Knowledge and medicinal plants in El Ach region (Algeria)

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Research

Abstract

Background: This ethnobotanical study intended to count the plants species according to their uses by people, whether as ethno-medicinal in the local traditional medicine, food or anything else in El Ach region southern Bordj-Bou-Arreridj (Algeria).

Methods: The ethnobotanical data were collected in 2023 from 130 local informants through structured questionnaires and interviews, focusing on medicinal plant names, parts used, preparation methods, applications, and treated ailments. Quantitative analysis involved two indices, Use Value (UV) and Fidelity Level (FL), to assess data significance and reliability, while Non-Metric Multidimensional Scaling (NMDS) was used to explore the relationship between plant use and participants' socio-demographic characteristics.

Results: An inventory recorded 53 medicinal plant species from 26 botanical families, with Asteraceae being the most represented (12 species), followed by Lamiaceae (7 species), and others having between 1 to 4 species each. Asteraceae species were widely used to treat various diseases using methods like decoction, compress, infusion, and powder. For example, *Artemisia herba-alba asso* with a fidelity level (FL) of 89.39%, is notably used to treat diabetes, stomach pain, colon issues. Additionally, Non-Metric Multidimensional scaling (NMDS) analysis showed significant relationships and differences in plant knowledge across different age groups.

Conclusions: This research explores the rich ethnobotanical heritage of the El Ach community, revealing a wide variety of traditional medicinal plants used locally. It emphasizes the community's strong bond with nature and the importance of ethnobotanical studies in preserving indigenous knowledge for the future.

Keywords: Ethnobotany, Medicinal Plants, Traditional Medicine, El Ach region, Algeria.

Background

Ethnobotany plays a crucial role in various fields by studying the relationship between populations and their natural environment to develop systematic methods for exploring plants. Phytotherapy, based on traditional plant use as a natural and diverse healthcare source, has been important historically and continues to grow due to factors like the wide variety of plant applications, heritage recipes, and minimal side effects (Bouafia *et al*. 2021). The global increase in natural plant product use stems from traditional medicine evolving into cultural heritage and growing worldwide interest, boosting the herbal market (Wahyuni & Afidah 2022). Ethnobotanical studies remain essential for discovering new medicinal plants while preserving existing knowledge (Lakhdari *et al*. 2016).

For the north Africa in general and Algeria in particular, the use of plants in medicine goes back to the history of Arab and Islamic medicine, especially which was transmitted with religious texts such as hijâma (cupping therapy), Ruqyah (recitation of the Quran) in addition to the traditional herbal mixtures and phytotherapy (Bouafia *et al.* 2021) as an primary mode of health care for the majority people in those areas (Rajaei & Mohamadi 2012), people resort to using the plants species as food or medicinal treatment according to their traditions and knowledge about plant therapy used to the health's preservation, and the old people are the main source of those recipes and skills which transmitted from generation to other (Hussain *et al.* 2022). According to that we make our investigations in south of Bordj-Bou-Arreridj province as an ethno-medicinal case study to promote human wellbeing in his environment by supporting conservation initiatives and preserving the herbal medicine tradition (Xiong *et al.* 2020), the specific objective was to estimate the use value and fidelity level of this herbal flora (Shaheen *et al.* 2023). Therefore, we attempt to show the importance of using the natural resources and the necessity of preserving them.

Materials and Methods

Study area

This research was conducted in El Ach region 35° 57' N 4° 41' E, in the southern part of the mountains in the Bordj-Bou-Arreridj province, Algeria. Notably, the region boasts lush mountainous forests. It is encircled by diverse vegetation, including a variety of medicinal plants that local communities have long utilized in traditional healing practices. The surrounding forests are particularly rich in plant biodiversity, serving as a valuable resource for alternative medicine aimed at treating diseases and promoting overall health (Shalukoma *et al.* 2016) (Fig. 1).

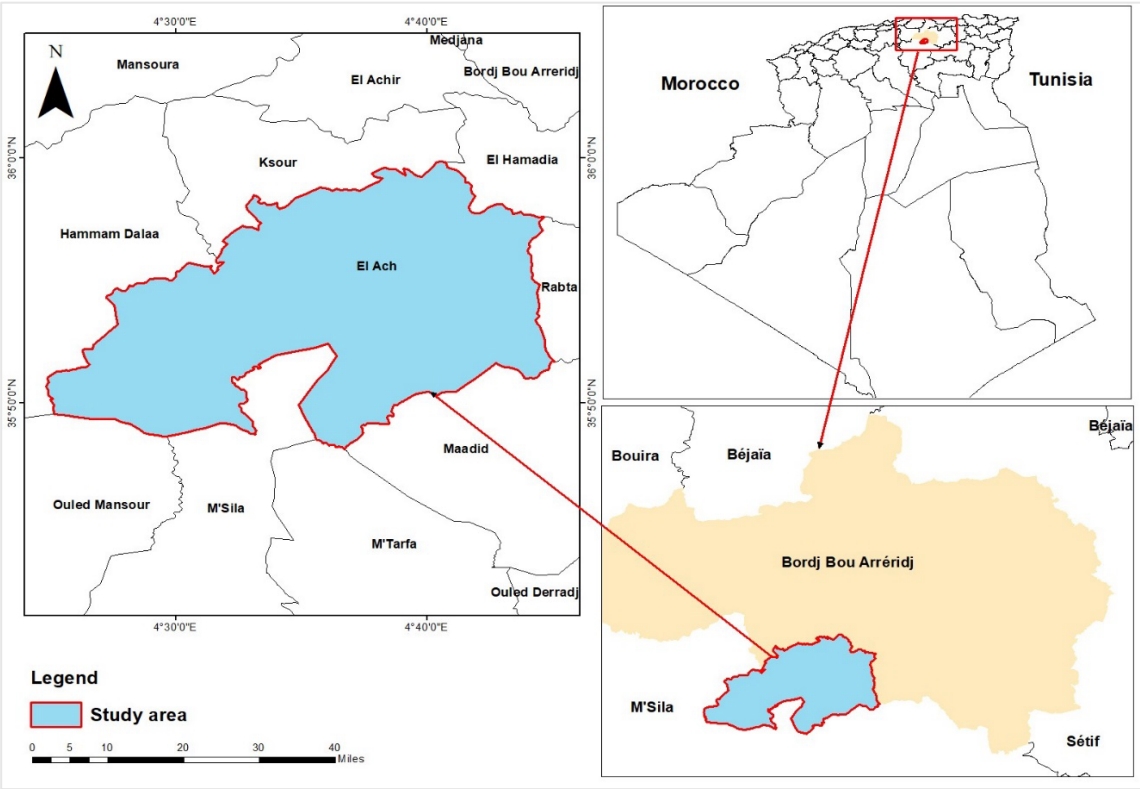

Figure 1. The location of the study area (El Ach region).

Data Analysis

Our ethnobotanical surveys have been carried out in 2023 spring in (El Ach region). Using interview sheet which contain more than 22 question with a total of 130 informants on both genders, they have different age stages and education levels. Our objective was to know more information about the natural herbal treatment methods and the most typical medicinal plants used in our study area and the all the species information's (vernacular names, diseases treated, part used, method of preparation).

Statistical Analysis

All data gathered from this ethnobotanical survey were first transcribed and subjected to descriptive statistical analysis using Microsoft Excel 2016. For more comprehensive multivariate analyses, we utilized PAST software (version 4.03). This approach enabled us to explore the complex relationships among plant species, human participants, and their surrounding environment (El Mekkaoui *et al.* 2024).

Ethnobotanical data analysis

The used value (UV): According to (Trotter & Logan 1986) the special use of UV is to determine the relative importance of local species. It was used to determine the most listed and recommended plant species for the treatment of a specific disease category, UV was calculated using this formula: $UV = \Sigma Ui / N$

UI: the number uses reports for each species,
N: the total number of informants (Bouafia *et al.* 2021)

The fidelity Level (FL): According to (Phillips 1993) FL is calculated to estimate the priority of species over other species and their specific use. The specificity of the treated disease is determined by plant species and can show that the utilization of plant for specific therapeutic purposes (Bouafia *et al.* 2021). It is determined using the formula used by: $FL= (Nr /N) \times 100$

Nr: the number of respondents that recom-mended the use of the plant for a specific disease,
N: the number of respondents that suggested the plant for several illnesses (Shaheen *et al.* 2023).

Scaling Analysis (NMDS)

Non-metric multidimensional scaling (NMDS) is a robust technique well-suited for analyzing non-normal, discontinuous data, such as those collected in this study. In our analysis, interview responses were incorporated as external variables to aid in the interpretation of the ordination results. Continuous variables, including age, gender, and education level, were adjusted within the ordination matrix to facilitate multivariate analysis. The primary data matrix consisted of useful plant species recorded during the interviews, with age categories and gender represented in rows and plant species in columns (Beltrán-Rodríguez *et al*. 2014).

Results and Discussion

In the study area we obtained as a result 53 species under 26 botanic families.

Ethnobotanical analysis

Age

The total number of people in our study was 130 interviewed with a deferent age stage distributing as follow: the young and moderate age {30-50} whit (31%), following by is greater than 70 was 15 %, and the last is less than 30 years (11 %), where the dominant category is {50-70} (43 %) depending on the result of Guechi (2022) in the Maadid region which get (53%) for 20 to 30 age group (Fig. 3).

Gender

Our study touched on both genders, women and men, but we noted that the female gender is predominated by 59 % (77) compared to 41% (53) for male gender which prove that the women are more concerned with treatment, the preparation of recipes and they are responsible for the health of their families, as the same result for the ethnobotanical study of Guechi (2022) and Marrouche *et al.* (2021), also because I am a woman, I was able to communicate with almost all the women of the region (Fig. 4).

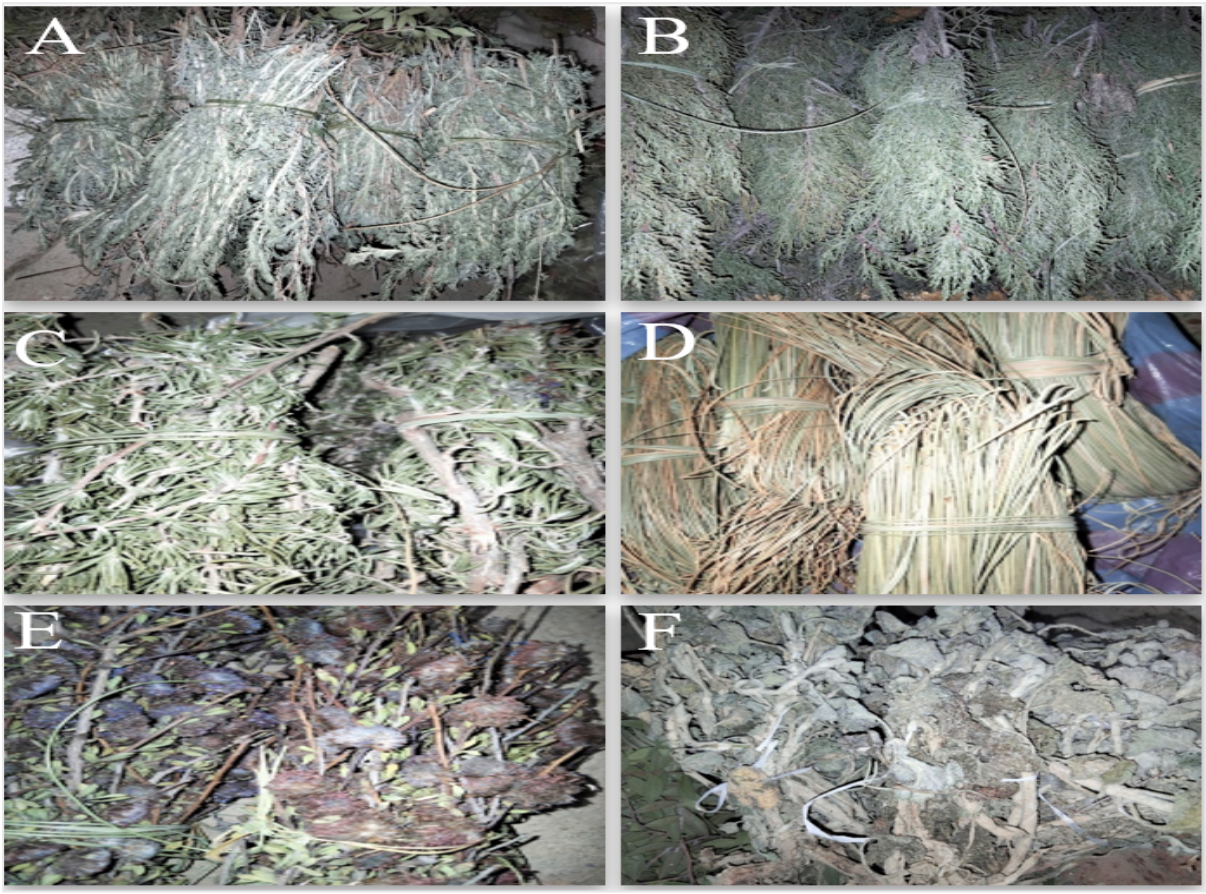

Figure 2. The medicinal plants species: *A- Artemisia herba-alba B- Juniperus oxycedrus C- Rosmarinus officinalis D- Macrochloa tenacissima E- Globularia alypu. F- Marrubium vulgare*

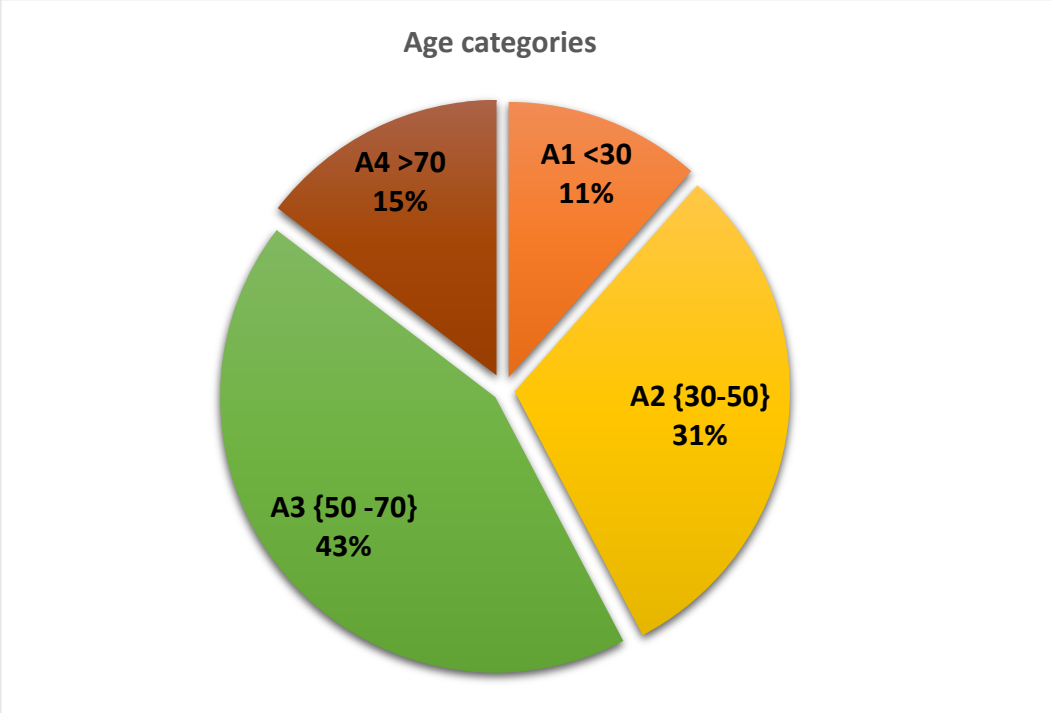

Figure 3. The age categories of informants.

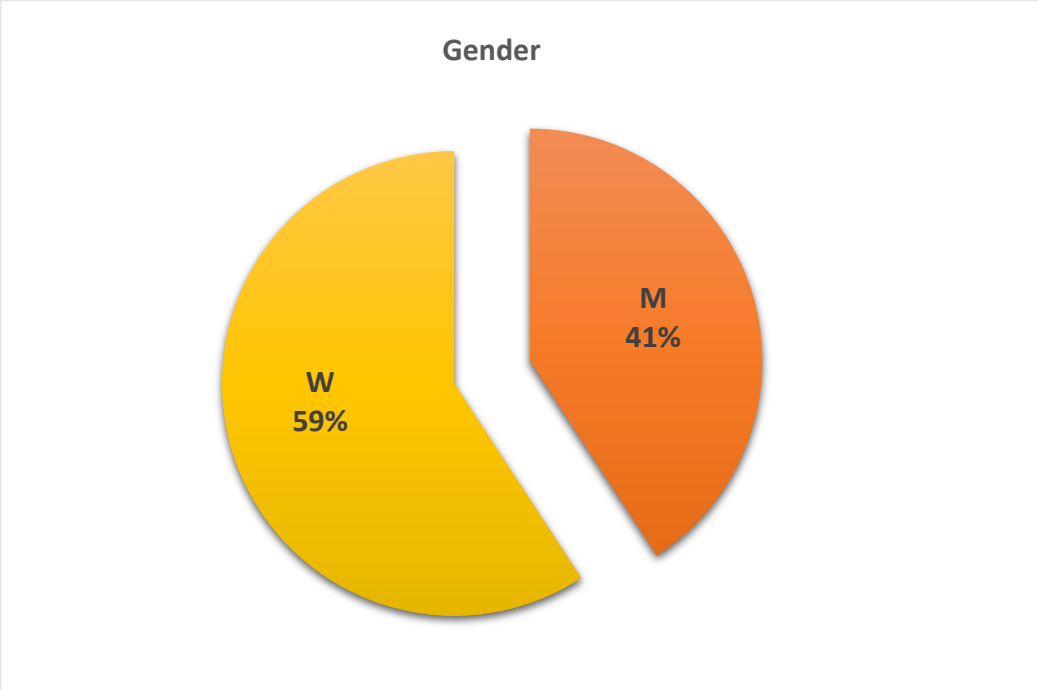

Figure 4. The dominant gender of informants.

Education level

According to Marrouche *et al.* (2021), the use of medicinal plants is most common among people with a primary level of education, accounting for 34% of users. This relatively high percentage is directly correlated with the education level of the local population using the plants. However, people with a secondary school education also have a significant percentage of medicinal plant use at 26%. In contrast, in our study the dominate are illiterate 52 % because most of them were women over 50 years old, following by 19 % middle school ,11% primary and 10 % high school & those 8 % with a university-level education have a lower percentage of medicinal plant use. They depend on the modern treatment. This correlation between education level and medicinal plant use highlights the complex interplay between traditional and modern healthcare practices in the local population (Fig. 5).

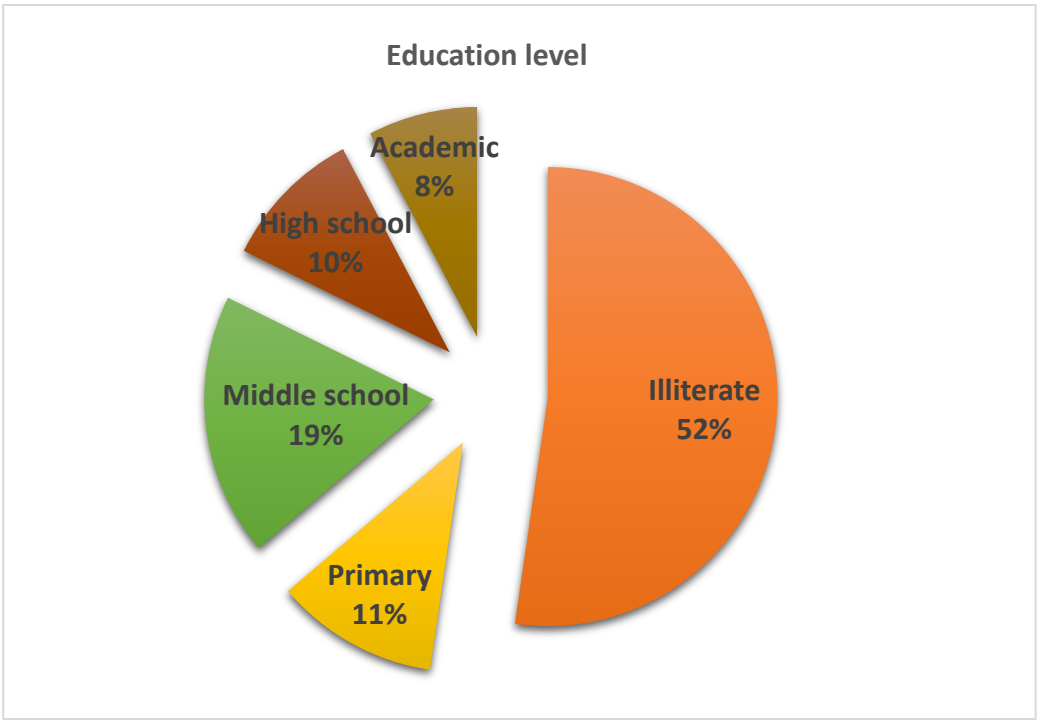

Figure 5. The education level categories of informants.

Profession

According to the population number affected by the investigation and taking the professional status into account, we obtained results indicating that the majority are common people whose profession is not related to plants 103 people out of 130 as a total (77%),14 as healers (11%) and 11 herbalists (8%) Boucherit & Benaradj (2023) in (Fig. 6).

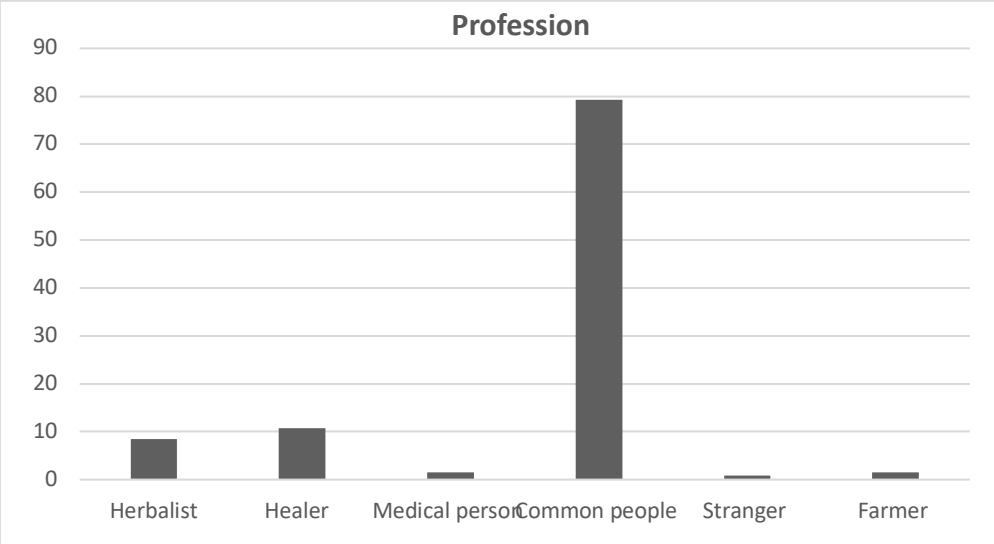

Figure 6. The deferent profession of informants.

The treatment type

Depending on Souilah *et al.* (2023) and Wendimu *et al*. (2024), and through the interviews with the local people the results indicate that the treatment type is varies, and that's depends on their traditions or experience, even the personal experience interferes in this, some of them resort to herbs (phytotherapy treatment) 44 % as an effective treatment, and only 25 % they prefer modern medicine, while the rest 31%are the category that uses the phytotherapy and also the medicines (Fig. 7).

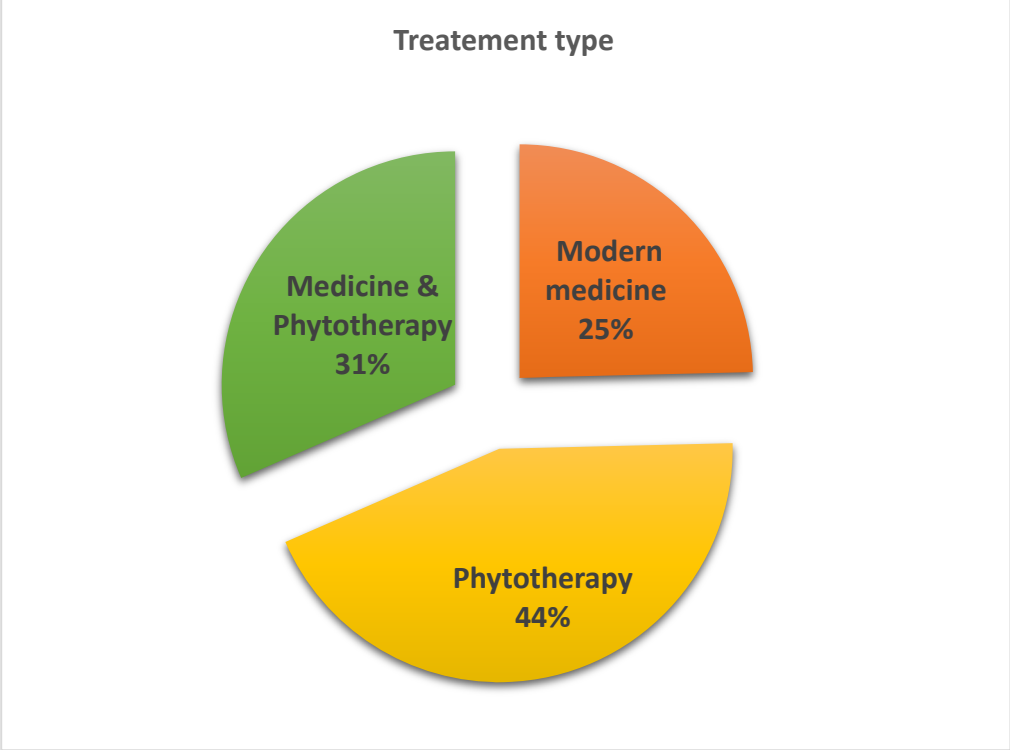

Figure 7. The dominant treatment type reported by informants.

Botanical diversity

Families and Species

Table 1. Medicinal species used by the population locale of El Ach.

Family	Species
ASTERACEAE	*Artemisia herba-alba* Asso.
	Carthamus pinnatus Desf.
	Cynara cardunculus L.
	Dittrichia viscosa (L.) Greuter
	Scolymus hispanicus L.
	Matricaria chamomilla L.
	Podospermum laciniatum (L.) DC.
	Sonchus oleraceus L.
	Pseudopodospermum undulatum (Vahl) Zaika, Sukhor. & N.Kilian
	Artemisia absinthium L.
	Santolina rosmarinifolia L.
	Anacyclus pyrethrum (L.) Link
LAMIACEAE	*Thymus algeriensis* Boiss. & Reut.
	Teucrium polium L.
	Ajuga chamaepitys (L.) Schreb.
	Rosmarinus officinalis L.
	Marrubium vulgare L.
	Mentha aquatica L.
	Mentha spicata L.
APIACEAE	*Macrochloa tenacissima* (L.) Kunth
	Bunium pachypodum P.W.Ball
	Cuminum cyminum L.
	Ferula communis L.
OLEACEAE	*Olea europaea* L. subsp. *europaea*
	Olea europaea L.
	Phillyrea angustifolia L.
PINACEAE	*Pinus halepensis* Mill.
	Cedrus atlantica (Endl.) Carrière
RHAMNACEAE	*Rhamnus alaternus* L.
	Ziziphus mauritiana Lam.
ROSACEAE	*Crataegus azarolus* L.
	Rubus incanescens (DC.) Bertol.
AMARANTHACEAE	*Atriplex halimus* L.
	Beta vulgaris L.
	Paronychia argentea Lam.
RUTACEAE	*Ruta angustifolia* Pers.
JUNCACEAE	*Juncus acutus* L.
FAGACEAE	*Quercus ilex* L.
MALVACEAE	*Malva sylvestris* L.
NITRARIACEAE	*Peganum harmala* L.
IRIDACEAE	*Romulea ligustica* Parl.
GLOBULARIACEAE	*Globularia alypum* L.
CUPRESSACEAE	*Juniperus oxycedrus* L.
ANACARDIACEAE	*Pistacia lentiscus* L.
RANUNCULACEAE	*Ranunculus bulbosus* L.
APOCYNACEAE JUUS	*Nerium oleander L.*
MYRTACEAE JUUS	*Eucalyptus globulus* Labill.
BUXACEAE	*Buxus sempervirens* L.
SOLANACEAE	*Lycium shawii* Roem. & Schult.
ERICACEAE	*Arbutus unedo* L.

POACEAE	*Ampelodesmos mauritanicus* (Poir.) T.Durand & Schinz
FABACEAE	*Trigonella foenum-graecum* L.
PLANTAGINACEAE	*Plantago major* L. subsp. *major*

Our result indicates that in total of 53 species distributed over 26 families were Asteraceae the most represented families (12 species) and Lamiaceae (7 species), then 4 species for Apiaceae, Oleaceae and Amaranthaceae (3 species), and Pinaceae, Ramnaceae (2 species), the rest species divided into small percentage Fagaceae, Rutaceae, Juncaeae, Iridaceae, Malvaceae, Nitrariaceae and author families (1 species) in (Fig. 8).

The significant representation of these botanical families relative to others can be linked to their specific richness at the local level, influenced by ecological factors that promote their growth and adaptation. Notably, the Asteraceae, Lamiaceae and Apiaceae families account for over 75% of all species identified in the area (Baziz *et al.* 2020). This also offers a strong indication of the local populations' extensive knowledge of plants and their development of this flora to meet their diverse needs. Comparable studies have been carried out in the surrounding area such as (Bouasla & Bouasla 2017; Chohra & Ferchichi 2019) or national scale (Ould el hadj *et al.* 2003; Hadjaiji-Benseghier & Der-ridj 2013; Lazli *et al.* 2019; Marrouche *et al.* 2021), these studies indicate that while the primary families remain consistent overall, the most prominently represented family varies from one study to another.

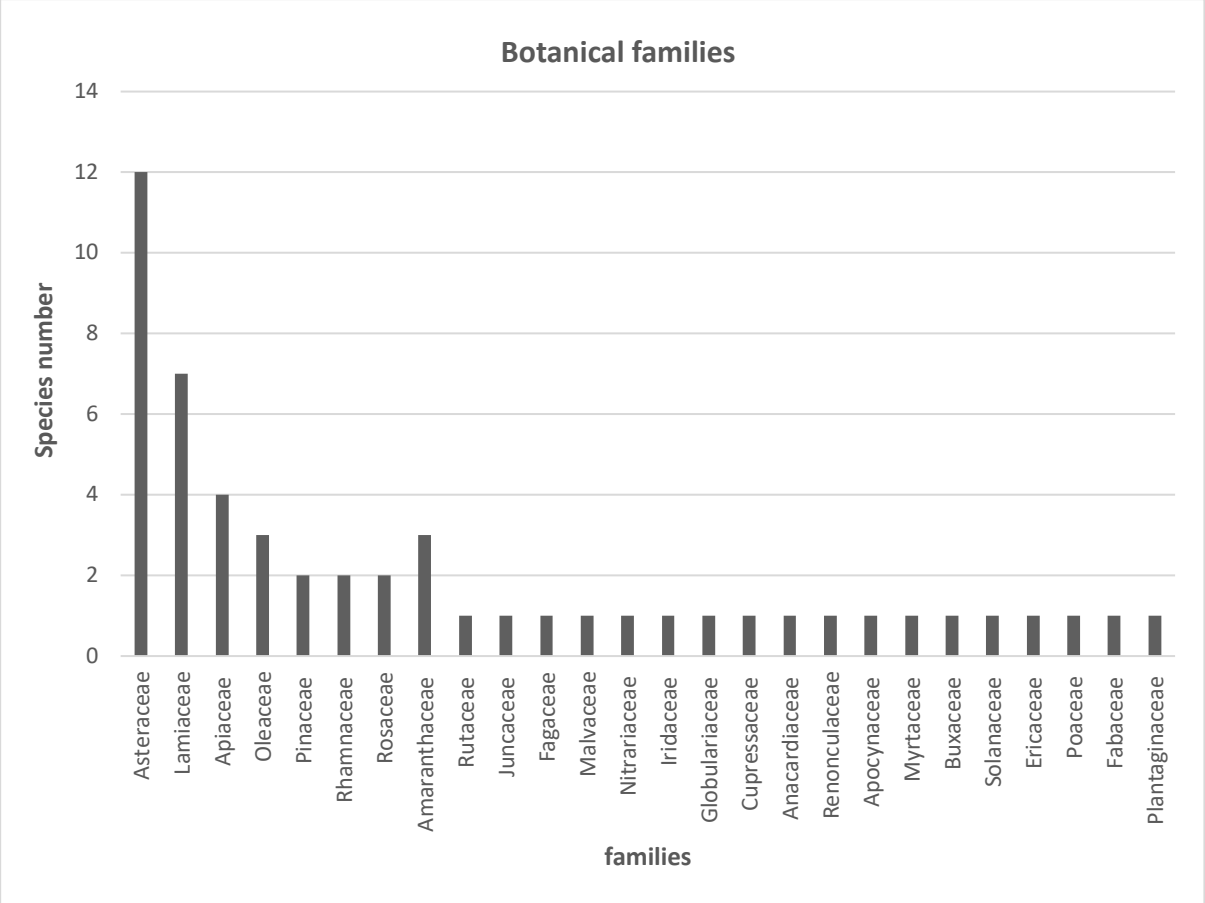

Figure 8. The botanical families.

Used part

According to Khusna *et al.* (2023), Guechi (2022) and Marrouche *et al.* (2021), the most commonly used parts of plants are leaves, which account for a significant percentage of plant usage. Other frequently used parts include roots, fruits, stems, bark, rhizomes, flowers, sap, branches, and tubers. We registered that the most used part was the leaves (77%) more used than the other parts 23% include flower (6%), in a similar proportion the seeds (6%), followed by stem and roots (4%), fruit (3%) in (Fig. 9).

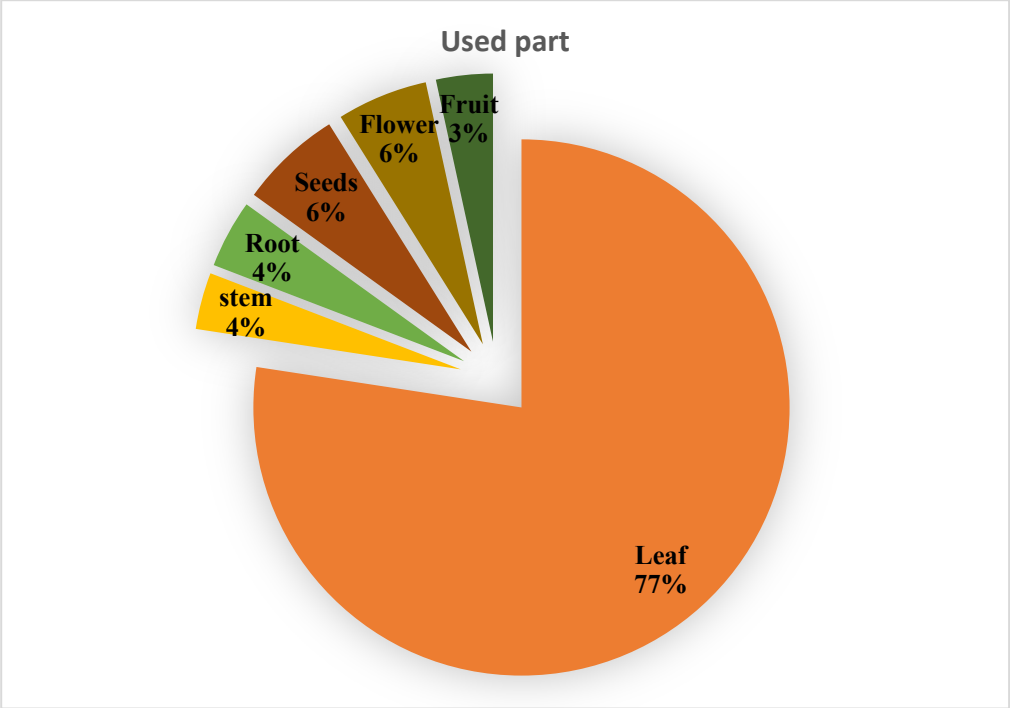

Figure 9. The dominant used part reported by informants.

Used purpose

This community and local population use the plants for a different purpose like treatment, they depending on it as a medicinal treatment (85%) where is the most common use, or for food (5%), in addition to other uses as aesthetic, aromatic (Ndlovu *et al.* 2024) (Fig 10).

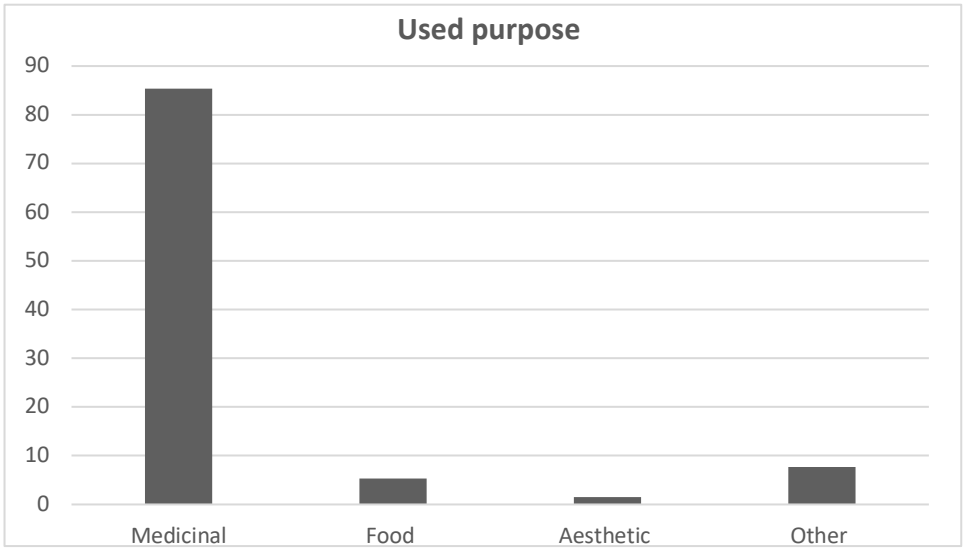

Figure 10. The dominant used purpose reported by informants.

Mode of preparation

To streamline drug administration, various preparation methods are utilized like: infusion, powder, fumigation, decoction, poultice, maceration and basting. Individuals consistently seek the most convenient approaches for preparing herbal remedies (Marrouche *et al.* 2021). Those preparation methods of herbs are differing and depending on the population's knowledge and the targeted treatment. Accordingly, in our study area, the results indicated that the concerned community uses the most typical methods as follow: the (67,69 %) use of drugs the preparation is carried out by boiling, which is they are considered easier and more effective by domestic community (Khusna *et al.* 2023) and (Boucherit & Benaradj 2023),

following by powder (12,30 %), the rest of the people chose other methods of use, such as maceration (7,62 %), infusion, vaporation, and cataplasma 3% for each beside other traditional methods. See the (Fig. 11).

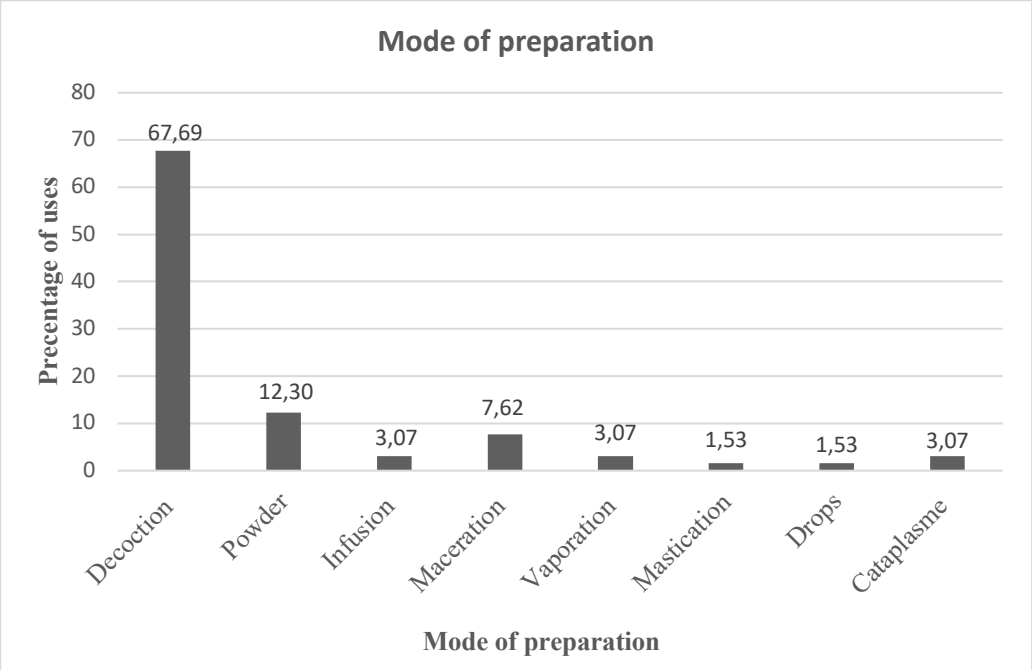

Figure 11. The dominant method of preparation reported by informants.

Medicinal plants used

The used values (UV): According to Xiong *et al*. (2020) and Belhacini *et al*. (2024) the plants used depending on the most popular plants in the area and the most abundant, easy to acquire, as well as effective in treating diseases, that represented in the used values (UV). The data collected from medicinal plants in our study area were collected in the complete inventory to all the medicinal plants and relevant information. The use value (UV) of each medicinal plant was calculated to assess the relative importance of each plant, based on the number of times mentioned and the number of informants. In this case we have 6 species with a high UV were *Artemisia herba-alba* (0,96), *Ruta angustifolia* (0,92)*, Rosmarinus officinalis* (0,88)*, Rhamnus alaternus.* (0,84)*, Juniperus oxycedrus.* (0,76)*, Teucrium polium.* (0,69) in (Table 2).

Table 2. The number uses reports for each species and UV.

Species	UI	UV
Artemisia herba-alba	125	0,96
Ruta angustifolia	120	0,92
Rosmarinus	115	0,88
Rhamnus alaternus	110	0,84
Juniperus oxycedrus	100	0,76
Teucrium polium	90	0,69

The fidelity level (FL): According to Nihayatul *et al*. (2023) FL is the priority of a plant species over other species and its specific use. It determines the specificity of treated disease by plant species. In the research area there are 7 plants with significant values and high FL category, including *Artemisia herba-alba* 89,39 % the plant is used to treat diabetes, *Rosmarinus officinalis L.* 76,92% to treat the colon, *Bunium incrassatum* specifically for the thyroid 75%, *Rhamnus alaternus* 69,23 % anemia, *Teucrium polium* 63,63% this plant is used as a treatment for the stomach pain, gastritis and wounds, we have also *Ranunculus bulbosus* and *Ruta chalipensis* 50% for gynecological diseases and flatulence (Khusna et al. 2023). Similar results were obtained in previous ethnobotanical surveys carried out in other parts of the world in which the number of plants with a higher FL representing by Idm'hand *et al*. (2020) in (Table 3).

Table 3. The number of respondents that recommended the use of the plant for a specific disease and FL.

Species	Nr	FL
Artemisia herba-alba.	59	89,39 %
Rosmarinus officinalis	50	76,92%
Bunium pachypodum	15	75%
Rhamnus alaternus	45	69,23 %
Teucrium polium	35	63,63%
Ranunculus bulbosus	10	50%
Ruta angustifolia	40	50%

The NMDS ordination

The primary objective of NMDS ordinations is to depict sample units derived from a complex, high-dimensional distance matrix in a simplified, low-dimensional space, facilitating the visualization of community composition gradients for more accessible interpretation (Adams *et al.* 2019; Roberts *et al*. 2020; Duan *et al*. 2025). In this study, the analysis incorporated four age categories of informants (A1, A2, A3, and A4) as well as their gender (Fig. 3 & 4). and the plant species they used, revealed clear patterns of similarity and dissimilarity in ethnobotanical knowledge among these groups. In the NMDS plot, points representing informants or groups with similar knowledge of plant species cluster closely together, while those with more divergent knowledge are positioned farther apart. Distinct groupings or gradients among the four age categories suggest that plant knowledge varies significantly with age. Specifically, older informants particularly those over 50 years old (A3, A4) demonstrated greater familiarity with useful plant species compared to younger individuals. This pattern likely reflects the cumulative nature of ethnobotanical knowledge, which tends to deepen throughout the life cycle. Our findings align with previous studies, such as a study conducted in Sidi Belabbes, Algeria, by Belkessam *et al*. (2022) found that individuals aged 40 to 60 possess a significantly stronger knowledge of local medicinal practices, representing 51.02% of the respondents with the greatest understanding compared to other age groups (Dahmane *et al.* 2023) and (Beltrán-Rodríguez *et al.* 2014) that emphasize knowledge differences between younger and older people and suggest that ethnobotanical knowledge continues to accumulate well beyond 30 years of age where the ethnomedicinal knowledge is primarily held by the elderly within the local community, who play a crucial role in passing this wisdom to younger generations. One key factor influencing the use of medicinal plants is the level of education. In the research area, individuals without formal education possess the greatest knowledge of medicinal plants (44%), followed by those with a primary education (Kaci *et al*. 2022; Belhaj *et al.* 2022). Additionally, our study revealed gender differences, with female participants demonstrating greater knowledge and usage of plant species such as *Mentha aquatica*. Traditionally, this plant has been used medicinally to treat colds and gastrointestinal issues in various regions of Algeria and other parts of the world (Benabdallah *et al.* 2016; Hadjadj *et al.* 2024; Piers *et al.* 2024) as well *Marrubium vulgare* which its medicinal applications include wound healing, managing diabetes, regulating blood pressure, and treating respiratory diseases (Boutabia *et al*. 2020). This is likely related to their traditional roles in family care and resource management, the prevalence of women's use of this plant can be attributed to their engagement with it for purposes beyond therapy, as well as their maternal roles, in which they often administer first aid, particularly to their children (Abbes *et al*. 2025; Benchohra *et al* .2025) which provide them with more opportunities to acquire and apply ethnobotanical knowledge. These results highlight significant implications for the preservation and transmission of ethnobotanical knowledge within the community. The observed distinct clustering by age and gender underscores the critical role of intergenerational knowledge transfer, particularly given that younger individuals currently possess a less extensive understanding of local plant resources. Without deliberate efforts to document and disseminate traditional practices, there is a substantial risk that valuable ethnobotanical knowledge may erode over time (Lestari *et al.* 2020). Moreover, the prominent involvement of women in maintaining and applying plant-related knowledge suggests that empowering and actively engaging female community members is essential for sustaining ethnobotanical heritage (Howard 2003; Oduro & Arkese 2021). These findings call for the development of targeted educational and cultural initiatives designed to facilitate knowledge sharing between older and younger generations, while also acknowledging and supporting gender-specific contributions to traditional ecological knowledge (Reyes-García *et al.* 2016; Pearson & Pearson 2019). (Fig.12)

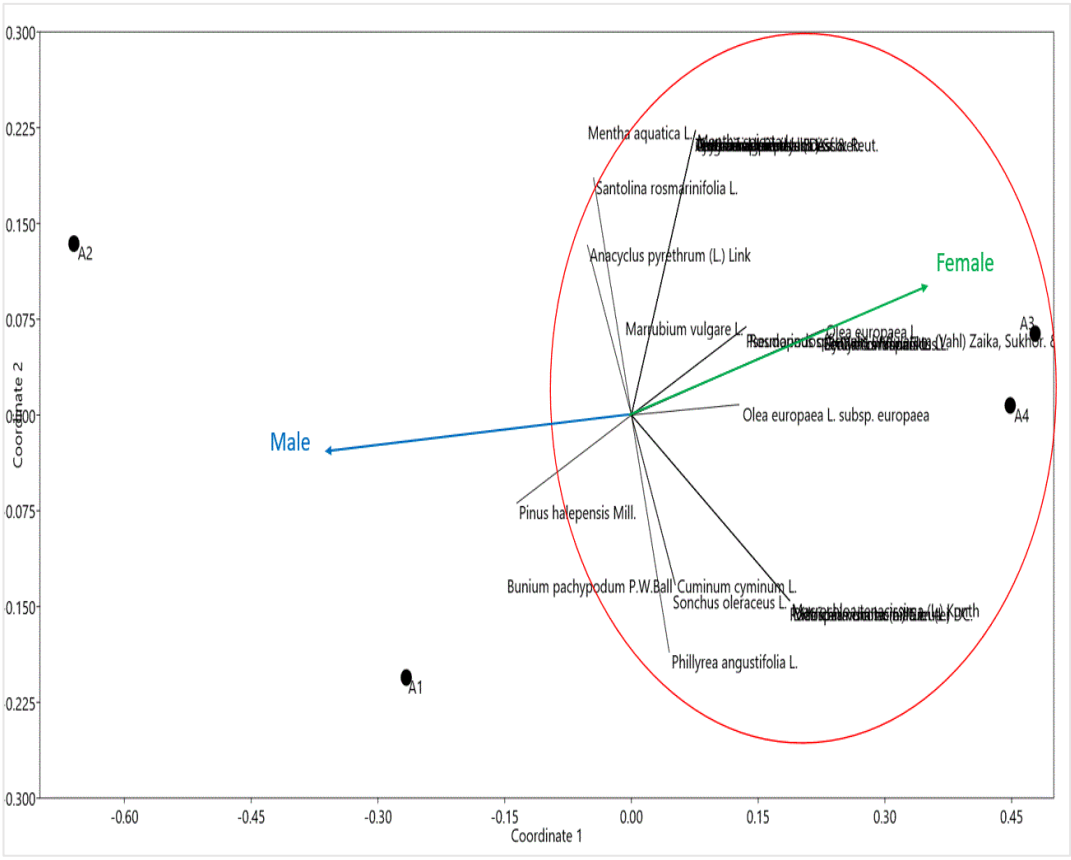

Figure 12. Nonmetric multidimensional scaling (NMDS) plots depicting the relationship between age, gender of informants & knowledge of plant species.

The ethnobotanical of our region in COVID-19 period

Ethnobotany traditional medicine in Algeria has received considerable focus during the COVID-19 pandemic, as there has been an increased reliance on traditional medicinal plants for their healing properties. Algeria's rich biodiversity, which encompasses around 4,000 plant species, serves as a vital resource for local communities seeking alternative therapies during health emergencies (Chebaibi *et al.* 2022; Benaradj& Boucherit 2023).

Research released Brahmi *et al*. (2022) and Soudani *et al*. (2024) additionally to Belmouhoub *et al*. (2024) and Belhacini *et al.* (2024) indicates that many Algerians turned to traditional herbal remedies to prevent and treat COVID-19. Various studies have documented the specific plants used, revealing that local knowledge plays a crucial role in health care practices. For instance, an ethnobotanical survey in the Bejaia region identified 23 medicinal plants commonly adopted by the population to combat COVID-19 and 27 species in other study in Tiaret region, which highlighting the cultural significance and reliance on traditional medicine during the pandemic.

In our study at El Ach our investigation obtained a total of 5 plant species used for the treatment of COVID-19 such as *Thymus algeriensis, Juniperus oxycedrus L. Artemisia herba-alba, Mentha spicata, Eucalyptus globulus* along with a collection of deferent recipes which is recommended by the local informants (healers), like a refreshing infusion of mint and lemon every morning and was cited for its use in treating influenza and cough (Benarba 2016, Miara *et al*. 2019) as well as COVID-19 (Chaachouay *et al*. 2021, Benamar *et al*. 2024 & Ahmed-Gaid *et al*. 2025). Additionally, consider using fumigation with the caletus plant to help clear your respiratory tract and alleviate fever symptoms, were The smoke from burning cletus leaves is believed to have a fever-reducing effect. The active compounds in the plant may help lower body temperature when inhaled, also we have the *Thymus algeriensis* has been utilized for its health benefits, including its role in managing respiratory conditions. This historical context supports the exploration of *Thymus algeriensis* as a complementary treatment for COVID-19 symptoms as it mentioned by Lahlou *et al*. (2022) and Sadawe *et al*. (2021).

This trend underscores the importance of integrating traditional medicinal knowledge into broader health strategies, especially in times of crisis. And all of these studies collectively illustrate the reliance on traditional medicinal practices in

Algeria during the COVID-19 pandemic, reflecting a significant cultural response to the global health crisis (Sadawe *et al*. 2021; Nouidjem *et al.* 2021). Overall, the ethnobotanical practices in Algeria during the COVID-19 pandemic illustrate a blend of cultural heritage and modern health challenges, emphasizing the need for further research and documentation of these valuable resources (Brahmi *et al.* 2022).

Conclusion

The ethnobotanical study conducted in the Mediterranean region of Algeria, specifically in El Ach, reveals a remarkable richness in medicinal plant diversity and traditional knowledge within the local community. The study documented 53 plant species from 26 families, with Asteraceae and Lamiaceae being the most dominant, reflecting their widespread traditional use in managing diverse health conditions such as diabetes, gastrointestinal disorders, thyroid dysfunction, and anemia. This highlights the essential role these plants play in sustaining local healthcare systems and preserving cultural heritage.

The NMDS ordination analysis revealed clear patterns in the distribution of medicinal plant knowledge across different age groups, demonstrating a significant age-related variation. Older informants, particularly those above 50 years old (age groups A3 and A4) especially female participants, possessed a richer and more comprehensive understanding of medicinal plants compared to younger generations. This disparity underscores an urgent concern regarding the potential loss of invaluable ethnobotanical knowledge as younger individuals appear less familiar with traditional practices.

These findings highlight the urgent need to further explore traditional medicinal knowledge in El Ach, develop targeted conservation strategies, and implement knowledge transmission programs to preserve this valuable cultural heritage. Integrating such ethnobotanical wisdom into modern healthcare could offer sustainable and culturally appropriate solutions to health challenges, while fostering greater respect and interest in indigenous knowledge among younger populations internationally. Future research should also explore the mechanisms behind knowledge erosion and develop community-based approaches to ensure the continuity and revitalization of ethnomedicinal traditions.

Declarations

Ethics approval and consent to participate: Before beginning the ethnobotanical study, we obtained verbal consent from all participants.
Data availability: The data featured in this manuscript can be obtained from the corresponding author.
Competing interests: The authors declare that they have no competing interests.
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Author contributions: All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Aida Radjai, Djamel Sarri and Abdelghani Zedam. The first draft of the manuscript was written by Aida Radjai and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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