



Ethnobotany in Morocco from 1990 to 2023: Part II- Analysis of Floristic Diversity, Conservation Status and treated diseases

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Review

Abstract

Background: The medicinal and aromatic plants (MAPs) have been used in Moroccan traditional medicine. This review aims to make a synthesis of floristic data from ethnobotanical studies conducted between 1990 and 2023, in order to highlight plant diversity, use pattern, and conservation status.

Methods: A total of 1427 plant species were cited across 230 ethnobotanical studies. The relative frequency of citation (RFC) index was calculated as an indicator of cultural importance. Phylogenetic relationships between the species that were commonly reported to possess antidiabetic potential were generated by MEGA X software through the Neighbor-Joining method. The IUCN status of the plants and native origin of plants were also assessed.

Results: The most frequently cited botanical families were Lamiaceae, Asteraceae, Apiaceae, Fabaceae and Rosaceae, whereas *Marrubium vulgare* L., *Mentha pulegium* L., *Rosmarinus officinalis* L., *Artemisia herba-alba* Asso and *Olea europaea* L., were the most cited species. Native plants represented 65.53% of reported species, largely characterized as Least Concern (42.89%). The commonest treated diseases were diabetes, bronchopulmonary, and gastrointestinal diseases. Phylogenetic analysis revealed clustering of key antidiabetic species, suggesting potential links between evolutionary relationships and therapeutic properties.

Conclusions: The ethnobotanical knowledge in Morocco is floristically rich, culturally varied and therapeutically important. The identification of most cited species and their conservation status can provide a reference for sustainable use, drug discovery, and traditional knowledge preservation.

Keywords: Ethnobotanical review; medicinal plants; Morocco; plant citation index; phylogenetic analysis; IUCN conservation.

Background

The Kingdom of Morocco is well known for its extraordinary ecological and floristic diversity, due to the presence of different biogeographical zones such as the Mediterranean, the Atlantic, and the Saharan regions. Its distinct topography, as well as

the climatic diversity, supports the growth of an estimated 4,200 vascular plant species and subspecies, of which around 20 % are endemic (Fennane *et al.* 2014). This variety of habitats has a profound influence on the lives, customs and health practices of its residents for generations. Use of plants for medicinal, culinary, artisanal, and religious practices in Morocco is an integral component of its cultural heritage and is a central element of its ethnobotanical knowledges systems.

Ethnobotanical studies in Morocco have progressively increased since 1990, associated with global and local awareness of the role of traditional knowledge in biodiversity conservation, health care, and sustainable development (Elachouri, 2018); Rankou *et al.* 2015). These investigations have led to the documentation of a wide range of plant species as medicinal plants. Species like *Artemisia herba-alba* Asso, widely used for its antiseptic and anti-inflammatory properties, and *Nigella sativa* L., mainly employed for its immuno-stimulant and therapeutic effects are extensively reported in the literature (Jamila & Mostafa, 2014).

Although much progress has been made, the floristic information obtained from ethnobotanical studies is still fragmented. Therefore, a comprehensive understanding of the general features of plant use, distribution, and conservation could not be achieved. Ethnobotanical investigations conducted in Moroccan areas including the Rif, the Middle Atlas and the Anti-Atlas revealed a high diversity of plant use, but no study to date focused on the main plant species used by Moroccan people for curative purposes.

Furthermore, increasing rates of urbanization, agricultural intensification and commercialization, have further increased the pressure on plant resources especially on wild medicinal and aromatic species (Bencheikh *et al.* 2021). This increasing demand for medicinal and aromatic plants, combined with unsustainable crop-harvesting practices, has subsequently led to great concerns regarding conservation status of important species. According to the IUCN Red List, some Moroccan endemic plants are threatened by overexploitation and destruction of their habitats (Rankou *et al.* 2013). Hence, we emphasize IUCN status of the most popular species in the current review.

This second part of the review synthesizes the floristic data of the ethnobotanical studies undertaken in Morocco, during the last three decades, from the point of view of species diversity, use patterns and conservation implications. Its aim is to answer the following questions: which plant species are the most frequently used, and for which purposes? What is the status of these heavily exploited or culturally important plants? What are the primary diseases targeted? Through consideration of these themes, this review not only introduces the richness of Moroccan flora but also addresses the necessity to protect plant resources and the traditional knowledge related to them.

Materials and Methods

Data collection

This floristic analysis is based on a compilation of ethnobotanical studies conducted in Morocco and published between 1990 and August 2023. Articles were retrieved from major academic databases including Google Scholar, Scopus, ScienceDirect, Springer, Web of Science, JSTOR, and PubMed. The year 1990 was selected as a starting point, marking the emergence of modern ethnobotanical research efforts in Morocco. Only peer-reviewed articles written in English or French were included in this review. The literature search was performed using a combination of keywords in both French and English, such as: "ethnobotanique Maroc", "plantes médicinales Maroc", "usages traditionnels des plantes Maroc", "enquête ethnobotanique", "ethnopharmacologie", "ethnomédecine", "pharmacopée traditionnelle et Maroc", and their equivalents in English: "Medicinal plants of Morocco", "Traditional uses of plants in Morocco", "Ethnobotanical survey", "Ethnopharmacology", "Ethnomedicine", and "Traditional pharmacopoeia and Morocco".

Floristic analysis

The verification and correction of species scientific names were carried out by referring to the international online database used, World Flora Online. In addition, the synonyms of the names of the species cited in the studied articles were standardized, and their families and origins (native/exotic) were determined using Moroccan botanical books (Fennane *et al.* 1999; Fennane *et al.* 2007; Fennane *et al.* 2014)

Graphical visualization of the most used plant species, was carried out using an online word clouds generator (<http://www.nuagedemots.fr>). Among 1427 species cited in the studied articles, only the 287 which are cited in more than ten articles were represented.

The conservation status of the listed plant species in the studied articles was assessed in accordance with the International Union for Conservation of Nature (IUCN) criteria, as adapted and applied at the national level for the Moroccan flora, based on the framework and guidelines presented in the Elements for a Red Book of the Vascular Flora of Morocco (Fennane, 2016, 2017, 2018a-e).

Ethnomedicinal and biological traits of the cited species

Relative Frequency of Citation (RFC)

For quantifying the relative cultural importance of each medicinal and aromatic plant species cited in the reviewed ethnobotanical studies, the Relative Frequency of Citation index has been computed following the proposed formula by Tardío and Pardo-de-Santayana : $RFC = FC / N$, defined as the quotient of the Frequency of Citation and the number of reports, where FC corresponds to the number of studies in which a given species was cited and N is the total number of ethnobotanical studies included in this review. In the context of this work, this index reflects the relative frequency with which the species is cited across the studied articles compared to other species.

Bioactive compounds and their pharmacological properties

Furthermore, to give an insight in the pharmacological properties and the main bioactive compounds of the 10 most cited plant species, we have collected the data from the above-mentioned databases, as well as from recent reviews and articles published in this context (since 2020). Moreover, the molecular structures of the bioactive constituents identified in these plant species were represented using data from the PubChem database.

Determination of the main treated diseases

The names of the diseases treated with plants, as reported in the ethnobotanical surveys described in the studied articles, were extracted. The processing of the obtained data required the categorization of diseases and allowed the determination of the frequency of their use.

Phylogenetic analysis of plant species

In order to analyze the evolutionary relationships between the most commonly cited medicinal plant species used for diabetes treatment in Morocco (1990-2023), a phylogenetic tree was constructed based on the species cited at least 10 times for this purpose. The phylogenetic tree was generated using MEGA X software with the Neighbor-Joining (NJ) method based on simple taxonomic distances. The groups and clusters found reflect the evolutionary closeness of the species, and could point out similar phytochemicals profile and therapeutic effects.

Statistical analysis

In order to analyze the collected data and highlight floristic information related to ethnobotanical research in Morocco, we employed descriptive statistics, relying on the calculation of frequencies and percentages. Since the information extracted from published articles does not meet the requirements for inferential or multivariate analyses, only descriptive statistics were used.

Results and Discussion

Floristic analysis

Plant families reported in the studied articles

In total, 180 plant families were recorded across the ethnobotanical investigations conducted in Morocco between 1990 and 2023. Among these, two families represent non-vascular taxa (Bryophyta and Usnea), whereas the rest are vascular plants.

The largest number of families reported in one study was 122, and the minimum reported was a single family. This variation illustrates the variability of the ethnobotanical studies analyzed and emphasizes the high floristic diversity listed.

Distribution of plant families according to the number of their citation

Figure 1 shows the distribution of plant families according to the number of their citation. It appears that in the majority of the articles (51.11 %), more than one family was cited by informants; 2-10 families in 26.11 % of articles, and 11-50 plant families in 25 % of articles. This result reveals the important number of plant families used by informants, and reflects the high knowledge of respondents on the therapeutical use of a variety of plants. However, in an important proportion of articles (24.44 %), only one plant family was cited by informants. This result could be explained by the limited knowledge of informants on the therapeutical use of other plant species, or the lack of availability of different plant families in the

geographical area of these respondents. These findings underline both the richness and the variability of traditional plant knowledge across different regions of Morocco.

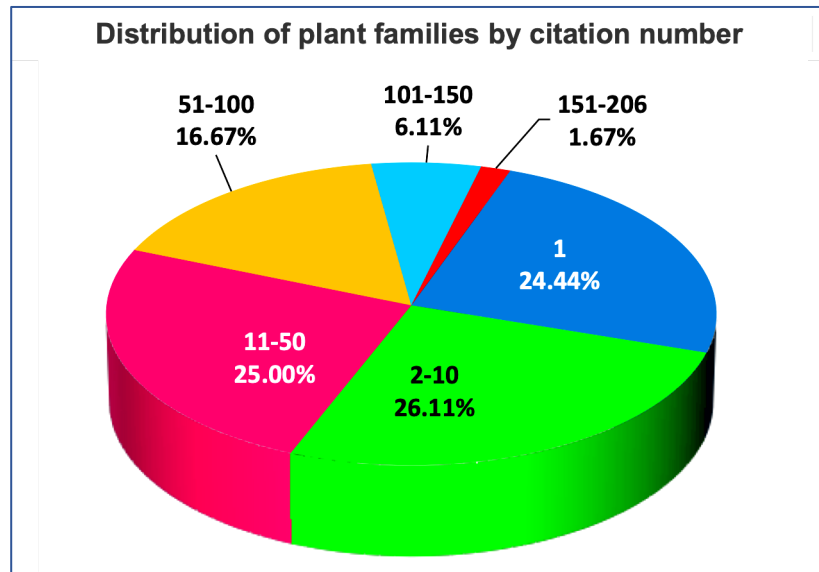


Figure1. Distribution of plant families according to the number of their citation.

Table 1 gives the names of 7 botanical families cited in 50% or more of the studies, namely Lamiaceae, Asteraceae, Apiaceae, Fabaceae, Rosaceae, Ranunculaceae and Brassicaceae which are cited in 76.09 %; 73.04 %; 67.83 %; 64.35 %; 51.74 %; 51.30 %; and 50.00% of articles, respectively. The dominant reported use of plants belonging to these botanical families could be related to their availability in different Moroccan areas and their easy access as natural therapeutical resources. Moreover, it's important to mention that different plant species from these botanical families were demonstrated to contain a variety of bioactive compounds with a great healing potential (Awuchi & Morya, 2023; Derouich *et al.* 2020; Kicel, 2020; Tungmunnithum *et al.* 2021; Lesellier *et al.* 2021; Mattosinhos *et al.* 2022; Goo, 2022).

Table 1. Names of 7 botanical families cited in more than 50% of studies .

Botanical families	Citation number	Proportion of studies (%)	Examples of some corresponding studies (Indexed Scopus Q1 or Q2)
Lamiaceae	175	76.09	(Belhaj <i>et al.</i> 2021; Amrati <i>et al.</i> 2021; Chaachouay <i>et al.</i> 2021a; Chaachouay <i>et al.</i> 2021b; Chaachouay <i>et al.</i> 2021c; Radi <i>et al.</i> 2022; Najem <i>et al.</i> 2022; El-Gharbaoui <i>et al.</i> 2017)
Asteraceae	168	73.04	(Chaachouay <i>et al.</i> 2019a; Chaachouay <i>et al.</i> 2019b; Chaachouay <i>et al.</i> 2019c; Bouayyadi and Zidane, 2020; Najem <i>et al.</i> 2021; Chaachouay and Zidane, 2021)
Apiaceae	156	67.83	(Redouan <i>et al.</i> 2020; Salhi <i>et al.</i> 2019; Idm'Hand <i>et al.</i> 2020; Orch <i>et al.</i> 2020)
Fabaceae	148	64.35	(León-González <i>et al.</i> 2018; Jaadan <i>et al.</i> 2020; Kharchoufa <i>et al.</i> 2021; Aboukhalaf <i>et al.</i> 2022; Benkhignie <i>et al.</i> 2023)
Rosaceae	119	51.74	(Lamrani-Alaoui and Hassikou, 2018; Bencheikh <i>et al.</i> 2021; Bencheikh <i>et al.</i> 2022; El-Assri <i>et al.</i> 2021; Alami-Merrouni <i>et al.</i> 2021; Benamar <i>et al.</i> 2023)
Ranunculaceae	118	51.30	(Ziyat <i>et al.</i> 1997; Belhaj <i>et al.</i> 2020; Es-Safi <i>et al.</i> 2020; Labiad <i>et al.</i> 2020; Mechchate <i>et al.</i> 2020)
Brassicaceae	115	50.00	(Teixidor-Toneu <i>et al.</i> 2016; Alves-Silva <i>et al.</i> 2017; Teixidor-Toneu <i>et al.</i> 2017; Najem <i>et al.</i> 2019; Chaachouay <i>et al.</i> 2019a; Chaachouay <i>et al.</i> 2019b)

Distribution of articles according to the number of plant species they report

Figure 2 shows the distribution of articles according to the number of plant species reported by respondents. It's noticed that in most of the articles (82 %), more than one species was cited by informants; 11-50 species in 33% of articles, 51-100 species in 28 % of articles, and 101-200 in 21% of articles, respectively. Whereas, only a low proportion of articles is characterized by only one cited species (3 %). These results reflect the high number of plant species used by informants according to the majority of articles. Moreover, very important number of plant species was reported in only 9 % of articles: 201-500 species in 6 % of articles, 501- 1000 species in 2% of articles, and 1000-1039 plant species in 1% of articles. Thus, it's interesting to carry out ethnobotanical studies enabling to gather more data on the species used in traditional Moroccan phytotherapy, in order to build up a broader database in this field, that will help in the development of ethnopharmacology.

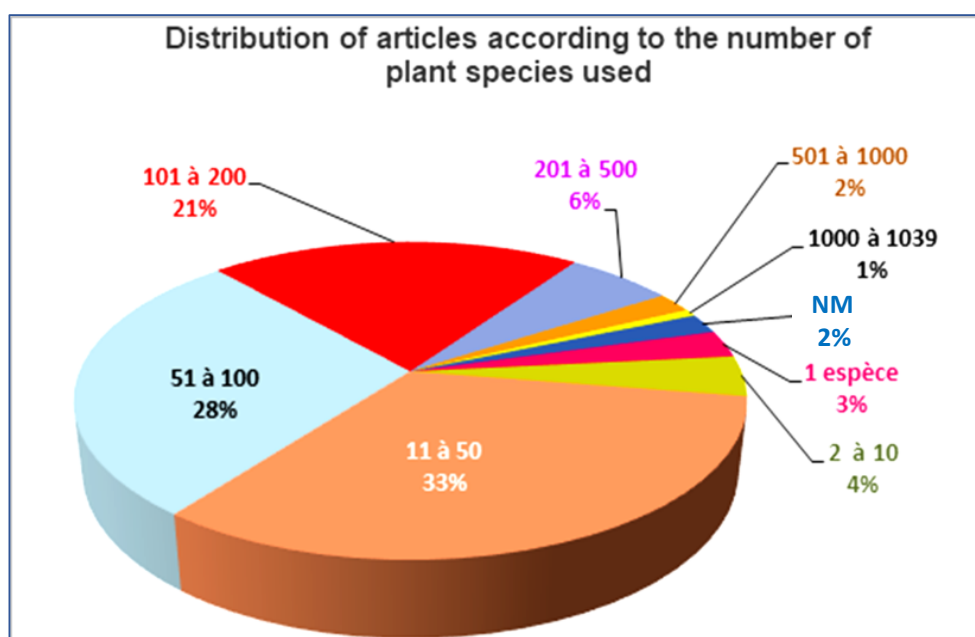


Figure 2. Distribution of articles according to the number of plant species they report; NM: no plant species were mentioned in the article.

Plant species reported in the studied articles

The refined list (see Materials and methods) of medicinal plant species cited in the reviewed articles revealed their great diversity. A total of 1427 species were recorded, distributed across 650 genera. In addition, 20 subspecies and 7 varieties were also cited. The number of species citations per study varied from 1 to 388.

Similarly, the occurrence of species across the different reviewed articles ranged from 1 to 116. Figure 3 visually illustrates this variability and highlights the most frequently cited species. The three most highlighted plant names in the figure 3 are *Marrubium vulgare* L., *Mentha pulegium* L., *Rosmarinus officinalis* L. belonging to the family Lamiaceae.

Distribution of the cited plant species according to their RFC values

To determine the bibliographic prominence of a medicinal and aromatic plant species in Moroccan ethnobotanical studies, we adapted the RFC index to the context of our work.

Table 2 gives the names of the 10 most cited plant species which have the highest RFC values. The dominant use of these plant species could be related to their natural presence in Morocco (Fennane et al. 1999, Fennane et al. 2007, Fennane 2021), thus, their availability to Moroccan people.

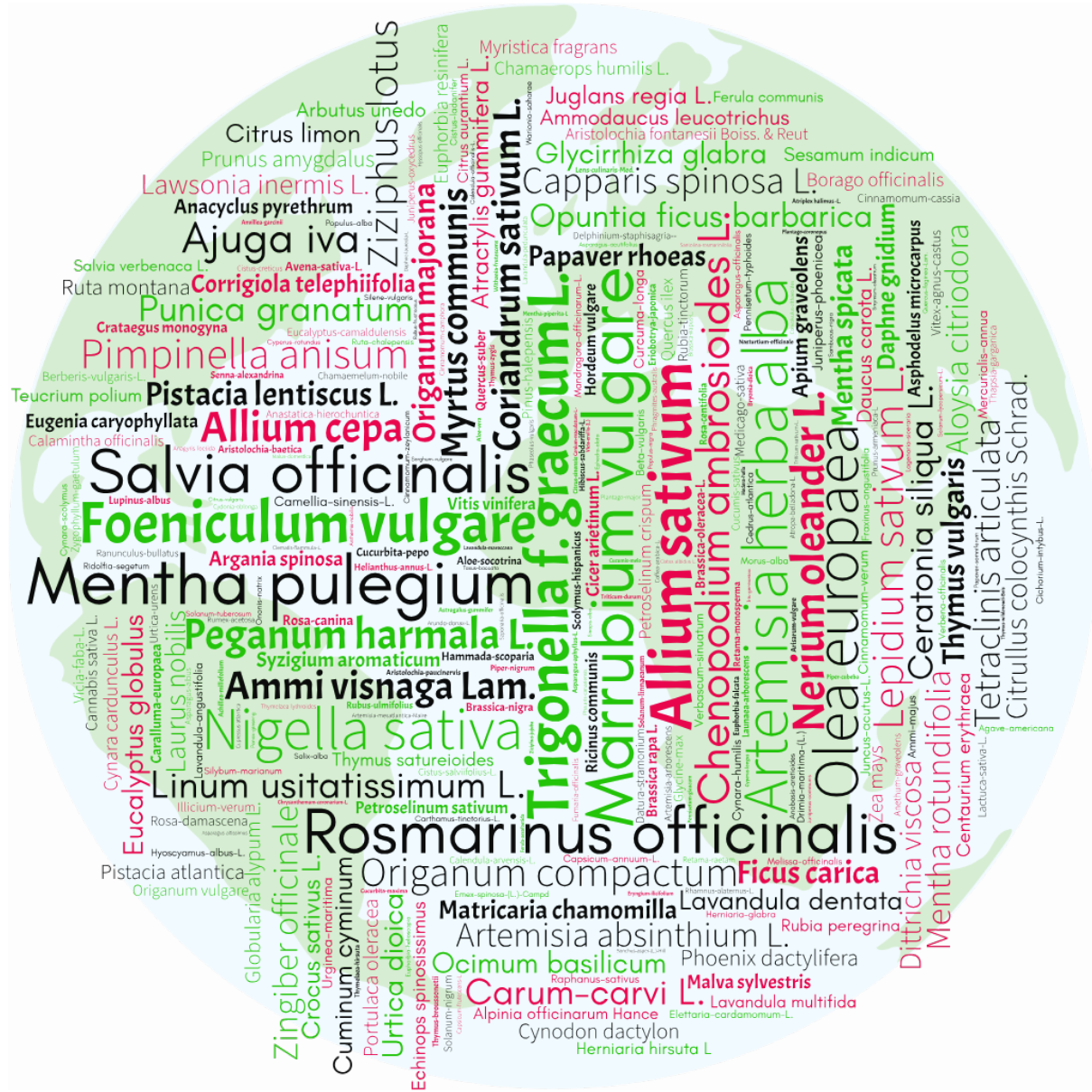


Figure 3. Graphical visualization of the most cited species. Among 1427 cited in the studied articles, the figure represents only 287 species which are cited in more than ten articles. The font size of the plant species names is proportional to their citation frequency.

Table 2. Names of the 10 most cited plant species (citation in up to 50 % of articles; RFC).

Plant species	RFC	Percentage (number studies)	Examples of some corresponding studies of
<i>Marrubium vulgare</i> L.	0.504	50.43	(Mikou <i>et al.</i> 2015; Jamaledine <i>et al.</i> 2017; Jouad <i>et al.</i> 2001; Eddouks <i>et al.</i> 2002; El-Hilaly <i>et al.</i> 2003)
<i>Mentha pulegium</i> L.	0.500	50.00	(Lahsissene and Kahouadji, 2010a; Lahsissene and Kahouadji, 2010b; Chebat <i>et al.</i> 2014; Fadil <i>et al.</i> 2014. Daoudi <i>et al.</i> 2015)
<i>Rosmarinus officinalis</i> L.	0.495	49.57	(Benkhaira <i>et al.</i> 2021; Ez-Zoubi <i>et al.</i> 2022; Eddouks <i>et al.</i> 2007; El-Amrani <i>et al.</i> 2010; Fadil <i>et al.</i> 2014)
<i>Artemisia herba-alba</i> Asso	0.465	46.52	(Ghanimi <i>et al.</i> 2022a; Ghanimi <i>et al.</i> 2022b; Ghanimi <i>et al.</i> 2022c; El-Midaoui <i>et al.</i> 2011; Chakit <i>et al.</i> 2022; Drioiche <i>et al.</i> 2021; Jeddi <i>et al.</i> 2021)
<i>Olea europaea</i> L.	0.456	45.65	(El-Ouahdani <i>et al.</i> 2021; Eddouks <i>et al.</i> 2009; Bellakhdar <i>et al.</i> 1991; El-Hachlafi <i>et al.</i> 2020; Chaachouay <i>et al.</i> 2021a)

<i>Salvia officinalis</i> L.	0.456	45.65	(Khabbach <i>et al.</i> 2012; El-Boullani <i>et al.</i> 2022; Amagnouje <i>et al.</i> 2020; Doukkali <i>et al.</i> 2015)
<i>Trigonella foenum-graecum</i> L.	0.434	43.48	(Lyoussi <i>et al.</i> 2023; Lemhadri <i>et al.</i> 2023; Benkhniqie <i>et al.</i> 2022; El-Brahimi <i>et al.</i> 2022)
<i>Allium sativum</i> L.	0.426	42.61	(Tahraoui <i>et al.</i> 2007; Fakchich and Elachouri., 2020; Eddouks <i>et al.</i> 2016; Barkaoui <i>et al.</i> 2017)
<i>Nigella sativa</i> L.	0.426	42.61	(El-Yaagoubi <i>et al.</i> 2023; Achour <i>et al.</i> 2022; Ajjoun <i>et al.</i> 2022; El-Hachlafi <i>et al.</i> 2022)
<i>Foeniculum vulgare</i> Mill.	0.417	41.74	(Tahraoui <i>et al.</i> 2007; Fakchich and Elachouri, 2014; Blanco and Carrière, 2016; Eddouks <i>et al.</i> 2016; Barkaoui <i>et al.</i> 2017)

Figure 4 shows the distribution of RFC values of all the mentioned species in the studied articles. It appears that the most of species (89.63 %) are characterized by a low RFC ($0.004 < RFC < 0.094$). This result indicates that the majority of cited species don't have a common use by informants. This may be related to many factors, such as the region in which the interviewees live, their knowledge of plant species with healing potential, the local existence of these species, and their availability to the interviewees. The other remaining species, are characterized by a higher RFC value: 6.38% of species with $0.094 < RFC < 0.205$; 1.82% of species with $0.205 < RFC < 0.290$; 2.18% of species with $0.290 < RFC < 0.504$. These species are probably available for Moroccan people from different areas and well recognized for their medicinal effects.

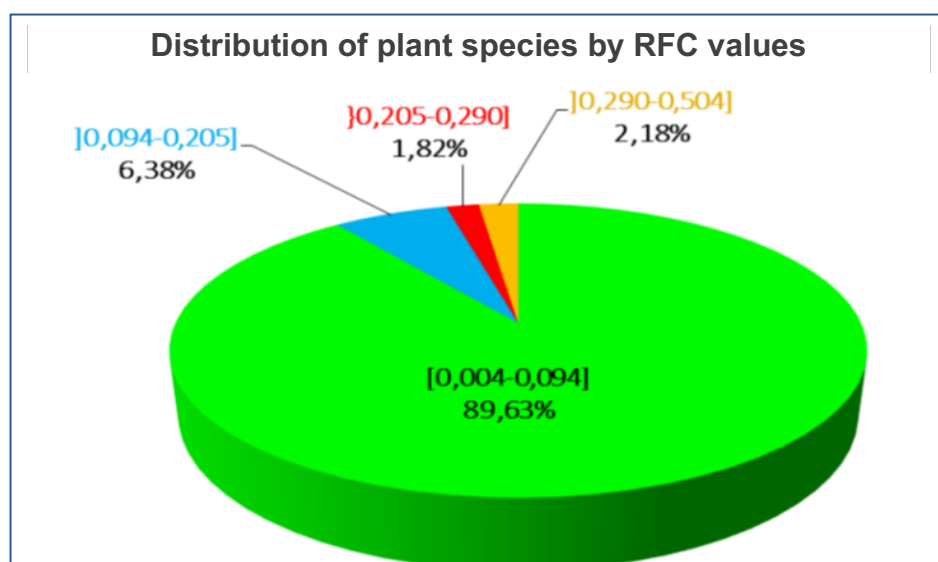


Figure 4. Distribution of the cited plant species according to their RFC values.

Furthermore, the frequent use of the 10 most used plant species in herbal remedies can be explained, also by their richness in bioactive compounds, as well as by their several therapeutical properties (Table 3, Fig. 5).

Table 3. Insight into the main bioactive compounds and pharmacological properties of the 10 most cited plant species according to different studies.

Plant species	Pharmacological properties/Main bioactive compounds	References
<i>Marrubium vulgare</i> L.	<ul style="list-style-type: none"> - Anti-inflammatory - Analgesic/ Marrubin - Antioxidant - Anticancer/ Acacetin, Apigenin, Ladanein - Antimicrobial - Hepatoprotective/ Vulgarin - Cardiovascular effects/Marrubenol - Hypolipidemic - Antiedematogenic effects/Marrubin - Gastroprotective effect/ Marrubin - Antispasmodic 	(Al-Snafi <i>et al.</i> 2021)

<i>Mentha pulegium</i> L.	<ul style="list-style-type: none"> - Antioxidant, antimicrobial, anti-inflammatory/pulegone - Anticancer, anti-hemolytic/neophytadiene, luteolin, chrysoeriol and kaempferol. - Antidiabetic, anti-alzheimer/ Gallic acid, p-coumaric acid, ferulic acid, naringenin and quercetin - Anti-hypertensive, antispasmodic, wound healing 	<ul style="list-style-type: none"> -(Luís and Domingues, 2021) -(Al-Rajhi <i>et al.</i> 2022) -(Abbou <i>et al.</i> 2022) -(Amtaghri <i>et al.</i> 2024)
<i>Rosmarinus officinalis</i> L.	<ul style="list-style-type: none"> - Antioxidant/rosmarinic, carnosic and ursolic acids, thymol and myrcene - Anti-inflammatory/carnosic and rosmarinic acids - Antidiabetic activity - Antimicrobial activity/carnosic, rosmarinic acids, carnosol, borneol - Anticarcinogenic activity/carnosic, ursolic, and betulinic acids, alpha pinene, 1,8-cineol, camphor - Cognitive effects - Spasmolytic effects/1,8-cineol and bornyl acetate 	(Lešnik <i>et al.</i> 2021)
<i>Artemisia herba-alba</i> Asso	<ul style="list-style-type: none"> - Anticancer/artesunate, chlorogenic acid, artemisin - Neuroprotective and antidepressant/caruifolin - Immuno-modulatory - Hepatoprotective/Thujane - Renal and hypoglycemic effects/ pinene 	(Batiha <i>et al.</i> 2020)
<i>Olea europaea</i> L.	<ul style="list-style-type: none"> - Cytotoxic , antihyperglycemic, antimicrobial/ Oleuropein, hydroxytyrosol - Antihypercholesterolemic/Hydroxytyrosol , oleuropein, tyrosol - Antihypertensive/Oleanolic acid, uvaol 	(Alesci <i>et al.</i> 2022)
<i>Salvia officinalis</i> L.	<ul style="list-style-type: none"> - Antioxidant, antimicrobial, anti-inflammatory, neuroprotective, anti-diabetic, anticancer, antimutagenic, antinociceptive (pain-relieving), antiseptic, and hepatoprotective properties/alpha-thujone and beta-thujone, Camphor, 1,8Cineole, ursolic acid 	(Benamar <i>et al.</i> 2025)
<i>Trigonella foenum-graecum</i> L.	<ul style="list-style-type: none"> - Hypoglycemic /diosgenin, 4-hydroxyisoleucine - Hypocholesterolemic effect - Anti-cancer and adjustment of male testosterone levels /Diosgenin - Anti-fungal and anti-bacterial activity - Anti-oxidant - Fight obesity/Galactomannan - Neuroprotective and gastroprotective activities - Breast milk supply - Hair growth promotion 	(Ruwali <i>et al.</i> 2022)
<i>Allium sativum</i> L.	<ul style="list-style-type: none"> - Antimicrobial, antithrombotic/ Allicin, ajoene - Anticancer/Allicin, kaempferol, Diallyl sulfide - Antioxidant/alliin, kaempferol - Anti-inflammatory - Antihypertensive - Antidiabetic - Anti-obesity - Anti-alzheimer 	(Okoro <i>et al.</i> 2023)
<i>Nigella sativa</i> L.	<ul style="list-style-type: none"> - Antioxidant, anti-inflammatory, antihepatotoxic, analgesic, antimutagenic, anti-nephrotoxic, immunomodulatory, hypoglycemic, antiulcer, antimicrobial, antiviral, cardioprotective, antihypertensive, and anti-obesity properties/ Thymoquinone, Thymohydroquinone, Thymol 	(Dalli <i>et al.</i> 2021)
<i>Foeniculum vulgare</i> Mill.	<ul style="list-style-type: none"> - Antimicrobial properties/5-hydroxy furanocoumarin, Anethole, Scopoletin - Antioxidant/caffeoylquinic acid, rosmarinic acid, quercetin 3-O-galactoside, and kaempferol-3-O-glucoside - Anti-inflammatory 	(Noreen <i>et al.</i> 2023)

- Anti-anxiety
- Gastro-protective, anticancer/Anethole
- Cardiovascular and lipid activity
- Diabetes prevention
- Hepato-protective

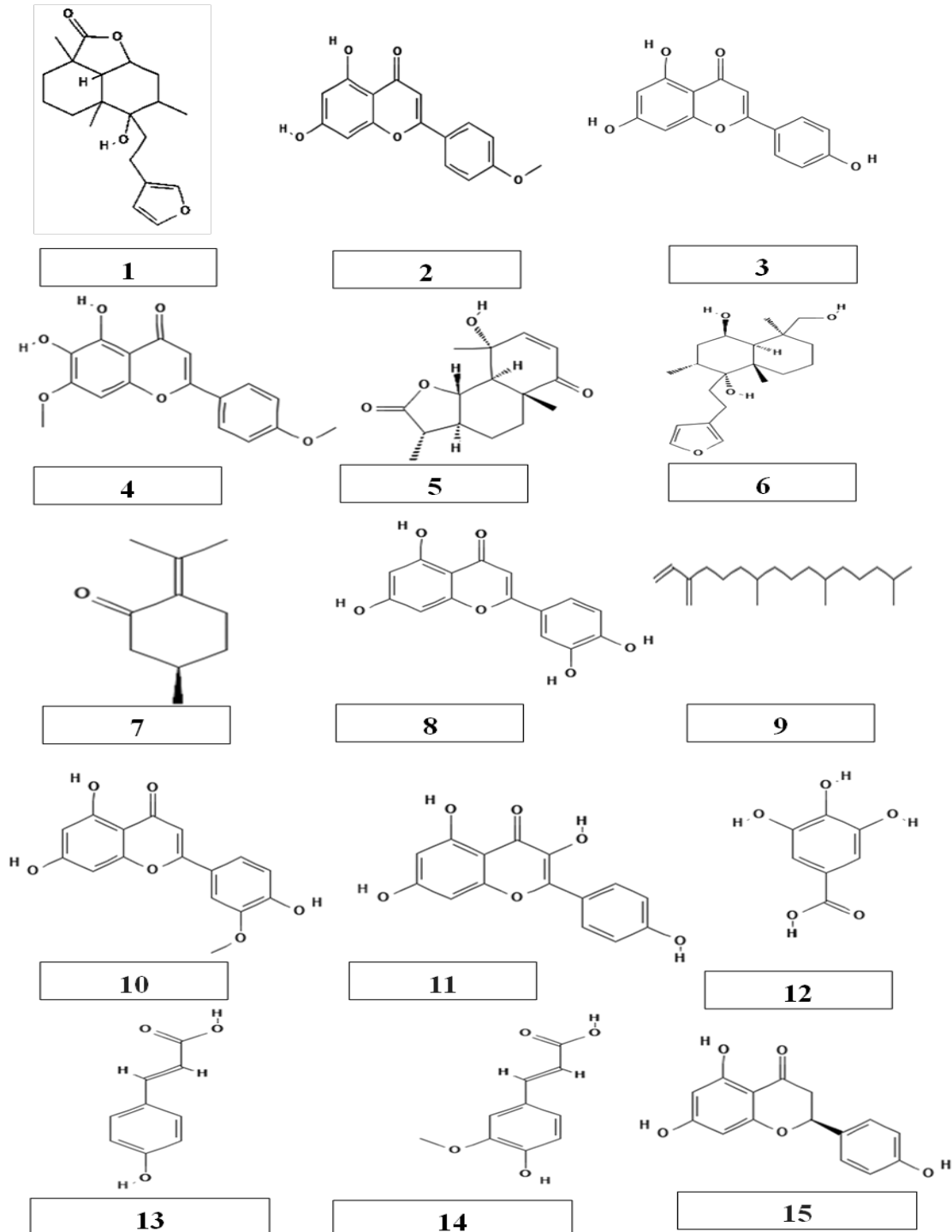


Figure 5 (1-15). Main bioactive compounds of the 10 most cited plant species in the analysed studies; 1) Marrubin, 2) Acacetin, 3) Apigenin; 4) Ladanein, 5) Vulgarin, 6) Marrubenol, 7) Pulegone, 8) Luteolin, 9) Neophytadiene, 10) Chrysoeriol, 11) Kaempferol, 12) Gallic acid, 13) p-Coumaric acid, 14) Ferulic acid, 15) Naringenin.

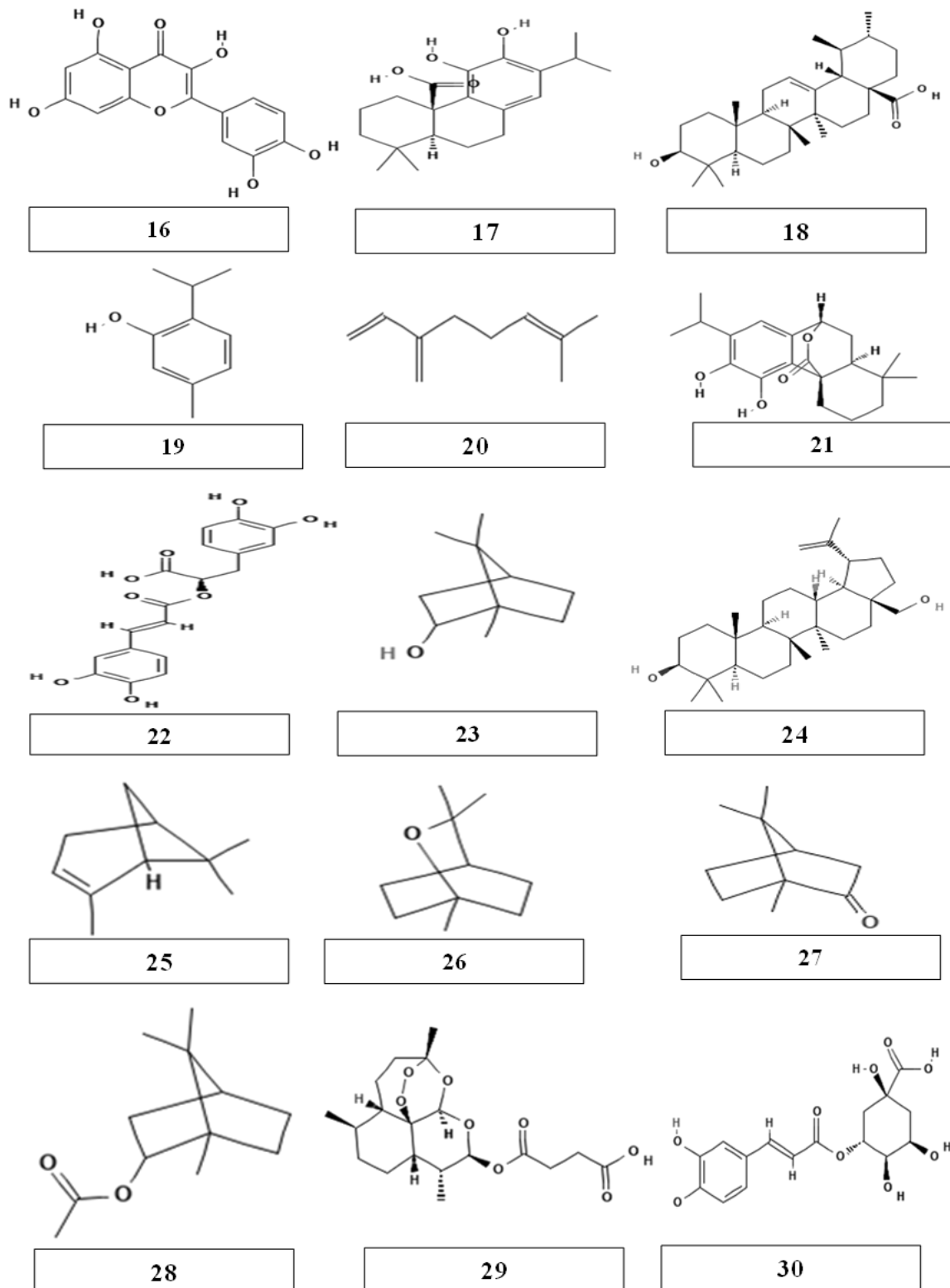


Figure 5 (16-30). Main bioactive compounds of the 10 most cited plant species in the analysed studies; 16) Quercetin, 17) Carnosic acid, 18) Ursolic acid, 19) Thymol, 20) Myrcene, 21) Carnosol, 22) Rosmarinic acid, 23) Borneol, 24) Betulinic acid, 25) Alpha pinene, 26) 1,8-Cineole, 27) Camphor,, 28) Bornyl acetate, 29) Artesunate, 30) Chlorogenic acid

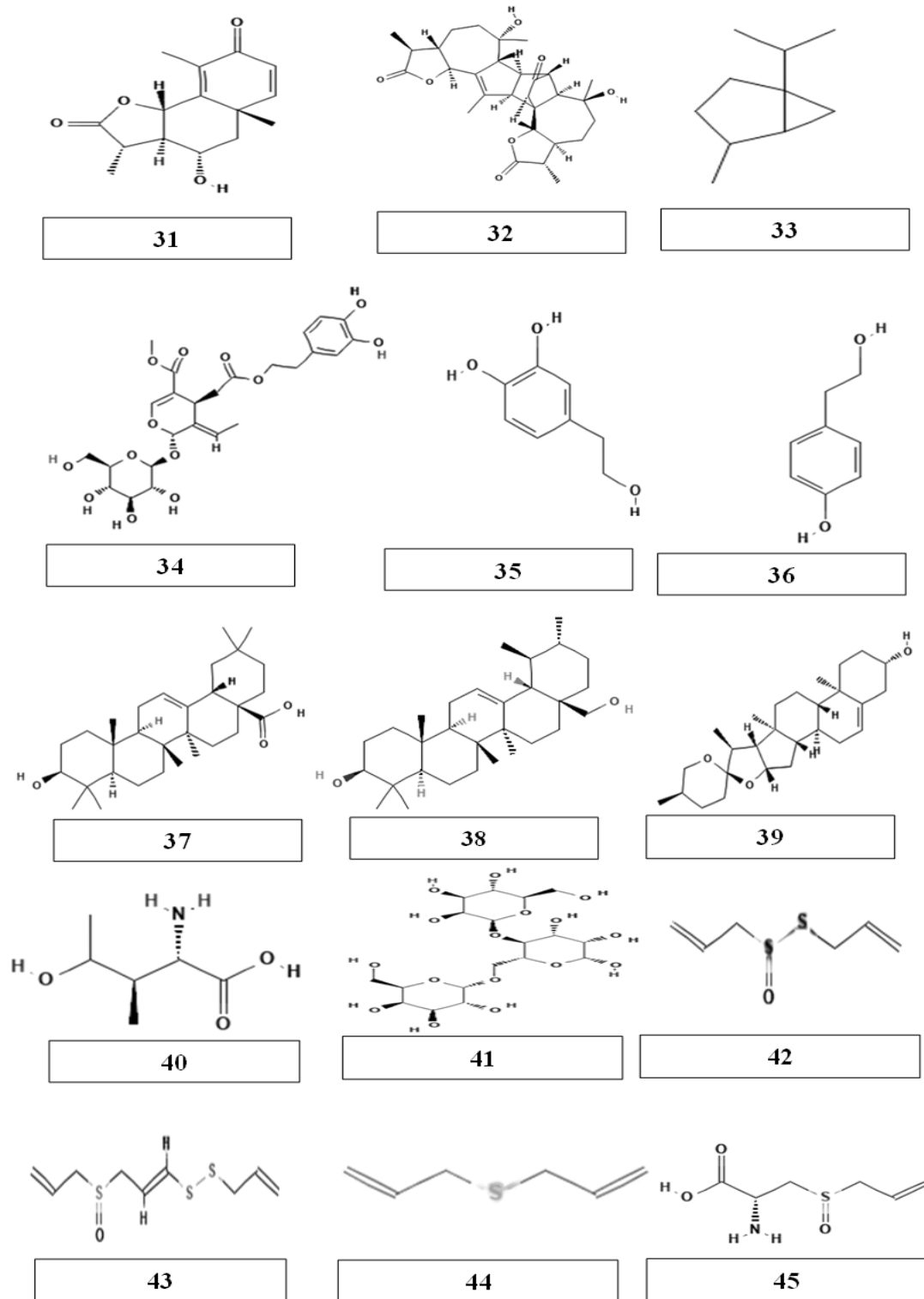
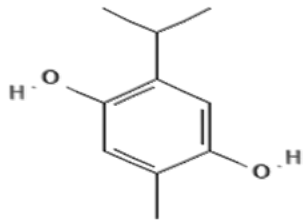
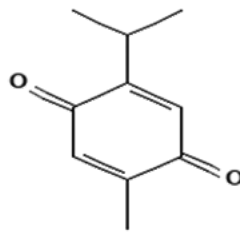


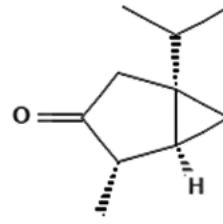
Figure 5 (31-45). 31) Artemisin, 32) Caruifolin, 33) Thujane, 34) Oleuropein, 35) Hydroxytyrosol, 36) Tyrosol, 37) Oleanolic acid, 38) Uvaol, 39) Diosgenin, 40) hydroxyisoleucine, 41) Galactomannan, 42) Allicin, 43) Ajoene, 44) Diallyl sulfide, 45) Alliin



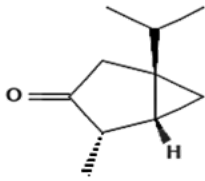
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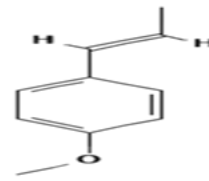
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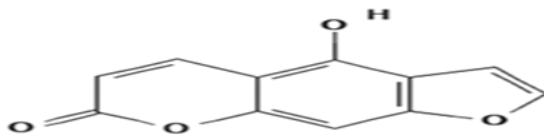
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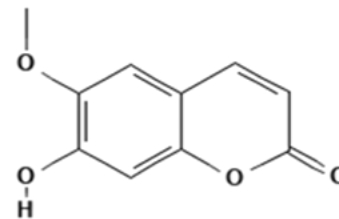
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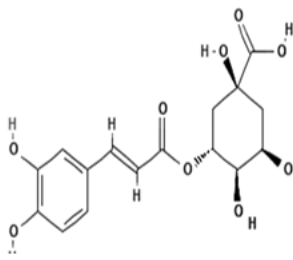
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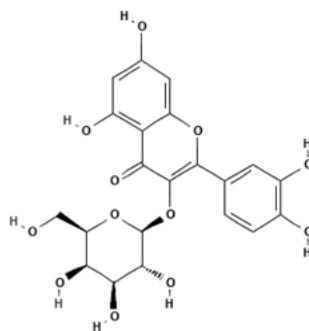
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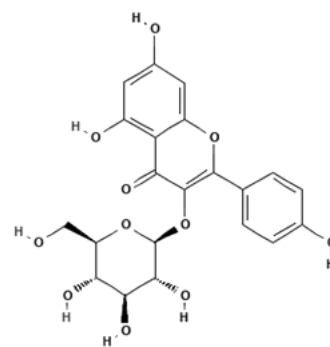
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Figure 5 (46-56). 46) Thymohydroquinone, 47) Thymoquinone, 48) Alpha thujone, 49) Beta thujone, 50) 1,8-Cineole, 51) Anethole, 52) 5-hydroxyfuranocoumarin, 53) Scopoletin, 54) Caffeoylquinic acid, 55) Quercetin 3-O-galactoside, 56) Kaempferol-3-O-glucoside

In contrast, Table 4 gives the names of 21 plant species mentioned once among the analysed articles. The sparsity of this plant species citation may be due to the fact that their therapeutic properties are not well known among the Moroccan population. Moreover, the literature contains only rare studies on the pharmacological effects of these plants, which highlights the importance for researchers to focus on these plants and deepen studies on their medicinal properties and bioactive molecules.

Table 4. List of 21 plant species mentioned exclusively in one article each.

Plant species	Reference
<i>Agave karatto</i> Mill.	(Chaachouay <i>et al.</i> 2020)
<i>Ajuga chamaepitys</i> (L.) Schreb.	(Redouan <i>et al.</i> 2023)
<i>Anethum sowa</i> Roxb.	(Saleh-EdIn and Choi, 2021)
<i>Artemisia inculta</i> Sieber ex DC.	(Ouhaddou <i>et al.</i> 2014)
<i>Betula pubescens</i> Ehrh.	(Rastogi <i>et al.</i> 2015)
<i>Calamintha alpina</i> (L.) Lam.	(Skalli <i>et al.</i> 2019)
<i>Cytisus battandieri</i> Maire	(Naceiri-Mrabti <i>et al.</i> 2021)
<i>Eucalyptus gomphocephala</i> DC.	(El-Abbouyi <i>et al.</i> 2014)
<i>Ficus abelii</i> Miq.	Chaachouay <i>et al.</i> 2019b)
<i>Indigofera tinctoria</i> L.	(Geromettaa <i>et al.</i> 2020)
<i>Inula graveolens</i> (L.) Desf.	(Boufous <i>et al.</i> 2017)
<i>Linaria maroccana</i> Hook.f.	(Bachiri <i>et al.</i> 2015)
<i>Narcissus poeticus</i> L.	(Naceiri-Mrabti <i>et al.</i> 2022)
<i>Panax quinquefolius</i> L.	(Slighoua <i>et al.</i> 2019)
<i>Scrophularia scorodonia</i> L.	(Mominur-Rahman <i>et al.</i> 2022)
<i>Solanum muricatum</i> Bertero ex Dunal	(Sakah-Kaunda and Zhang, 2019)
<i>Teucrium brachyandrum</i> Puech	(Najem <i>et al.</i> 2020)
<i>Thuja occidentalis</i> L.	(Zougagh <i>et al.</i> 2018)
<i>Thymus leptobotrys</i> Murb.	(Barkaoui <i>et al.</i> 2022)
<i>Urginea noctiflora</i> Batt. & Trab.	(Abouri <i>et al.</i> 2012)
<i>Withania somnifera</i> (L.) Dunal	(Afewerky <i>et al.</i> 2021)

Plant species origin and IUCN status

Figure 6 shows that the majority of plant species used by people according to the analysed studies, are native species (65.53%). Moreover, according to the International Union of Conservation of Nature (IUCN), they are mostly belonging to the least concern (LC) category (42.89%).

The other species belonging to the near threatened (NT), vulnerable (Vu), endangered (EN) and critically endangered (CR) categories, present a low proportion; 5.40%; 2.66%; 1.96%; and 0.77%, respectively.

These findings reveal that people are tending to use native species with least concern as affordable natural resources with easy access and low risk of extinction.

Furthermore, some few used species (8.73%) are not yet evaluated (NE) according to IUCN, or data are deficient (DD) to make assessment of their extinction risk (3.22%).

Moreover, it's important to note that the ethnomedicinal use of vulnerable species, such as *Dryopteris filix-mas* (L.) Schott, *Laurus nobilis* L., and *Origanum compactum* Benth. (Table 5) should be avoided in order to prevent these plant species from extinction.

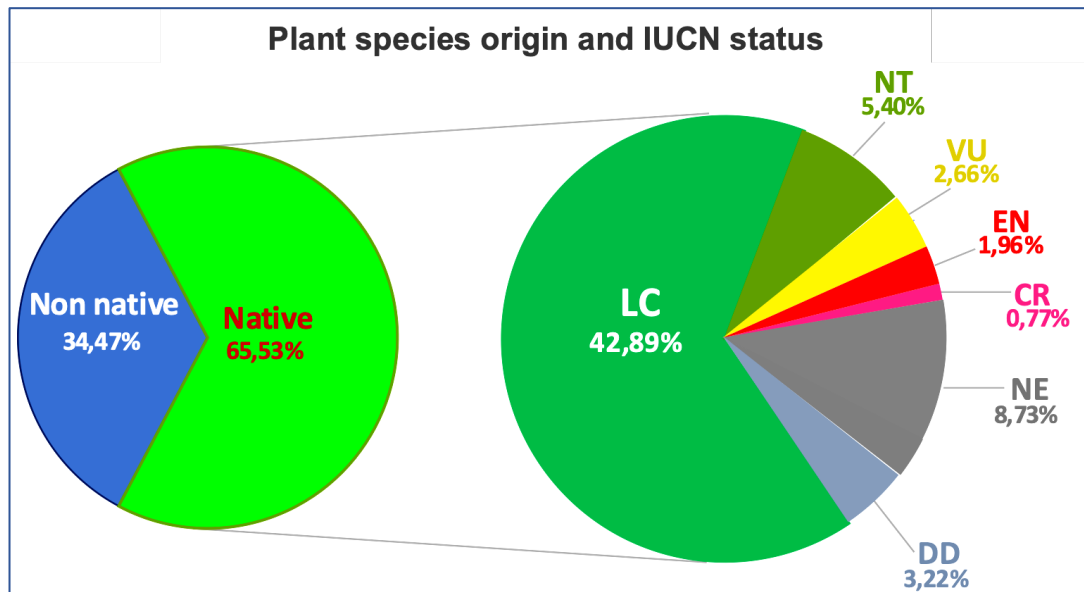


Figure 6. Plant species origin and their status according to the IUCN; NT: near threatened; Vu: vulnerable; EN: endangered; CR: critically endangered; NE: not yet evaluated; DD: deficient.

Table 5. Example of plant species cited in the studied articles attributed with vulnerable status (IUCN criteria applied at the Moroccan national level).

Plant species	IUCN status	Reference of the IUCN	Reference citing the species status
<i>Dryopteris filix-mas</i> (L.) Schott	VU	(Fennane, 2016)	(Chaachouay <i>et al.</i> 2022)
<i>Laurus nobilis</i> L.	VU	(Fennane, 2018d)	(Beniaich <i>et al.</i> 2021)
<i>Origanum compactum</i> Benth.	VU	(Fennane, 2018c)	(Aboufaras <i>et al.</i> 2022)
<i>Thymus broussonetii</i> Boiss. & Reut.	VU	(Fennane, 2018c)	(Sbai-Jouilil <i>et al.</i> 2017)
<i>Erica ciliaris</i> L.	VU	(Fennane, 2018a)	(Chaachouay <i>et al.</i> 2021b)
<i>Anacyclus pyrethrum</i> (L.) Lag.	VU	(Fennane, 2017)	(Najem <i>et al.</i> 2020)
<i>Thymus satureioides</i> Coss.	VU	(Fennane, 2018c)	(Benkhniqie <i>et al.</i> 2014)
<i>Delphinium staphisagria</i> L.	VU	(Fennane, 2018e)	(Benlamdini <i>et al.</i> 2014)
<i>Acacia albida</i> Delile	VU	(Fennane, 2018b)	(Benkhniqie <i>et al.</i> 2010)
<i>Thymelaea lythroides</i> (Aiton) Webb & Berthel.	VU	(Fennane, 2018e)	(Aboufaras <i>et al.</i> 2021)

Analysis of treated diseases

Distribution of diseases according to the number of their citation

The distribution of diseases according to the citation frequency among the ethnobotanical studies in Morocco for the period 1990-2023 is presented in the pie chart of Figure 7. Most of the diseases (42.66%) were cited between 2-10 times which would suggest broad and current focus on wide range of diseases. Significantly, 27.98% of the diseases were recorded once reflecting that they are less targeted in the Moroccan traditional medicinal knowledge based on herbal remedies.

Moreover, the proportion of diseases that are more frequently cited is low: only 11.01% of diseases were cited 11-20 times, and 1.83% of diseases were reported between 82-93 times. Such important attention towards a limited number of health issues is probably related to the most culturally or epidemiologically significant diseases.

This distribution indicates that Moroccan ethnobotanical knowledge is widespread and specialized, with a large variety of plants used for curing a wide range of diseases. However, some diseases receive more intensive focus, possibly due to their prevalence or treatment efficacy using plant-based remedies

Moreover, Table 6 lists ten diseases which are the most cited in all the ethnobotanical surveys undertaken in Morocco from 1990 to 2023. Diabetes is the most reported having been cited in 93 studies (40.43% of the total), highlighting its major significance in traditional medicine, and possibly reflecting its growing prevalence as a chronic health issue in Moroccan

society. This is closely followed by bronchopulmonary diseases (92 citations, 40%), and gastrointestinal diseases (89 citations, 38.70%), suggesting that problems related to the respiratory and digestive systems are also dominant problems alleviated through the use of medicinal plants.

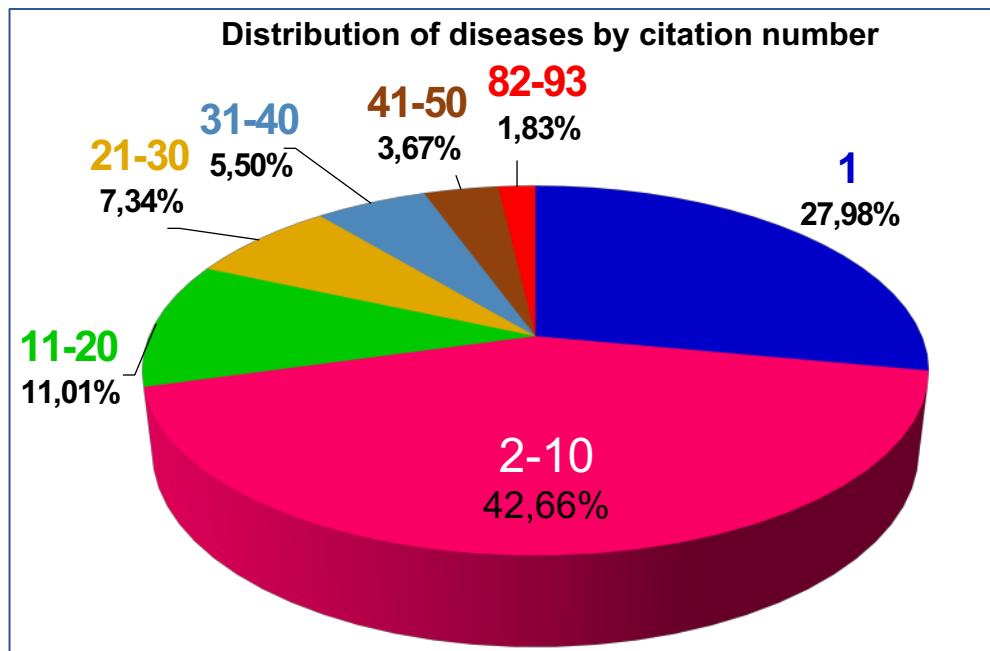


Figure 7. Distribution of diseases according to the number of their citation.

Another widely investigated disease classes are dermatology diseases (82 citations, 35.66%), gastralgia and cardiovascular diseases (each 50, 21.74%) and high blood pressure (47 citations, 20.43%). These numbers indicate the significant ethnomedical emphasis on both internal and chronic diseases.

Rheumatism, fever, and renal failure are also included in the list of diseases which are the most cited in the reported ethnobotanical studies with approximately 40 citations or greater, demonstrating the broad range of diseases treated using traditional medicinal. The present results reveal that the Moroccan ethnobotanical heritage is based on the management of several ailments, including infectious diseases, chronic non-communicable diseases and symptoms of pain and inflammation.

Overall, the table shows that Moroccan ethnobotany is characterized not only by floristic richness, but also by functional flexibility, addressing a broad range of health issues with Phyto therapeutic responses deeply embedded in the culture.

Table 6. Names of the 10 most frequently cited diseases in studies

Diseases	Number of citations	Percentage of total number of studies	Examples of references
Diabetes	93	40.43	Hinad <i>et al.</i> 2022; El-Khomsy <i>et al.</i> 2022; El-Mihsyaoui <i>et al.</i> 2022; El-Ghazouani <i>et al.</i> 2021; Fakchich and Elachouri, 2020
Bronchopulmonary conditions	92	40.00	Chaachouay <i>et al.</i> 2021c; Najem <i>et al.</i> 2021; Aabdousse <i>et al.</i> 2020; Touiti <i>et al.</i> 2020
Gastrointestinal affections	89	38.70	Redouan <i>et al.</i> 2020; Kharchoufa <i>et al.</i> 2018; Najem <i>et al.</i> 2018; Alaoui and Laaribya, 2017
Dermatological conditions	82	35.65	Bouiamrine <i>et al.</i> 2017; Ennacerie <i>et al.</i> 2017; Benali <i>et al.</i> 2017; Briguiche and Zidane, 2016
Gastralgia	50	21.74	El-Azzouzi and Zidane, 2015; Ouarghidi <i>et al.</i> 2013; Hseini and Kahouadji, 2007; Hseini <i>et al.</i> 2007; Bammi and Douira, 2002

Cardiovascular conditions	50	21.74	El-Rhaffari and Zaid, 2002; Chlif <i>et al.</i> 2021; Bachar <i>et al.</i> 2016; El-Yaagoubi <i>et al.</i> 2021; Khatib <i>et al.</i> 2022
High blood pressure	47	20.43	Seca <i>et al.</i> 2014; Mushagalusa-Kasali <i>et al.</i> 2021; El-Hachlafi <i>et al.</i> 2021; Annaz <i>et al.</i> 2022; Lahrizi <i>et al.</i> 2022
Rheumatism	46	20.00	Bouyahya <i>et al.</i> 2017; Zeggwagh <i>et al.</i> 2013; Babangida-Abubakar <i>et al.</i> 2018; Ghanimi <i>et al.</i> 2022 b; Hosseini <i>et al.</i> 2019
Fever	44	19.13	Teixidor-Toneu <i>et al.</i> 2016; Marmouzia <i>et al.</i> 2021; Marmouzi <i>et al.</i> 2021; El-Yaagoubi <i>et al.</i> 2023
Renal failure	42	18.26	Messaoudi <i>et al.</i> 2015; El Yaagoubi <i>et al.</i> 2023; Teixidor-Toneu <i>et al.</i> 2016; Jouad <i>et al.</i> 2001

Interpretation of the Phylogenetic Tree of Plants Used for Diabetes Treatment

The evolutionary relationships among the most frequently cited medicinal plant species used in Morocco for diabetes treatment, as documented between 1990 and 2023 is illustrated in figure 8. Indeed, according to this dendrogram, several clusters are revealed, which indicates taxonomic proximity and potential similarities in phytochemical composition or therapeutic action. An important cluster comprises members of Lamiaceae family like *Marrubium vulgare* L., *Ajuga iva* (L.) Schreb., *Rosmarinus officinalis* L., and *Lavandula* species, probably as a result of the common evolutionary ancestry and possibly similar bioactive compounds responsible for the antihyperglycemic effect. Other families establish well-defined groups, including Apiaceae (*Foeniculum vulgare* Mill., *Carum carvi* L., and *Coriandrum sativum* L.), and Amaryllidaceae (*Allium cepa* L. and *Allium sativum* L.) both widely known for their anti-diabetic properties. Some species, such as *Nigella sativa* L., *Citrullus colocynthis* (L.) Schrad., *Artemisia herba-alba* Asso, although phylogenetically more distinct, also appear prominently, which correlates with their high cultural and pharmacological importance despite being less closely related. This tree highlights the ethnopharmacological value and botanical variation present in Moroccan folk medicine. It also reveals important plant species for subsequent pharmacological research based on phylogenetic relationships and may be beneficial to select new candidates for the treatment of diabetes.

Conclusion

This review analyses floristic data from publications regarding more than 30 years ethnobotanical research in Morocco, in order to highlight the rich diversity and uses of medicinal and aromatic plants (MAPs) across all regions of the country. Moroccan folk medicine uses a variety of plant species, among which Lamiaceae, Asteraceae, Fabaceae, Rosaceae and Apiaceae are the most cited families. Diabetes, gastro-intestinal and respiratory diseases appear to be the most important diseases to treat considering the cultural importance and prevalence of these conditions. The Relative Frequency of Citation (RFC) revealed that most species have limited and localized use, while only a small proportion are widely recognized and consistently used across Morocco for their medicinal properties.

Phylogenetic analysis provided evidence for evolutionary grouping of the most cited species used against diabetes, suggesting potential links between taxonomy, phytochemistry, and therapeutic efficacy.

However, the present review also highlights important conservation issues, as some of the most commonly used species are vulnerable, endangered, or critically endangered. It is therefore important to establish sustainable harvesting and cultivation programs, and also to raise awareness among people about the importance of preserving threatened species

Altogether, these assembled datasets represent a useful resource for researchers, revealing species selection, use patterns and conservation priorities. Future research that would combine the ethnobotanical knowledge with phytochemical and pharmacological studies can play an important role in the establishment of evidence-based plant remedies and in the conservation of biodiversity in Morocco.

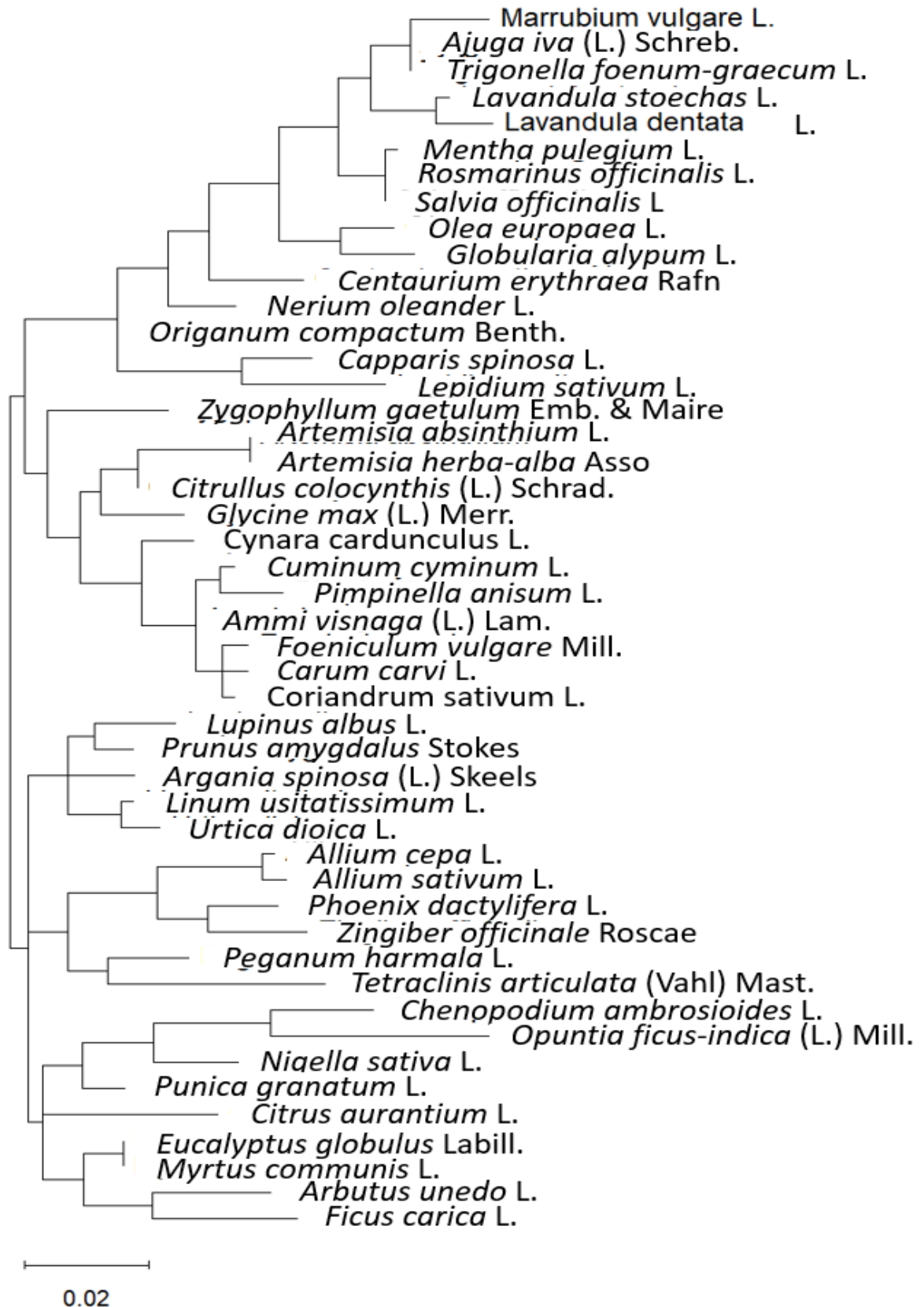


Figure 8. Phylogenetic tree based on plant species cited at least 10 times for diabetes treatment.

Declarations

List of abbreviations: MAPs- Medicinal and Aromatic plants; IUCN- the International Union of Conservation of Nature; NT- near threatened; Vu-vulnerable EN- endangered; CR-critically endangered; LC- least concern; RFC-relative frequency of citation

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