight wild and forest-derived foods as critical to resilient food systems and human well-being (Ickowitz et al., 2014; Powell et al., 2015; IPBES, 2019). Agroforestry systems further strengthen these linkages by enhancing soil fertility and ecosystem resilience through processes such as litter decomposition and nutrient cycling, which regulate long-term productivity in forest–farm landscapes (Dorjee & Orong, 2026).

Across the Himalayas and similar rural contexts, WEMPs are shaped by forest access, customary practices, gendered labour, and intergenerational knowledge transfer (Howard, 2003; Turner et al., 2011; Bussmann et al., 2018; Zehra et al., 2022). Gender-specific roles influence plant collection, processing, storage, and commercialization, affecting both knowledge distribution and conservation outcomes (Howard, 2003; Alqethami et al., 2020). Cross-cultural evidence confirms that such gendered systems are central to biodiversity management and knowledge continuity (Pfeiffer and Butz, 2005; Chao et al., 2025). However, WEMPs face increasing pressures from land-use change, overharvesting, commercialization, and climate variability, threatening both species availability and traditional knowledge (Kala, 2012; Bussmann et al., 2018).

In Bhutan, institutions such as the National Biodiversity Center (NBC) and the Department of Forests and Park Services (DoFPS) emphasize plant conservation and sustainable forest management (NBC, 2009; DoFPS, 2022). However, these frameworks provide limited village-level evidence on WEMP use, knowledge transmission, and community perceptions of threats and management. Existing studies largely remain regional or global in scope, with few grounded case

studies from Bhutan. This gap reflects broader global trends, where cultural change, land-use intensification, and declining reliance on wild resources contribute to the erosion of ethnobotanical knowledge (Aswani et al., 2018; Schulp et al., 2014).

The literature highlights four key dimensions: WEMPs support food security and dietary diversity under seasonal or unreliable production (Turner et al., 2011; Leakey, 2012); medicinal uses address gaps in formal healthcare access (Kala, 2012; Bussmann et al., 2018); gendered labour structures knowledge systems and conservation outcomes (Howard, 2003; Alqethami et al., 2020); and sustainable management increasingly integrates WEMPs into agroforestry, domestication, and community-based conservation approaches (Leakey, 2012; Zehra et al., 2022).

No single study in Bhutan has yet integrated species diversity, household roles, gendered labour, knowledge transmission, perceived threats, and management options at the village level. Without such evidence, policy and extension remain generalized and insufficiently grounded. Addressing this gap requires linking local empirical data with broader sustainability and food-system frameworks that connect biodiversity conservation with rural livelihoods (IPBES, 2019; Jamnadass et al., 2013). This study examines Yagang and Gengu as a context-specific case, providing grounded insights without overgeneralization.

1.2 Study objectives

This study had four objectives:

1. To document the diversity and principal use categories of WEMPs in Yagang and Gengu villages.
2. To assess household dependence on WEMPs for food, nutrition, medicine, income, and related livelihood functions.
3. To examine gendered household roles and indigenous knowledge transmission in relation to WEMP collection, preparation, processing, and domestication.
4. To analyze community perceptions of availability, population change, threats, and opportunities for sustainable management.

2. Materials and Methods

2.1 Study area

The study was conducted in Yagang and Gengu villages under Darla Gewog in Chhukha District, Bhutan (Figure 1). The two villages lie between 26° 49′ 14.32″ and 26° 50′ 14.70″ N, and between

89° 33′ 33.33″ and 89° 34′ 54.3″ E, at elevations ranging from 776 to 1516 m above sea level. The area falls within Bhutan's humid subtropical agroecological zone and is dominated by subtropical broadleaved forest interspersed with agricultural land and community-managed forest patches (NBC, 2009; DoFPS, 2022).

Both villages were selected because they combine forest access, farming livelihoods, and ongoing reliance on local plant resources for food and health. Households from Ngalop, Gurung, Chhetri, Sanyasi, Bhujel, and Monger communities are represented, making the area a useful context for examining how ecological access and social organization together shape the utilization and management of WEMPs

2.2 Research design and case-study framing

A descriptive, exploratory mixed-method case-study design was used (Lehmann, 2010; Bernard, 2017). Semi-structured interviews provided quantitative data on respondent backgrounds, household use patterns, and management preferences, while open-ended questions and field notes added interpretive depth. Given the purposive, two-village sampling frame, the findings speak to conditions in Yagang and Gengu rather than to rural Bhutan more broadly. The archived data covers reported practices and perceptions; it contains neither direct ecological measurements nor market-survey data.

2.3 Sampling and participants

Respondents were selected purposively: only adults with direct experience of identifying, collecting, consuming, processing, or managing WEMPs were enrolled. All participants were permanent residents of Yagang or Gengu and were engaged in farming or other livelihoods connected to local forest resources. One row in the raw workbook was a data-entry artefact and was removed; the final sample comprised 58 valid records.

Of the 58 respondents, 32 were from Gengu and 26 from Yagang. Men accounted for 39 respondents (67.2%) and women for 19 (32.8%). The sample was concentrated in the 31–40-year (29.3%), 51–60-year (36.2%), and more than 60-year (24.1%) age groups. Most respondents reported no formal education (86.2%), and farming was the main income source for 36 respondents (62.1%), while 22 (37.9%) reported off-farm income.

2.4 Data collection

Field data were collected between 4 May and 30 May 2023 using a semi-structured questionnaire grounded in established ethnobotanical interviewing methods (Martin, 1995; Cotton, 1996; Alexiades, 1996; Fakchich & Elachouri, 2023). The questionnaire covered four domains: (i) respondent familiarity with WEMPs and plant-use records, (ii) household dependence on WEMPs for food, nutrition, medicine, and income, (iii) knowledge transmission and household responsibilities by gender, and (iv) community perceptions of availability, threats, propagation, and domestication.

All interviews were conducted in the local dialect to minimize misunderstanding and allow respondents to describe plant uses in their own terms. Plant names given by respondents were checked against available volumes of the Flora of Bhutan and confirmed through field observation. For each species, the plant part used, preparation or processing method, mode of administration, and dietary or medicinal purpose were recorded. The complete species inventory, including plant parts, preparation methods, and associated ethnobotanical uses, is provided in Supplementary Table S1. No herbarium specimens were collected or deposited, and no independent taxonomic verification was carried out; the species list reflects field-based identifications rather than a formally verified floristic inventory. Ethical practice followed guidelines set by the American Anthropological Association (2012) and the International Society of Ethnobiology (2006). Data were collected by the lead author with the assistance of trained field assistants. All enumerators were briefed on the questionnaire, interview protocols, and ethical considerations prior to fieldwork.

2.5 Variable construction and analysis

The archived social and plant files were cleaned before analysis to standardize categorical labels, remove coded prefixes from response values, harmonize multi-response items, and rebuild the plant inventory with a proper header structure. The cleaned datasets were then saved as analysis-ready CSV files and used for all tables and figures in the revised manuscript.

The plant inventory was summarized by use group (edible only, medicinal only, or dual use), plant part used, preparation/processing mode, and route of administration. Household survey variables were summarized using counts and percentages. For multi-response items such as knowledge sources, dependence reasons, and propagation methods, frequencies were calculated

across the number of respondents who answered the item. Figures were generated from the cleaned datasets in Python using pandas and matplotlib.

Perception items on threats and management options were treated as five-point agreement responses ranging from strongly agree to strongly disagree. Because some of these items had non-response, valid sample sizes are reported for each analysis. Fisher's exact tests were used for selected 2 x 2 comparisons where cell counts were small: village versus reported utilization decrease, village versus male-led collection, income source versus female-led preparation, income source versus female-led processing and storage, and income source versus male-led planting/domestication. Open-ended responses were reviewed thematically and used to interpret the survey patterns, especially for knowledge transmission, perceived decline, and management opportunities.

The archived dataset does not preserve respondent-by-species citation frequencies, ailment-specific use reports, or repeated use-report structure in a form suitable for quantitative ethnobotanical indices. Accordingly, indices such as use value (UV), relative frequency of citation (RFC), cultural importance (CI), and informant consensus factor (ICF) were not calculated. These indices would require, at minimum, respondent-level species citation matrices and, for ICF, ailment-category use reports for each cited species.

3. Results and Discussion

3.1 Respondent profile and diversity of WEMPs

Table 1 and Figure 2 summarize the respondent profile. The sample covered both villages, both genders, and a broad age range, but it was dominated by middle-aged and older respondents with strong experience in farming and forest-based livelihoods. No respondent fell in the 41-50 age category, which is why that class does not appear in the frequency summary. The inventory covered 101 WEMP species. A full species-level breakdown is provided in Supplementary Table S1.

Of these, 48 (47.5%) had recorded medicinal uses only, 38 (37.6%) were edible only, and 15 (14.9%) served both purposes. Counting dual-use taxa in both columns gives 63 medicinal and 53 edible species in total. Medicinal-only taxa were therefore the single largest use group. Shoots were the most frequently cited plant part (23 records), ahead of fruits (17), seeds (15), and leaves (13), after harmonizing synonymous labels in the archived plant file. Oral administration

accounted for 77 species (76.2%); oral-and-topical use was recorded for 11 species (10.9%), topical for 10 (9.9%), and inhalation-based use for three (3.0%). Figure 3 illustrates the distribution across use groups and plant parts. The profile points to a repertoire built around direct consumption, herbal drinks, and home-prepared remedies rather than specialized clinical treatment. It also means the inventory includes both relatively low-impact plant parts such as fruits and leaves, and more extractive ones like roots and bark, a distinction worth keeping in mind when considering harvest sustainability.

3.2 Socio-economic importance of WEMPs

Household dependence on WEMPs was near-universal (Table 2). Fifty-seven of 58 respondents (98.3%) said their household relied on them. Most used WEMPs are occasional rather than daily (89.7% chose "sometimes"), which fits seasonal availability and opportunistic harvesting. Medicine stood out as the primary reason, cited by 55 of 57 respondents who answered this item (96.5%), followed by food and nutrients, each mentioned by 46 respondents (80.7%). Income generation was noted by just one person (1.8%). Figure 4 shows the dominance of medicine, food, and nutrition as livelihood functions. Within this dataset, WEMPs functioned mainly as subsistence and health resources; cash income was not a significant driver for most households. Similar patterns have been documented globally, where wild foods contribute significantly to dietary diversity but remain underrepresented in formal economic systems (Powell et al., 2015; Ickowitz et al., 2014).

The agreement items told the same story. Nearly all respondents agreed or strongly agreed that families depended on WEMPs (98.3%) and that they contributed to household nutrition (98.3%). Most also agreed WEMPs could provide income (94.8%), yet explicit income dependence was rare in the stated-use responses. Three-quarters of respondents (79.3%) rejected the idea that WEMPs were only for poorer households. The gap between confidence in income potential and near-absence of income as a stated current reason for use suggests respondents recognized commercial possibility but did not yet rely on it as a primary function of these plants.

3.3 Gendered roles and indigenous knowledge

WEMP knowledge moved mainly within families. Among the 56 respondents who answered the multi-source question, 55 (98.2%) named grandparents as a knowledge source; friends were cited second (35; 62.5%), personal experience third (5; 8.9%), and local healers last (2; 3.6%). When

asked who held WEMP knowledge within the household, 37 respondents (63.8%) pointed to men, 13 (22.4%) said both genders, and eight (13.8%) pointed to women. Figure 5 presents the task-based labour division and the perceived household knowledge holder together.

Task responsibilities were not evenly distributed (Table 3). Collection was most often male-led (41.4%) or shared (34.5%), with female-led collection reported by 24.1%. Among the 32 respondents who answered questions on preparation, processing, and storage, the pattern shifted: 53.1% reported female-led preparation and 65.6% said processing and storage were female-led. Planting and domestication were male-led in 53.1% of valid responses, with 34.4% describing them as shared.

The village comparison was notable. In Gengu, 21 of 32 respondents (65.6%) said collection was male-led; in Yagang the figure was 3 of 26 (11.5%), a difference well beyond chance (Fisher's exact $p < 0.001$; $n = 58$). Among farming households, female-led preparation and storage were far more common than among off-farm households (preparation: 14/18, 77.8% vs 3/14, 21.4%, Fisher's exact $p = 0.0036$; processing and storage: 16/18, 88.9% vs 5/14, 35.7%, Fisher's exact $p = 0.0028$). Off-farm households showed stronger male-led planting and domestication (12/14, 85.7% vs 5/18, 27.8%, Fisher's exact $p = 0.0016$). These are associations within a small purposive sample and should not be read as causal effects, but they show that WEMP task roles shifted with both village location and livelihood type.

3.4 Availability, population trend, and perceived threats

Respondents described current local WEMP availability as moderate in nearly all cases (56 of 58; 96.6%), with one person each describing stocks as abundant or rare. Yet 48 respondents (82.8%) said utilization had decreased. Among those who answered the population-trend item ($n = 51$), 48 (94.1%) agreed or strongly agreed that WEMP populations had declined. Community members also felt they could name the causes: 43 of 51 (84.3%) agreed or strongly agreed that local threats were identifiable. Neglect of traditional uses (60.8%) and changing lifestyles (64.7%) were each linked to declining use. The overall picture is of plants still present but perceived as less used and less secure than in the past.

Among the 46 respondents who completed the threat scale, population decline and cattle grazing tied for the highest agreement (84.8% each), followed by unsustainable harvesting and increasing harvesting pressure (82.6% each), loss of diversity (80.4%), tree felling (76.1%), and land-use change (73.9%). Pests, diseases and climate change were each flagged by 63.0%. Market

access (47.8%) and rising demand (39.1%) drew less concern (Table 4). Respondents did not see threats as separate problems: Figure 6 shows harvesting pressure, grazing, tree felling, and land-use change linked together in a broader pattern of decline. These findings record what respondents perceived, not what ecological surveys would confirm; abundance, regeneration rates, and harvest intensity were not measured in this study.

Perceptions of declining use differed by village. All 32 respondents in Gengu reported decreased utilization, compared with 16 of 26 in Yagang (61.5%), and this gap was statistically significant (Fisher's exact $p < 0.001$; $n = 58$). Perceived changes in WEMP populations were based on respondents' personal observations over time; no fixed recall period was imposed.

3.5 Opportunities for sustainable management

Support for domestication and agroforestry was near-unanimous (Table 5). This strong preference aligns with evidence that agroforestry systems enhance soil fertility and ecosystem resilience through gradual nutrient release from decomposing litter, which supports long-term productivity in Bhutanese landscapes (Dorjee & Orong, 2026). Fifty-seven respondents (98.3%) were familiar with at least one propagation method, and the same number saw opportunities for domestication. Among those 57, seeds were the top method (49; 86.0%), followed by air layering (39; 68.4%) and vegetative propagation (20; 35.1%), with one additional response categorized as other. Figure 7 shows how these preferences are connected with broader openness to integrating WEMPs into consumption, sale, shade, and medicinal use in farming systems. Seeds and air layering dominated because both are accessible at the household level without specialized equipment (Table 5).

Support for on-farm integration held across all items. All 57 valid respondents agreed or strongly agreed that WEMPs suited household consumption and shade-tree use. Fifty-five (96.5%) agreed they could support both consumption and sale, 56 (98.2%) agreed they could be maintained as medicinal plants within agroforestry systems, and all agreed they had aesthetic value. Respondents did not see conservation and continued use as opposing priorities; domestication and agroforestry were viewed as practical ways to maintain access while reducing pressure on wild stocks. Tree domestication and agroforestry integration have been widely proposed as effective strategies to enhance food security while conserving biodiversity (Jamnadass et al., 2013). That said, this dataset contains no quantities sold, no price data, and

no household income shares from WEMP trade. Willingness to sell is not the same as an operating market chain.

3.6 Species-use structure, livelihood roles, and policy relevance

The 101-species inventory confirms that WEMP use in these two villages goes well beyond occasional foraging. With 63 medicinal and 53 edible species when dual-use taxa are included, the collection points to an active, embedded local practice. Medicinal-only species outnumbered edible-only ones, which means these plants function as a household health resource and not just a dietary supplement. Oral administration dominated, and the most frequently used plant parts were shoots, fruits, seeds, and leaves. This profile points to a repertoire built around everyday foods, herbal drinks, and home-prepared remedies rather than specialist therapeutic treatment.

The dataset has clear limits. Because the archived files do not preserve respondent-level citation frequencies, the inventory can describe the overall structure of use groups, plant parts, and administration routes but cannot rank which species were most widely cited or culturally most salient for medicine. The part-use breakdown is still informative for management: it flags that some species involve more extractive organs such as roots and bark, even though leaves, fruits, shoots, and seeds account for most records overall.

The socio-economic picture calls for careful reading. Medicine, food, and nutrition dominate the stated reasons for use; cash income is barely mentioned. High agreement that WEMPs can provide income sits alongside near-silence on income as an actual current reason for relying on them. This gap suggests respondents recognize commercial possibility, perhaps occasional sale at local markets, but do not yet depend on it. Within this dataset, WEMPs function primarily as subsistence and health resources; cash income appears marginal and irregular rather than a primary livelihood function.

These findings connect to Bhutan's existing resource management frameworks. The NBC (2009) and DoFPS (2022) both emphasize sustainable use over extraction without replenishment. The evidence here points toward village-level domestication of priority species, on-farm integration, and harvesting guidance grounded in local practice. For Darla Gewog specifically, the more pressing need is alignment between household use patterns, propagation support, and community-based management of forest-adjacent plants rather than large-scale commercial expansion.

3.7 Gender, knowledge, and perceived decline

The gender findings resist simple summary. No single gender dominates WEMP management across all tasks. Collection was more often male-led or shared; preparation and storage were more strongly female-led; planting and domestication were more often male-led or shared among respondents who answered those questions. This matches broader literature showing gendered biodiversity roles track task type, labour availability, and livelihood context rather than a single universal rule (Howard, 2003; Alqethami et al., 2020). This aligns with ethnobiological research demonstrating that gendered divisions of labor are context-specific and shape both resource use and knowledge transmission (Pfeiffer & Butz, 2005; Chao et al., 2025). The Fisher's exact results by village and income type sharpen the picture further: household task patterns shifted across a small geographic area and across farming versus off-farm contexts, which have direct implications for how extension programs should be designed.

WEMP knowledge still passes through families. Grandparents were named as a source by 98.2% of respondents, confirming that elder-based transmission is the main channel; friends were cited by 62.5%, suggesting lateral diffusion without replacing family learning. Yet the same respondents widely perceived declining use, linking it to neglect of traditional practices and changing lifestyles. The knowledge chain may remain intact even as the practical occasions to use that knowledge shrink, a pattern consistent with findings on local ecological knowledge under economic and social change (Howard, 2003; Bussmann et al., 2018). Similar dynamics have been observed globally, where knowledge persists within communities even as practical engagement declines (Aswani et al., 2018; Chao et al., 2025).

The threat data requires careful interpretation. Respondents linked WEMP decline to population decrease, harvesting pressure, cattle grazing, tree felling, land-use change, and loss of diversity. Knowing which pressures communities consider most serious is useful for initiating management discussions. But it does not indicate which threats are ecologically most damaging. No plot measurements, abundance counts, regeneration records, or harvest data underpin these responses. The ecological magnitude of each threat and whether perceived decline tracks actual population change cannot be determined from this dataset alone. However, perceived declines often parallel documented global trends where cultural change and reduced reliance on traditional practices lead to measurable knowledge erosion (Aswani et al., 2018).

The propagation and management findings were consistently positive. Nearly all respondents knew at least one technique and expressed willingness to integrate WEMPs into their farming systems, with seeds and air layering preferred as accessible, low-equipment methods. This supports wider arguments that WEMPs can contribute to more resilient land-use systems when conservation is connected to household practice rather than separated from it (Leakey, 2012; Turner et al., 2011; Zehra et al., 2022). One qualification: the survey records attitude, not adoption. Actual planting rates, seedling survival, and any income outcomes are unknown, so the results should be read as evidence of openness to management change rather than change already achieved.

3.8 Limitations and future research

Several limitations define the analytical reach of the study. First, the research is a purposive two-village case study and should not be generalized to all rural Bhutan. Second, non-response reduced valid sample sizes for some modules, particularly the threat items and the task-allocation items, so these results should be interpreted cautiously. Third, the archived dataset does not preserve respondent-by-species citation matrices, ailment-specific use reports, or repeated use-report structure in a form that would support stronger ethnobotanical indices such as UV, RFC, CI, or ICF. UV, RFC, and CI would require each respondent's citation pattern for each species, while ICF would additionally require therapeutic-use reports grouped by ailment category.

Plant identification used vernacular names checked against available Flora of Bhutan volumes and field notes. No herbarium specimens were deposited, and no independent taxonomic verification was conducted; the species list should be treated as a field-based record rather than a voucher-verified floristic inventory. Fifth, the study contains no direct ecological data. There is no harvest monitoring, no price series, and no household income accounting. Perceived decline and commercial potential are analytically real but remain unverified ecologically and economically. Future research should combine multi-site ecological field measurements with voucher-verified plant identifications, respondent-level species citation matrices, and household income analysis to move beyond what perception-based surveys alone can show.

4. Conclusion

WEMPs in Yagang and Gengu are household resources used mainly for health and food, held together by intergenerational knowledge, and broadly supported for future domestication. Evidence from agroforestry systems in Bhutan shows that such integration can improve soil

fertility and sustain nutrient cycling through gradual litter decomposition, reinforcing the ecological basis for these management strategies (Dorjee & Orong, 2026). Nearly all households depended on them; knowledge passed predominantly through grandparents; respondents widely supported propagation and agroforestry integration. These findings sit alongside a clear, widespread perception that WEMP populations have declined, linked to harvesting pressure, cattle grazing, land-use change, and associated local pressures. These findings reinforce global evidence that sustaining wild plant systems requires aligning biodiversity conservation with local food systems, knowledge systems, and livelihood strategies (Powell et al., 2015; IPBES, 2019).

The gender findings add specificity that matters for intervention design. Collection, preparation, storage, and domestication each fell more often to different household members, with patterns varying by village and by farming versus off-farm livelihood. Programs that treat the household as a single undifferentiated actor are likely to overlook key participants. Village-specific approaches that support intergenerational learning, strengthen on-farm propagation, and connect conservation to tangible livelihood benefits are more likely to gain traction in this setting.

This is a two-village case study, not a national survey, and the findings should not be extended to all of rural Bhutan. Within existing biodiversity and forest-resource frameworks, the evidence supports village-level conservation and management tailored to Darla Gewog conditions. Broader conclusions about national trends in ecological decline, market value, or species distribution will require multi-site studies with plot-based ecological measurements, voucher-verified plant identifications, respondent-level citation data, and household income accounting.

Author Contributions

Karma Orong: Conceptualization; Methodology; Supervision; Validation; Writing – review and editing.

Sangay Dorjee: Conceptualization; Methodology; Investigation; Data curation; Formal analysis; Visualization; Writing – original draft; Project administration; Correspondence.

Wangdi: Methodology; Validation; Formal analysis; Writing – review and editing; Interpretation of results.

All authors contributed to the interpretation of results, critically reviewed the manuscript, approved the final version for publication, and agree to be accountable for all aspects of the work.

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Tables

Table 1: Socio-demographic profile of respondents in Yagang and Gengu villages (n = 58).

Variable	Category	n	%
Village	Gengu	32	55.2
Village	Yagang	26	44.8
Gender	Male	39	67.2
Gender	Female	19	32.8

Variable	Category	n	%
Age group	Below 20	3	5.2
Age group	21-30	3	5.2
Age group	31-40	17	29.3
Age group	51-60	21	36.2
Age group	More than 60	14	24.1
Education level	No formal education	50	86.2
Education level	Up to class 6	6	10.3
Education level	Up to class 10	2	3.4
Primary income source	Farming	36	62.1
Primary income source	Off-farm	22	37.9

Note: Percentages are based on the full analytic sample of 58 respondents. No respondents were recorded in the 41-50 age category.

Table 2: Indicators of household dependence and socio-economic functions of WEMPs**.**

Indicator	Category	n	%
Household dependence on WEMPs	Yes	57	98.3
Household dependence on WEMPs	No	1	1.7
Frequency of use	Sometimes	52	89.7
Frequency of use	Monthly	5	8.6
Frequency of use	Never	1	1.7
Dependence reason (multi-response, valid n = 57)	Medicine	55	96.5
Dependence reason (multi-response, valid n = 57)	Food	46	80.7
Dependence reason (multi-response, valid n = 57)	Nutrients	46	80.7
Dependence reason (multi-response, valid n = 57)	Food and nutrients	1	1.8
Dependence reason (multi-response, valid n = 57)	Income generation	1	1.8
Families depend on WEMPs	Agree or strongly agree	57	98.3
WEMPs are a source of nutrients	Agree or strongly agree	57	98.3
WEMPs are a source of income	Agree or strongly agree	55	94.8
WEMPs are only for poorer households	Disagree or strongly disagree	46	79.3

Note: Multi-response percentages are calculated from respondents who answered that item; totals for multi-response items may exceed 100%.

Table 3: Sources of indigenous knowledge and gendered household responsibilities for WEMP management.

Indicator	Category	n	%
Knowledge source (multi-response, valid n = 56)	Grandparents	55	98.2
Knowledge source (multi-response, valid n = 56)	Friends	35	62.5
Knowledge source (multi-response, valid n = 56)	Experience	5	8.9
Knowledge source (multi-response, valid n = 56)	Local healer	2	3.6
Main household knowledge holder	Male	37	63.8
Main household knowledge holder	Female	8	13.8
Main household knowledge holder	Both	13	22.4
Collection responsibility	Male	24	41.4
Collection responsibility	Female	14	24.1
Collection responsibility	Both	20	34.5
Preparation responsibility (valid n = 32)	Male	3	9.4
Preparation responsibility (valid n = 32)	Female	17	53.1
Preparation responsibility (valid n = 32)	Both	12	37.5
Processing and storage responsibility (valid n = 32)	Male	2	6.2
Processing and storage responsibility (valid n = 32)	Female	21	65.6
Processing and storage responsibility (valid n = 32)	Both	9	28.1
Planting/domestication responsibility (valid n = 32)	Male	17	53.1
Planting/domestication responsibility (valid n = 32)	Female	4	12.5
Planting/domestication responsibility (valid n = 32)	Both	11	34.4

Note: Multi-response knowledge-source percentages are based on the 56 respondents who answered the item. Task-allocation items were answered by 32 respondents and are reported on that valid-response basis.

Table 4: Respondent perceptions of availability, perceived decline, and perceived threats to WEMPs.

Indicator	Category	n	%
Local availability	Moderate	56	96.6

Indicator	Category	n	%
Local availability	Abundant	1	1.7
Local availability	Rare	1	1.7
Utilisation has decreased	Yes	48	82.8
Utilisation has decreased	No	10	17.2
Population of WEMPs has decreased (valid n = 51)	Agree or strongly agree	48	94.1
Threats can be identified locally (valid n = 51)	Agree or strongly agree	43	84.3
Neglect of traditional uses (valid n = 51)	Agree or strongly agree	31	60.8
Lifestyle change reduces use (valid n = 51)	Agree or strongly agree	33	64.7
Decrease in population (valid n = 46)	Agree or strongly agree	39	84.8
Cattle grazing (valid n = 46)	Agree or strongly agree	39	84.8
Unsustainable harvesting (valid n = 46)	Agree or strongly agree	38	82.6
Increased harvesting pressure (valid n = 46)	Agree or strongly agree	38	82.6
Loss of diversity (valid n = 46)	Agree or strongly agree	37	80.4
Tree felling (valid n = 46)	Agree or strongly agree	35	76.1
Land-use change (valid n = 46)	Agree or strongly agree	34	73.9
Pests and diseases (valid n = 46)	Agree or strongly agree	29	63.0
Climate change (valid n = 46)	Agree or strongly agree	29	63.0
Market access (valid n = 46)	Agree or strongly agree	22	47.8
Rising demand (valid n = 46)	Agree or strongly agree	18	39.1

Note: Threat percentages are based on valid responses for each item owing to item non-response in the threat scale. All threat data are perception-based; they do not reflect direct ecological measurement of population abundance, regeneration, or harvest intensity.

Table 5: Reported propagation methods and management opportunities for sustainable WEMP use.

Indicator	Category	n	%
Knows propagation methods	Yes	57	98.3
Sees domestication opportunities	Yes	57	98.3
Propagation method (multi-response, valid n = 57)	Seeds	49	86.0
Propagation method (multi-response, valid n = 57)	Air layering	39	68.4
Propagation method (multi-response, valid n = 57)	Vegetative propagation	20	35.1

Indicator	Category	n	%
Propagation method (multi-response, valid n = 57)	Other	1	1.8
Suitable for household consumption (valid n = 57)	Agree or strongly agree	57	100.0
Suitable for consumption and sale (valid n = 57)	Agree or strongly agree	55	96.5
Can be integrated as shade trees (valid n = 57)	Agree or strongly agree	57	100.0
Can be maintained as medicinal plants in agroforestry (valid n = 57)	Agree or strongly agree	56	98.2
Provides aesthetic value (valid n = 57)	Agree or strongly agree	57	100.0

Note: Propagation-method percentages are calculated from valid responses to the multi-response propagation item and may exceed 100%.

Figures

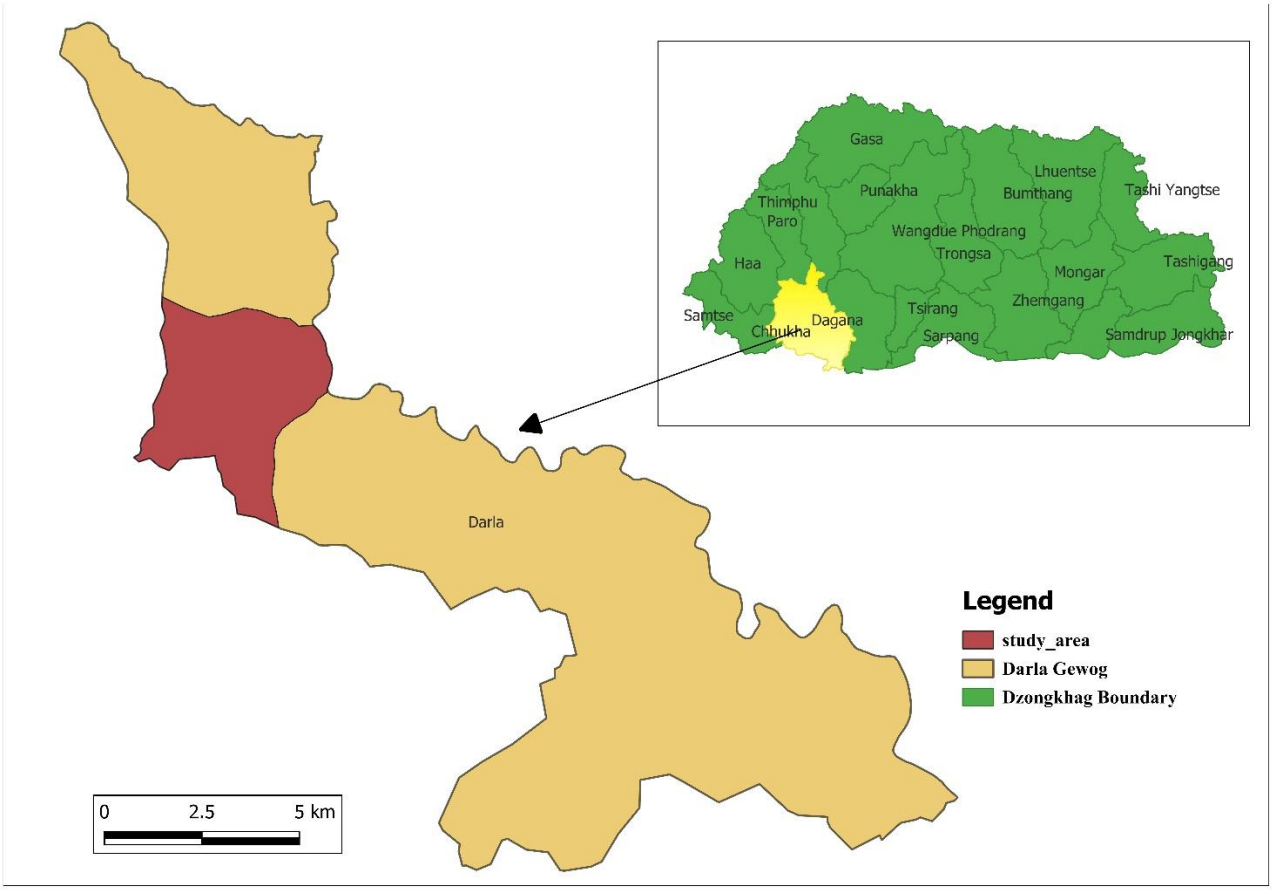

Figure 1: Map of the study area showing Yagang and Gengu villages under Darla Gewog, Chhukha District, Bhutan. Village locations are indicated relative to district and gewog boundaries. Coordinate system: WGS 84.

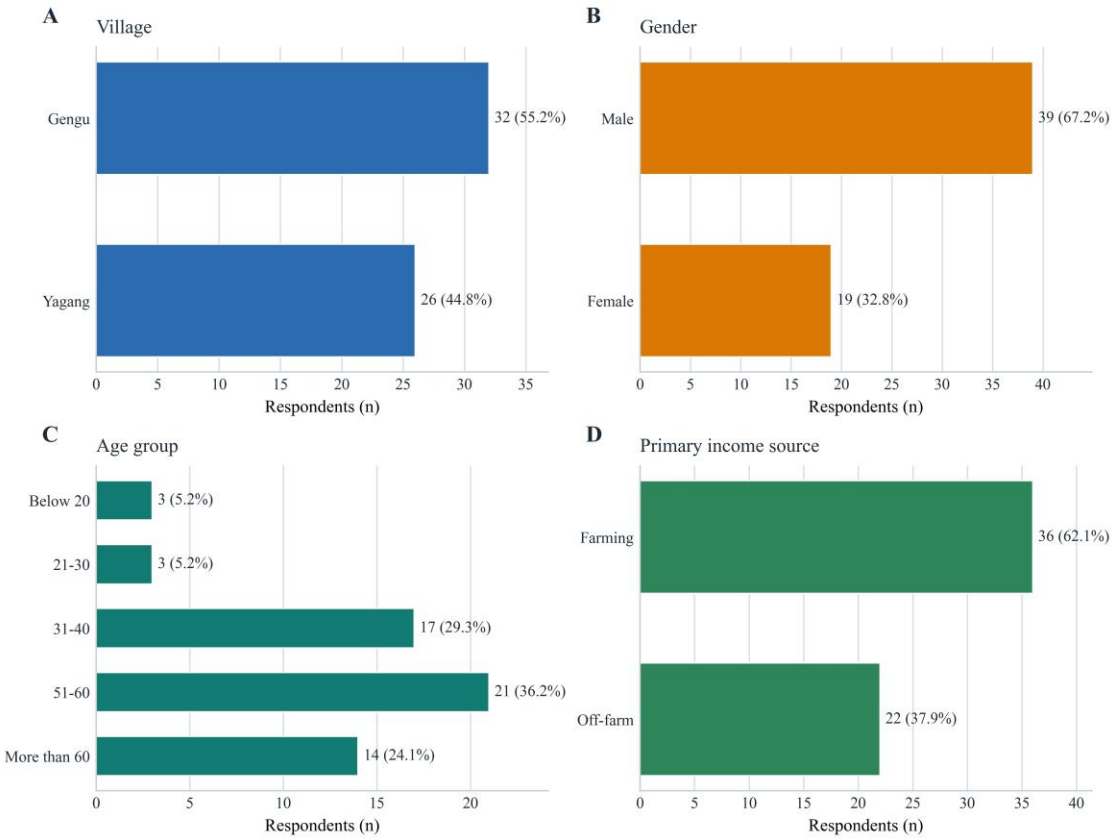

Figure 2: Socio-demographic distribution of respondents in the analytic sample (n = 58). Panel A: respondents by village (Gengu, n = 32; Yagang, n = 26). Panel B: respondents by gender (male, n = 39; female, n = 19). Panel C: respondents by age group (years); no respondents were recorded in the 41-50-year category. Panel D: respondents by primary income source (farming vs. off-farm).

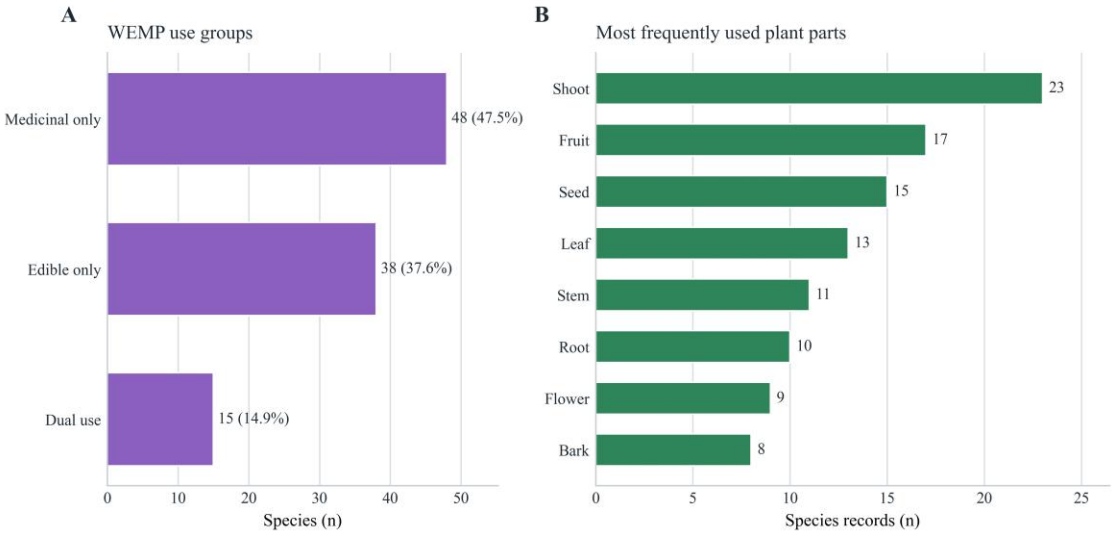

Figure 3: Composition of the documented wild edible and medicinal plant (WEMP) flora (n = 101 species). Panel A: species classified by use group (medicinal only, n = 48; edible only, n = 38; dual use, n = 15). Panel B: the eight most frequently recorded plant parts in the species inventory after harmonization of synonymous labels; shoots were the most commonly recorded part.

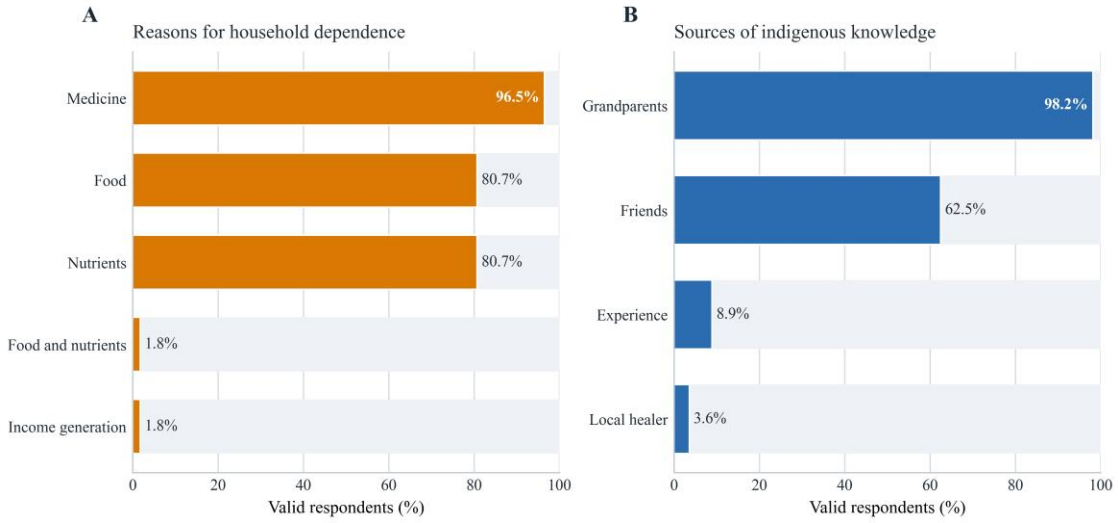

Figure 4: Stated reasons for household dependence on wild edible and medicinal plants (WEMPs) and reported sources of indigenous knowledge. Panel A: frequency of each stated reason for WEMP dependence among respondents who answered the multi-response item (valid n = 57); percentages may sum to more than 100% because multiple reasons could be selected. Panel B: reported sources of WEMP knowledge among respondents who answered the multi-source item (valid n = 56); grandparents were the most frequently cited source.

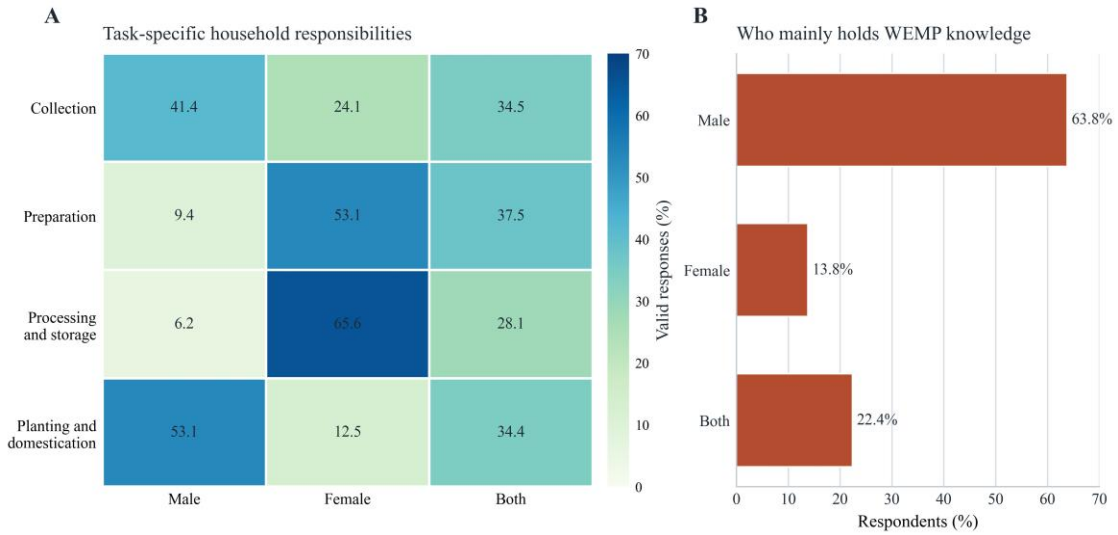

Figure 5: Gendered household responsibilities for wild edible and medicinal plant (WEMP) management tasks and perceived household knowledge holder. Panel A: proportion of respondents reporting each task as male-led, female-led, or shared; collection module valid n = 58, all other task modules valid n = 32. Panel B: proportion of respondents identifying men, women, or both genders as the primary holder of WEMP knowledge within the household (n = 58).

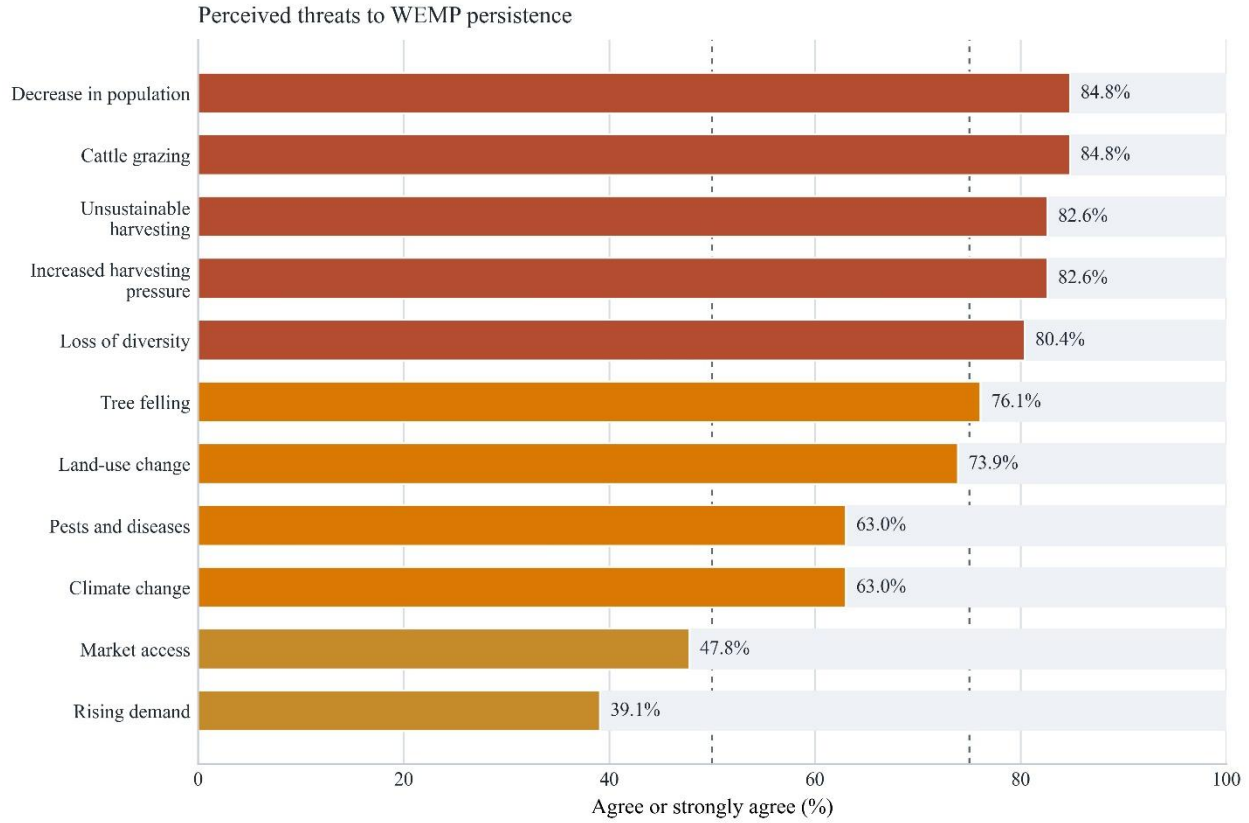

Figure 6: Proportion of respondents agreeing or strongly agreeing with each perceived threat to wild edible and medicinal plant (WEMP) persistence in Yagang and Gengu villages (valid n = 46 for the threat module). Threat items were derived from a five-point Likert-type agreement scale; non-response reduced the valid sample below 58 for this module.

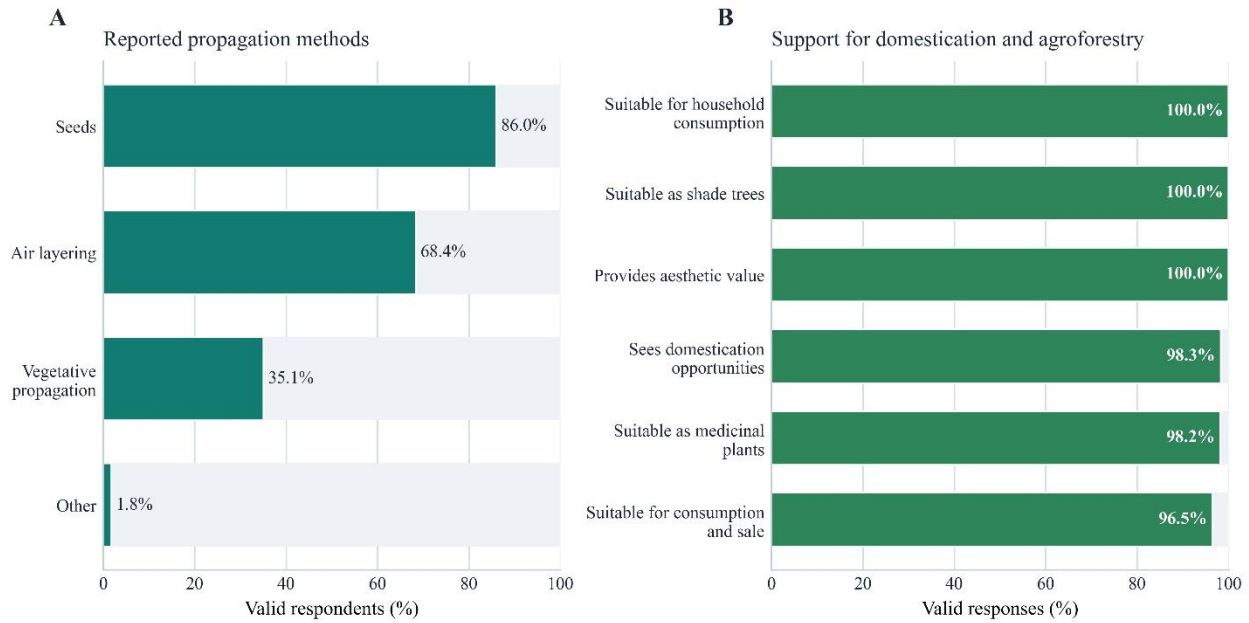

Figure 7: Reported propagation methods and expressed support for domestication and agroforestry integration of wild edible and medicinal plants (WEMPs). Panel A: frequency of each reported propagation method among respondents who answered the multi-response item (valid n = 57); percentages may sum to more than 100% because multiple methods could be selected. Panel B: proportion of respondents agreeing or strongly agreeing with each statement about potential on-farm integration of WEMPs (valid n = 57).

Supplementary Tables

S_1: Ethnobotanical uses of wild edible and medicinal plants, including plant parts utilized, modes of preparation, and associated traditional values.

Sl. No.	Scientific Name	Parts Used	Preparation/Processing	Mode of Administration	Ethnomedicinal/Dietary Use
1	*Achyranthes bidentata*	Stem	Processed to Extract Juice and Consumed	Oral	Treatment of Mumps, Sore Throat, Fever, Jaundice, and Body Pain
2	*Aconogonon molle*	Shoot	Consumed as Food	Oral	Consumed as Salad
3	*Acorus calamus*	Root, Leaf & Stem	Processed to Extract Juice (Root) and Pound into Paste (Leaf/Stem)	Oral and Topical	Treatment of Weakness (Juice) and Scabies, Heat Rashes and Cuts. Leaf/Stem Boiled in Water Used for Bathing Infants
4	*Actinidia callosa*	Fruit	Consumed Ripened	Oral	Consumed as Food
5	*Allium hookeri*	Leaf	Cooked and consumed	Oral	Consumed as Food
6	*Alpinia nigra*	Shoot	Cooked and consumed	Oral	Consumed as Food
7	*Alsophila spinulosa*	Shoot	Cooked and consumed	Oral	Consumed as Food
8	*Amorphophallus paeoniifolius*	Shoot	Cooked and consumed	Oral	Consumed as Food
9	*Ampelocalamus patellaris*	Shoot	Cooked and consumed	Oral	Consumed as Food

10	*Angiopteris helferiana*	Root	Boiled to Extract Juice	Oral	Treatment of Weakness
11	*Astilbe rivularis*	Root	Pound to Paste and Processed to Extract Juice	Topical (Paste) and Oral (Juice)	Treatment of Bleeding, Fever, Jaundice, Bone Fracture, and Body Pain
12	*Baccaurea ramiflora*	Fruit	Consumed Ripe Fruit	Oral	Consumed as Food
13	*Bauhinia purpurea*	Flower	Cooked and consumed	Oral	Consumed as Food and Treatment of Blood Pressure
14	*Bauhinia variegata*	Flower	Cooked and consumed	Oral	Consumed as Food and Treatment of Hypertension
15	*Bergenia ciliata*	Leaf & Root	Dry and Brew (Leaf), Pound into Paste, and Process to Extract Juice	Oral and Topical	Treatment of Bone Fractures (Root). Leaf Consumed as Herbal Tea
16	*Betula alnoides*	Root & Bark	Pound into a Paste (Root), and Make Shampoo (Bark + Lemon + Egg)	Topical	Treatment of Bone Fractures and Cuts, and Used as Shampoo for Cleansing Hair/Scalp
17	*Calamus acanthospathus*	Shoot	Cooked and consumed	Oral	Consumed as Food
18	*Calamus erectus*	Shoot & Stem	Cooked and Consumed and Boiled to Extract Juice	Oral	Consumed as Food and Treatment of Cough and Cold
19	*Calamus latifolius*	Stem	Processed to Extract Juice	Oral	Treatment of Urinary Tract Infections (UTIs)

20	*Callicarpa vestita*	Bark	Processed to Extract Juice	Oral	Treatment of Constipation
21	*Cannabis sativa*	Leaf	Mixed with Fodder/Feed	Oral	Treatment of Gastrointestinal Discomfort
22	*Cassia fistula*	Leaf & Fruit	Processed to Extract Juice (Leaf), and Consumed Raw (Fruit)	Oral	Treatment of Fever (Leaf) and Gastritis (Fruit)
23	*Chenopodium album*	Shoot	Cooked and Consumed	Oral	Consumed as Food
24	*Choerospondias axillaris*	Fruit & Seed	Consumed Directly (Fruit), and Seed Processed into Powder and Mixed with Water	Oral	Consumed as Food
25	*Cinnamomum glaucescens*	Bark & Seed	Pound into Paste (Bark) and Powder (Seed)	Topical and Oral	Treatment of Bone Fractures, Wounds, and Cough and Cold
26	*Citrus medica*	Fruit	Cut and Squeezed to Extract Juice	Oral	Treatment of Diarrhoea and Gastrointestinal Discomfort
27	*Colocasia esculenta*	Fruit	Processed to Extract Juice	Oral	Treatment of Diarrhoea
28	*Costus lacerus*	Stem	Consumed Raw/Juice	Oral	Treatment of Urinary Tract Infections and Gastrointestinal Discomfort
29	*Crateva religiosa*	Shoot & Root	Cooked and Consumed (Shoot) and Pound into Paste (Root)	Oral and Topical	Consumed as Food and Treatment of Bone Fractures and Wounds

30	*Cymbidium spp.*	Flower	Pound into Paste	Topical	Treatment of Bone Fractures
31	*Datura metel*	Fruit & Seed	Processed into Powder and Smoke, and Apply on Infected Part (Seed)	Inhale Smoke and Topical	Treatment of Toothache
32	*Dendrocalamus hamiltonii*	Shoot	Cooked and Consumed and Processed into Pickle	Oral	Consumed as Food and Pickle
33	*Dioscorea belophylla*	Tuber	Cooked and consumed	Oral	Consumed as Food
34	*Dioscorea bulbifera*	Tuber	Cooked and consumed	Oral	Consumed as Food
35	*Diplazium esculentum*	Shoot	Cooked and consumed	Oral	Consumed as Food
36	*Diplazium himalayense*	Shoot	Cooked and consumed	Oral	Consumed as Food
37	*Diploknema butyracea*	Fruit	Consumed Raw	Oral	Consumed as Food
38	*Docynia indica*	Fruit	Consumed Raw and Processed to Extract Juice	Oral	Treatment of Diarrhea and Gastrointestinal Discomfort
39	*Edgeworthia gardneri*	Root	Processed to Extract Juice	Oral	Treatment of Food Poisoning

40	*Elatostema lineolatum*	Shoot	Cooked and Consumed	Oral	Consumed as Food
41	*Engelhardia spicata*	Bark	Pound into Paste	Topical	Treatment of Mumps, Boils, and Bone Fractures
42	*Entada rheedii*	Seed	Processed into Paste	Topical	Treatment of Bone Fractures and Mumps
43	*Exbucklandia populnea*	Bark	Processed into Paste	Topical	Treatment of Bone Fractures
44	*Fraxinus floribunda*	Bark	Processed into Paste	Topical	Treatment of Bone Fractures
45	*Girardinia diversifolia*	Flower	Cooked and Consumed	Oral	Consumed as Food and Treatment of Hypertension
46	*Gmelina arborea*	Bark	Cooked and Consumed (Flower), Processed to Extract Paste and Juice (Bark)	Oral (Juice) and Topical (Paste)	Treatment of Bone Fracture, Wounds, Cuts, Fever, and Weakness, and Consumed as Food
47	*Gynocardia odorata*	Seed	Cook Processed Oil and Consumed	Oral	Consumed as Cooking Oil
48	*Hedyotis scandens*	Root	Processed to Extract Juice	Oral	Treatment of Fever
49	*Himalayacalamus brevinodus*	Shoot	Cooked and Consumed	Oral	Consumed as Food
50	*Jatropha curcas*	Seed	Consumed Raw	Oral	Treatment of Food Poisoning

51	*Juglans regia*	Kernel	Consumed Raw	Oral	Consumed as Food
52	*Justicia adhatoda*	Flower	Cooked and Consumed	Oral	Consumed as Food
53	*Kaempferia rotunda*	Root, Seed & Stem	Pound into Paste	Topical	Treatment of Bone Fractures and Cuts
54	*Laportea bulbifera*	Leaf	Cooked and consumed	Oral	Consumed as Food and Treatment of Blood Pressure
55	*Litsea cubeba*	Seed	Processed to Extract Oil	Oral and Topical	Treatment of Cough, Fever, Tonsillitis, and Joint Pain
56	*Machilus edulis*	Fruit	Consumed Raw	Oral	Consumed as Food
57	*Macropanax dispermus*	Shoot	Cooked and consumed	Oral	Consumed as Food
58	*Mangifera sylvatica*	Fruit	Consumed Raw	Oral	Consumed as Food
59	*Mentha spicata*	Leaf	Consumed Raw	Oral	Treatment of Gastric and Joint Pain
60	*Microlepia caudigera*	Shoot	Cooked and consumed	Oral	Consumed as Food
61	*Mimosa pudica*	All Parts	Processed into Powder	Oral	Treatment of Constipation
62	*Morus australis*	Root	Processed to Extract Juice	Oral	Treatment of Diabetes, Dysentery, Sore Throat, Tonsillitis, Fever, and Pneumonia

63	*Musa balbisiana*	Flower	Cooked and consumed	Oral	Consumed as Food
64	*Myrica esculenta*	Bark	Burn Powder and Inhale	Inhale Smoke	Treatment of Sinusitis
65	*Nasturtium officinale*	Shoot	Cooked and consumed	Oral	Consumed as Food
66	*Nephrolepis cordifolia*	Tuber	Consumed Raw	Oral	Treatment of Urinary Tract Infections, Diabetes, and Gastrointestinal Discomfort
67	*Oroxylum indicum*	Flower	Cooked and consumed, and Burn into Ash	Topical and Oral	Consumed as Food and Treatment of Hypertension, Burns, Wounds, and Cuts
68	*Paederia foeta*	Leaf/Stem	Cooked and Consumed (Leaf) and Pound into Paste	Oral and Topical (Tie Around the Injury)	Treatment of Gastritis and Relieve Pain
69	*Phlogacanthus thyrsiformis*	Flower & Leaf	Cooked and Consumed (Flower), and Boiled to Extract Juice and Consumed (Leaf)	Oral	Treatment of Blood Pressure, Headache, and Roundworms
70	*Phyllanthus emblica*	Fruit	Consumed Raw	Oral	Treatment of Pneumonia and Gastritis
71	*Phytolacca acinosa*	Leaf	Cooked and Consumed	Oral	Consumed as Food and Treatment of Blood Pressure and Food Poisoning

72	*Piper betleoides*	Leaf	Consumed Raw with Betel Nut	Oral	Chewed as Betel Nut (Doma)
73	*Piper hamiltonii*	Whole Plant	Consumed Raw	Oral	Treatment of Cough and Cold
74	*Piper longum*	Seed	Consumed Raw	Oral	Treatment of Blood Pressure, Cough and Cold
75	*Piper peepuloides*	Fruit & Seed	Consumed Raw	Oral	Treatment of Cough and Cold
76	*Plantago depressa*	Leaf and Stem	Pound into Paste	Topical	Treatment for Sprained Legs to Relieve Pain
77	*Plectocomia himalayana*	Shoot	Cooked and consumed	Oral	Consumed as Food
78	*Pogostemon amaranthoides*	Shoot	Cooked and consumed	Oral	Consumed as Food
79	*Poranopsis paniculata*	Stem	Processed to Extract Juice	Topical or Oral	Treatment of Fractured Bones and Cuts
80	*Pouzolzia hirta*	Whole Plant	Pound into Paste	Topical	Treatment of Bone Fractures and Wounds
81	*Rhus chinensis*	Seed	Boiled to Extract Juice	Oral	Treatment of Gastrointestinal Discomfort and Food Poisoning
82	*Rubus biflorus*	Fruit	Consumed Raw	Oral	Consumed as Food
83	*Rubus ellipticus*	Fruit	Consumed Raw	Oral	Consumed as Food
84	*Rubus nepalensis*	Fruit	Consumed Raw	Oral	Consumed as Food

85	*Rumex nepalensis*	Whole Plant	Processed to Extract Juice	Oral	Treatment of Jaundice and Ringworms
86	*Smilax aspera*	Shoot	Cooked and Consumed and Pound into Paste	Oral and Topical	Consumed as Food and Treatment of Toothache
87	*Solanum khasianum*	Seed	Processed into Powder and Smoke	Inhale Smoke	Traditionally Used for Treatment of Toothache
88	*Spatholobus parviflorus*	Stem	Soaked in Water and Consumed	Oral	Treatment of Diabetes
89	*Spondias pinnata*	Seed	Consumed Raw (Fruit) and Processed into Powder and Mixed with Water (Seed)	Oral	Consumed as Food and Treatment of Cough and Cold
90	*Stephania glabra*	Shoot & Tuber	Cooked and Consumed (Shoot) and Processed to Extract Juice and Consumed (Tuber)	Oral	Treatment of Blood Pressure for Humans; Diarrhoea and Haematuria for Animals
91	*Swertia chirayita*	Whole Plant	Boiled to Extract Juice	Oral	Treatment of Fever, Headache, and Joint Pain
92	*Terminalia chebula*	Seed	Consumed Raw	Oral	Treatment of Sore Throat
93	*Thysanolaena latifolia*	Shoot	Pound into Paste	Topical	Treatment of Boils
94	*Tinospora cordifolia*	Stem	Pound into Paste	Oral	Treatment of Blood Pressure

95	*Toddalia asiatica*	Fruit	Consumed Raw	Oral	Consumed as Food
96	*Trichosanthes tricuspidata*	Shoot	Cooked and Consumed	Oral	Consumed as Food
97	*Tupistra nutans*	Flower	Consumed Raw/Cooked	Oral	Consumed as Food
98	*Uncaria scandens*	Stem	Soaked in Water Overnight and Consumed Water (Stem), and Processed to Extract Juice (Root)	Oral	Treatment of Hypertension
99	*Viscum articulatum*	Leaf	Boiled to Extract Juice	Oral	Treatment of Fractured Bones and Body Pain
100	*Wendlandia puberula*	Leaf	Processed into Tea Leaves	Oral	Consumed as Traditional Beverage
101	*Zanthoxylum armatum*	Seed	Boiled to Extract Juice	Oral	Treatment of Headache and Gastric