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An overview of ethnobotanical investigations for primary healthcare: a case study from Mardan district, Pakistan

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ABSTRACT

The present study was conducted in Sudhum valley, Mardan district, Khyber Pakhtunkhwa, Pakistan. A total of 168 plant species from 56 families were documented, with Asteraceae (15 spp.) and Poaceae (13 spp.) being the most represented. Herbs (102 spp.) and trees (40 spp.) dominated the flora. Leaves (132 spp.) and seeds (69 spp.) were the most used plant parts in traditional medicine, treating 59 ailments, primarily skin diseases (86 spp.) and wounds (65 spp.). The highest fidelity level (94%) was recorded for Asparagus officinalis in treating urinary tract infections, while the highest use value was calculated for Allium cepa (0.86). Jaccard index ranged from 1.24 to 3.12. Seasonal collection was noted, with peak harvesting in April. Twenty-four species (14.28%) were used gastronomically, primarily for their fruits and leaves. Economically valuable species included Allium sativum, Coriandrum sativum, Aloe vera, and Carum carvi. A decline in traditional knowledge, especially among youth, was evident. Preserving and revitalizing this knowledge is crucial for cultural continuity, health care, and addressing local food insecurity through enriched traditional diets.

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Ethnobotany; conservation; phyto-cultural diversity; ethnomedicine

1. Introduction

The study of ethnomedicine reveals a rich tapestry of cultural practises and healing traditions that transcend generations. By examining how different societies utilise their local flora, we gain insight into the intricate relationship between humans and nature (Fayiah et al. 2024). This connection is not only practical but also reflects a deep-rooted belief in the healing powers of plants, often rooted in centuries-old traditions (Chaachouay and Zidane 2024). For example, indigenous tribes in the Himalayas have long relied on certain herbs not only for their medicinal properties, but also as integral components of their spiritual rituals (Thakur et al. 2025). Such examples illustrate the dual role of plants as physical healers and cultural symbols and highlight the need to document and understand these practises in today's health discourse before they are lost to rapidly growing urbanisation.

Pakistan has a remarkably diverse flora with about 6,000 plant species and 1,572 genera thriving in the Karakoram, Hindu Kush and Himalayan Mountain ranges (Manan et al. 2022). The country ranks seventh among Asian nations in terms of medicinal plant production (Anwar et al. 2024). Around 600 plant species are used in traditional medicine in Pakistan and most of the population relies on these remedies for most of their health needs (Anwar et al. 2024). According to Adnan et al. (2014), before the 1950s, about 84% of the Pakistani population depended on traditional medicine. Since then, however, there has been a rapid decline, and only the indigenous population in rural and mountainous areas still relies heavily on herbal medicines, with knowledge being passed down through generations mainly by oral tradition (Anwar et al. 2024). Meanwhile, other resource-poor farmers also rely on traditional medicine, such as indigenous communities (Khan et al. 2025). The local market systems known as "pansar" are particularly associated with the trade of plants with ethnomedicinal properties. In addition, nearly 50,000 traditional healers (tabib) and many unregistered health workers are active in remote areas such as the mountains and rural areas (Mussarat et al. 2021). Meanwhile, traditional knowledge is also being utilised for modern pharmacopoeia as nearly 4000 registered manufacturers of herbal market products are documented across the country (Jan et al. 2020).

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Shahbaz Garhi is a historically significant village on the south-western periphery of the district of Mardan in Pakistan. The population consists mainly of the Yousafzai and Utmanzai tribes, both of which belong to the Pashtun ethnic group (Hanif 1964; Virdee 2021). The region is characterised by a rural, agrarian way of life, with the local poor economy mainly focused on agriculture (Urbańczyk 2020). The main agricultural activities include the cultivation of wheat, maize and sugar cane as well as livestock farming. Due to limited economic resources, a large part of the population faces challenges such as poverty and insufficient access to modern health facilities, which is why most people rely on traditional practises, including ethnobotanical remedies, and are thus completely dependent on nature. Local people have valuable knowledge in an increasingly urbanised world.

As urbanisation is an inevitable and ongoing process, it is crucial to preserve this traditional knowledge in science before it is lost. Many ethnobiological studies have been conducted in Mardan, but there is no comprehensive scientific study documenting this knowledge in the region (Shahbaz Garhi and Rustam (Sudhum Valley)), so timely documentation is urgently needed. Considering this research gap, we have taken the opportunity to explore the role of nature in primary health care and socio-economic resilience of rural people in Shahbaz Garhi with the following main objectives: (a) To document the traditional ethnomedicinal knowledge along with its gastronomic associations. (b) To record the role of local flora in generational livelihoods.

2. Materials and methods

2.1. Study area

Shahbaz Garhi and Rustam (Sudhum valley) belong to the district of Mardan in Khyber Pakhtunkhwa, Pakistan. Shahbaz Garhi, a village steeped in history, is located on the south-western edge of Mardan district at coordinates 34°12′ N, 72°16′ E and an elevation of 293 meters above sea level (Parveen et al. 2021) as indicated in Figure 1. Rustam (Sudhum Valley), a tehsil in Mardan district, is located amidst the picturesque mountains of Chengay Baba, Shabaz Ghari, Sar Malang and Kashmir Smasta, which are up to 369 meters high and contribute to the scenic beauty (Ahmad et al. 2022). Shahbaz Garhi and Rustam are characterized by a subtropical climate with hot summers, mild winters and a notable monsoon season from July to September and have rich vegetation with a diverse mix of deciduous and evergreen trees, shrubs and various grasses, including widespread species such as Vachellia, Dalbergia and Eucalyptus (Parveen et al. 2021).

Despite the relatively sparse forest cover, ongoing reforestation efforts aim to strengthen ecological resilience. The landscape is crisscrossed by numerous rivers and streams, particularly the Kabul River, which plays a central role in irrigation and supports both agricultural endeavors and natural ecosystems, contributing to the ecological vibrancy of the region. Local inhabitants include Yousafzai and Utmanzai tribes belonging to the Pashtun ethnic group (Hanif 1964; Virdee 2021). Both these tribes practice agriculture, and the staple crops are wheat, and sugarcane (Parveen et al. 2021). Shahbaz Garhi and Rustam (Sudhum Valley) embody bastions of cultural, historical and environmental significance in Mardan district, where historical remains, diverse botanical landscapes, vital waterways and harmonious rural-urban lifestyles enrich the cultural, economic and environmental ethos of the district (Parveen et al. 2021; Ahmad et al. 2022).

2.2. Field interviews and data collection

The ethnobotanical study took place September 2021 to August 2023 and aimed to capture indigenous knowledge about the therapeutic uses of medicinal plants in the study region. Strategically important sites in the research area were selected for data collection, namely Shahbaz Garhi, Kando, Chanako Dheri, Saeed Abad, Hussai (Osai) Kalay, Daggar, Garyala, Charguli, Nawan Kali, and Rustam. Data collection was done through field surveys conducted at different times of the year, with informants selected through purposive sampling (Hassan et al. 2024). Local community members known for their deep understanding of traditional medicine were interviewed to gain insights into the use of medicinal plants and other botanical applications. Before the interviews, participants were informed about the objectives of the study. The semi-structured interviews, supported by standardized questionnaires, focused on various aspects such as informants' demographic data, local plant nomenclature, specific plant parts used, availability, methods of use, and diseases treated (Hassan et al. 2022). To ensure effective communication, interviews were conducted individually and in groups, speaking exclusively in Pashto, the local language. Interviews were also conducted with people involved in the procurement and trade of medicinal plants in the local markets. During the spring and summer seasons, field trips were organized with the help of local informants to identify and collect plant specimens. Each specimen, a total of 3 to 5 per plant, was carefully documented, photographed and stored in sterilized polythene bags. After drying, the plants were glued to standardized herbarium sheets and labelled with taxonomic information such as scientific name, family affiliation, colloquial name, collection locality, and collector and identification names were deposited in the Department of Botany, Islamia College Peshawar Pakistan to obtain an accession number (voucher number). The accuracy of the nomenclature was confirmed through consultation with World Flora Online (accessed on 05/02/2025) to ensure adherence to strict scientific standards and precision.

2.3. Demography and literacy data of the participants

The present study was conducted through field surveys from September 2021 to August 2023 in Shahbaz Garhi and Rustam (Sudhum Valley) in Pakistan. We interviewed 147 participants including 53 females and 94 males aged between 20 and 80 years from ten villages selected by snowball method (Table 1). We collected data through semi-structured interviews, focus group discussions and field observations, following the methods developed by Hassan et al. (2024). Information was collected on wild plants including their local names, growth

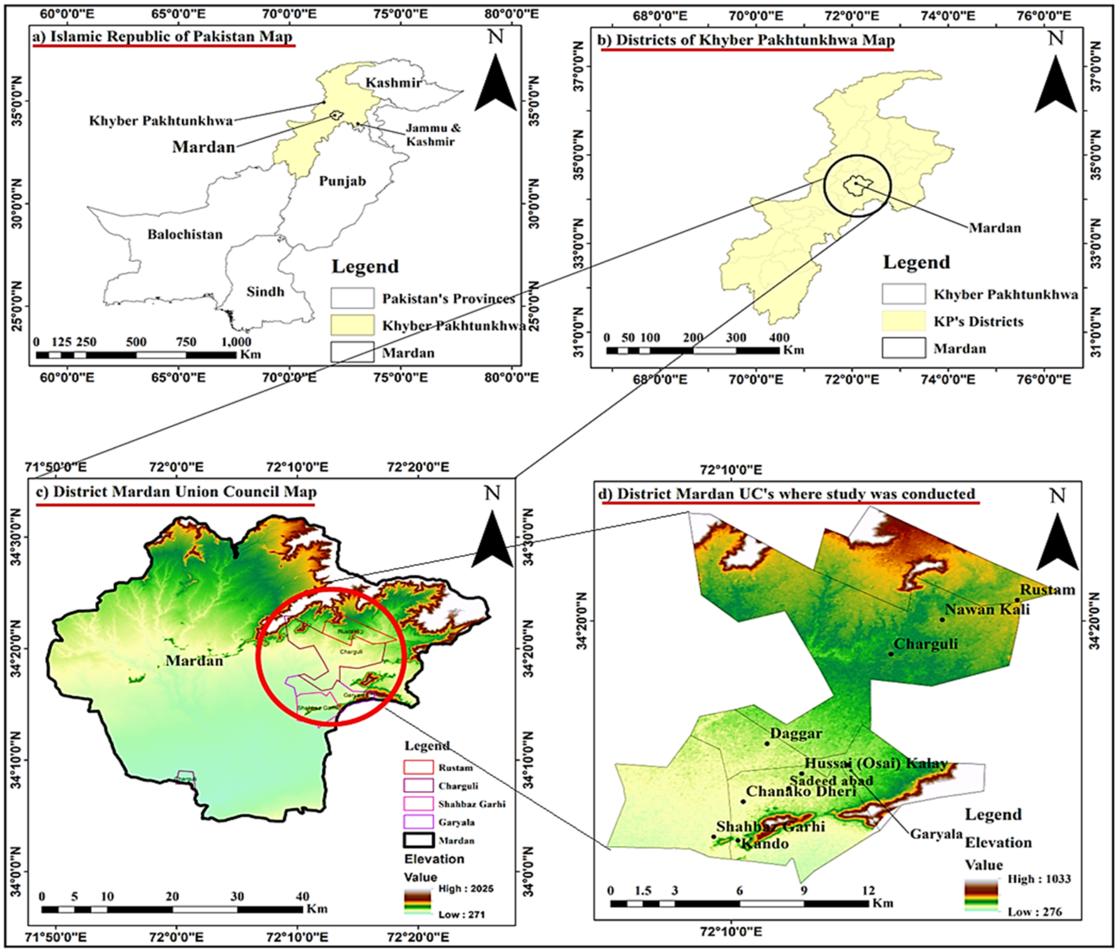

Figure 1. Map of the study area. (a) Islamic Republic of Pakistan; (b) Khyber Pakhtunkhwa Province; (c) Mardan district (black dots indicate the GPS points of the selected study areas).

habits, parts used, collection times, market value and medicinal properties. The questionnaires were written in Urdu and were supplemented with photographs and plant specimens collected during the survey to facilitate plant identification. Where necessary, individual interviews were conducted to supplement the questionnaire responses. The study strictly adhered to the ethical guidelines of the International Society of Ethnobiology (The ISE Code of Ethics https://www.ethnobiology.net/what-we-do/core-programs/ise-ethics-program/code-of-ethics/ accessed on 12/08/2021) and carefully collected traditional knowledge from different sites in selected regions. We worked with knowledgeable informants from each area to examine and prepare herbarium specimens. We relied on regional literature sources for accurate plant identification (Bahadur et al. 2020; Sulaiman et al. 2020; Jan et al. 2021; Parveen et al. 2021; Begum et al. 2022; Khan et al. 2023; Rehman et al. 2023; Rahman et al. 2024; Ullah and Badshah 2024; Rehman et al. 2024; Nazar et al. 2024; Amin et al. 2024). In cases where there was disagreement on local names, we reached a consensus through extensive discussions.

2.4. Socio-economic profile

The economy of Mardan in Pakistan's Khyber Pakhtunkhwa province is predominantly based on agriculture, and a significant proportion of the population is employed in agriculture (Khattak et al. 2024). The district is known for its highly fertile soils, which enable the cultivation of important crops such as wheat, sugarcane and tobacco (Iqbal et al. 2023). In addition to its agricultural base, Mardan is experiencing a burgeoning industrial sector with significant growth in the textile industry and marble processing, contributing to economic diversification (Khan et al. 2020). Despite these economic aspirations, Mardan struggles with persistent problems such as poverty and unemployment. Although the literacy rate has increased, it remains below the national average, which hinders the overall socio-economic progress of the district (Nasir 2024). Infrastructure in rural areas remains significantly underdeveloped, making access to essential education and health services difficult (Khan et al. 2024). This infrastructure deficit often forces residents to migrate to urban centres for better employment opportunities, underscoring the urgent need for targeted local economic development initiatives (Khan et al. 2024).

2.5. Data analysis

Pearson correlation analysis, performed with Online Bioinformatics & Evolutionary Genomics (https://www.bioinformatics.com.cn/en?p=5 accessed on 01/05/2024) was

Table 1. Demographic information of the respondents.

Villages ethnic group	GPS points		Altitude ecology	Language religion	Approximate population	Study participants		Age			Occupation
						Male	Female	Young	Middle	Old	
Shahbaz Garhi Pashtun	34°13′47″N	72°09′25″E	317 m Semi-arid	Pashto Islam	17,357	20	9	2	5	7	Farmers Skilled/semi-skilled worker Cultivator/agricultural labourer Herders Housewives Shopkeepers
Kando Pashtun	34°14′01″N	72°10′10″E	320 m Semi-arid	Pashto Islam	4,390	9	4	2	6	5	
Chanako Dheri Pashtun	34°15′10″N	72°10′55″E	321 m Semi-arid	Pashto Islam	3,730	5	4	3	5	5	
Saeed Abad Pashtun	34°15′27″N	72°11′25″E	322 m Semi-arid	Pashto Islam	5,493	7	3	3	5	7	
Hussai (Osai) Kalay Pashtun	34°15′48″N	72°11′35″E	329 m Semi-arid	Pashto Islam	9,983	15	6	2	4	8	
Daggar Pashtun	34°16′39″N	72°10′54″E	330 m Semi-arid	Pashto Islam	4,735	6	4	3	6	9	
Garyala Pashtun	34°16′05″N	72°12′56″E	338 m Semi-arid	Pashto Islam	6,368	5	4	2	4	7	
Charguli Pashtun	34°19′05″N	72°14′03″E	370 m Semi-arid	Pashto Islam	7,983	8	3	3	3	6	
Nawan Kali Pashtun	34°20′01″N	72°15′17″E	381 m Semi-arid	Pashto Islam	7,920	7	3	2	6	9	
Rustam Pashtun	34°20′24″N	72°17′18″E	393 m Semi-arid	Pashto Islam	15,735	15	10	3	7	8	
						Σ=97	Σ=50	Σ=25	Σ=51	Σ=71	

used to quantitatively investigate the relationships between each species and their respective collection months for ethnomedical use. In addition, the software (https://www.originlab.com/2021) was used to create chord diagrams illustrating the use of plant parts, the type of use and the corresponding species; the same tool was used to perform a principal component analysis (PCA) to identify the new species.

The application of quantitative data increases the precision in assessing the therapeutic significance of medicinal plants (Najmi et al. 2022). Moreover, qualitative assessment is crucial to recognize the importance of a medicinally used plant and thus plays a crucial role in exploring its pharmaceutical potential (Dhir et al. 2023). The data obtained from the interviews were analyzed using three different quantitative indices:

2.5.1. Fidelity level (FL)

The fidelity level (FL) assessment provides information on the depth of traditional knowledge and confidence in specific species for various uses, including medicinal applications. Methodologically, determining the FL involves conducting surveys and interviews in local communities to collect empirical data on the frequency and exclusivity of species use for specific purposes (Hassan et al. 2023; Zemede et al. 2024). The following equation was used to calculate the FL.

$$FL(\%) = \frac{Np}{Fc} \times 100$$

where Np indicates number of informants who reported the most important complaints for a given species and Fc is the frequency of mentions.

2.5.2. Use value (UV)

The UV is a metric used in ethnobotany to quantify the importance of a plant species based on the diversity of uses reported by informants (Hassan et al. 2024). The use value was calculated using formula:

$$UV = \sum \frac{UI}{N}$$

where Ui = Number of use reports for a particular medicinal plant by each informant; n = Total number of informants.

2.5.3. Jaccard index (JI)

To compare the study with published literature and to assess the similarity and dissimilarity of traditional knowledge among different areas, the Jaccard index was calculated using the following formula (Hassan et al. 2024).

$$JI = \frac{C}{(A + B)\text{-}C}$$

where “A” represents the total number of species in area A (present study area); “B” represents the total number of species from other published areas; “C” represents the common species in both A and B.

3. Results and discussion

3.1. Diversity of documented plant taxa

The present study recorded 168 plant species from $n = 56$ families (Table S1). The Asteraceae family was leading with 15 plant species, followed by Poaceae 13 plant species and Fabaceae, Solanaceae (12 plant species each) as shown in Figure 2. The dominance of the family Asteraceae can be attributed to its easy adaptability to a variety of environments and its easy accessibility to the local population (Hassan et al. 2024). Rehman et al. (2024) and Nazar et al.

(2024) reported that most of the species of this family are found in the nearby Himalayan regions.

As illustrated in Figure 3, the most common plant habit among the documented species were herbs with 102 plant species, followed by trees (40 species), shrubs (13 species), grasses (5 species), woody vines (3 species), vines (2 species) and woody grasses, succulents and subshrubs with 1species each, with a significant variation ($Y = -4.8382x + 68.662$, $R^2 = 0.4903$). A comprehensive list of catalogued species can be found in Table S1. The use of these documented species in the region can be attributed to factors such as plant diversity, accessibility, deep-rooted traditional medicinal knowledge, rich vegetation composition, healthy condition of forest flora and economic constraints.

Various plant parts are used in traditional medicinal preparations, with leaves (132), seeds (69), flowers (49), roots (46) and bark (36) being the most commonly used (Figure 4(a)). The predominant use of leaves can be attributed to their

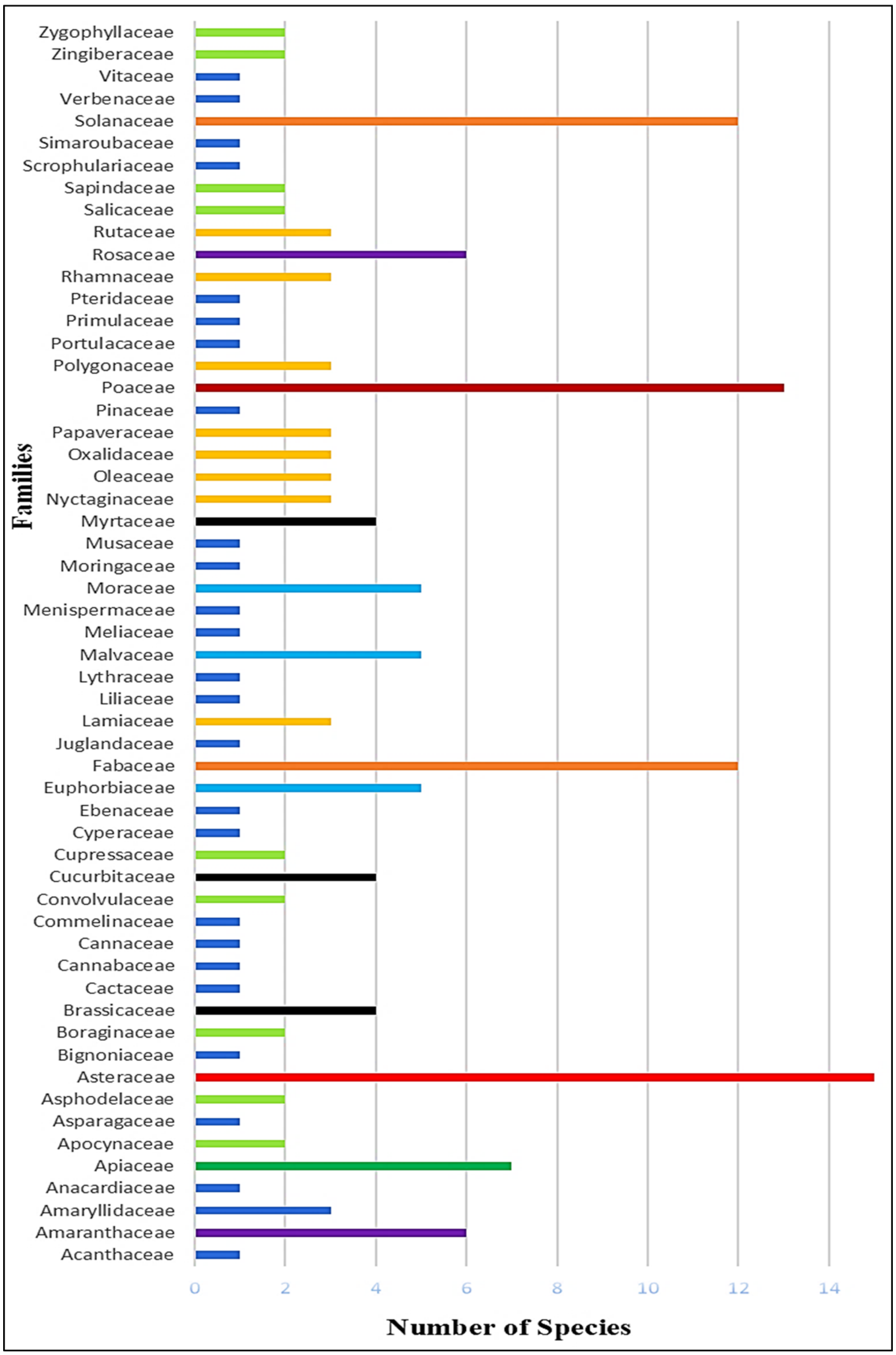

Figure 2. Bar chart showing the distribution of documented plants in Mardan district among the different families.

ease of collection; similar results were reported by Amin et al. (2024) who indicated maximum use in the traditional medicine of Kohistan, northern Pakistan. In addition, the leaves are commonly consumed as food in the region. Analysis of the results revealed that "extracts" were the most common use of the documented species (151) for the treatment of ailments, followed by powders (149) and decoctions and oils with 62 species each (Figure 4(b)). These results are confirmed by numerous other studies in nearby regions (Singh et al. 2020; Bhat et al. 2021; Lawal et al. 2022).

3.2. Ethnopharmacology

In the present study, we documented treatments for 59 ailments using the identified species (Figure 5). Most species (86), including *Curcuma longa, Vitis vinifera, Solanum tuberosum, Solanum nigrum, Solanum melongen*a and *Physalis angulate,* were used to treat skin ailments, followed by treatments for wounds (65 species) including *Curcuma longa, Lantana camara, Physalis angulata* and *Datura innoxia*, urinary tract infections (45 species) including *Tribulus terrestris, Lantana camara, Prunus persica, Fragaria vesca* and *Salix acmophyll*a), to treat cough (40 species) such as *Eriobotrya japonica, Prunus domestica, Populus nigra* and *Litchi chinensis*) and body aches (35 species) including *Murraya paniculata, Populus nigra, Dodonaea viscosa* and *Capsicum annuum*. A detailed list of diseases treated with each plant species can be found in Figure 5 and Table S1. The frequent use of these species for certain diseases is due to the strong belief in traditional knowledge, lush vegetation, good forest cover, high

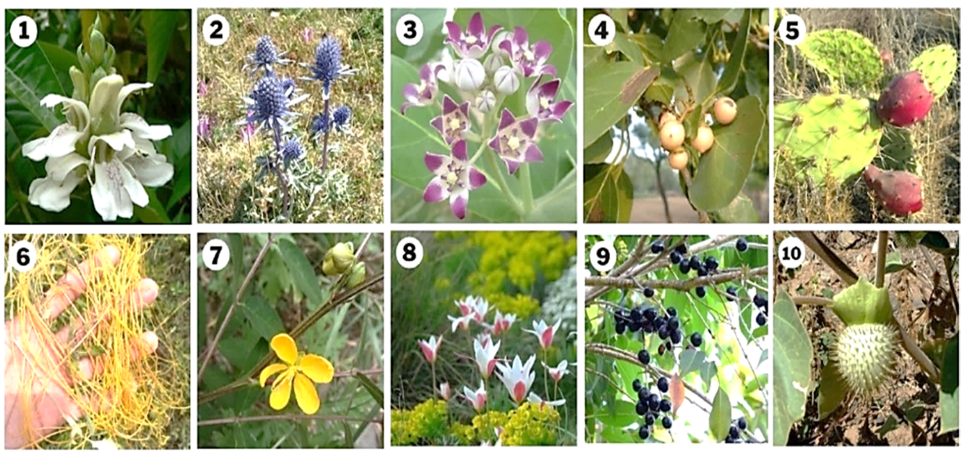

Figure 3. Photos of some documented taxa taken during the study period in Mardan district: (1) *Justicia adhatoda* (2) *Eryngium bourgatii* (3) *Calotropis procera* (4) *Cordia myxa* (5) *Opuntia littoralis* (6) *Cuscuta reflexa* (7) *Senna occidentalis* (8) *Tulipa clusiana* (9) *Syzygium cumini* (10) *Datura innoxia.*

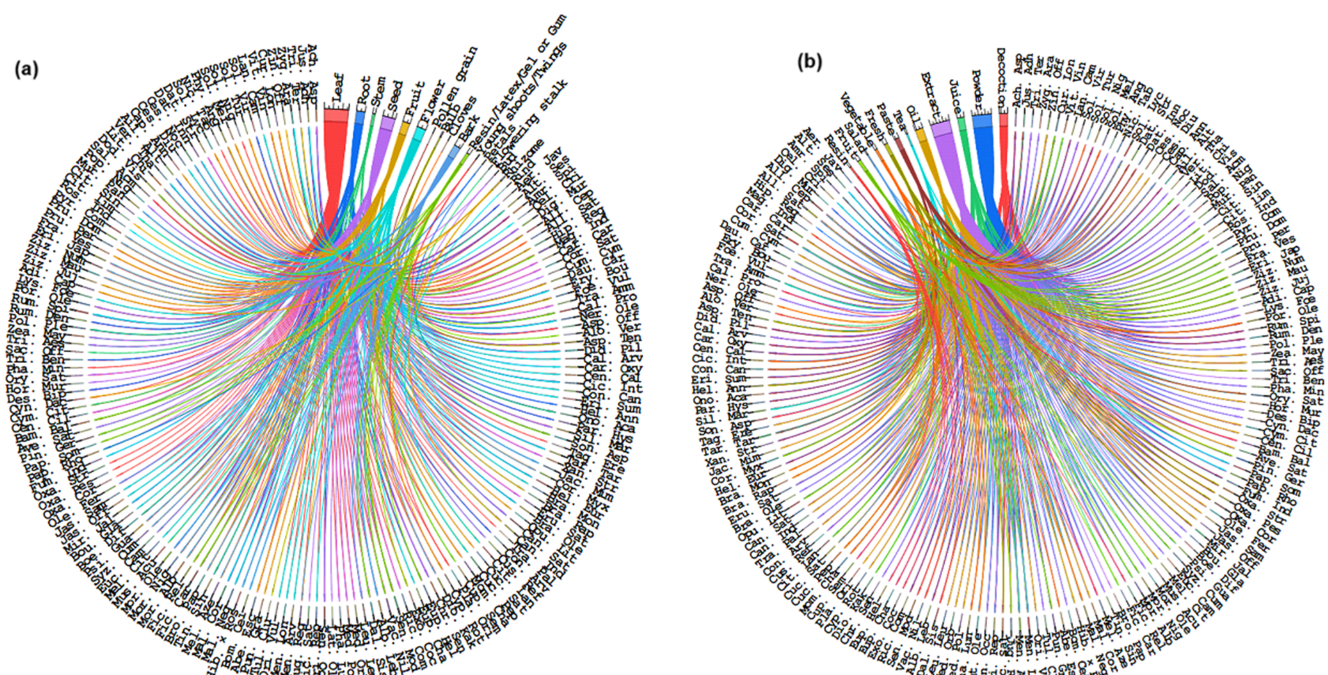

Figure 4. (a) Number of different parts of the documented species used for ethnomedicinal use (the thickness of the line for each part represents the most common use); (b) forms of preparation for ethnomedicinal use of the documented species (the thickness of the line for each preparation represents the most common use). The full names of the plant species can be found in Table S1.

dependence of the locals on nature and low urbanization. Amin et al. (2024) also reported the use of plant species to treat various ailments across different cultures upon reporting the medical ethnobotany of Kohistan, Pakistan.

Local traditional medicine attaches great importance to spring water, as it is believed to possess therapeutic properties and a divine essence that is beyond human comprehension. This water is used extensively in the preparation of medicinal herbs, including decoctions, pastes and infusions, to enhance the supposed efficacy of herbal formulations. The elders are the main knowledge holders who diagnose and treat the primary health conditions in the households and pass on the ethnomedicinal knowledge to the younger generations. As the healthcare infrastructure is limited, the local population relies heavily on natural remedies to maintain their health and treat illnesses. Financial constraints exacerbate the inaccessibility of healthcare, as many people cannot afford to travel to urban centres for medical treatment. Apart from economic barriers, deeply rooted cultural norms significantly influence behaviour when seeking medical care. Many women do not go to male doctors as it is culturally considered inappropriate to be treated by a male doctor outside the family. Similarly, men often prohibit their female relatives from seeking treatment from male doctors, a restriction that is particularly rigid for young, unmarried women. These socio-cultural dynamics reinforce traditional healing systems and shape health care decisions in the region. Our findings are consistent with numerous studies from the nearby region (Hassan et al. 2023; Amin et al. 2024; Ullah and Badshah 2024) and show that plant species continue to play a crucial role in modern health care.

In the present study, the FL ranged from 94.37 to 6.67 (Table S1). The highest value was calculated for Asparagus officinalis (FL = 94.37) for diseases (urinary tract infection) followed by Daucus carota (FL = 94.29) for diseases (digestive disorders). The lowest value was calculated for Physalis angulata (FL = 6.67) for diseases (rheumatic diseases). In the study area, Asparagus officinalis is a well-known traditional remedy for urinary tract infections. This plant has been historically valued in traditional Chinese medicine (TCM) and other healing systems for its health-promoting effects, largely due to its bioactive compounds, such as saponins, polyphenols and flavonoids (Guo et al. 2022). The Daucus carota, also known as Queen Anne's lace, has been valued for traditional medicinal uses, particularly for its diuretic properties (Ismail et al. 2023). Historically, its seeds and roots have been utilised in various cultures as a natural remedy for issues related to the urinary tract, such as kidney stones and water retention. It is also consumed as a natural cleaner for the digestive system. Other studies consistent with the present study are (Rana et al. 2019; Bibi et al. 2022).

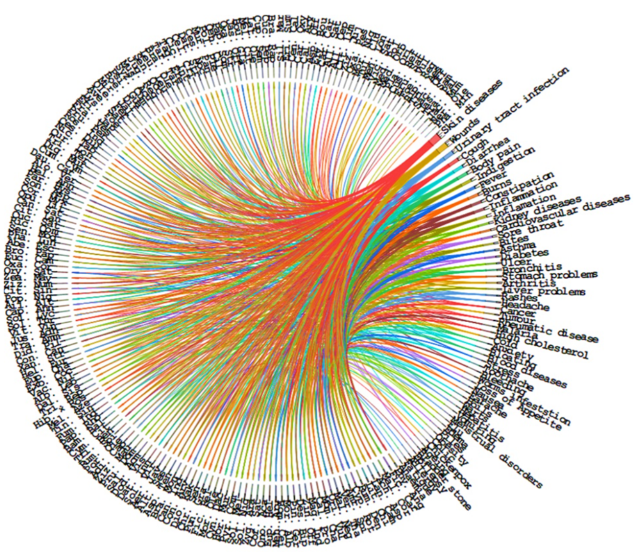

Figure 5. Chord diagram showing the diseases treated by the corresponding documented plant species in the study area in Mardan district, Pakistan. (the thickness of the chord for each disease represents the most common disease treated by the documented species) The full names of the plant species can be found in Table S1.

3.3. Period of collection

The present study has shown that the use of the documented species was seasonal, with collections taking place throughout the year. Most plant species were collected in April and May (76 species each), followed by June (74), August (63) and July (62) plant species (Figure 6(a)). The collection peak in April and May is likely due to the ripening of most species, which is thought to be associated with the highest concentration of phytochemicals, prompting locals to harvest them in this month. Detailed information on the plant species and the corresponding collection months can be found in Table S1. The prominent species with the highest FC collected in April include Cannabis sativa, Daucus carota, Opuntia littoralis and Musa acuminata. The information on the collection period is very crucial to the efficacy of traditional medicine. This efficacy of the drugs rates a traditional healer in the market. The local healers are well aware of the time of collection, some have developed a healing practice for a particular disease with the fluctuation in the collection of the species used to treat that disease and preparation method. To maintain a top position in the market these healers are reluctant to reveal the collection time and preparation methods. Many in-vitro studies have reported the change in the efficacy of the drug from nature (flora) with the change in time of collection (Calixto 2000; Rashid et al. 2021; Suteu et al. 2020). Awan et al. (2021) also reported that the collection of species in Kashmir Himalaya is seasonal. The Pearson's correlation coefficient clarified the strength and direction of the relationship between the month of collection and the species documented, with p-values given below (Figure 6(b)).

The UV is a measure used in ethnobotany to quantify the importance of a plant species based on the number of different uses reported by informants (Hassan et al. 2024). This measure helps determine the versatility or usefulness of a plant and reflects its cultural and practical importance. Analysis of our results showed that the UV value for the documented species ranged from 0.86 to 0.01 (Table S1). The highest UV value was calculated for Allium cepa (0.86), followed by *Allium sativum* (0.81). The lowest UV value was calculated for Tradescantia pallida (0.01). The highest UV value for Allium cepa can be attributed to the fact that the plant is

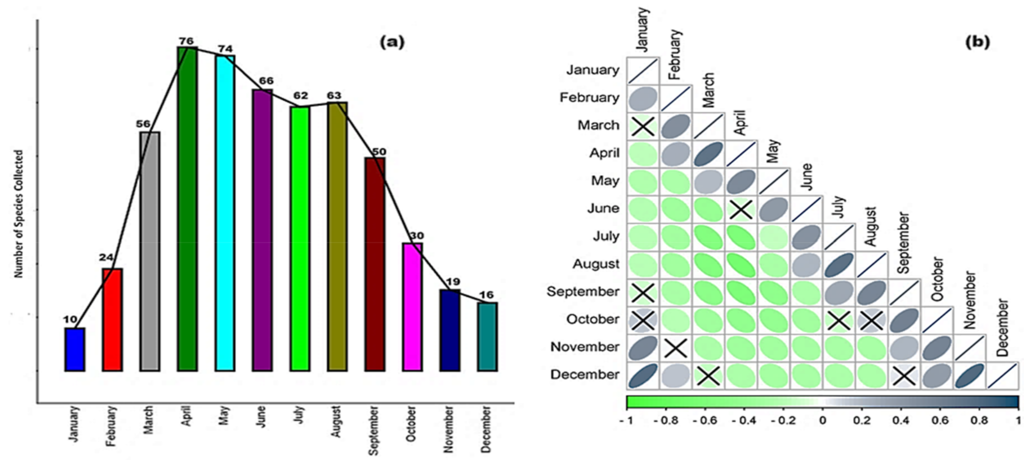

Figure 6. (a) Number of collected medicinal plants among the different months; (b) cladogram revealing Pearson correlation between the selected months and collected species.

used medicinally and gastronomically. In the local traditional culture, the people used to consume spicy food in which A. cepa plays a critical role. It is also consumed in various forms, i.e. salad, fried, cooked with any dish, especially meat, flavoring agent, and pickles. The ethnomedicinal attributions include wound healing, reducing inflammations, and treating cardiovascular diseases. Allium sativum (garlic) has long been valued for culinary purposes. The species is used to enhance the flavor of the food, mostly consumed in winter. It is believed that garlic keeps the body warm, and therefore is roasted in hot ashes, turns yellow, and eaten every day. It has a wide range of medicinal uses. The diseases it is traditionally used to treat include earache, skin conditions, and high cholesterol levels. Historically, garlic has been utilized as an antimicrobial agent. It has been reported that a sulfur compound namely allicin is responsible for this property (Bhatwalkar et al. 2021).

3.4. Comparison and Jaccard index

The present study shows significant differences in the ethnomedicinal use of plants in different communities of Pakistan. A comparative analysis was carried out with reference to 12 national ethnobotanical studies (Bahadur et al. 2020; Sulaiman et al. 2020; Jan et al. 2021; Parveen et al. 2021; Begum et al. 2022; Khan et al. 2023; Rehman et al. 2023; Rehman et al. 2024; Nazar et al. 2024; Amin et al. 2024; Ullah and Badshah 2024; Rahman et al. 2024) to assess the degree of similarity and divergence in the use of medicinal plants. The results show that 21 plant species documented in the present study have novel therapeutic uses not previously reported in the ethnomedicinal literature of Mardan district, Khyber Pakhtunkhwa, Pakistan.

Several species in the study area were found to have hitherto unknown medicinal uses. *Achyranthes aspera* was used to treat earache, *Datura innoxia* for toothache and *Eryngium bourgatii* for bladder stones. *Adiantum capillus-veneris* and *Cyperus rotundus* have also been identified as remedies for menstrual cramps. Remarkably, several species showed new applications in cancer treatment, including *Cichorium intybus*, *Conyza canadensis, Lantana camara, Senna occidentalis, Solanum nigrum, Xanthium strumarium* and *Zingiber officinale*. The study also listed *Amaranthus spinosus* and *Tripidium bengalense* as traditional remedies for haemorrhoids, a use not previously reported in this region. Further ethnobotanical findings led to the first documentation of *Calotropis procera* and *Xanthium strumarium* for ulcers, *Carthamus oxyacantha* for cardiovascular diseases, *Solanum virginianum* for epilepsy, *Tinospora sinensis* for hepatitis and *Zygophyllum arabicum* for smallpox. In addition, *Momordica charantia* and *Lantana camara* were newly recognised for their role in the treatment of chickenpox.

To quantify the degree of similarity between the use of medicinal plants in the Mardan district and the previously reported ethnobotanical studies, the Jaccard index was calculated. The index ranged from 1.24 to 3.12, indicating low to high ethnobotanical similarity between the present results and previous studies (Table 2). These differences indicate the potential for regional diversification in the use of medicinal plants. Also, based on PCA, considerable variation was found between the selected studies. The previously conducted studies were more closely related than the present study. PC1 (37%) and PC2 (12.84%) of the study comparison in the "current study" biplot clustered on one side of the PCA and formed a separate cluster based on species indication (Figure 7). Other studies that are in accordance to the present study include (Haq et al. 2022; Ahad et al. 2023).

3.5. Transfer of traditional knowledge

The intergenerational transmission of traditional knowledge plays a central role in preserving cultural heritage, protecting biodiversity and maintaining the vital link between communities and their local environment (Hassan et al. 2024). The transmission of knowledge from one generation to the next ensures that best practices, rituals and knowledge are not lost (Jacob et al. 2024). This transmission promotes resilience, maintains ecological balance and enriches the collective

Table 2. Jaccard index; comparative analysis between the present study and other studies from Pakistan.

Area	Study year	Number of recorded plant species	Plants with similar use	Plants with dissimilar use	Total species common in both areas	Jaccard index	Citation
Northern Waziristan	2024	69	1	6	7	3.04	Rehman et al. (2024)
Karak district	2024	38	2	3	5	2.48	Nazar et al. (2024)
Kohistan, northern Pakistan	2024	96	1	7	8	3.12	Amin et al. (2024)
Chitral, eastern Hindu Kush	2024	150	1	4	5	1.6	Ullah and Badshah (2024)
Buner district	2024	140	3	2	5	1.6	Rahman et al. (2024)
Malakand district	2023	76	2	1	3	1.24	Khan et al. (2023)
Waziristan district	2023	108	1	3	4	1.47	Rehman et al. (2023)
Malakand district	2022	62	1	4	5	2.22	Begum et al. (2022)
Charsadda district	2021	118	3	2	5	1.77	Jan et al. (2021)
Mardan district	2021	85	5	1	6	2.42	Parveen et al. (2021)
Peshawar district	2020	71	1	2	3	1.27	Bahadur et al. (2020)
Buner district	2020	109	2	3	5	1.83	Sulaiman et al. (2020)

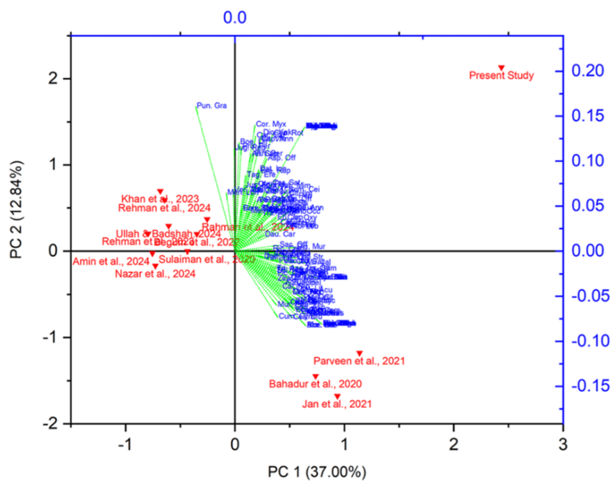

Figure 7. PCA shows the clustering of studies based on the indication of plant species.

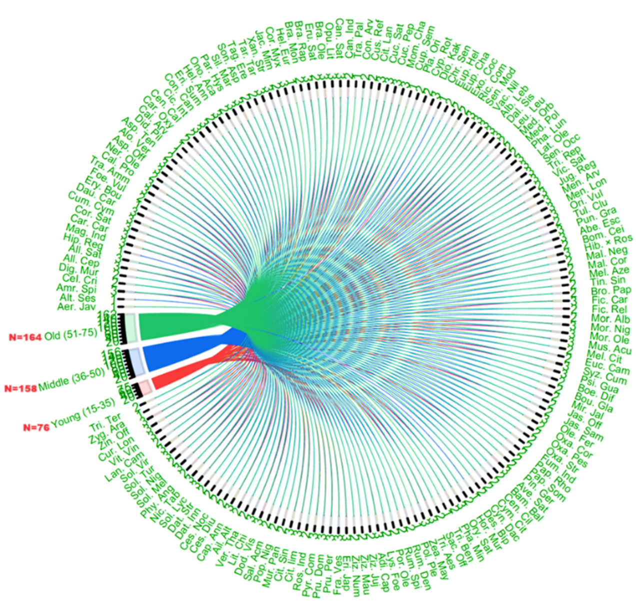

Figure 8. Chord diagram showing the traditional ethnobotanical knowledge in the different selected age groups (old, middle and young) of the respondents. The thickness of each chord in each age group represents the ethnobotanical knowledge on the use of the different plant species. The complete names of the plant species are given in Table S1.

identity of societies (Jacob et al. 2024). The transmission of traditional knowledge is a dynamic process that requires the active participation of both community members and external actors to ensure its preservation and relevance in the modern world (Mistry et al. 2021). In the present study, the highest number of information was recorded for the old age group ($n = 164$) in the selected sites, followed by the middle ($n = 158$) and young ($n = 76$) age groups (Figure 8).

No decline in traditional knowledge was observed across the generations (old and middle age groups), but a sharp decline was observed among the young generation. The decline can be attributed to several factors. Economic constraints often force families to send their children to work at a young age, sometimes in nearby regions, leading to a potential knowledge gap between generations. In addition, modern education in the region does not emphasise the usefulness, value or cultural significance of local ethnic knowledge. Social media has strongly influenced the mentality of the younger generation, resulting in many pursuing an urban lifestyle and working in hotels, restaurants and shopping centres. In addition, interest groups and non-governmental organisations have not provided effective scientific approaches to preserve traditional knowledge. Finally, geopolitical instability, border tensions, military conflicts, political disagreements and trade restrictions with neighbouring countries such as Afghanistan are also contributing factors.

The preservation of traditional food knowledge in the region (study area) requires the education of the population, the active involvement of indigenous peoples, gender-specific approaches, documenting recipes & practice, legal and policy support, support of indigenous language and transmission, and targeted efforts to combat land loss. These multi-faceted efforts protect cultural heritage and promote sustainable practices that both benefit local communities and contribute to a broader global understanding of humanity's intricate relationship with the environment. Many countries have adopted laws that safeguard indigenous knowledge and cultural practices. For example, the Convention on Biological Diversity and the Nagoya Protocol support the fair sharing of benefits arising from the use of genetic resources compared to the traditional knowledge, ensuring the Indigenous communities are compensated and acknowledged.

By combining tradition and innovation, we enrich our culinary landscape and celebrate the diversity of food cultures.

In the context of modern food science, the rediscovery of ancient grains, herbs and spices holds great promise due to their potential health-promoting properties (Mavrogonatou and Kletsas 2024). These traditional ingredients offer unique flavors, nutritional benefits and bioactive compounds that contribute to overall well-being and culinary innovation (Salta and Du 2024).

3.6. Livelihood, gastronomy, cultural significance and food security

Apart from the ethnomedicinal classifications, this study identified numerous species that have a market value and are used by the local population to generate income. When analyzing our results, we found that most plant species (109) had a market value and $n=59$ had no market value (Table S1). Most of the plant species with market value were cultivated (86) and 82 were collected in the wild. The main cultivated species include *Allium cepa, A. sativum, Coriandrum sativum, Aloe vera, Carum carvi.* Of the wild species, *Cannabis sativa, Asparagus officinalis, Opuntia littoralis,* and *Ziziphus jujuba* were of commercial importance. It is important to note that cultivating wild species apart from collection by the local people can play a vital role in the livelihood of generations. For instance, Paris polyphylla is primarily used in the Far Eastern Himalayan Landscape, including parts of Myanmar. The plant is considered a significant non-timber product (NTEP) and is extensively collected and traded for cash income. Local communities, particularly the Rawang and Lisu (ethnic groups), manage and cultivate this species, reflecting that wild species are important to the livelihoods (Aryal et al. 2020). Further, the wild species have the potential to withstand the diseases, if cultivated by adopting the scientific approach can be proven beneficial in assisting the local economy. Wild species are also highly resilient in diverse climates and require minimal inputs like water and fertilizers which makes cultivation cost-effective and sustainable allowing the local communities to save on resources while maintaining steady yields (Goldringer et al. 2010).

Regarding the wild gastronomy, a total of 24 species were recorded, representing 14.28% of all recorded taxa. Different parts of the documented species were also found to be used for gastronomic purposes, with the fruits being the most commonly used part of most species, followed by the leaves (Figure 9(a)). The main use of the fruits can be attributed to their appealing nature and the local belief (that anything edible from nature that does not require further processing has healing and life-prolonging properties). The documented plants were consumed in various forms, i.e. as vegetables, tea, juice, oil, raw and as a flavor enhancer (Figure 9(b)), out of all these forms, most of the parts consumed were "raw" followed by "vegetables". The reason for the maximum use of "raw" is that most of them are fruits, which are preferably consumed raw. Ogidi (2023) reported on the use of fruit in Africa.

In recent decades, research has focused intensively on the biological and cultural history of medicinal and food plants worldwide. In the present study, several plant species have a unique cultural significance. *Mangifera indica* (Mango) symbolizes prosperity and good fortune. Mango leaves are commonly used in local festivals and ceremonies. Sharma et al. (2024) reported the importance (traditional medicine) of *M. indica* in India. *Calotropis procera* (Sodom apple, giant milkweed) is considered sacred in some local customs and is used in religious rituals. Bansal et al. (2023) reported on the use and importance of *C. procera* in Ayurveda in India. *Nerium oleander* (Oleander, Rose Bay) is valued for its beautiful flowers and used in local festivals, although it is known to be poisonous and should be handled with care. *Ficus religiosa* (Bodhi Tree, Sacred Fig) is considered sacred and is often associated with various religious and cultural practices. It is considered auspicious and is often found near religious sites. Sharma et al. (2023) report in their review article on the importance of *F. religiosa* in ethnomedicine.

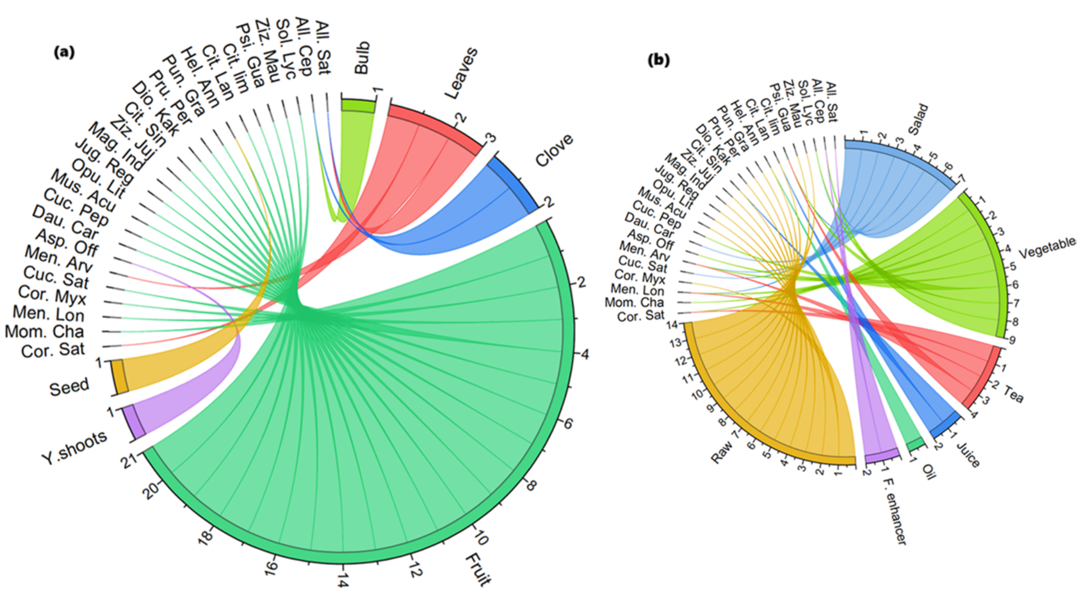

Figure 9. (a) Chord diagram showing the different parts used for gastronomic purposes; (b) chord diagram showing the use of the documented gastronomic species consumed in various forms. The complete names of the plant species are given in Table S1.

The study area is in the province of Khyber Pakhtunkhwa (KPK) in north-west Pakistan and shares a western border with Afghanistan. Pakistan is highly dependent on vegetable imports, including onions, tomatoes, potatoes, ginger and garlic, from neighbouring countries such as Afghanistan, Iran and China. These imports are important to stabilise domestic markets and mitigate the impact of local production bottlenecks. However, geopolitical tensions, trade restrictions and border conflicts significantly disrupt vegetable supply chains and lead to price fluctuations and food insecurity. Trade embargoes, logistical challenges, increased transport costs and smuggling exacerbate market instability and lead to acute shortages of essential vegetables. As a result, inflationary pressures are escalating, disproportionately affecting economically vulnerable groups and fuelling popular discontent. To combat food insecurity when the supply chain is disrupted, an approach based on scientific and traditional knowledge can be taken by incorporating edible wild plants into the local diet. Several nutrient-rich wild plant species, including *Amaranthus spinosus, Digera muricata, Asphodelus tenuifolius, Cichorium intybus, Opuntia littoralis, Medicago orbicularis, Medicago polymorpha, Mentha longifolia, Malva neglecta, Oxalis corniculate, Oxalis pes-caprae, Oxalis stricta* and *Ziziphus nummulari*a, have significant gastronomic potential.

Domestication and cultivation of these species in local agricultural systems can provide a sustainable alternative to imported vegetables, reduce dependence on external supply chains and improve regional food resilience. The integration of edible wild plants into the cultural diet not only supports food security in times of crisis but also promotes biodiversity conservation and agroecological sustainability in the region.

4. Research gap for future studies

Despite the extensive documentation of plant species and their ethnomedicinal uses in the Mardan district, Khyber Pakhtunkhwa, Pakistan, there are still some gaps that need further investigation. While the study highlights the therapeutic applications of these plants, there is a lack of pharmacological validation to substantiate these claims. Future research should focus on biochemical and clinical evaluations to verify the efficacy, safety and potential bioactive compounds of these medicinal plants. The economic and cultural importance of certain plant species demonstrates the need for market-orientated conservation strategies. However, there is insufficient research on the sustainable harvesting and commercialisation of these high-value medicinal plants. Although the study emphasises the importance of preserving traditional knowledge, the intergenerational transmission of ethnomedicinal knowledge remains a critical gap. Future research should investigate the socioeconomic and educational factors that influence knowledge preservation and explore community-driven conservation models to preserve traditional practises. Although the study provides a statistical correlation of plant distribution, a more detailed ecological assessment of the environmental factors that influence plant growth, availability and climate resilience is needed. Understanding these dynamics can contribute to the long-term conservation and sustainable use of medicinal plants in the region.

5. Conclusions

Given the global dependence on plants, the continued use of various species is essential to meet the basic medical needs of a large proportion of the world's population. These plants play an important role in traditional medicine, cultural identity, food security and the creation of economic opportunities, but also have an impact on the environment. This study highlights the important role of traditional knowledge in maintaining the health, traditional medicine and cultural practices of the local people of Shahbaz Garhi and Rustam (Sudhum Valley). By documenting the plant species used as medicine and food, the study shows how traditional practices are closely linked to the well-being of the community, especially in areas where modern health care is limited. These practices not only provide important health resources but also contribute to the preservation of cultural heritage and strengthen the connection between local people and their environment. The knowledge of these traditional practises is predominantly in the hands of older people and is passed on orally to subsequent generations. The erosion of this knowledge transfer poses a significant threat to these traditions. It is crucial to document, preserve and revitalise traditional knowledge to maintain cultural practises that promote health and well-being, and to ensure that these time-honoured methods continue to benefit future generations in a rapidly changing world.

The economic and cultural importance of certain plant species emphasises the need for market-driven conservation strategies. However, there is little research on the sustainable harvesting and commercialisation of these high-value crops. Future research should investigate the socio-economic and educational factors that influence knowledge conservation and explore community-driven conservation models to preserve traditional practises. In addition, the local market is affected by geopolitical and other challenges such as the unavailability of food and increased prices. These problems can be mitigated by utilising traditional knowledge and a scientific approach to incorporate various wild species, including *Digera muricata, Amaranthus spinosus, Medicago polymorpha, Malva neglecta* and *Oxalis corniculata*, into the local diet.

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Authors' contributions

Conceptualization: MH and AMA; methodology: MH, MM, MAA and QZO; data collection MM; data analysis MH, MSA; initial draft MM; supervision: MH and AMA; Revision IVK, SW, AMA, MAA, MSA, RWB and MAA. All authors read and approved of the final manuscript.

Disclosure statement

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Data availability statement

All the required data is provided in the article.

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