Spatio-temporal evolution of health-related ethnobotanical studies in Morocco since 1991: Quantitative analysis of more than 420 studies as a basis for biochemical and microbiological research on medicinal plants

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Review

Abstract

Background: Historically, Moroccan ethnobotanical and ethnopharmacological research has benefited human health and continues to provide a valuable foundation for biochemical and microbiological investigations.

Methods: A critical analysis of ethnobotanical and ethnopharmacological field studies conducted between 1991 and October 2025 was performed using major databases (Scopus, Web of Science, PubMed, ScienceDirect, and others). Publications were categorized by year and region and analyzed using principal component analysis (PCA), clustering, slope trend analysis, and evaluation of links between ethnobotanical surveys and biochemical or microbiological studies.

Results: A total of 423 studies were analyzed, showing a marked increase in publications after 2010, particularly since 2015. Research is concentrated in northern and central regions, notably Fez–Meknes (32.5%), while southern regions remain underrepresented. *Ethnobotany Research and Applications* accounts for 15.4% of publications, and Lamiaceae are the most studied species. A strong link was observed between ethnobotanical inventories and subsequent biochemical and microbiological analyses, confirming their role as a source for experimental research. PCA explains 73.37% of total variance, revealing a spatial gradient between dynamic northern/central regions and less active southern regions, along with increased activity in recent years. Hierarchical clustering confirmed regional disparities, identifying Fez–Meknes as a major research hub and highlighting a clear temporal structure, with 2021–2025 representing a peak in scientific output.

Conclusions: Moroccan ethnobotanical research shows significant spatiotemporal disparities but has grown rapidly since 2010. It remains a key pillar for biochemical and microbiological studies, and further efforts are needed to explore still understudied regions.

Keywords: Morocco, Historical plant-population, Ethnobotany, Biochemical, Microbiological, Health.

Background

Ethnobotany and ethnopharmacology are closely related scientific disciplines that document, preserve, and valorize traditional knowledge of medicinal plants. Despite advances in modern pharmacology, medicinal plants remain a fundamental component of healthcare systems worldwide, particularly in regions where traditional medicine remains deeply rooted in cultural practices. Ethnobotany is defined as the scientific study of human–plant interactions across time and space, particularly in relation to food, protection, and remedies for treating diseases (Bennett 2002, Rahman *et al.* 2019). The term "ethnobotany" was formally introduced in 1895 by botanist John William Harshberger, who initially defined it as the study of plants used by indigenous peoples (De Albuquerque *et al.* 2017, Rahman *et al.* 2019). He later expanded this concept to include plants used for food, protection, medicine, clothing, hunting, and ornamentation. Nevertheless, the intellectual foundations of ethnobotany predate this formalisation, as scholars such as Alphonse De Candolle had already investigated plant–civilisation relationships through studies on the origin and distribution of cultivated plants (De Albuquerque *et al.* 2017).

Over time, ethnobotany evolved from a descriptive discipline focused primarily on indigenous knowledge into a broader interdisciplinary field integrating ecological, sociocultural, economic, and medical dimensions. Several scholars contributed to this evolution, including Wilfred Williams Robbins (1916), who approached ethnobotany through the economic perspective of plant–human interactions, and Richard Ford (1978), who later defined it as "the study of the direct interrelationships between humans and plants" (Brousse 2011). In parallel, ethnopharmacology emerged as a complementary discipline linking traditional medicinal knowledge with scientific validation of bioactive natural substances (Heinrich 2015, Bruhn & Rivier 2019, Süntar 2019). The term "ethnopharmacology" was first introduced in 1967 by Bo, who emphasised its dependence on pharmacology and experimental validation of traditional remedies (Heinrich 2015, Bruhn & Rivier 2019). Since then, ethnopharmacology has progressively developed into an interdisciplinary field combining botany, chemistry, pharmacology, and medical sciences (Süntar 2019).

In this context, Morocco represents a particularly important area for ethnobotanical and ethnopharmacological research due to its exceptional floristic richness and longstanding traditional medical heritage. Located at the crossroads between Europe and Africa, Morocco constitutes a major biodiversity hotspot within the Mediterranean basin (Bussmann 2006). The country hosts approximately 3900 spontaneous plant species, including more than 600 medicinal plants and nearly 800 endemic species (Fennane & Ibn Tattou 2012, Ismaili *et al.* 2021). Moroccan traditional medicine predates Arab influence and has been enriched over centuries through prophetic medicine, classical Arab-Islamic scholarship, and diverse local cultural traditions (Mouhib & El Omari 1997, Elachouri *et al.* 2021). Early medical education at Al-Qaraouiyine University in Fez and in the madrasas of Marrakech incorporated the works of Avicenna, Al-Rhazi, and other classical physicians.

Among Moroccan regions, the province of Taza occupies a particular ethnobotanical importance. Located in northern Morocco, it is recognised as an ecological and ethnobotanical hotspot harboring more than 200 medicinal plant species (Ghabbour *et al.* 2024a). Ethnobotanical investigations in this region were initiated by Khabbach *et al.* (2011), and subsequent studies highlighted the richness of traditional medicinal knowledge among local populations (Ghabbour *et al.* 2024a, El Aboui *et al.* 2024, El Aboui *et al.* 2025, El Mouzazi *et al.* 2024, El Aarage *et al.* 2026). This traditional knowledge includes diverse therapeutic practices used for the treatment of major diseases (Ghabbour *et al.* 2023, El Hajli *et al.* 2024).

Ethnobotanical and ethnopharmacological research plays a crucial role in the identification of medicinal plants with potential pharmacological applications, while also contributing to biodiversity conservation, food security, and the preservation of cultural heritage (Espinosa *et al.* 2014, Rahman *et al.* 2019). Furthermore, ethnopharmacology has gained increasing importance in the context of the global rise in medicinal plant use, particularly regarding the evaluation of efficacy, safety, toxicity, and potential interactions associated with traditional remedies (Chassagne 2024).

Despite the increasing number of ethnobotanical and ethnopharmacological investigations conducted in Morocco, comprehensive spatio-temporal analyses integrating historical evolution, methodological approaches, regional disparities, and the relationship between ethnobotanical surveys and subsequent laboratory-based biochemical and microbiological

studies remain limited. Therefore, this critical review aims to analyze the historical, temporal, and spatial evolution of ethnobotanical and ethnopharmacological studies in Morocco between 1991 and 2025, with particular emphasis on methodological approaches, regional distribution patterns, and the role of ethnobotanical investigations as a foundation for biochemical and microbiological research on medicinal plants. Furthermore, advanced statistical approaches, including Principal Component Analysis (PCA), temporal trend analysis, and hierarchical clustering, were applied to better elucidate the spatio-temporal structuring of ethnobotanical research in Morocco.

Materials and Methods

Study Design and Data Collection Strategy

This critical review was conducted to provide a comprehensive and systematic synthesis of ethnobotanical and ethnopharmacological surveys carried out in Morocco between 1991 and October 2025. Data collection was performed from 2021 to 2025 through an extensive search. The literature search was conducted exclusively on scientific articles retrieved from indexed databases, including Scopus, Web of Science, PubMed, ScienceDirect, and other recognized platforms. The objective was to compile all available studies reporting field-based ethnobotanical and/or ethnopharmacological research.
A total of 423 studies were identified, screened, and analyzed. Each publication was classified according to: Year of publication, to assess temporal trends; Geographical location, including both region and province; Disciplinary orientation, i.e., ethnobotany, ethnopharmacology, or combined approaches; Methodological approach, encompassing qualitative and quantitative techniques.

Temporal trends were evaluated through chronological analysis, while spatial distribution was mapped according to Morocco's administrative regions as defined by Decree No. 2-15-40 (2015). Special attention was given to the Fez–Meknes Region and Taza Province to assess their relative contributions at both regional and national levels. Taza Province was selected because of its rich floristic diversity, important ethnomedicinal heritage, and increasing contribution to Moroccan ethnobotanical research. The province also represents a biogeographical transition zone characterized by diverse ecological conditions and valuable traditional knowledge associated with medicinal plant use.

Among the 423 studies included in this review, all publications were systematically categorized according to their journal of publication as part of the data classification process. The proportion of articles published in Ethnobotany Research and Applications was calculated as part of this classification, as it represented the journal with the highest number of Moroccan ethnobotanical studies within the dataset.

To ensure the comprehensiveness and reliability of this review, only studies explicitly based on ethnobotanical or ethnopharmacological field surveys were included. Publications focusing solely on experimental pharmacology or phytochemistry without a documented field component were excluded. Each selected study was critically evaluated to identify methodological approaches, study scope, and the degree to which quantitative or qualitative analyses were applied.

Overall, this methodology enabled a systematic assessment of the historical and spatial evolution of ethnobotanical research in Morocco, while contextualizing the impact of Ethnobotanical Research and Applications as a key platform supporting this scientific field.

The Lamiaceae family was specifically highlighted because it represented the most frequently reported medicinal plant family in the reviewed ethnobotanical studies and showed a strong association with subsequent biochemical and microbiological investigations due to its rich diversity of bioactive compounds and extensive traditional medicinal use in Morocco.

Ethnobotany-Guided Biochemical Studies

Moroccan phytochemical and antioxidant studies were reviewed to evaluate the extent to which biochemical investigations were guided by ethnobotanical evidence. Studies were included when plant selection was explicitly based on ethnobotanical surveys or on previously published ethnobotanical data. Priority was given to species with high ethnobotanical relevance, particularly those belonging to the Lamiaceae family (e.g., *Rosmarinus officinalis* L., *Salvia officinalis*, *Origanum compactum* Benth., *Thymus vulgaris* L., *Mentha pulegium* L., *Calamintha nepeta* (L.) Savi, and *Lavandula stoechas* L.). Reported biochemical methods included total phenolic and flavonoid content determination, antioxidant assays (DPPH, FRAP, ABTS), and compound profiling using HPLC–MS and GC–MS.

Ethnobotany-Guided Microbiological Studies

Moroccan antimicrobial, antifungal, and antiparasitic studies were analyzed to assess their ethnobotanical basis. Microbiological investigations were considered ethnobotany-driven when plant selection relied on ethnobotanical field surveys or on documented traditional anti-infective uses. Special attention was given to Lamiaceae species frequently cited in ethnobotanical studies, including *Origanum compactum* Benth., *Thymus vulgaris* L., *Rosmarinus officinalis* L., *Salvia officinalis* L., *Mentha pulegium* L., *Lavandula dentata* L., and *Ocimum basilicum* L.. Most studies employed in vitro antimicrobial assays using plant extracts or essential oils.

Data Processing and Data Synthesis

The data collected from Scopus, Web of Science, and other scientific databases were entered and processed using Microsoft Excel software. Data analysis was based on descriptive statistics, employing simple calculations of frequencies and percentages. Graphical representations were generated to illustrate temporal and spatial trends. The map of the study area used in this study was created by Ghabbour Issam.

Ethnobotanical, biochemical, and microbiological data were synthesized to develop a conceptual framework illustrating the role of ethnobotanical research as a scientific foundation for laboratory-based studies on medicinal plants in Morocco.

Principal Component Analysis (PCA) was performed using XLSTAT version 2016 to explore patterns of variation among regions and temporal periods. The first two principal components were retained for visualization of the main trends.

The temporal trend for each region was quantified using a linear regression model:

$$Y=a+bt$$

where: Y represents the observed value, t represents the time period, a is the intercept, and b is the slope, representing the trend (average change per period).
The slope b was calculated as:

$$b = \frac{\sum(t_i - \bar{t})(Y_i - \bar{Y})}{\sum(t_i - \bar{t})^2}$$

A higher value of b indicates a stronger increasing trend over time.

Results and Discussion

Ethnobotany in Morocco

In the Moroccan context, ethnobotany is essential for documenting and preserving traditional medicinal knowledge, which is widely used across rural and urban populations. By combining qualitative and quantitative methods, researchers can provide a comprehensive understanding of plant uses, their cultural significance, and their potential therapeutic value. Such research informs pharmacological studies, supports biodiversity conservation, and offers guidance for integrating traditional remedies into evidence-based healthcare systems. Morocco's rich flora and longstanding traditional medicine practices make ethnobotanical studies particularly valuable for public health, sustainable resource management, and the safeguarding of cultural heritage.

Qualitative and quantitative approaches reported in Moroccan ethnobotanical research

The analysis of the reviewed ethnobotanical literature revealed the extensive use of both qualitative and quantitative research approaches in Moroccan ethnobotanical investigations. These approaches constitute the principal methodological frameworks employed by researchers to document traditional medicinal knowledge and evaluate the cultural importance of medicinal plants.

The qualitative approach in ethnobotany is mainly exploratory and aims to understand the dynamic relationships between plants and local populations through various field investigation methods (Ashebo 2019). Among the most commonly reported techniques, semi-structured questionnaires and interviews are frequently employed because they allow the collection of reliable ethnobotanical information while maintaining flexibility during interactions with informants (De

Albuquerque *et al.* 2017, Ashebo 2019). Depending on the objectives of each study, interviews may be structured, semi-structured, or unstructured; however, semi-structured approaches clearly dominate Moroccan ethnobotanical research.
The reviewed Moroccan studies also reported the use of complementary qualitative methods closely linked to fieldwork practice. These include participant observation, particularly with pastoral and rural communities; focus group discussions to capture collective perceptions and shared traditional knowledge; and free-listing exercises to identify culturally important medicinal plants. In some cases, pile sorting techniques based on plant photographs were also used to explore local cognitive categorization of medicinal species. These methods were generally applied in combination with semi-structured interviews to enrich ethnobotanical datasets.

The bibliographic analysis also highlighted the increasing integration of quantitative approaches in Moroccan ethnobotanical research. Quantitative ethnobotany commonly relies on probabilistic or non-probabilistic sampling methods to analyze ethnobotanical field data (Espinosa *et al.* 2014). Several reviewed studies reported the use of structured surveys applied to households or specific target groups, particularly to assess environmental changes, herd dynamics, production systems, and patterns of plant use over time.

In addition, statistical software such as SPSS is frequently used for the classification of medicinal plant families and species and for the calculation of ethnobotanical indices related to plant use frequency and cultural importance (Mikou *et al.* 2016). Among the most commonly reported analytical tools are cluster analysis, principal component analysis, regression analysis, and log-linear modelling (Höft *et al.* 1999).

The reviewed literature also demonstrated the widespread application of several ethnobotanical indices, including Informant Consensus Factor (ICF), Informant Agreement Ratio (IAR), Relative Frequency of Citation (RFC), Fidelity Level (FL), Relative Importance Index (RI), Use Value (UV), Rank Order Priority (ROP), and Cultural Importance Index (CI), to quantify the medicinal and cultural significance of plant species (Ghabbour *et al.* 2023).

These quantitative indices enable the transformation of qualitative ethnobotanical observations into measurable and comparable scientific data within biological and social science research frameworks (Zain-ul-Abidin *et al.* 2018, Hoffman & Gallaher 2007). They also provide valuable insights into the importance of medicinal plants in traditional healthcare systems and local cultural practices.

Furthermore, the reviewed studies highlighted the relevance of the six quantitative criteria proposed by Ghabbour *et al.* (2024b) for facilitating the standardization and quantitative interpretation of qualitative ethnobotanical characteristics. These criteria include the Criterion of Collection Period (CCP), Criterion of Plant State (CPS), Criterion of Part Used (CPU), Criterion of Preparation (CP), Criterion of Administration (CA), and Criterion of Type of Use (CTU).

Ethnopharmacology in Morocco

In Morocco, ethnopharmacology is particularly relevant due to the widespread reliance on medicinal plants in traditional healthcare. Scientific documentation and validation help ensure safe usage, identify potential toxicities, and guide integration into modern medical practices. The field also supports public health initiatives by informing healthcare professionals and policymakers about effective traditional remedies, while safeguarding the country's rich biodiversity and cultural knowledge. By combining field surveys with laboratory studies, Moroccan ethnopharmacology can bridge traditional knowledge and contemporary healthcare needs, promoting evidence-based use of medicinal plants.

After reviewing the literature, it is clear that providing a single, unified definition of ethnopharmacology is challenging. Definitions vary according to disciplines, researchers' perspectives, and historical context, reflecting the interdisciplinary nature of the field. Some definitions focus solely on the documentation and description of traditional knowledge, without mentioning laboratory work. This includes the etymological definition ("the science of the people's remedies") and Schultes (1988), who considered ethnopharmacology a sub-branch of ethnobotany. Other definitions implicitly suggest scientific validation without specifying field data collection. This applies to Holmstedt & Bruhn (1982), Dos Santos & Fleurentin (1990), Heinrich & Jäger (2015), Moerman, and Leonti (Heinrich 2014), who emphasize the evaluation or analysis of traditional uses while leaving laboratory validation implicit. This group also includes the recent view of Bruhn & Rivier (2019), which describes ethnopharmacology as the interdisciplinary study of biologically active agents traditionally used or observed by humans, linking traditional practices with scientific validation and drawing on both natural medicine and pharmacology. Finally, some definitions explicitly state that ethnopharmacology combines fieldwork and laboratory validation, such as Rivier & Bruhn (1979), who mention observation and description in the field alongside experimental investigation of indigenous drugs.

Accordingly, and considering these perspectives, we propose: *"Ethnopharmacology is the interdisciplinary scientific study of biologically active agents from plants, animals, or other materials, traditionally used or observed by human communities, combining documentation of traditional knowledge, analysis of local uses, and, when possible, biological and pharmacological validation to ensure their efficacy, safety, and responsible integration into healthcare systems."*

Historical temporal evolution of ethnobotanical and ethnopharmacological surveys in Morocco

Over the past three decades, Morocco has witnessed a substantial increase in ethnobotanical and ethnopharmacological studies documenting traditional medicinal knowledge, reflecting growing scientific interest in the pharmacological potential of its flora since the works of Bellakhdar *et al.* (1991) and Bellakhdar (1997).

Figure 1 shows the *Historical evolution of ethnobotanical and ethnopharmacological surveys in Morocco from 1991 to 2025.* was developed based on an exhaustive literature review covering all available Moroccan ethnobotanical and ethnopharmacological studies indexed in major scientific databases. The data compilation, conducted between 2021 and 2025, included all published and accessible studies from 1991 to 2025. In total, 423studies were identified and analyzed.

The figure clearly illustrates a steady increase in the number of studies over time, particularly after 2010, with an exponential rise observed from 2015 onwards. This trend reflects the growing scientific interest in Morocco's medicinal flora, as well as the recognition of traditional knowledge as a valuable resource for pharmacological and biotechnological research. Notably, the data for 2025 are partial, representing studies collected up to October 2025, and the final count is expected to be higher by the end of the year. This growing body of work has significantly enhanced understanding of Morocco's ethnomedicinal heritage, while also promoting the scientific validation of traditional remedies and supporting their potential integration into modern healthcare systems and biodiversity conservation strategies.

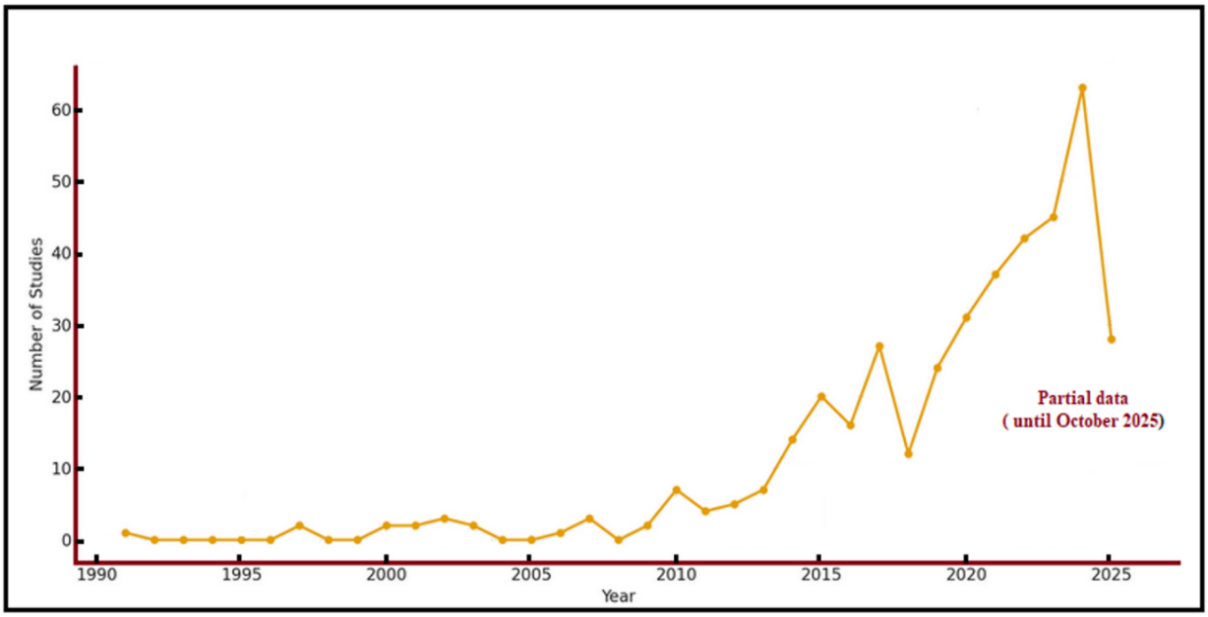

Figure 1. Historical evolution of ethnobotanical and ethnopharmacological surveys in Morocco from 1991 to 2025.

Historical spatial distribution of ethnobotanical and ethnopharmacological surveys in Morocco

The analysis and processing of data from 423 Moroccan ethnobotanical and ethnopharmacological studies, which together trace the historical evolution of research in this field, enabled us to map the historical distribution of these studies across Moroccan regions between 1991 and October 2025 (Figure 2).

The spatial distribution of ethnobotanical and ethnopharmacological studies in Morocco shows a clear regional imbalance. The Fez–Meknes region leads with 32.48% of studies, reflecting its major academic institutions, rich biodiversity, and strong medicinal plant tradition. Tanger–Tétouan–Al Hoceïma ranks second with 15.31%, highlighting growing interest in the northern Rif's endemic flora and cultural practices. Next, Béni Mellal–Khénifra contributes 13.46%, indicating an emerging focus on Middle Atlas phytodiversity and local traditional knowledge. The Rabat–Salé–Kénitra region follows with 8.58% studies, benefiting from its proximity to national research centers and universities, despite being less rich in plant endemism compared to the mountainous regions. The Oriental region (6.27% studies) and Drâa–Tafilalet (5.34% studies) occupy

intermediate positions, illustrating moderate research activity mainly oriented toward the arid and semi-arid ecosystems and their adaptive medicinal flora. The Marrakech–Safi region, with 5.57% studies, shows a balanced contribution linked to the biodiversity of the High Atlas and the availability of academic centers in Marrakech.

In contrast, regions such as Casablanca–Settat (4.41%), Souss–Massa (4.18%), Laâyoune–Sakia El Hamra (2.32%), Guelmim–Oued Noun (1.86%), and especially Dakhla–Oued Ed-Dahab (0.23%), remain underrepresented in ethnobotanical research. This underrepresentation can be explained by the limited accessibility, low population density, and scarcity of research structures in southern and desert areas.

Ethnobotanical and ethnopharmacological research in Morocco is concentrated in the northern and central regions, where biodiversity and academic infrastructure converge. Southern regions remain largely unexplored despite their unique xerophytic and halophytic flora and Saharan traditional pharmacopoeia. However, despite this expansion, research remains unevenly distributed temporally and spatially, and methodological heterogeneity persists. This uneven distribution highlights the need to focus future research on underexplored areas to achieve comprehensive national mapping and better valorize Morocco's biocultural diversity.

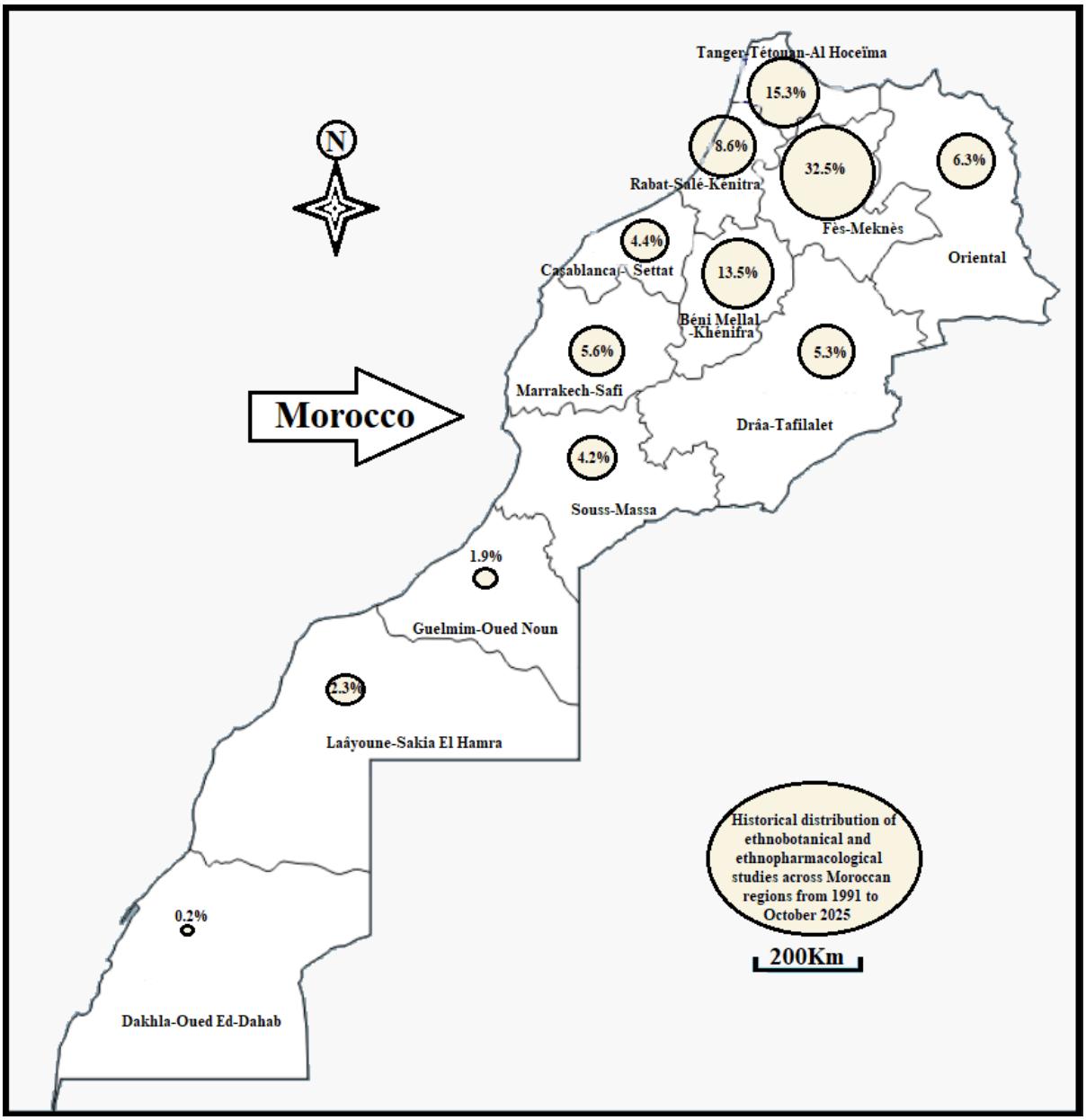

Figure 2. Historical distribution of ethnobotanical and ethnopharmacological studies across Moroccan regions between 1991 and October 2025.

Historical evolution of ethnobotanical and ethnopharmacological research in Taza province

The historical analysis of ethnobotanical and ethnopharmacological research in Taza Province (2011–October 2025) (Figure 3) reveals a steady rise in scientific interest over the past fifteen years.

The first study appeared in 2011, followed by a modest continuation in 2012, marking the early recognition of Taza's rich ethnobotanical heritage. After several inactive years, research activity resumed from 2018 onward, showing continuous growth, particularly after 2020. Between 2021 and 2023, studies increased steadily, reaching a peak in 2024 with six publications, the highest annual number recorded. By October 2025, two new studies had already been reported, confirming this ongoing momentum. Overall, this upward trend highlights Taza Province's increasing significance in Morocco's ethnobotanical research, reflecting its rich traditional knowledge, diverse plant biodiversity, and pharmacological potential.

This richness is accompanied by extensive traditional medicinal knowledge among the local population (Ghabbour *et al.* 2024a, El Aboui *et al.* 2024, El Aboui *et al.* 2025, El Mouzazi *et al.* 2024, El Aarage *et al.* 2026), with various therapeutic modalities being employed (Ghabbour *et al.* 2024a, El Hajli *et al.* 2024) to treat major diseases (Ghabbour *et al.* 2023), which warrants further investigation to clarify its specific position in the history of Moroccan ethnobotany.

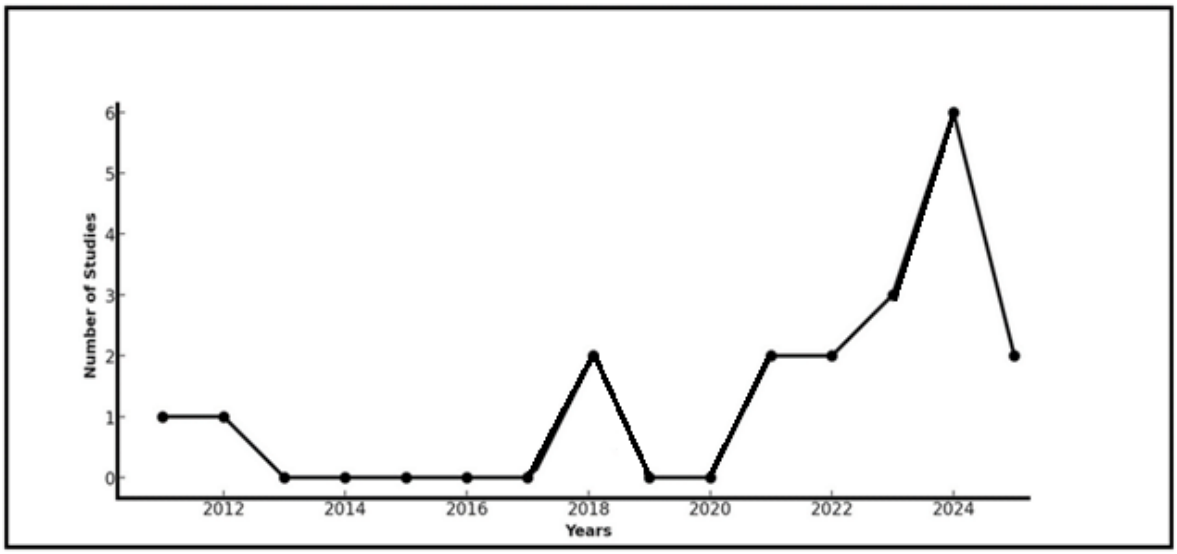

Figure 3. Historical evolution of ethnobotanical and ethnopharmacological studies in Taza Province between 1991 and October 2025.

Figure 4 illustrates the percentage of studies conducted exclusively in Taza Province relative to the Fez-Meknes Region and Morocco. Knowing that the administrative framework established by Decree No. 2-15-40 of February 20, 2015, which defines 12 regions, 13 prefectures, and 62 provinces, makes a total of 75 prefectures and provinces.

Within this national administrative structure, the Fez-Meknes Region, composed of nine provinces, stands out with 32.5% (140 studies) of all ethnobotanical investigations carried out in Morocco. This proportion reflects a remarkable scientific concentration, highlighting the ecological and cultural richness of this region.

Of particular importance, Taza Province alone accounts for 4.5% of all ethnobotanical studies conducted at the national level, corresponding to 13.6% within the Fez-Meknes Region. It is important to note that this percentage represents studies carried out exclusively within Taza Province, and does not include research conducted in broader areas that encompass Taza, such as the entire Fez-Meknes Region.

From a statistical and scientific perspective, these values are particularly significant given that Morocco comprises 75 prefectures and provinces. The contribution of Taza, both at the national (4.5%) and regional (13.6%) levels, is therefore disproportionately high, demonstrating its strong representativeness, research intensity, and ethnobotanical importance. Consequently, Taza Province emerges as one of the most active and scientifically valuable territories within the Fez-Meknes Region, contributing substantially to the advancement of ethnobotanical knowledge in Morocco.

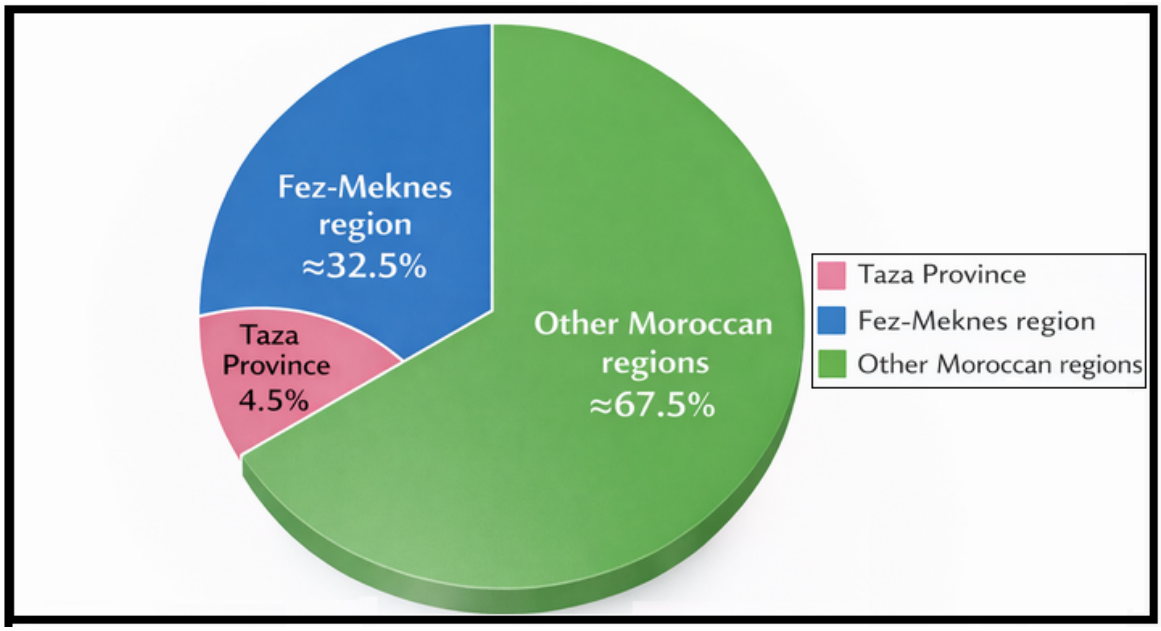

Figure 4. Percentage of studies conducted exclusively in Taza Province relative to the Fez-Meknes Region and Morocco

Contribution of Ethnobotany Research and Applications to Moroccan Ethnobotanical Research

A critical analysis of publication outlets revealed that Ethnobotany Research and Applications accounted for 65 out of 423 Moroccan ethnobotanical and ethnopharmacological surveys, representing 15.4% of the total indexed literature (Figure 5).

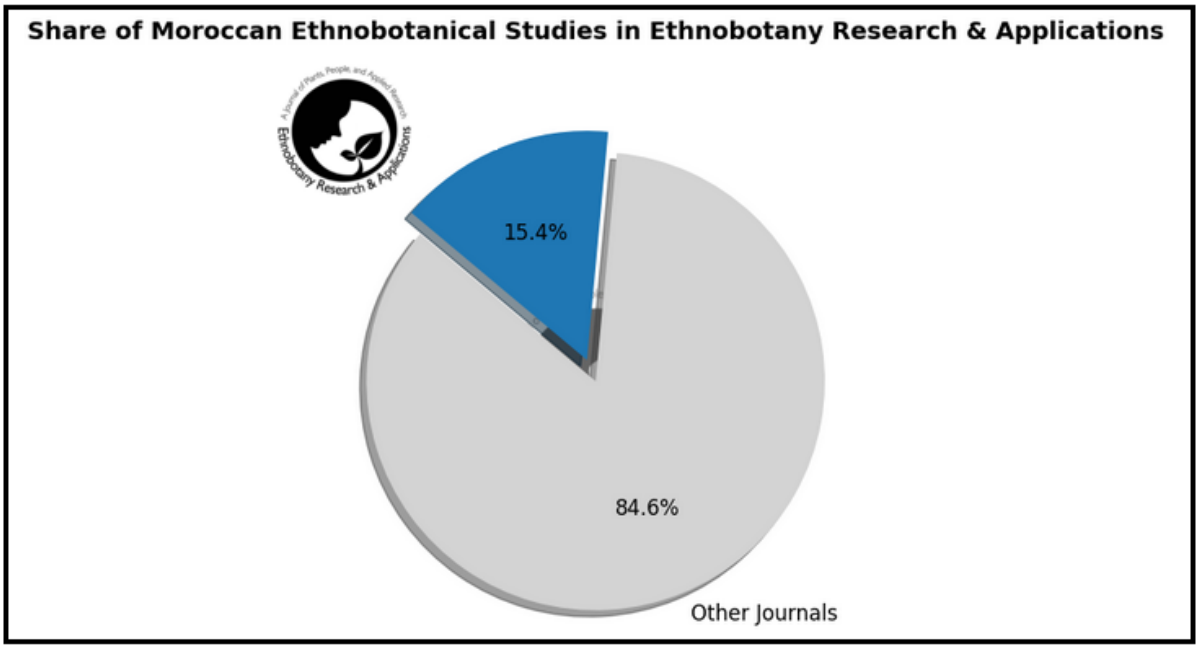

Figure 5. Contribution of Ethnobotany Research and Applications to Moroccan Ethnobotanical Research

This uneven distribution of publications highlights the central role of Ethnobotany Research and Applications in shaping the visibility and orientation of Moroccan ethnobotanical research. While this concentration reflects thematic coherence, it also raises questions regarding journal selection strategies, methodological standardization, and international dissemination pathways.

Traditional medicine and health practices in Morocco

Analysis of the 423 ethnobotanical and ethnopharmacological surveys conducted across Morocco clearly indicates that a large proportion of the Moroccan population continues to rely on traditional medicine and medicinal plants for maintaining

health and well-being. This widespread use reflects a deeply rooted belief that natural remedies derived from plants and local resources play a central role in preventing illness, supporting recovery, and promoting overall wellness.

The persistence of these practices highlights the cultural significance of medicinal plants and the enduring trust in nature as a source of health. Ethnobotanical knowledge, transmitted across generations, not only contributes to individual and community well-being but also underscores the potential for integrating traditional remedies into modern healthcare strategies, particularly in rural and underserved areas. In addition, it contributes to the protection of natural resources, food security, habitat conservation, and the development of remedies for various ailments (Rahman *et al.* 2019).

This cultural reliance on natural medicine emphasizes that in Morocco, health is not solely defined by clinical interventions but also by the sustainable use of local biodiversity and traditional knowledge systems that have long supported physical, mental, and social wellbeing. By analyzing and interpreting the interrelationships between human societies and plants, ethnobotany highlights the processes of transformation and utilization of plant species while integrating modern scientific knowledge into this ancestral field (Portères 1961). The increasing use of plants in the West and worldwide for treating or preventing diseases highlights the current importance of ethnopharmacology. Tourist practices involving plants, such as shamanic tourism in the Amazon, can also lead to misuse, accidents, or abuse despite educational or conservation intentions (Amselle 2014). Misinterpretation of scientific results by local populations can be dangerous, as shown by the use of rosemary essential oil for ciguatera in Polynesia following studies on Tahinu (*Heliotropium arboreum*) and rosmarinic acid (Borges *et al.* 2019, Rossi *et al.* 2012). Other factors affecting plant safety include confusion between medicinal and toxic species, chemical variations caused by biotic and abiotic factors, and user behavior despite known toxicity, such as with Metuapua'a (*Microsorum grossum*) in Polynesia (Chassagne 2024). By documenting plant parts used, harvesting conditions, preparation methods, and storage practices, ethnopharmacologists contribute significantly to risk assessment and prevention strategies (Chassagne 2024).

Ethnobotanical research as a foundation for biochemical studies of medicinal and aromatic plants in Morocco

Health-oriented ethnobotanical surveys play a fundamental role in guiding biochemical investigations of medicinal and aromatic plants in Morocco (Figure 6). By documenting traditionally used species, plant parts, preparation methods, and therapeutic indications, ethnobotanical studies provide a rational and scientifically grounded framework for selecting candidate plants for phytochemical screening and bioactivity evaluation. Quantitative ethnobotanical indices such as Relative Frequency of Citation, Use Value, Fidelity Level, and Informant Consensus Factor are commonly used to prioritize culturally important species, thereby increasing the efficiency, relevance, and success rate of subsequent biochemical analyses.

A critical analysis of Moroccan biochemical studies reveals that the majority of phytochemical and antioxidant investigations are ethnobotany-driven, either through direct ethnobotanical field surveys or through reliance on previously published ethnobotanical data. Ethnobotany, therefore, plays a critical role in supporting pharmacological and chemical research by identifying medicinal plants capable of treating prevalent diseases (Espinosa *et al.* 2014). Among the medicinal plant families, Lamiaceae emerge as the most extensively studied, owing to their high citation frequency in ethnobotanical surveys and their widespread traditional use for treating inflammatory, infectious, digestive, and respiratory disorders. Species such as *Rosmarinus officinalis* L., *Salvia officinalis* L., *Origanum compactum* Benth., *Thymus vulgaris* L., *Mentha pulegium* L., *Calamintha nepeta* (L.) Savi and *Lavandula stoechas* L. are consistently highlighted in ethnobotanical studies and subsequently subjected to detailed biochemical investigations.

Biochemical analyses of these ethnobotanically selected species have repeatedly demonstrated a rich diversity of bioactive compounds, particularly phenolic acids (such as rosmarinic acid and caffeic acid), flavonoids (including luteolin, apigenin, and quercetin derivatives), diterpenes (such as carnosic acid and carnosol), tannins, and essential oil constituents (monoterpenes and sesquiterpenes). Antioxidant assays (DPPH, FRAP, ABTS), total phenolic and flavonoid content measurements, and HPLC–MS or GC–MS profiling are most often performed on plants with strong ethnobotanical relevance, confirming the predictive value of traditional knowledge in biochemical research.

In several Moroccan studies, authors explicitly conducted ethnobotanical surveys to identify plants reputed by local populations for health-promoting effects before undertaking phytochemical characterization and bioactivity testing. In other cases, biochemical investigations were based on species already recognized in ethnobotanical literature, without new field surveys, illustrating an indirect but clear dependence on ethnobotanical knowledge. This recurring methodological pattern demonstrates that ethnobotany not only preserves traditional medicinal practices but also serves as a strategic tool for

guiding compound discovery, antioxidant evaluation, and structure–activity relationship studies. Moreover, numerous laboratory-based studies (Bouyahya *et al.* 2017, Benali *et al.* 2020, El Mouzazi *et al.* 2025, Ghabbour *et al.* 2026) have been conducted based on ethnobotanical surveys across various Moroccan regions.

Overall, these findings confirm that biochemical research on medicinal and aromatic plants in Morocco is largely structured around ethnobotanical evidence, with Lamiaceae species and phenolic-rich compounds being the primary focus. Consequently, ethnobotanical research should be regarded as a prerequisite and scientific foundation for biochemical investigations aiming to validate, standardize, and valorize Moroccan medicinal plants for health-related applications.

Ethnobotanical knowledge as a basis for antimicrobial investigations of medicinal plants in Morocco

Traditional ethnobotanical knowledge constitutes a fundamental foundation for microbiological research on medicinal plants (Figure 6), particularly studies targeting antimicrobial, antifungal, and anti-parasitic activities. Through the analysis of Moroccan microbiological studies, we observed that the majority of experimental investigations are either directly preceded by ethnobotanical surveys or explicitly rely on previously published ethnobotanical data. Ethnobotanical studies frequently document the use of plants for treating infectious, inflammatory, and dermatological diseases (Ghabbour *et al.* 2023), thereby providing a rational basis for selecting candidate species for microbiological assays.

In several Moroccan studies, authors first conducted ethnobotanical field surveys to identify medicinal plants most commonly used by local populations against infections, before evaluating their antimicrobial potential through in vitro assays. In other cases, microbiological investigations did not include new field surveys but were clearly based on ethnobotanical literature, using plants already recognized for their traditional anti-infective uses. This approach demonstrates a clear methodological continuity between ethnobotanical documentation and laboratory-based microbiological evaluation (Ghabbour *et al.* 2026).

Notably, the Lamiaceae family emerges as the most extensively investigated botanical group in Moroccan ethnobotany-driven microbiological research. Species such as *Origanum compactum* Benth., *Thymus vulgaris* L., *Rosmarinus officinalis* L., *Salvia officinalis* L., *Mentha pulegium* L., *Lavandula dentata* L., and *Ocimum basilicum* L. are repeatedly reported in ethnobotanical surveys for the treatment of infectious diseases and are among the most frequently subjected to antimicrobial and antifungal testing. In many cases, these species were selected following ethnobotanical prioritization based on frequency of citation, use value, or fidelity level, while in others they were chosen based on earlier ethnobotanical reports documenting their traditional antimicrobial use. While plants are often perceived as natural and harmless, they may pose risks related to harvesting, storage, concurrent use with conventional medicine, or preexisting conditions. The spread of information online further increases these risks, as illustrated by remedies used during the COVID-19 pandemic in Madagascar (*Artemisia annua* L., Covid-Organics) and French Polynesia (Chassagne 2024). Ethnopharmacologists can document these remedies and evaluate their benefit–risk balance through bibliographic and analytical studies, revealing potential side effects and interactions (Chassagne 2024).

This strong methodological linkage demonstrates that ethnobotanical research in Morocco does not merely preserve traditional medical practices but actively guides rational microbiological experimentation. By grounding laboratory investigations in culturally validated knowledge, ethnobotanical surveys enhance the relevance, efficiency, and translational value of antimicrobial studies. Consequently, ethnobotany should be considered a prerequisite framework for microbiological research aiming to develop safer and more effective plant-based antimicrobial agents. This pattern confirms that microbiological research on medicinal plants in Morocco is largely ethnobotany-driven, whether through direct field investigations or indirect reliance on existing ethnobotanical knowledge.

Comparative discussion with the previous study

The recently published article (Ousaaid *et al.* 2025) offers a useful bibliometric overview of Moroccan ethnobotanical research, based exclusively on the Scopus database. Using a keyword search strategy combined with VOSviewer analysis, the authors identified 146 publications indexed in Scopus between 1997 and 2025 and highlighted publication trends over time, influential authors, international collaborations, and emerging research themes.

In contrast, the present critical analysis identified a significantly larger body of literature, comprising 423 ethnobotanical and ethnopharmacological field studies conducted in Morocco between 1991 and October 2025. This difference does not reflect contradictory results but rather stems from fundamental methodological differences regarding data sources, inclusion criteria, and research objectives. Notably, our results also indicate that the number of articles identified according to our

adopted methodology exceeds the 230 articles reported in previous analyses (Benamar *et al.* 2026) up to 2023, further supporting the robustness and broader coverage of our approach. This discrepancy can be explained by differences in search strategies, inclusion criteria, and the comprehensiveness of the databases explored, which allowed a more exhaustive capture of the available literature.

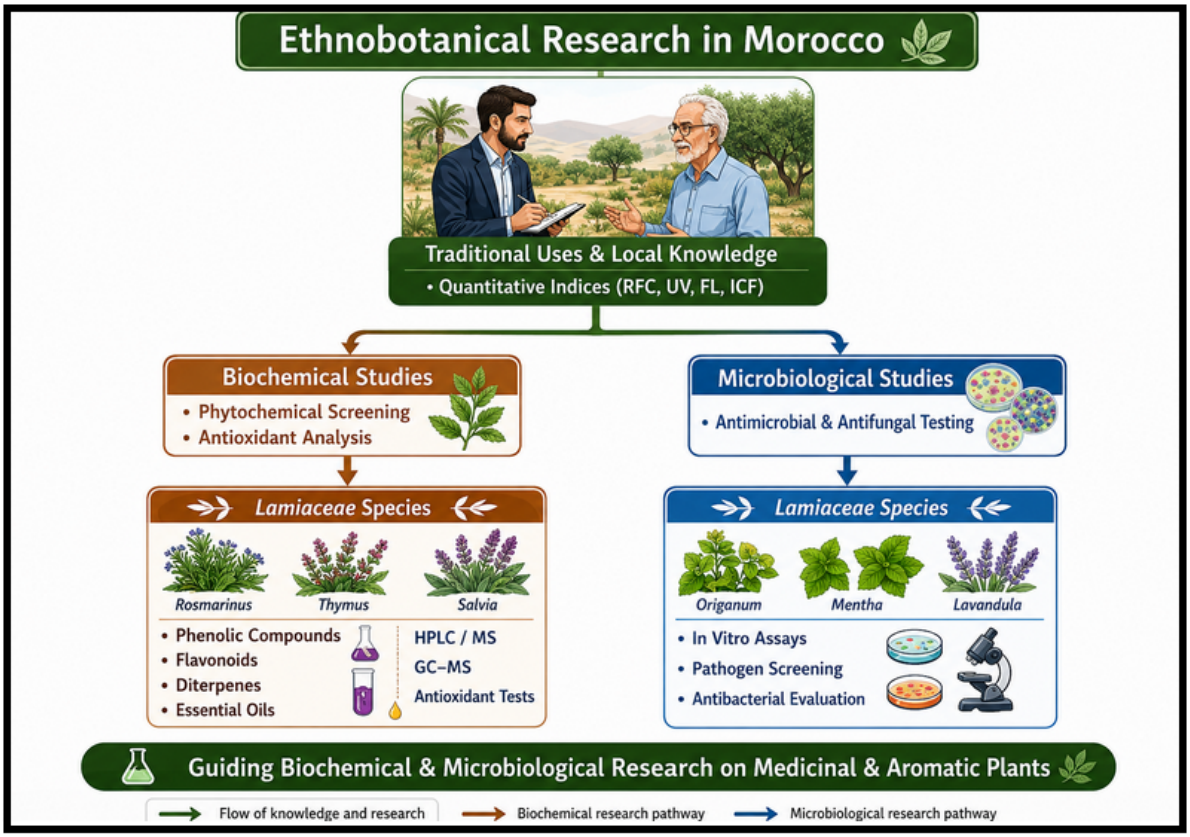

Figure 6. Conceptual Framework Illustrating the Role of Ethnobotanical Research in Guiding Biochemical and Microbiological Studies of Medicinal Plants in Morocco

First, the published bibliometric study relied exclusively on the Scopus database. While Scopus is a major international indexing platform, it does not comprehensively cover ethnobotanical fieldwork conducted in Morocco. Many of these studies are published in journals not indexed by Scopus. In contrast, the present study adopted a multi-database, multi-source approach, combining Scopus, Web of Science, and other peer-reviewed scientific journals, with the explicit aim of ensuring that no ethnobotanical fieldwork conducted in Morocco was overlooked.

Secondly, the scope of the two studies differs significantly. While the bibliometric analysis focuses on scientometric indicators such as citation count, co-author networks, and keyword co-occurrence, the present work specifically targets ethnobotanical and ethnopharmacological field surveys, excluding purely experimental phytochemical or pharmacological studies lacking an ethnobotanical component. This approach allows for the identification of a large number of local surveys underrepresented in international databases, thus explaining the higher number of studies identified.

Thirdly, and most importantly, this critical analysis goes beyond bibliometric mapping by examining the functional and methodological role of ethnobotanical research within the Moroccan scientific landscape. The results demonstrate that the majority of biochemical, phytochemical, and microbiological studies on Moroccan medicinal plants are explicitly guided by ethnobotany, with plant selection, preparation methods, and therapeutic indications largely derived from prior fieldwork. This essential methodological link, where ethnobotanical research forms the basis of laboratory research, is not addressed in the Scopus-based bibliometric study and represents a major contribution of this analysis.

Ultimately, while the Scopus-based bibliometric study offers a valuable quantitative overview of indexed scientific output, this critical analysis proposes a broader, historically informed, and methodologically integrative perspective, highlighting

research imbalances, database limitations, and, above all, the fundamental role of ethnobotanical surveys in guiding biochemical and microbiological investigations of Moroccan medicinal plants.

Principal component analysis (PCA)

The Principal Component Analysis (PCA) showed that the first two principal components explained 73.37% of the total variance, with PC1 (54.84%) and PC2 (18.53%), indicating a strong representation of the dataset on the factorial plane (Figure 7A–C).

The distribution of regions along PC1 (Figure 7A) reveals a clear gradient opposing regions with high recent dynamics to those with relatively low progression. Fez–Meknes is distinctly separated on the positive side of PC1, reflecting a markedly higher contribution to the overall variability. Similarly, Tangier–Tetouan–Al Hoceima, Beni Mellal–Khenifra, and Rabat–Sale–Kenitra are positioned on the positive side, indicating strong evolution patterns. In contrast, southern regions such as Dakhla–Oued Ed-Dahab, Laayoune–Sakia El Hamra, and Guelmim–Oued Noun are located on the negative side, forming a more homogeneous group characterized by lower variability.

Along PC2, Tangier–Tetouan–Al Hoceima is clearly distinguished from the other regions (Figure 8A), indicating a specific temporal behavior. This separation suggests that this region experienced a distinct evolution compared to the general trend observed in other regions.

The variables projection (Figure 7B) highlights a temporal structuring of the dataset. Earlier periods are positively correlated with PC2, while intermediate and recent periods tend to align along PC1, reflecting a progressive shift in the system. The most recent periods are strongly associated with the positive side of PC1, confirming the increasing contribution of certain regions over time.

The biplot (Figure 7C) further illustrates the relationship between regions and temporal evolution. Fez–Meknes and Tangier–Tetouan–Al Hoceima are strongly associated with recent periods, indicating accelerated growth or change. In contrast, regions located on the negative side of PC1 are weakly associated with these periods, suggesting slower dynamics.

Intermediate regions such as Draa–Tafilalet and Marrakech–Safi show moderate associations, reflecting transitional behaviors.

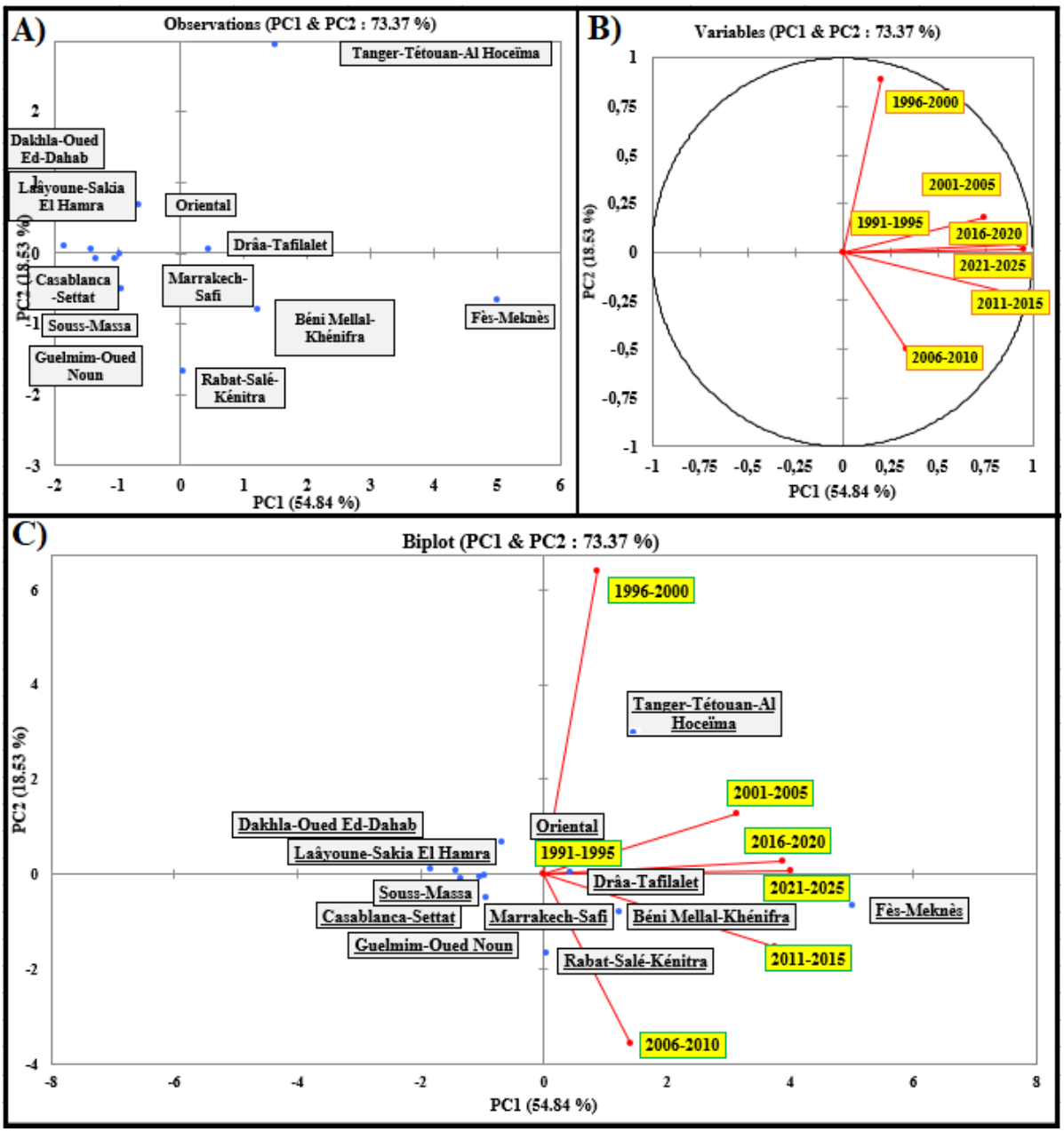

Figure 7. Principal Component Analysis of Spatiotemporal Dynamics Revealing Regional Disparities and Temporal Trends Across Moroccan Regions (1991–2025).

Overall, the PCA reveals a clear spatial differentiation between regions combined with a strong temporal gradient, highlighting unequal development patterns and suggesting that the observed variability is driven by both geographic disparities and progressive temporal changes.

Regional temporal trends in Morocco from 1991 to 2025

The analysis of regional trends shows a clear spatial differentiation in temporal dynamics across Morocco. Fez–Meknes exhibits the highest slope (12.96), indicating markedly stronger evolution over the 1991–2025 period compared to all other regions. Tangier–Tetouan–Al Hoceima (5.54) and Beni Mellal–Khenifra (4.93) also show relatively high slopes, suggesting significant changes over time.

Intermediate slopes are observed in Rabat–Sale–Kenitra (3.39), Oriental Region (3.29), Marrakech–Safi (3.11), Souss–Massa (2.64), Casablanca–Settat (2.57), and Draa–Tafilalet (2.39), reflecting moderate temporal progression.

Southern regions, including Laayoune–Sakia El Hamra (1.64), Guelmim–Oued Noun (1.29), and Dakhla–Oued Ed-Dahab (0.96), show minimal change, indicating relatively stable conditions.

Overall, the figure highlights a north-to-south gradient in temporal evolution, with northern and central regions experiencing faster dynamics, whereas southern regions remain comparatively stable. These patterns may reflect geographical, socio-economic, and environmental factors influencing regional development over the 1991–2025 period.

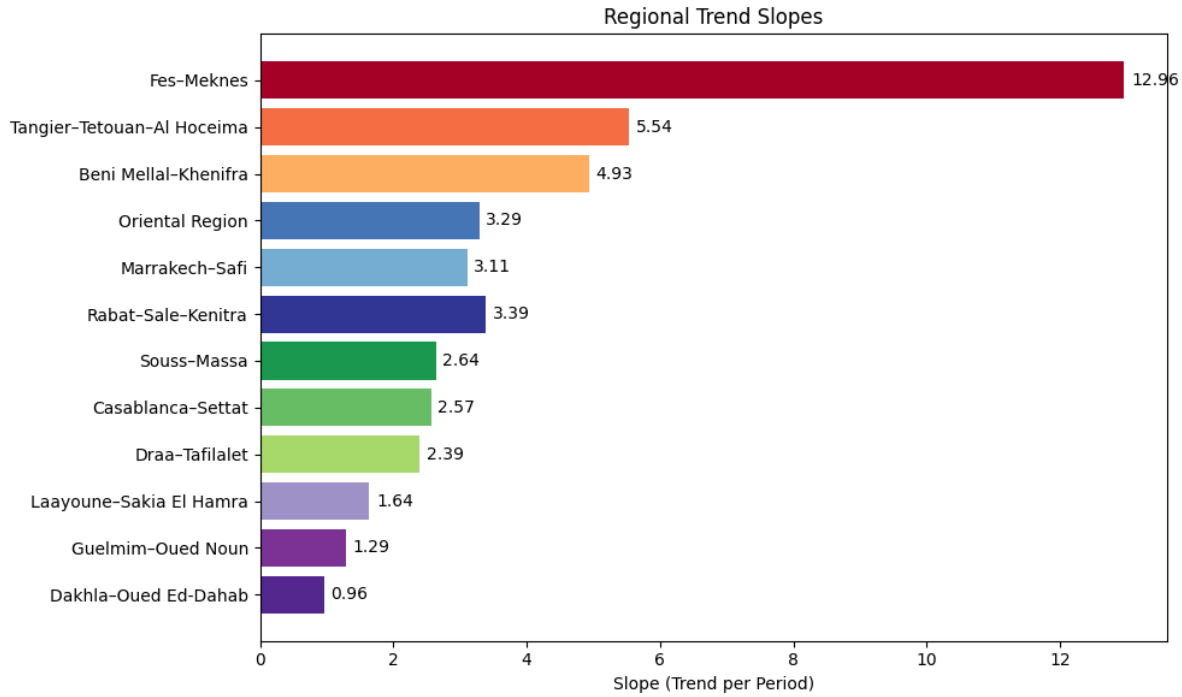

Figure 8. Regional slope of temporal trends in Morocco (1991–2025).

Spatio-temporal distribution and clustering of ethnobotanical studies in Morocco (1991–2025)

The hierarchical clustering analysis revealed a clear spatio-temporal structuring of ethnobotanical studies in Morocco, highlighting significant regional disparities alongside a progressive evolution of scientific activity over time. In the regional dendrogram (Figure 9A), five distinct clusters (C1–C5) were identified. Cluster C5, represented solely by the fez–Meknes region, appears highly distinct and dominant, reflecting its exceptional research output, particularly in the most recent period (93 studies during 2021–2025), and thus indicating its role as a major hub of ethnobotanical research. Cluster C3 groups regions such as Tanger–Tétouan–Al Hoceïma and Béni Mellal–Khénifra, which exhibit strong recent growth, with notable increases in publication counts (41 and 32 studies, respectively), suggesting an emerging and dynamic research activity. Cluster C2 includes regions with moderate to high levels of production, such as Drâa–Tafilalet and Rabat–Salé–Kénitra, characterized by a steady increase in studies, particularly after 2010. Cluster C1 encompasses regions with relatively homogeneous and moderate activity, including Souss-Massa and Marrakech-Safi, while Cluster C4 corresponds to regions with consistently low contributions, indicating limited research development. Overall, this spatial classification underscores a pronounced territorial inequality, with research efforts concentrated in a limited number of regions.

The temporal dendrogram (Figure 9B) further distinguishes four main phases in the evolution of ethnobotanical research. The period 2021–2025 (C4) forms a clearly isolated cluster, reflecting a substantial surge in publications across nearly all regions and marking a phase of scientific maturity. The 2011–2020 period (C3) represents a phase of strong growth and transition toward intensified research activity. Earlier periods, grouped within C1 (1991–2010), correspond to an initial phase characterized by low-to-moderate output and a relatively slow field development. Intermediate clustering patterns (C2) indicate gradual transitions between these phases. Taken together, these results demonstrate a marked acceleration in ethnobotanical research after 2010, culminating in a pronounced expansion in the most recent years. This spatio-temporal pattern highlights both the uneven geographic distribution of research and the rapid overall growth of the field in Morocco.

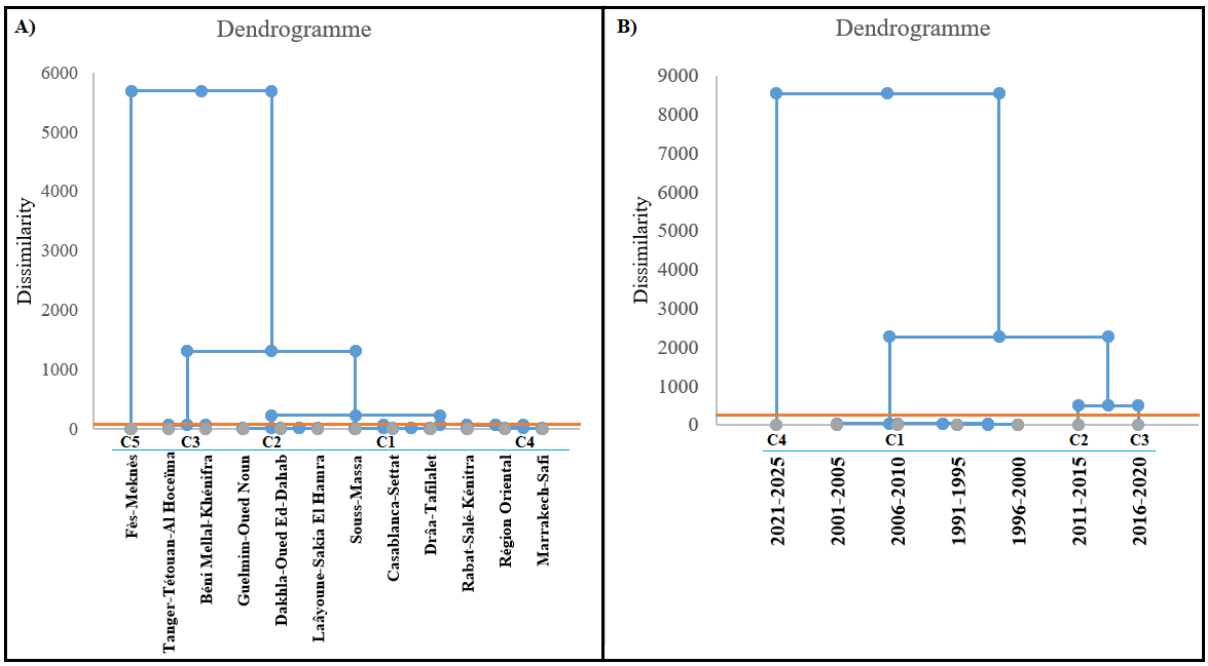

Figure 9. Hierarchical clustering of ethnobotanical studies in Morocco: (A) regional distribution patterns and (B) temporal evolution across study periods (1991–2025)

Limitations of the study

Ethnobotanical research in Morocco contributes significantly to the documentation of traditional knowledge and provides useful insights for biodiversity conservation by identifying key medicinal plant species and their cultural importance. However, the implications of these findings for direct conservation strategies should be interpreted with caution, as they are primarily based on published ethnobotanical surveys, which may not fully represent the actual distribution, abundance, or ecological status of plant species.

Despite providing a comprehensive spatio-temporal and methodological analysis of ethnobotanical and ethnopharmacological research in Morocco, this study has several limitations that should be acknowledged. The analysis is based on published literature indexed in major scientific databases, which may introduce publication bias by excluding grey literature and non-indexed studies. Although multiple databases were consulted, some relevant studies published in regional journals may not have been captured. In addition, the classification of methodological approaches relied on information reported in the original publications, which may vary in detail and reporting quality. Finally, the statistical analyses applied (PCA, trend analysis, and clustering) are descriptive and exploratory in nature, aimed at highlighting general spatio-temporal structuring and research patterns across Morocco.

Nevertheless, the large dataset analyzed in this study provides a robust overview of ethnobotanical research dynamics in Morocco and offers a valuable baseline for future methodological and geographical expansion of this field, as well as for supporting more targeted biodiversity conservation and sustainable management strategies.

Conclusion

Ethnobotany explores how human populations use and interact with plants for food, medicine, and other practical purposes, while ethnopharmacology focuses on the interdisciplinary study of bioactive substances derived from natural resources traditionally used by communities, combining documentation of traditional knowledge with biological and pharmacological validation to ensure efficacy, safety, and integration into healthcare systems. This critical and quantitative review highlights the substantial growth of ethnobotanical and ethnopharmacological research in Morocco over the past three decades, while revealing pronounced temporal and spatial disparities. Northern and central regions, particularly Fez–Meknes and Taza Province, dominate the scientific landscape, whereas southern and desert regions remain largely underexplored despite their rich biodiversity and valuable traditional knowledge. The combined use of qualitative and quantitative approaches has improved the robustness and comparability of field studies, enabling the identification of key medicinal species and their links to traditional therapeutic practices. The continued reliance of Moroccan populations on medicinal plants underscores their cultural and healthcare significance and highlights the need for rigorous documentation and safe use. In this context, journals such as *Ethnobotany Research and Applications* play a central role in disseminating knowledge and shaping research

dynamics. Importantly, the results of principal component analysis (PCA), hierarchical clustering, and slope trend analysis consistently confirm the observed spatio-temporal patterns. These approaches reveal a clear gradient opposing dynamic northern and central regions to less active southern areas, as well as a strong temporal acceleration of research activity, particularly after 2010. They further highlight Fez–Meknes' dominant position as a major research hub and the progressive structuring of ethnobotanical research into distinct developmental phases. Moreover, biochemical and microbiological studies in Morocco are largely driven by ethnobotanical knowledge, with plant selection primarily based on field surveys and existing literature. Lamiaceae species are the most extensively investigated, reinforcing the role of ethnobotany as a foundational framework for phytochemical and antimicrobial research. Ethnobotanical surveys not only preserve traditional knowledge but also serve as a key basis for subsequent laboratory investigations, guiding species selection, preparation methods, and therapeutic indications. Moving forward, targeted efforts to investigate underrepresented regions, standardize methodologies, and integrate field surveys with experimental validation are essential to achieve comprehensive national coverage, promote sustainable valorisation of medicinal flora, and support the integration of traditional remedies into modern healthcare systems. Overall, this review provides both a historical and analytical framework for Moroccan ethnobotanical research and emphasizes its central role in guiding biochemical and microbiological studies, as well as in informing public health strategies and biodiversity conservation.

Declarations

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