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Original Article

Bibliometric and comparative analysis of research on essential oils and aromatic and medicinal plants in Morocco: Positioning and perspectives in the world

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ABSTRACT

Essential oils and aromatic and medicinal plants play a vital role in the pharmaceutical, cosmetic, and food industries due to their therapeutic properties and diverse applications. Morocco's rich biodiversity offers great potential for the exploration and development of these natural resources. However, in order to fully exploit this potential, it is important to understand current trends in scientific research in this field and position Morocco in relation to other African countries. The aim of this study was to conduct a bibliometric and comparative analysis of research on essential oils and aromatic and medicinal plants in Morocco. By examining scientific publications, researcher collaborations, and citations, we sought to identify the strengths and weaknesses of Moroccan research. Furthermore, a comparison with trends in other African countries would help position Morocco in a wider regional context and highlight its contributions and gaps.

1. Introduction

Essential oils and aromatic and medicinal plants have been an integral part of human civilization, valued for their therapeutic, aromatic, and functional properties (Ghorbanpour et al., 2017). These natural resources have widespread applications across industries, such as pharmaceuticals, cosmetics, and food, owing to their rich composition of bioactive compounds, which include antioxidants, antimicrobial agents, and anti-inflammatory substances. Recent advances in extraction and processing technologies have further expanded their potential uses, enabling the creation of high-value products tailored for specific applications in health, wellness, and environmental sustainability (El Ahmadi et al., 2024).

Morocco, situated at the crossroads of Africa and the Mediterranean, is endowed with a rich biodiversity that includes over 4,200 species of plants, of which many are endemic and recognized for their medicinal and aromatic properties (Ganaie et al., 2020). This remarkable natural wealth is deeply rooted in the country's traditional practices and knowledge systems, which have been passed down through generations (Giannenas et al., 2020). The growing global interest in natural products, coupled with Morocco's unique flora, presents significant opportunities for the development and commercialization of essential oils and medicinal plants. However, despite these advantages, the scientific and economic exploitation of this potential remains underdeveloped (El Allaoui et al., 2019).

In recent years, the global scientific community has shown increasing interest in bibliometric studies as a means of analyzing research trends, collaborations, and impact across various domains (Inoue et al., 2019). Bibliometric tools offer a comprehensive approach to assessing the evolution of scientific activity, identifying key contributors, and highlighting emerging themes. In the context of essential oils and medicinal plants, bibliometric analyses can provide valuable insights into the global and regional research landscape, enabling stakeholders to make informed decisions about funding, policy, and collaboration (Aziz et al., 2018).

In Morocco, the current state of research on essential oils and medicinal plants reflects both its achievements and challenges. While Moroccan researchers have produced notable studies and established international collaborations, the overall volume of publications and their citation impact remain modest compared to leading countries like China, India, and the United States (El Ahmadi et al., 2024). The lack of substantial funding, limited infrastructure, and the absence of a cohesive national strategy for scientific research in this field are some of the critical barriers. To become a leading nation in the continent, Morocco's position within Africa highlights the need to leverage its strengths while addressing its weaknesses (Djilani et al., 2012).

This study aims to address these gaps by conducting a bibliometric and comparative analysis of research on essential oils and aromatic and medicinal plants in Morocco. Utilizing the Scopus database, which is renowned for its comprehensive coverage of scientific literature, this analysis examines trends in publication rates, researcher collaborations, and citation impact from 1995 to 2024 (Zhang et al., 2024). Furthermore, the study benchmarks Morocco's performance against other African countries, offering a nuanced understanding of

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its scientific contributions within a regional context (El Allaoui et al., 2024).

The objectives of this article are twofold. First, it seeks to provide a detailed overview of the research landscape in Morocco, highlighting its strengths, limitations, and opportunities. Second, it aims to assess Morocco's positioning within Africa by identifying key trends and potential areas for growth. By bridging these insights, the study aspires to offer actionable recommendations for researchers, policymakers, and industry stakeholders to foster innovation, strengthen international collaboration, and maximize the sustainable utilization of Morocco's natural resources.

Ultimately, this analysis underscores the importance of strategic investments in research and development, enhanced infrastructure, and interdisciplinary collaborations to unlock the full potential of essential oils and medicinal plants. As the demand for sustainable and natural products continues to rise globally, Morocco has the opportunity to position itself as a key player in this dynamic field, contributing not only to scientific advancement but also to economic and social development.

2. Materials and methods

2.1 Data source and collection process

The primary database used for this bibliometric study is Scopus, renowned for its extensive and comprehensive catalog of scientific publications across various disciplines (Baas et al., 2020). Scopus is particularly valued in bibliometric research for its broad coverage, making it an ideal tool for conducting in-depth analyses in the fields of Science, Technology, and Medicine (STM) (Singh et al., 2021). Scopus was chosen over other databases due to its wide base of international scientific literature and its robust citation tracking capabilities, essential for assessing research impact and trends. Unlike databases that specialize in specific fields or regions, Scopus provides the global perspective crucial for this study's aim to map research activities and collaborations for essential oils and aromatic and medicinal plants (Raut et al., 2014).

The research parameters were meticulously defined to focus on scientific literature related to essential oils and aromatic and medicinal plants from Morocco. Keywords such as "essential oils," "aromatic plants," "medicinal plants," and "Morocco" were used in a structured query to ensure the retrieval of relevant articles. An advanced search was conducted via the Scopus search interface using the specified keywords. The search was strategically filtered to include only peer-reviewed research articles, reviews, and conference proceedings that are pertinent to the defined study objectives, ensuring the relevance and quality of the data collected.

2.2 Bibliometric analysis methods

For the analysis of the bibliometric data extracted from Scopus, R Studio version 4.3.3 was employed, utilizing specialized packages like bibliometrix (Guerreschi et al., 2023). This setup allowed for the extraction and analysis of bibliographic data, computation of bibliometric indicators such as the H-index and journal impact factor, and generation of statistical and graphical outputs (Bonilla-Chaves et al., 2023). Bibliometrix facilitated the assessment of citation networks, keyword co-occurrence, and author co-citation networks, providing a comprehensive toolkit for this study (Kipper et al., 2020). To further augment the analysis, bibliometric data were imported into VOSviewer version 1.6.20 for network visualizations. This tool was instrumental in mapping the connections between co-authors, co-citations, and keywords, thereby illuminating the most influential contributors, prevalent research clusters, and dominant themes within the field (Aziz et al., 2018). These visualizations not only highlight the intellectual landscape but also suggest areas for potential future research (El Hammoudani et al., 2024).

By employing these sophisticated bibliometric tools and techniques (Fig. 1), the methodology ensures a rigorous and thorough exploration of the bibliometric data, revealing the dynamics and evolution of research on essential oils and aromatic and medicinal plants in Morocco. This analysis not only highlights the current research status but also guides future studies by identifying emerging trends and potential research gaps.

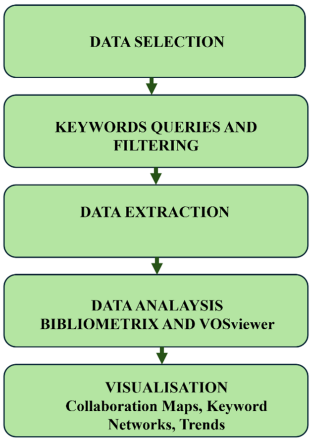

Fig. 1. Workflow of bibliometric analysis and data visualization.

2.3 Background behind choosing the keywords

The selection of keywords for this bibliometric study was crucial to ensure the retrieval of relevant and comprehensive data on the research related to essential oils and aromatic and medicinal plants in Morocco (AlRyalat et al., 2019). The chosen keywords were "essential oils," "aromatic plants," "medicinal plants," and "Morocco." Each keyword was carefully selected for its significance and relevance to the study's objectives. "Essential oils" were included to capture a wide range of studies focused on their extraction, chemical composition, and applications due to their importance in aromatherapy, pharmaceuticals, and cosmetics. "Aromatic plants" ensured the inclusion of research on plants known for their fragrance and essential oil content, broadening the scope to cover their aromatic properties. "Medicinal plants" extended the search to include studies on the healing properties and medicinal uses of these plants, reflecting their role in both traditional and modern medicine. Finally, "Morocco" was essential to geographically constrain the search, allowing for a focused analysis of contributions and advancements made by Moroccan researchers. This combination of keywords was designed to comprehensively cover the relevant literature, setting a solid foundation for analyzing research trends, impacts, and collaborations in the field within the Moroccan context.

3. Results

3.1 Bibliometric analysis overview

The bibliometric data on research related to essential oils and aromatic and medicinal plants in Morocco from 2010 to 2024 highlight several key points. The research has shown steady growth with an annual growth rate of 5.26%, indicating increasing interest and activity in this field. The 612 documents produced, with an average of 15.12 citations per document, demonstrate the relevance and impact of Moroccan research on a global scale. The high level of international collaboration, with 42.32% of publications involving international co-authorship, underscores the integration of Moroccan researchers into the global scientific community, thus enhancing the quality and visibility of their work. The predominant use of English (587 documents) for publications shows the focus on reaching a broad international audience, although some research has also been published in French (27 documents), Spanish (2 documents), and Chinese (1 document). The diverse types of publications, predominantly articles (546), followed by reviews (28) and conference papers (17), reflect a wide dissemination of research findings. Overall, the data indicates a robust and growing field of study in Morocco, with strong international ties and significant academic impact (Table 1).

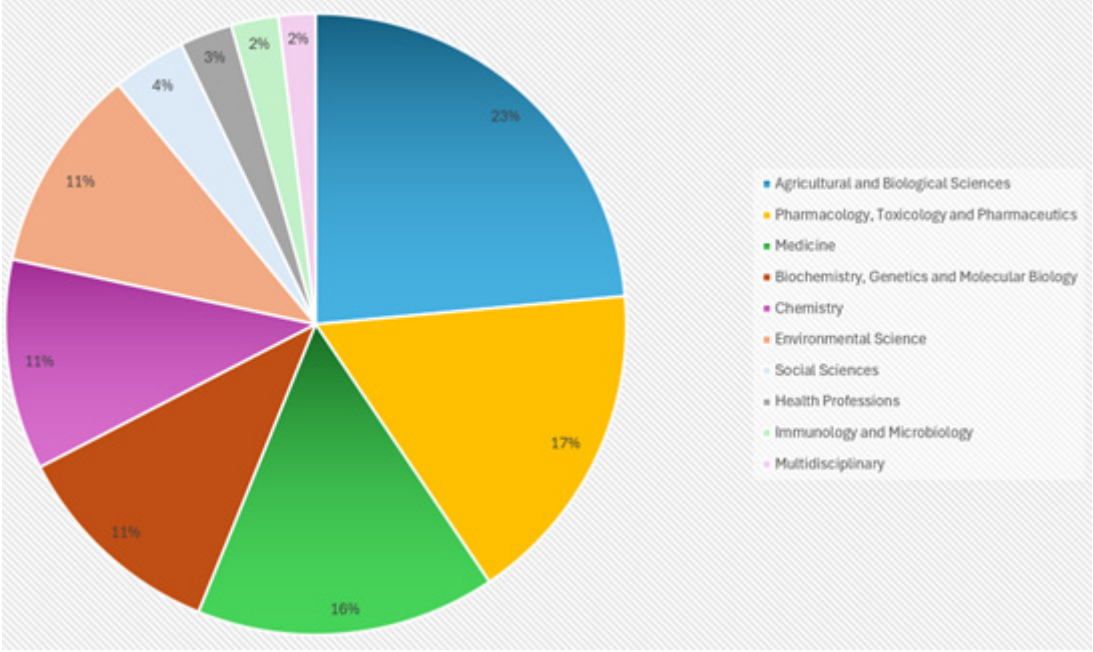

Fig. 2. Documents by subject area.

3.2 Interdisciplinary trends and distribution across research fields

The interdisciplinary nature of the research on essential oils and aromatic and medicinal plants is evident from the diverse fields contributing to the body of literature. Fig. 2 illustrates the distribution of publications across various disciplines, showcasing the broad applications and relevance of this research. Agricultural and Biological Sciences account for the largest share (23%), emphasizing the foundational importance of plant biology and cultivation techniques in understanding and utilizing these natural resources. Pharmacology, Toxicology, and Pharmaceutics collectively represent the second-largest category (17%), highlighting the therapeutic applications of essential oils in modern medicine. Medicine (16%), Biochemistry, Genetics, and Molecular Biology (11%) also play significant roles, reflecting the growing interest in the chemical composition and bioactive properties of these compounds.

Interestingly, fields such as Environmental Science (11%) and Chemistry (4%) underline the focus on sustainable extraction methods and the environmental impact of essential oil production. The smaller contributions from social sciences, health professions, immunology, microbiology, and multidisciplinary studies demonstrate the emerging but still limited exploration of these areas in relation to essential oils.

This distribution reflects the inherently interdisciplinary nature of the field. Traditional disciplines, such as agriculture and chemistry, intersect with applied sciences like pharmacology and environmental studies. These trends not only underscore the versatility of essential oils and aromatic plants but also highlight the potential for further integration of less-represented fields and fostering innovative approaches and solutions.

Table 1.
Bibliometric data summary for document analysis.

Description	Bibliometric indicators	Results
Main information about the data	Timespan	2010-2024
	Sources	255
	Documents	612
	Annual growth rate%	5.26%
	Document average age	5.51
	Average citations per Doc	15.12
Document contents	Keywords plus (id)	4134
	Author's keywords (de)	1450
Authors	Authors	2140
	Authors of single-authored Docs	10
Authors collaboration	Single-authored docs	10
	Co-authors per doc	6.44
Document types	International co-authorships %	42.32%
	Article	546
	Book chapter	14
	Conference paper	17
	Retracted	1
	Review	28
Language	English	587
	French	27
	Spanish	2
	Chinese	1

3.3 Pioneering research: Key articles and leading journals in essential oils and aromatic and medicinal plants

Table 2 provides an overview of the key journals with research on essential oils and aromatic and medicinal plants, and highlights various impact metrics. The Journal of Essential Oil-Bearing Plants, classified as Q2 with an H-index of 39 and an SJR of 0.43, stands out with 34 articles, 472 total publications, and 1956 citations, indicating moderate impact and quality. Natural Product Research, also classified as Q2 with an H-index of 71 and an SJR of 0.41, has 19 articles leading to 3109 publications and 15882 citations. Conversely, the Journal of Materials and Environmental Science and Pharmacology online has missing data on citations and SJR but shows a moderate to low quality with Q3 and Q4 classifications. Chemistry and Biodiversity and South African Journal of Botany show strong research impact with high H-indexes (83) and solid SJR values, 0.41 and 0.54, respectively, reflecting significant contributions in their fields. Overall, the diversity in journal classifications (Q2 to Q4) and impact metrics (H-index and SJR) indicates a wide range of research quality and influence within the domain of essential oils and medicinal plants.

Table 3 highlights the top ten most-cited articles on essential oils and aromatic and medicinal plants from Morocco, underscoring their significant impact in the scientific community. The leading article, "Antioxidant and Antiacetylcholinesterase Activities of Some Commercial Essential Oils and Their Major Compounds" (2011), published in *Molecules*, has received 201 citations, showing its high relevance. Other notable articles include studies on the chemical composition and antimicrobial activity of various essential oils, such as those from *Mentha pulegium*, *Juniperus phoenicea*, and *Cyperus longus*, published in *Food Research International* (2012) with 158 citations, and

Table 2.
Top 10 journals on Scopus for research on essential oils and aromatic and medicinal plants.

Sources journals	Articles	Total publication/document	Total citation	Journal quality	H-index	SJR 2023
Journal of Essential Oil-Bearing Plants	34	472	1 956	Q2	39	0,43
Journal of Materials and Environmental Science	21	N/A	N/A	Q3	52	0,00
Natural Product Research	19	3109	15 882	Q2	71	0,41
Phytotherapie	17					
Industrial Crops and Products	16	160	150	Q4	22	0,16
Chemistry and Biodiversity	15	1829	6 197	Q2	83	0,41
Pharmacologyonline	14	N/A	N/A	Q4	31	0,00
Natural Product Communications	13	993	3 071	Q3	63	0,3
South African Journal of Botany	13	2195	11 445	Q2	83	0,54
Tropical Journal of Natural Product Research	13	1257	1 396	Q3	11	0,18

H-index: Hirsch index, SJR: SCImago Journal Rank

Table 3.
Most ten cited articles on essential oils and aromatic and medicinal plants.

	Article title	Total citations	Year of publication	Journal	Authors
1	Antioxidant and Antiacetylcholinesterase Activities of Some Commercial Essential Oils and Their Major Compounds	201	2011	Molecules	Smail Aazza, Badiâ Lyoussi, Maria G. Miguel.
2	Evaluation of the chemical composition and antimicrobial activity of *Mentha pulegium*, *Juniperus phoenicea*, and *Cyperus longus* essential oils from Morocco	158	2012	Food Research International	Abdenour Ait-Ouazzou, Susana Lorán, Abdelhay Arakrak, Amin Laglaoui, Carmen Rota, Antonio Herrera, Rafael Pagán, Pilar Conchello.
3	Chemical composition of *Mentha pulegium* and *Rosmarinus officinalis* essential oils and their antileishmanial, antibacterial, and antioxidant activities	139	2017	Microbial Pathogenesis	Abdelhakim Bouyahya, Abdeslam Et-Touys, Youssef Bakri, Ahmed Talbaui, Hajiba Fellah, Jamal Abrini, Nadia Dakka.
4	Therapeutic potential of argan oil: a review	125	2010	Journal of Pharmacy and Pharmacology	Hanae El Monfalouti, Dom Guillaume, Clément Denhez, Zoubida Charrouf.
5	Chemical composition and antioxidant properties of *Laurus nobilis* L. and *Myrtus communis* L. essential oils from Morocco and evaluation of their antimicrobial activity acting alone or in combined processes for food preservation	99	2013	Journal of the Science of Food and Agriculture	Lamia Cherrat, Laura Espina, Mohammed Bakkali, Diego García-Gonzalo, Rafael Pagán, Amin Laglaoui.
6	Effect of processing on the quality of edible argan oil	121	2009	Food Chemistry	Bertrand Matthäus, Dominique Guillaume, Saïd Gharby, Aziza Haddad, Hicham Harhar, Zoubida Charrouf.
7	Insecticidal activities of essential oils from leaves of *Laurus nobilis* L. from Tunisia, Algeria, and Morocco, and comparative chemical composition	119	2012	Journal of Stored Products Research	Jouda Mediouni Ben Jemâa, Nesrine Tersim, Karima Taleb Toudert, Mohamed Larbi Khouja.
8	Chemical composition and antimicrobial activity of essential oils of *Thymus algeriensis*, *Eucalyptus globulus,* and *Rosmarinus officinalis* from Morocco	88	2011	Journal of the Science of Food and Agriculture	Abdenour Ait-Ouazzou, Susana Lorán, Mohammed Bakkali, Amin Laglaoui, Carmen Rota, Antonio Herrera, Rafael Pagán, Pilar Conchello.
9	Indigenous knowledge of the use of medicinal plants in the North-West of Morocco and their biological activities	111	2017	European Journal of Integrative Medicine	Abdelhakim Bouyahya, Jamal Abrini, Abdeslam Et-Touys, Youssef Bakri, Nadia Dakka.
10	Chemical composition, antioxidant and antimicrobial properties of *Mentha pulegium*, *Lavandula stoechas,* and *Satureja calamintha* Scheele essential oils and an evaluation of their bactericidal effect in combined processes	108	2014	Innovative Food Science & Emerging Technologies	Lamia Cherrat, Laura Espina, Mohammed Bakkali, Rafael Pagán, Amin Laglaoui.

the therapeutic potential of argan oil reviewed in *Journal of Pharmacy and Pharmacology* (2010) with 125 citations. These articles collectively illustrate the diverse research interests in Morocco, ranging from antioxidant and antimicrobial properties to insecticidal activities and traditional knowledge of medicinal plants. The authors' contributions, often in collaboration with international researchers, highlight the integration of Moroccan research into the global scientific discourse, further enhancing its visibility and impact.

Global Dynamics and Impactful Contributions in Essential Oils and Aromatic and Medicinal Plants. The co-authorship network visualization (Fig. 3) generated by VOS viewer illustrates the collaborative relationships among researchers in the field of essential oils and medicinal plants in Morocco. The different color clusters represent groups of researchers who frequently collaborate, such as the green cluster centered around El Guerrouj, Bouchra, and Addi, Mohamed. Key researchers like Bouyahya and Abdelhakim (yellow cluster), and Bourhia and Mohammed (purple cluster) are central figures, connecting various research groups, indicating their pivotal role in the research community. The network also highlights international collaborations with researchers like Zengin and Gokhan. The thickness of the lines between nodes indicates the frequency of collaborations, with thicker lines representing more frequent interactions. This visualization underscores the strong collaborative network within Morocco's research community and its integration into the global scientific landscape.

3.4. Bibliometric mapping keywords

The keyword co-occurrence network (Fig. 4) generated by VOS viewer highlights the central themes and connections in Moroccan research on essential oils and medicinal plants. The terms "essential oil," "essential oils," and "Morocco" are prominently positioned at the center, indicating their high frequency and importance. The network is divided into distinct thematic clusters: the red cluster focuses on phytochemistry and traditional medicine, the blue cluster on antimicrobial activity, the green cluster on specific chemical compounds like pinene and camphor, and the yellow cluster on chemical composition and analysis methods. The connections between keywords show frequent co-occurrences, revealing key research interests such as antimicrobial and antioxidant properties, chemical analysis, and medicinal applications of essential oils.

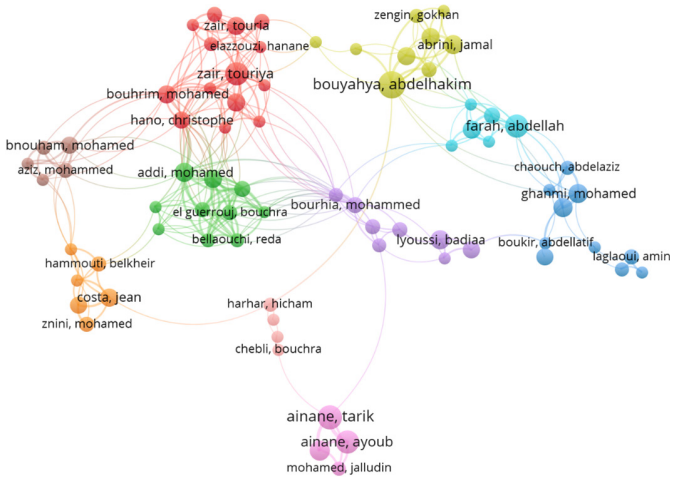

Fig. 3. Collaboration network of authors.

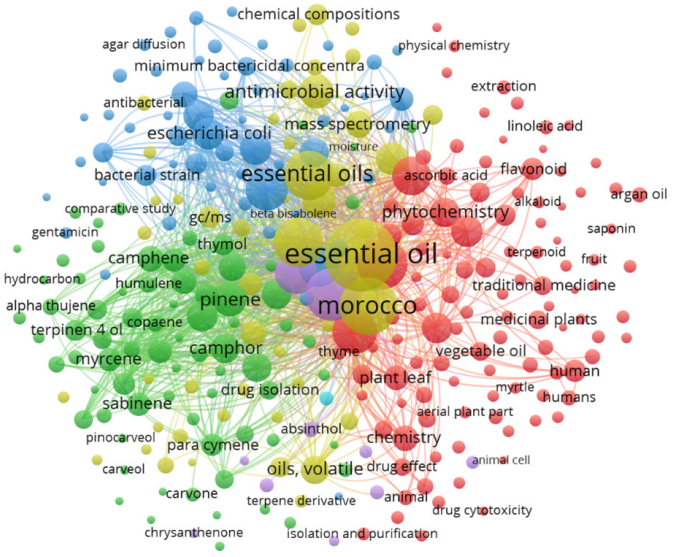

Fig. 4. Co-occurrence map of the keywords.

3.5. Geographical distribution

The geographical distribution of publications related to essential oils and aromatic and medicinal plants highlights Morocco's active contribution to global scientific research. As shown in Table 4, Morocco has produced 544 documents with 8,381 citations, achieving an average of 13 citations per article. This positions Morocco as a leader within the African research landscape, although there is still room for improvement when compared to global leaders.

Fig. 5 illustrates the geographical distribution of scientific output, showcasing Morocco as a central hub for collaboration. Strong links

Table 4.
Top ten countries with the highest number of publications.

Sr. No.	Country	Total link strength	Documents	Citation	Average article citations
1	Morocco	304	544	8381	13.00
2	France	121	91	1477	22.20
3	Saudi Arabia	73	36	351	10.00
4	Italy	40	35	565	16.90
5	Portugal	30	24	603	38.90
6	Spain	28	25	927	52.10
7	Australia	21	16	523	00.00
8	Tunisia	20	15	363	48.00
9	Egypt	19	13	242	14.70
10	Djibouti	18	16	93	05.00

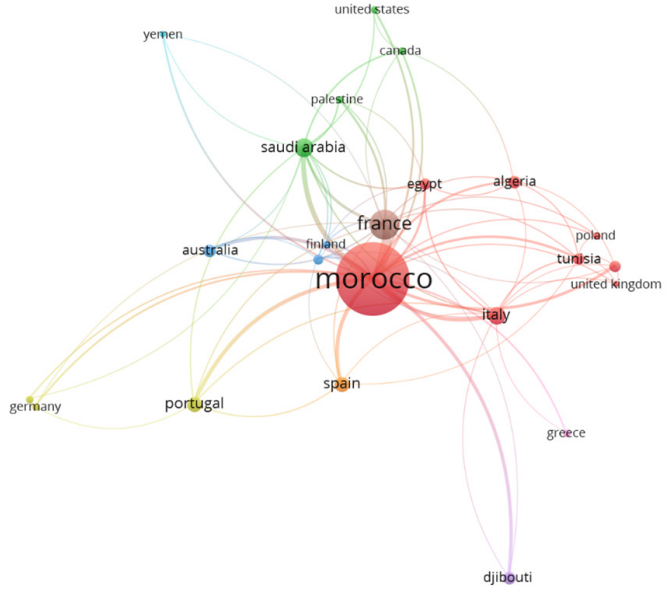

Fig. 5. Geographical distribution map.

with countries such as France, with 91 co-authored publications and an average of 22.2 citations per article, underscore the importance of these partnerships in enhancing research quality and visibility. Similarly, Morocco collaborates actively with Saudi Arabia, Italy, Spain, and Portugal, reflecting a diverse network of scientific relationships that span continents.

The partnerships with European countries like Spain and Portugal are particularly noteworthy. Spain leads in terms of citation impact, with an average of 52.1 citations per article, followed closely by Portugal at 38.9 citations per article. These high averages indicate that collaborative research with these countries often results in impactful publications, likely due to shared expertise, advanced methodologies, and access to international funding.

Within the African context, Morocco collaborates with neighbors, such as Tunisia and Egypt, leveraging shared biodiversity and traditional knowledge systems to address common challenges. Despite these strong regional ties, the limited number of publications from some African countries indicate potential opportunities for fostering new collaborations to advance continental research initiatives.

The co-authorship network visualized in Fig. 3 provides further insights into Morocco's scientific ecosystem. This figure highlights clusters of collaboration, with prominent Moroccan researchers connecting with international institutions in thematic areas such as phytochemistry, antimicrobial studies, and sustainable extraction techniques. The thickness of the lines between nodes signifies the frequency of collaborations, while the clustering reflects thematic specializations.

Despite these achievements, Morocco faces challenges as compared to global leaders such as the United States, China, and India, which dominate this field with larger scientific outputs and more diverse research themes. Addressing these gaps will require strategic investments in research infrastructure, increased funding allocations, and broader international partnerships.

This analysis underscores Morocco's pivotal role as a bridge between African and European research networks. By capitalizing on its rich biodiversity and enhancing its research capabilities, Morocco can further strengthen its global scientific standing and contribute to advancements in the sustainable exploitation of natural resources.

3.6. Trends and perspectives

Research on essential oils and aromatic and medicinal plants in Morocco has witnessed significant growth in recent years, driven by the country's unique biodiversity and the increasing global demand for sustainable and natural products (Fig. 6). A key trend is the adoption of

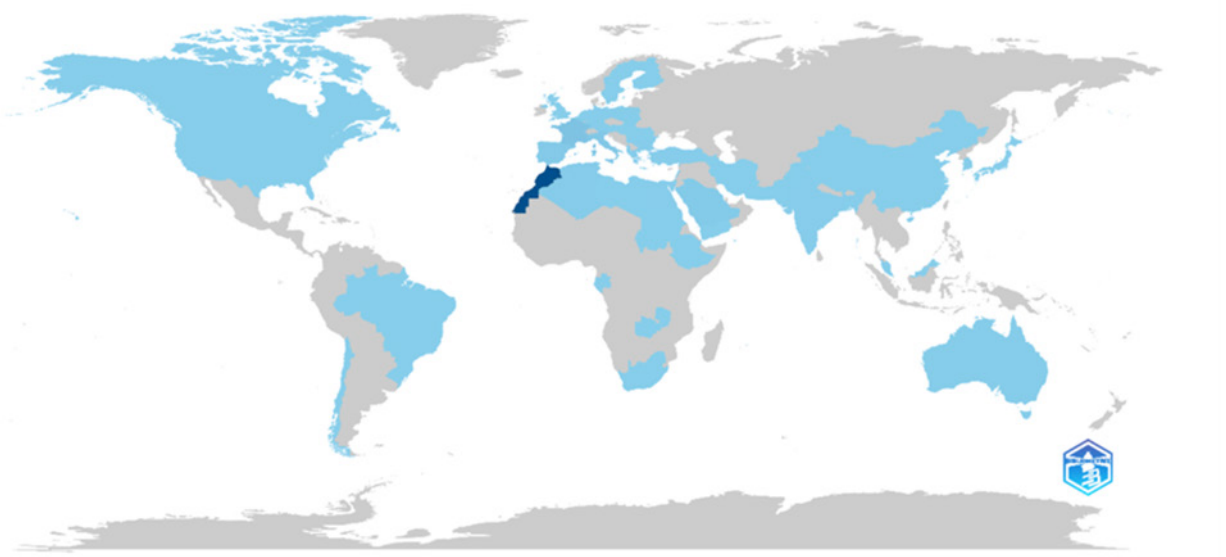

Fig. 6. Geographical spread of essential oils and aromatic and medicinal plants: A global bibliometric perspective.

environmentally friendly extraction methods, particularly supercritical CO_2 extraction, which offers the dual benefit of preserving bioactive properties of essential oils while minimizing environmental harm. This focus on green technologies reflects a broader global shift towards sustainable practices. Furthermore, the field is becoming increasingly interdisciplinary, with significant contributions from agricultural sciences, pharmacology, biochemistry, and environmental science. These collaborations have opened pathways for diverse applications, ranging from pharmaceutical innovations to eco-friendly pest control solutions.

At the same time, Morocco's scientific community is increasingly engaging in international collaborations, particularly with European and Middle Eastern researchers. These partnerships have proven essential for accessing advanced technologies, increasing funding opportunities, and enhancing the visibility of Moroccan research on a global scale. However, challenges remain, including limited research infrastructure, inadequate funding, and underrepresentation in high-impact international journals. Addressing these issues will require strategic investments in research and development, as well as efforts to strengthen local capacities and global outreach.

Looking ahead, the future of this field in Morocco lies in leveraging digital technologies, such as artificial intelligence and machine learning for bibliometric analyses, as well as expanding the applications of essential oils into emerging areas like antimicrobial resistance, biodegradable materials, and eco-friendly agriculture. Moreover, clear regulatory frameworks and certifications such as GACP and ISO standards will be pivotal in ensuring quality and competitiveness in the global market. By capitalizing on its rich natural resources and addressing existing challenges, Morocco has the potential to solidify its position as a global leader in the research and sustainable development of essential oils and aromatic plants.

4. Discussion

When Moroccan research on essential oils, aromatic plants, and medicinal plants is analyzed in a global context, it becomes evident that, while Morocco is a significant contributor within Africa, its output remains modest compared to global leaders such as the United States, China, and India. These countries dominate due to their substantial research funding, state-of-the-art facilities, and large-scale production capabilities (Hirsch-Kreinsen et al., 2003). For instance, the United States alone invests billions annually in natural product research, facilitating the development of thousands of commercial products derived from essential oils and medicinal plants (Aceto et al., 2019). Similarly, China and India, with their rich histories of traditional medicine and biodiversity, have integrated modern technologies and robust industrial frameworks to position themselves as global leaders in this domain (Raju and Das 2024).

In contrast, Morocco's output, as reflected by its 544 publications and 8,381 citations, indicates a relatively limited level of research activity. However, the average of 13 citations per article demonstrates the competitive quality and impact of Moroccan research. This is further supported by a high rate of international co-authorship (42.32%), which highlights Morocco's ability to collaborate with global scientific communities. These partnerships are crucial for enhancing the quality, visibility, and relevance of Moroccan research and in accessing advanced analytical technologies and methodologies (Inoue et al., 2014).

Despite these achievements, several challenges constrain Morocco's ability to compete at the global level. The primary limitation lies in insufficient funding for research and development. Unlike leading nations, Morocco allocates a small fraction of its GDP to scientific research, which restricts the scope of studies, access to cutting-edge technologies, and the ability to attract top-tier researchers. Additionally, the lack of modern research infrastructure, such as advanced laboratories and pilot-scale extraction facilities, limits the capacity for innovation and commercialization of essential oils (Lambert et al., 1997).

Another critical issue is the underrepresentation of Moroccan research in high-impact journals. While the quality of individual studies is commendable, strategic efforts to target globally recognized journals could significantly enhance the visibility and influence of Moroccan contributions (Firmansyah et al., 2022). This underrepresentation is partly linked to language barriers, limited resources for publishing fees, and the absence of a cohesive national strategy for promoting scientific output (El Bastrioui et al., 2024).

To address these challenges and strengthen its global position, Morocco must adopt a multi-faceted approach. Increasing investment in research and development is paramount, as it would enable the establishment of specialized centers for researching essential oils and medicinal plants (Cavatorta et al., 2001). These centers could serve as hubs for innovation, fostering collaboration between academic institutions, private industries, and international partners. Furthermore, enhancing the infrastructure by equipping laboratories with modern tools and scaling up production capabilities will facilitate the translation of research into marketable products (Moreira 2019).

Expanding international collaboration is another vital strategy. By partnering with countries that excel in essential oil research, such as France, Italy, and Spain, Moroccan researchers can benefit from knowledge exchange, access to advanced technologies, and joint funding opportunities. At the same time, fostering intra-African collaboration could strengthen regional research networks and create

a unified approach to addressing shared challenges in biodiversity conservation and sustainable development (Scherer 2019).

Finally, diversifying research topics to address emerging global trends is crucial. While much of Morocco's research focuses on the pharmaceutical and cosmetic applications of essential oils, expanding into areas such as food technology, biodegradable materials, and climate-resilient agriculture could open new avenues for innovation (Chavula et al., 2024). Emphasizing environmentally sustainable practices, such as green extraction technologies, would also align Moroccan research with global priorities and increase its relevance on the international stage.

In conclusion, while Morocco's contribution to research on essential oils and medicinal plants is significant within Africa, strategic efforts are needed to elevate its global standing. By addressing funding and infrastructure gaps, fostering international collaborations, and diversifying research topics, Morocco can fully leverage its rich biodiversity to achieve greater scientific innovation and sustainable development. These efforts will not only enhance the country's scientific reputation but also contribute to economic growth and environmental conservation (Western 2003).

5. Conclusions

Moroccan research on essential oils, aromatic plants, and medicinal plants has emerged as a significant contributor to scientific advancements in Africa, reflecting the country's rich biodiversity and its untapped potential for innovation. This research highlights Morocco's capacity to explore and utilize its natural resources, particularly through high levels of international collaboration that enhance the quality and visibility of its scientific output. These collaborations position Morocco as an integral part of the global research community, providing opportunities for knowledge exchange and technological advancements.

Despite these achievements, the scope and scale of Moroccan research remain modest compared to global leaders like the United States, China, and India. These countries benefit from substantial funding, advanced infrastructure, and large-scale production capabilities that enable them to dominate the field of essential oils and medicinal plants. To bridge this gap and fully capitalize on its resources, Morocco must adopt strategic measures, including increased investment in research funding, the development of modern research infrastructure, and a concerted effort to publish in high-impact international journals. Expanding interdisciplinary collaboration, both regionally and globally, and diversifying research themes to address emerging global challenges, such as sustainability and climate resilience, are equally critical.

This study provides a roadmap for future growth and innovation in the field. By focusing on green extraction technologies, promoting sustainable development practices, and exploring novel applications for essential oils in areas like agriculture, bioplastics, and healthcare, Morocco can position itself as a global leader. Furthermore, strengthening local research capacities and fostering private-public partnerships will ensure that Moroccan research not only meets global standards but also contributes to addressing pressing local and international challenges.

In conclusion, while Moroccan research has made significant progress, there is considerable untapped potential that, if harnessed strategically, can elevate the country's scientific reputation. By addressing funding, infrastructure, and thematic diversification, Morocco can achieve greater scientific innovation, enhance its contributions to the field of essential oils and medicinal plants, and promote sustainable economic and environmental development. This comprehensive analysis underscores the importance of continued investment and strategic planning to ensure that Morocco remains a vital player in this critical area of research, paving the way for impactful contributions in the years to come.

CRediT authorship contribution statement

Kawthar El Ahmadia: Conceptualization, methodology, investigation, resources, writing—original draft preparation, **Hasnae El Allaouia:** Conceptualization, methodology, validation, formal analysis, supervision, **Aouatif El Abdounia:** Methodology, **Mohamed Bouhrimb:** Software, validation, visualization, **Bruno Etuc:** Software, writing—review and editing, visualization, **Imane Diraa:** Formal analysis, **Abdelaaty Shahat:** Validation, writing—review and editing, funding acquisition, **Rashed N. Herqashe:** Validation, data curation, writing—review and editing, supervision, **Khadija Haboubia:** Validation, formal analysis, supervision, **Mohamed El Bastriouia:** Validation, formal analysis, writing—review and editing, visualization, **Yahya El Hammoudania:** Conceptualization, investigation, writing—review and editing, supervision, **O.N.:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding author.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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