Adıyaman University Journal of Science
https://dergipark.org.tr/en/pub/adyujsci
DergiPark AKADEMİK
ISSN 2147-1630
e-ISSN 2146-586X

Bibliometric Analysis of *Sideritis* L. based on Phytochemical Composition, Biological and Pharmacological Activities

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Received: 13.05.2025 **Accepted:** 01.09.2025 **Published:** 31.12.2025

Abstract

The genus *Sideritis* L. is a phytochemically rich group of plants that have been used in traditional folk medicine for many years. It has attracted pharmacological attention in recent years because it contains a large number of bioactive components such as flavonoids, phenolic compounds, diterpenoids and essential oils. In this study, the phytochemical composition, biological activities such as antioxidant, antimicrobial, anti-inflammatory and neuroprotective activities and potential therapeutic uses of *Sideritis* species were comprehensively reviewed. In addition, scientific publications in this field between 1983 and 2025 were examined by bibliometric methods, and the number of publications, most active countries, authors and collaboration networks were analyzed. The findings show that *Sideritis* species have come to the forefront in pharmacological research, especially in European countries, and there has been a significant increase in this field in the last decade. This study aims to shed light on new research on the genus *Sideritis* and identify gaps in the scientific literature.

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DOI: 10.37094/adyujsci.1698751

Keywords: *Sideritis* L.; Phytochemical; Pharmacological activity; Biological activity; Bibliometrics.

Sideritis L.'nin Fitokimyasal Bileşimi, Biyolojik ve Farmakolojik Aktiviteleri, Bibliyometrik Analizi

Öz

Sideritis L. cinsi, geleneksel halk tıbbında uzun yıllardır kullanılan ve fitokimyasal açıdan zengin bir bitki grubudur. Flavonoidler, fenolik bileşikler, diterpenoidler ve uçucu yağlar gibi çok sayıda biyoaktif bileşen içermesi nedeniyle son yıllarda farmakolojik açıdan dikkat çekmektedir. Bu çalışmada, *Sideritis* türlerinin fitokimyasal bileşimi, antioksidan, antimikrobiyal, antiinflamatuvar ve nöroprotektif gibi biyolojik aktiviteleri ile potansiyel terapötik kullanımları kapsamlı bir şekilde ele alınmıştır. Ayrıca 1983–2025 yılları arasında bu alanda yapılmış bilimsel yayınlar bibliyometrik yöntemlerle incelenmiş, yayın sayıları, en aktif ülkeler, yazarlar ve iş birliği ağları analiz edilmiştir. Elde edilen bulgular, *Sideritis* türlerinin farmakolojik araştırmalarda ön plana çıktığını, özellikle Avrupa ülkelerinde yoğun olarak çalışıldığını ve son on yılda bu alanda belirgin bir artış olduğunu göstermektedir. Bu çalışma, *Sideritis* cinsi üzerine yapılacak yeni araştırmalara ışık tutmayı ve bilimsel literatürdeki boşlukları belirlemeyi amaçlamaktadır.

Anahtar Kelimeler: *Sideritis* L.; Fitokimyasal; Farmakolojik aktivite; Biyolojik aktivite; Bibliyometrik.

1. Introduction

Plants belonging to the Lamiaceae family are among the widely used medicinal plants due to their essential oils and various secondary metabolites [1]. Plants of this family, which has approximately 397 genera and 23,623 species in the world, are used in many fields such as food, perfumery, cosmetics, pharmaceuticals and aromatherapy, and many species are included in traditional medicine [2- 4]. Türkiye contains 48 genera and 782 taxa (603 species, 179 subspecies and varieties) belonging to this family and has a wide flora, of which 346 taxa (about 44%) are endemic [5].

The genus *Sideritis* L. (“mountain tea”/“shepherd's tea”) consists of annual or perennial herbaceous plants that usually grow at high altitudes (> 1000 m), on rocky and clayey soils. The genus has ~150 species worldwide and 46 species (39 endemic) in Türkiye, making it prominent in the Lamiaceae with a 78% endemism rate [6, 7]. Representing a taxonomically complex group,

Sideritis species are distributed mainly in the Mediterranean basin countries, the Balkans, the Iberian Peninsula, Macaronesia and Western Asia [8, 9].

Phytochemical studies have revealed that *Sideritis* species have a rich content profile. Diterpenes, flavonoids, phenolic acids and essential oils are the main bioactive groups of this genus and offer a wide range of effects, including antioxidant, antimicrobial, anti-inflammatory, analgesic, neuroprotective, anticancer and antidiabetic activities [9- 11]. The European Medicines Agency (EMA) has approved *Sideritis scardica*, *S. clandestina*, *S. raeseri* and *S. syriaca* species as traditional herbal medicinal products for cough, cold and gastrointestinal disorders (EMA/HMPC/39453/2015) [12, 13].

In this study, the phytochemical constituents and biological and potential pharmacological effects of the species belonging to the genus *Sideritis* L. were compiled through a comprehensive literature review; simultaneously, scientific publication trends between 1983 and 2025 were analyzed by bibliometric methods. Thus, the current status of the chemical and biological potential of the genus and its research dynamics are systematically presented.

1.1. Phytochemical Composition of *Sideritis* L. (Mountain Tea)

All *Sideritis* species contain phytochemical compounds such as terpenes, flavonoids, phenylethanoid glycosides, essential oils, iridoids, coumarins, sterols and lignans as chemical components responsible for their pharmacological efficacy and biological activity [14-18].

Essential oils of *Sideritis* species are rich in terpenoids, alcohols and aldehyde compounds. *Sideritis* spp. contains 1-octen-3-ol,3-carene, α-copaene, β-bourbonene, bicyclogermacrene, carvacrol, caryophyllene oxide, germacrene D, limonene, linalool, myrcene, naphthalene, nonanal, sabinene, spathulenol, valeranone, α-bisabolol, α-cadinene, α-pinene, β-caryophyllene, β-farnesene, β-phellandrene and β-pinene [1].

Sideritis species are plants rich in phenolic compounds and these compounds play an important role in the biological activities of plants. *Sideritis* L. contains phenolic compounds, including rosmarinic acid, quercetin, caffeic acid, luteolin and apigenin, which have the capacity to scavenge free radicals [19].

The synthesis and composition of phytochemical constituents (from essential oils and extracts) of medicinal and aromatic plants are controlled by genetic factors but also influenced by physiological processes, agricultural practices, ecological conditions (temperature, humidity, light, *etc*.) [20].

1.2. Pharmacological Activities of *Sideritis* L.

The pharmacological effects of the main essential oil and phenolic compounds isolated from *Sideritis* L. and identified in 1.1 are summarized in Table 1.

The pharmacological effects of *Sideritis* species are based on the activities of the phytochemical compounds they contain through various biological mechanisms. Antioxidant activity is related to the free radical scavenging and metal ion chelating capacities of phenolic compounds, especially chlorogenic acid, acacetin, gallic acid, rosmarinic acid and caffeic acid [11, 19]. Antibacterial activity is mediated by sesquiterpenes such as bicyclogermacrene, germacrene D, (E)-caryophyllene and spathulenol [1, 9], while antifungal activity is mediated by monoterpene and sesquiterpene essential oil components such as β-pinene, limonene and manoyl oxide [25]. Acetozide and lavandufolioside stand out among flavonoid glycosides effective in anti-inflammatory, analgesic and neuropathic pain models [27]. The antidiabetic effect is attributed to the ability of phenolic compounds to inhibit the protein tyrosine phosphatase 1B (PTP1B) enzyme [26], while anticancer activities are mediated by secondary metabolites that trigger apoptotic pathways and stop cell proliferation [28, 32]. These pharmacological data support the therapeutic potential of *Sideritis* species and provide a scientific basis for its use in traditional medicine.

2. Materials and Methods

2.1. Data Sources

The data in this study were obtained from the WOS database [33]. Search with in: All fields option was used. A comprehensive literature review on the phytochemical composition and pharmacological activities of *Sideritis* L. was conducted. In data collection, “sideritis” AND (“pharmacological” OR “biological activity” OR “anticancer” OR “cytotoxicity” OR “antidiabetic” OR “antioxidant” OR “antifungal” OR “antibacterial” OR “antimicrobial” OR “antiviral” OR “neuroprotective” OR “gastroprotective” OR “antiulcer” OR “insecticidal” OR “analgesic” OR “anti- pyretic” OR ‘hepatoprotective’ OR ‘wound healing’ OR ‘antivenom’ OR ”anti- inflammatory” OR ‘immunomodulatory’ OR ‘enzyme inhibition’ OR ‘acetylcholinesterase inhibition’ OR ‘cardioprotective’ OR ‘antihypertensive’ OR ‘hypotensive’ OR ”anti-aging” OR

Table 1: Pharmacological effects and bioactive components of *Sideritis* L. species

Pharmacological Effect	Spices	Active Components	Mechanism of Effect	Reference
Antioxidant	*S. cilicica* *S. erythrantha* *S. libanotica* subsp. *linearis* *S. ozturkii* Aytaç & Aksoy *S. leptoclada* *S. albiflora*	Phenolic compounds, Essential oil	Free radical scavenging, metal ion chelating, enzyme inhibition	[11, 15, 21, 22]
Antibacterial	*S. romana* L. subsp. p*urpurea* *S. trojana* *S. scardica* *S. raeseri*	Phenolic compounds, Essential oil	Growth inhibitory effect against pathogenic microorganisms, synergistic effect with antibiotics	[9, 21, 23, 24]
Antifungal	*S. germanicopolitana*	Essential oil	Inhibition of mycelial growth	[25]
Antidiabetic	*Sideritis sp.*	Phenolic compounds	PTP1b inhibition	[26]
Anti-inflammatory, analgesic, anti-neuropathic	*S. bilgeriana*	Phenolic compounds	Reduction of NF-κB, TNF-α, IL-1β, IL-6 levels, Suppression of MPO activity	[27]
Anticancer Antiproliferative	*S. ozturkii* Aytaç & Aksoy *S. raeseri* *Sideritis sp.* *S. perfoliata*	Phenolic compounds, Essential oil	Inhibition of cell growth by induction of apoptosis in the MDA-MB-231 cell line. Inhibits the proliferation of cancer cells; particularly effective in A375 (melanoma) cells. Interaction with drugs that cause DNA damage; cytotoxic effect in multiple tumor cell lines. Reducing cell proliferation in HELA cell by inducing apoptosis.	[9, 11, 28, 29]
Neurodegenerative diseases (Alzhimer, Parkinson's)	*S.leptoclada* *S. albiflora* *Sideritis sp.*	Phenolic compounds	AChE, BChE, tyrosinase, MAO enzyme inhibition	[15, 30]
Peptic ulcer and gastritis	*S. leptoclada* *S. albiflora*	Phenolic compounds, Essential oil	Urease enzyme inhibition	[15, 31]

'ethnobotany' OR 'traditional use' OR 'phytochemical*' OR 'phenolic compound*' OR 'flavonoid*' OR 'terpenoid*' OR 'essential oil*' OR 'secondary metabolite*' OR 'bioactive compound*' OR 'IC50' OR 'MIC' OR 'EC50' OR 'LD50' OR 'MBC' OR 'minimum inhibitory concentration' OR 'HPLC' OR 'GC-MS') search terms were used. In the search strategy, the Boolean operator "AND" was used to find publications with both keyword groups together. The search covered literature published from 1983 to April 2025. Out of 497 publications containing the identified keywords, only 414 publications that were research articles and written in English were included. By keeping the choice of keywords broad, it was aimed to fully screen all potential biological and pharmacological effects of *Sideritis* species in the literature and to minimize the risk of missing important studies. Thus, a review covering the vast majority of the existing literature on the subject was carried out (Fig. 1).

To ensure the quality and validity of the included data, specific inclusion and exclusion criteria were applied during the screening process. The inclusion criteria were: (i) publications published between 1983 and April 2025, (ii) articles defined as original research, and (iii) written in English. The exclusion criteria were: (i) non-articles such as reviews, meeting abstracts, proceedings papers, notes, letters, book chapters, early access material and editorials, (ii) non-English publications, and (iii) documents irrelevant to the study scope or lacking sufficient bibliometric metadata. This filtering resulted in the exclusion of 83 records.

The bibliometric analysis of the obtained literature was carried out using Rstudio (R.4.4.3) software. In this analysis, the open source Bibliometrix [34] package developed for scientific measurement and bibliometric evaluations was used. Analyses of the publication pattern include elements such as the number of publications per year, author contributions, journals, institutions, and keyword distributions.

2.2. Bibliometric Analysis

Bibliometric analyses were performed using the Bibliometrix package and its visual interface, Biblioshiny software [34, 35]. Biblioshiny is a Java-based software developed by Massimo Aria from the University of Naples Federico II, which combines the functionality of the R-based Bibliometrix package with a user-friendly web interface through the Shiny package. This software allows for comprehensive scientific analysis on many parameters such as publication year, number of citations, authors, institutions, countries, keywords, and international collaborations, thus contributing to the assessment of global knowledge [36]. In this study, the basic data obtained within the scope of both bibliometric analyses and systematic literature reviews were analyzed through this software.

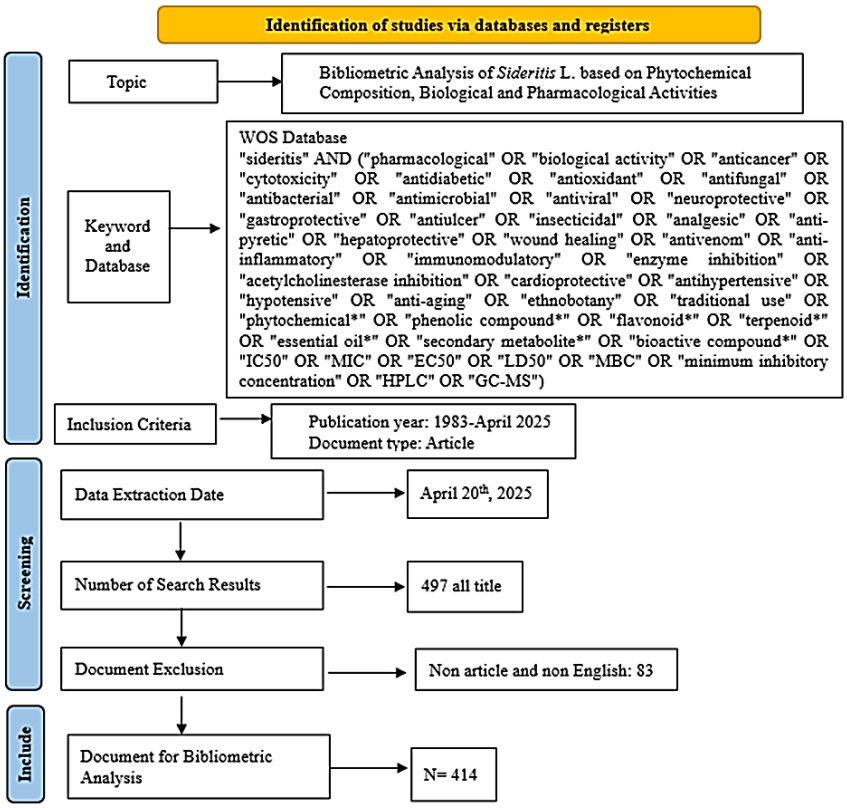

Figure 1: Flowchart

3. Results and Discussion

Research on *Sideritis* species has increased significantly in recent years, especially with the demonstration of the pharmacological potential of the plant [37]. This trend is remarkable both globally and in Türkiye. In Türkiye, the increased interest in the agricultural production and medicinal potential of *Sideritis* species has led to the acceleration of breeding efforts, especially for the development of high-yielding varieties rich in bioactive compounds. For example, the Ministry of Agriculture and Forestry has carried out selection breeding studies on *Sideritis perfoliata* and a registered variety has been developed. These developments demonstrate that *Sideritis* is of strategic importance not only for scientific research but also for agricultural production, economic value and public health [38, 39].

The bibliometric analysis conducted in this study is based on a total of 414 scientific documents published between 1983 and 2025 by searching the WOS database. These publications were obtained from 178 different sources including journals. There were 1600 authors in the documents analyzed. The average number of co-authors per author is 5.54 and the rate of international collaboration is 24.88%. This shows that interdisciplinary and international collaborations have an important place in the analyzed literature. The average age of the documents was 12.7 years and each document received 25.92 citations on average. While 1294

different author keywords were used in the documents, the total number of references reached 11,130. The fact that the number of single-author publications was limited to only 11 reveals that teamwork is dominant in the research field. Furthermore, the average annual growth rate was 4.74%, indicating a steady increase in academic interest in this field (Fig. 2).

Figure 2: Main information

The trend of scientific publications in the period 1983-2025 is shown in Fig. 3. Since 1983, according to the publications analyzed, there is a clear upward trend in the research field over time. While in the 1980s and 1990s the number of publications per year was generally below 5, this number has steadily increased since the mid-2000s (Fig. 3).

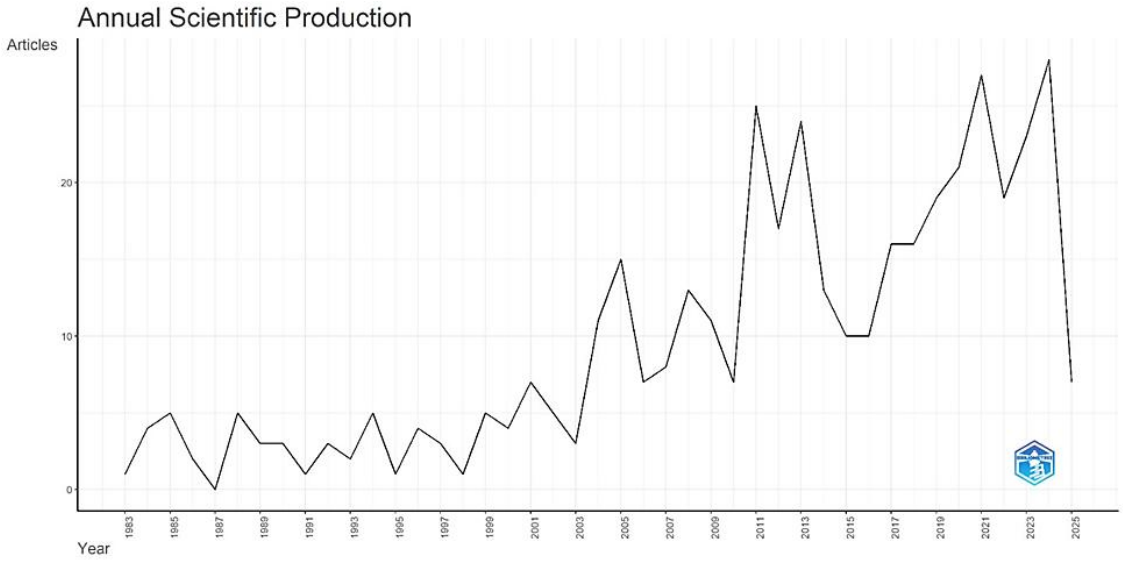

Figure 3: Annual Scientific Production from 1983-2025

Figure 4 (A, B, C) shows the distribution of scientific publications on *Sideritis* L. by country. Türkiye stands out among other countries and is the most productive country in this field with a total of 426 publications. Greece, Spain and Italy follow Türkiye with 302, 132 and 114 publications, respectively.

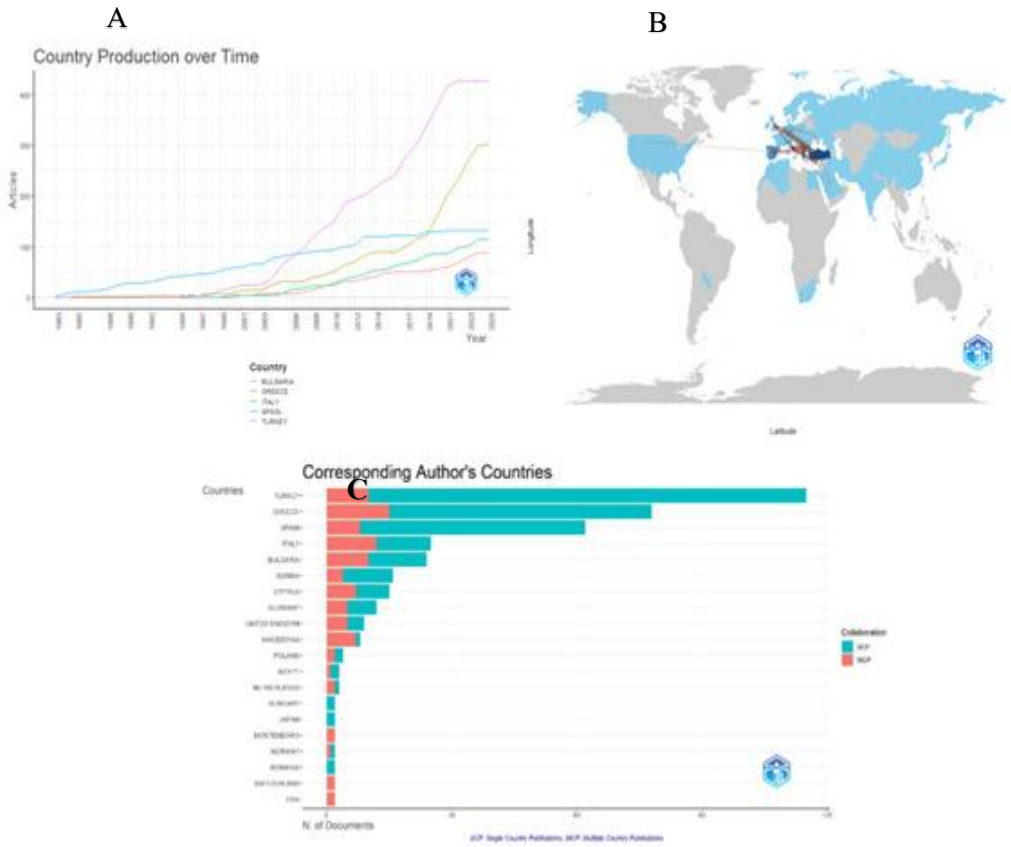

Figure 4: Country production over time (A), Country Scientific Productivity (B), Corresponding author's countries (C)

These data are consistent with the distribution areas of *Sideritis* species, especially in the Mediterranean and Balkan regions [8, 9]. The high publication rates of countries such as Turkey and Greece can be attributed to the fact that the natural habitat of this plant is located in these regions and it is intensively studied in terms of ethnobotany. According to the results, *Sideritis* research has a wide network of international cooperation. Especially intensive collaborations between the Balkans and Mediterranean countries are noteworthy. Close relations have been established with Greece, Cyprus, Italy and Serbia, while a remarkable internal regional cooperation has been observed between Macedonia and North Macedonia. Türkiye is the most active with the United Kingdom, Germany, Italy, Italy, Serbia and Saudi Arabia, with more than 20 international collaborations. This structure points to significant potential for sharing regional resources and integrating research infrastructures.

Many universities in the world have published articles on *Sideritis*. Among these universities, National and Kapodistrian University of Athens, Aristotle University of Thessaloniki, Balıkesir University, Anadolu University and Cyprus University of Technology stand out with more than 30 articles (Fig. 5).

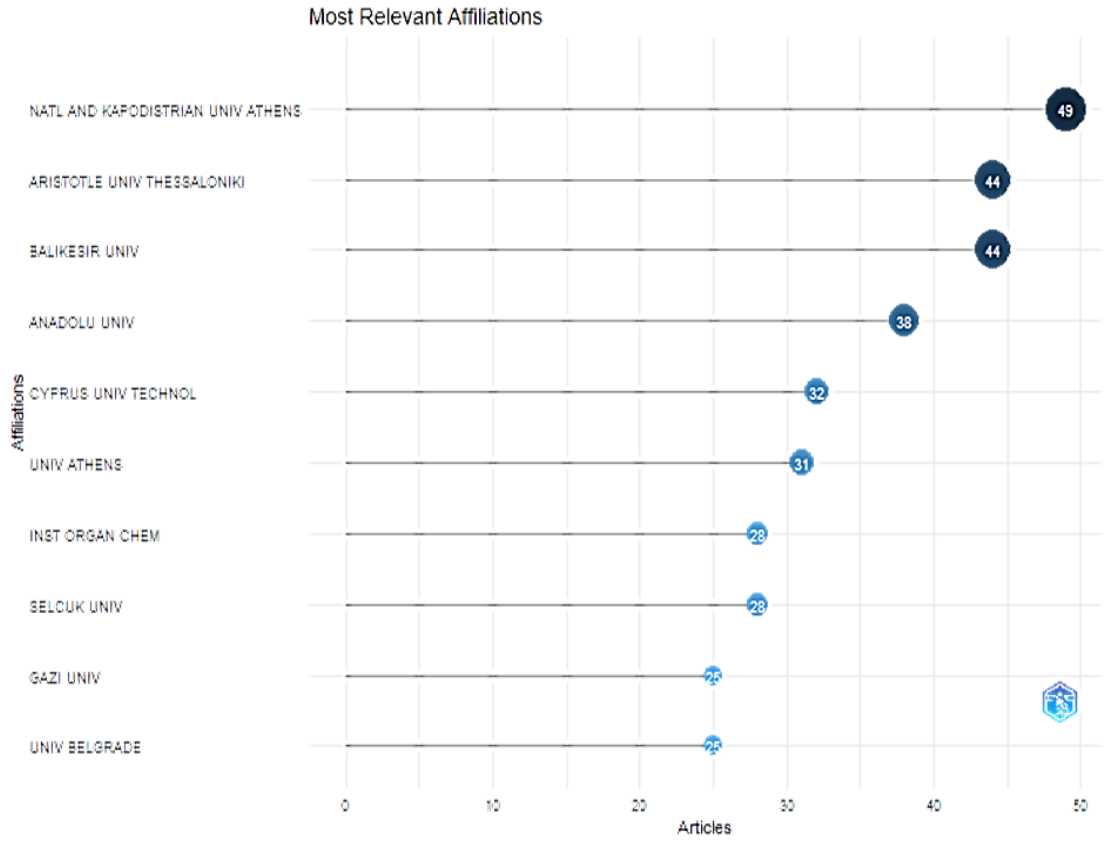

Figure 5: Most relevant affiliations

Figure 6 (A, B) summarizes the results of the collaborative network analysis between countries and institutions. The thickness of the lines indicates the strength of the relationship between collaborators. Türkiye stands out as one of the most influential countries in the analysis, followed by the other important countries such as Spain and Greece. According to this data, Turkey and the UK, Greece and Cyprus are in global cooperation. In contrast, countries such as Paraguay, Kosovo and Ireland have more limited connections in the network structure. However, Anadolu University and Natl. and Kapodistrian Univ. Athens are the central nodes and have important collaborations.

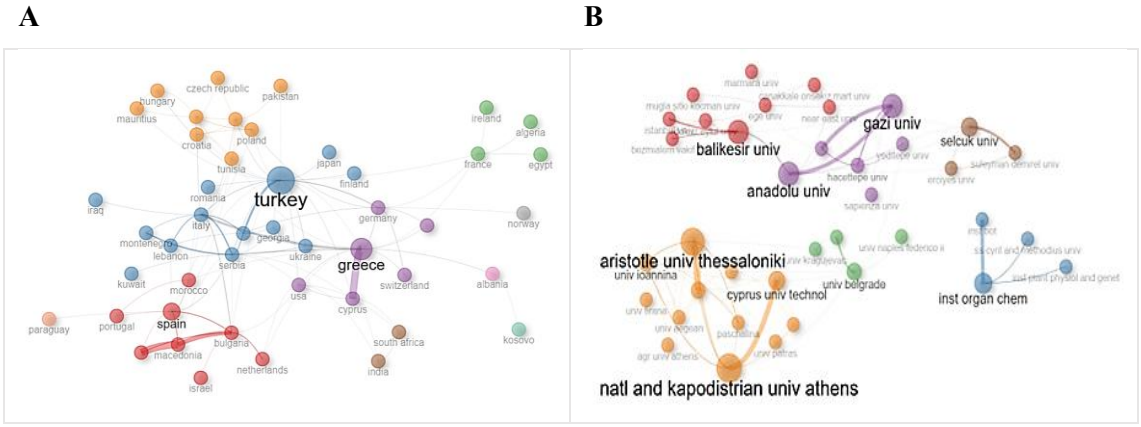

Figure 6: Collabration network countries (A), institutions (B)

In the bibliometric analysis covering 1600 authors, the most productive and influential authors were identified. Kılıç T. stands out in terms of both productivity and impact with 15 publications and an average of 4.28 citations. He is followed by Baser KHC, Stefova M. and Tzortzakis N. with 13 publications each, of which Tzortzakis N. has higher visibility with an average of 3.07 citations. Authors such as Chrysargyris A. (2.93) and Stefova M. (2.80) also stand out with their average number of citations. When indicators such as the h-index and m-index are evaluated, Tomou EM stands out for its high impact in a short time since 2019. Overall, these authors ranked high in the analysis in terms of both productivity and scientific contribution (Fig. 7).

The most frequently used keywords by the authors in the studies were analyzed (Fig. 8). Accordingly, the most recurring word was “sideritis” with the highest frequency of 72 times (10%). This was followed by “lamiaceae” 54 times (8%), “antioxidant activity” 43 times (6%), “flavonoids” 35 times (5%) and “antioxidant” 30 times (4%). These findings indicate that research has largely focused on plants of the genus *Sideritis* and their antioxidant activities. In addition, the high frequency of words such as “essential oil”, “antimicrobial activity”, “polyphenols”, “medicinal plants” reveals that these studies are concentrated in the fields of ethnobotany, pharmacology and phytochemistry. Thus, keyword analysis identifies the most prominent topics in the literature and helps to identify which topics can be studied in future studies.

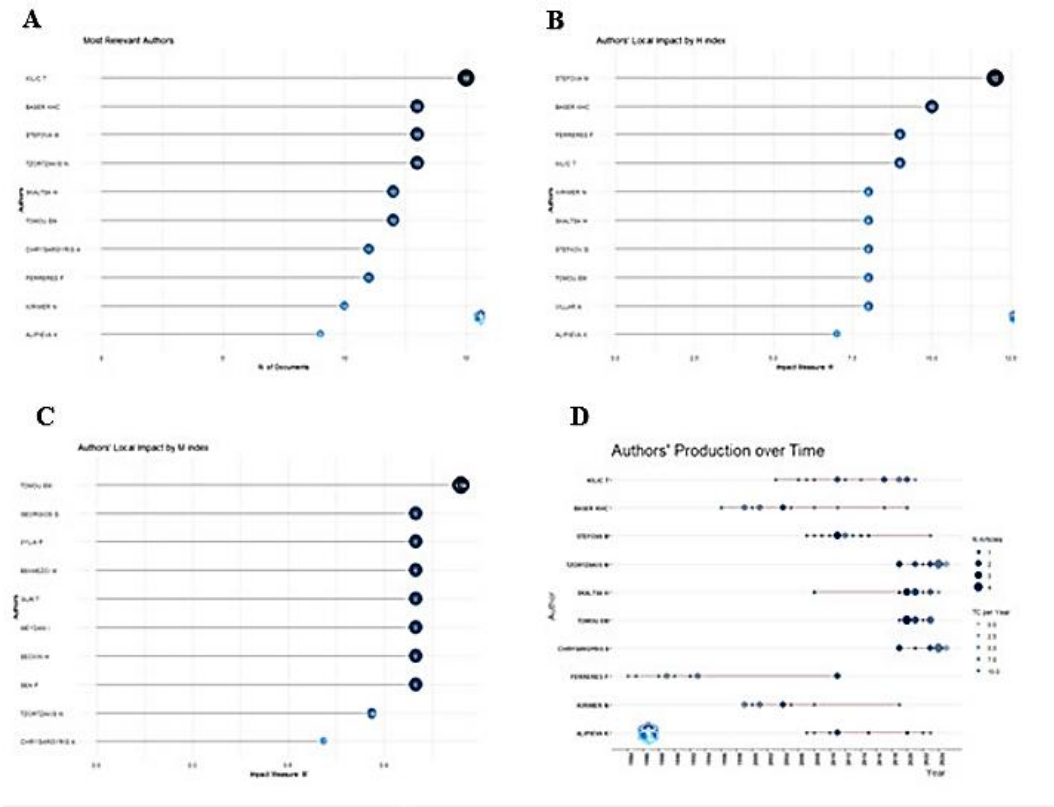

Figure 7: Most relevant authours (A), Authours' local impact by H-index (B), Authours' local impact by M-index (B), Authours' production over time (D)

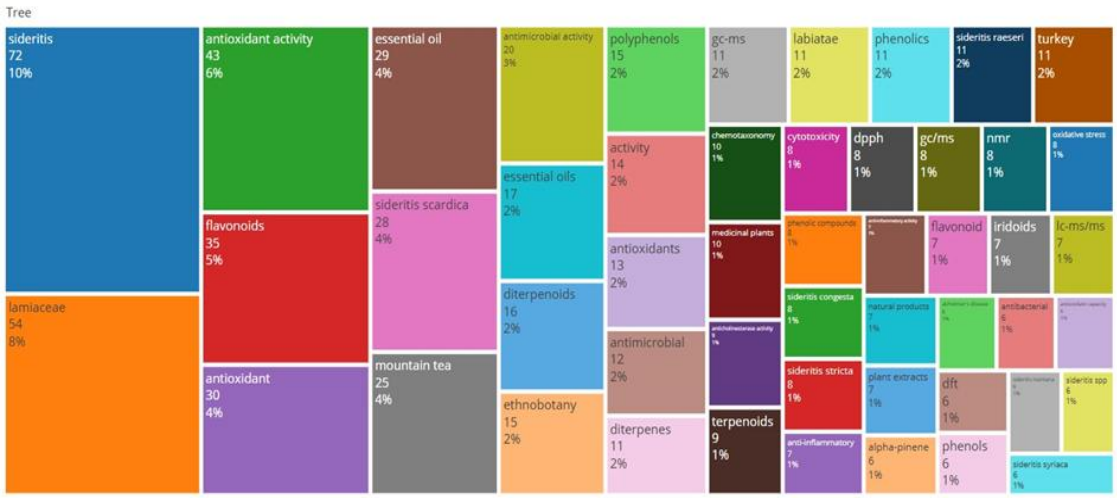

Figure 8: Tree map of keywords

Figure 9 shows the prominent keywords in the literature on *Sideritis*, their clusters and centrality measures as a result of the bibliometric analysis. The findings reveal that the literature is concentrated around themes such as ethnobotany, diterpenoids, phenolic compounds, antioxidant and antimicrobial activities. According to the results of the analysis, terms such as 'sideritis', 'lamiaceae', 'antioxidant activity' and 'essential oil' stand out as the most frequently encountered and central concepts in the research. These findings indicate that these terms are the

main focal points in scientific studies. It is also noteworthy that species names such as "*Sideritis raeseri*", "*Sideritis trojana*", "*Sideritis montana*" are frequently studied.

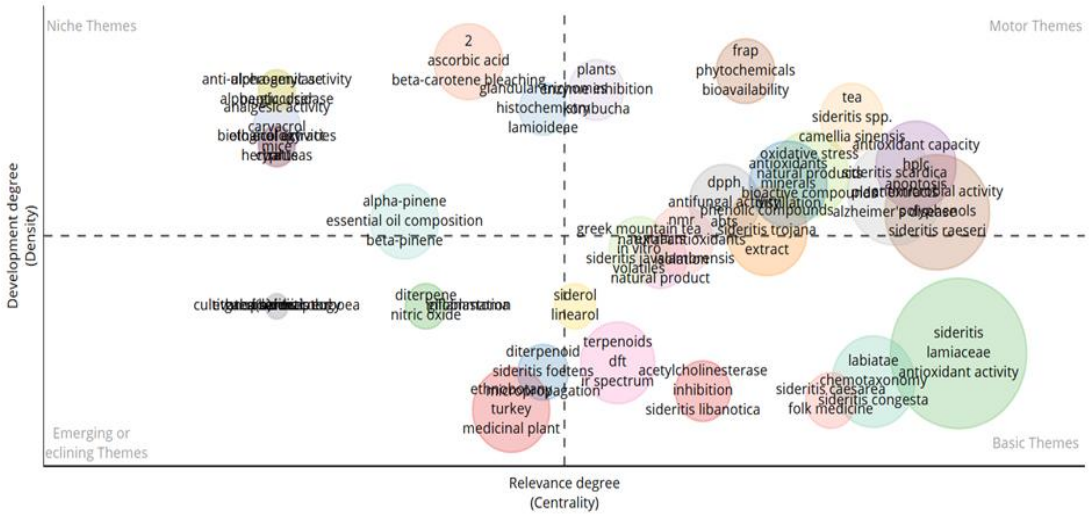

Figure 9: Thematic map

The term "Sideritis" has the highest frequency in the literature and stands out as a key concept. In the same cluster, terms such as "*Sideritis scardica*, flavonoids and mountain tea" are frequently used together (Fig. 10). It shows that *Sideritis* species have a central place in pharmacological and biological research, especially in terms of their phenolic components and their positive effects on health.

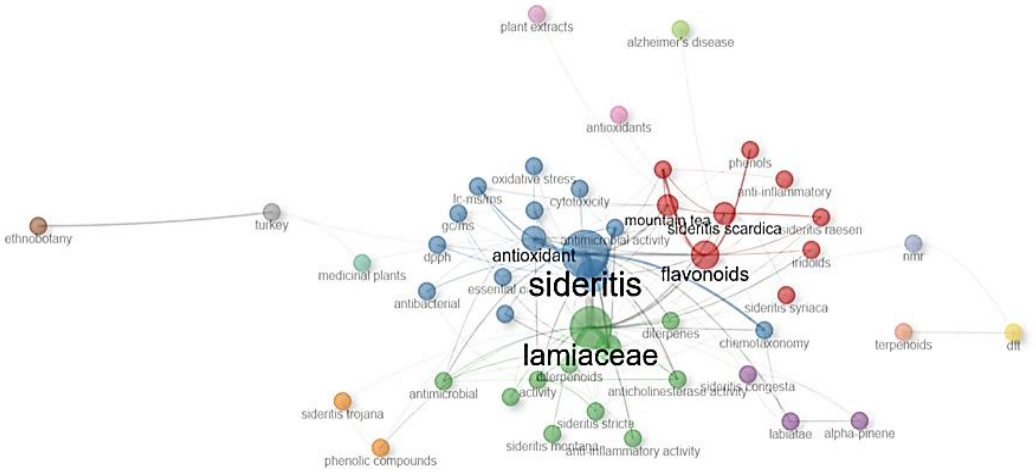

Figure 10: Co-occurence network

The links between countries, journals, authors and institutions are indicated in Fig. 11. For example, most of the studies on the phytochemical and pharmacological properties of *Sideritis* are published in Molecule, and most of them are written by academics from Turkey and Greece, especially from Balıkesir University and National and Kapodistrian University of Athens.

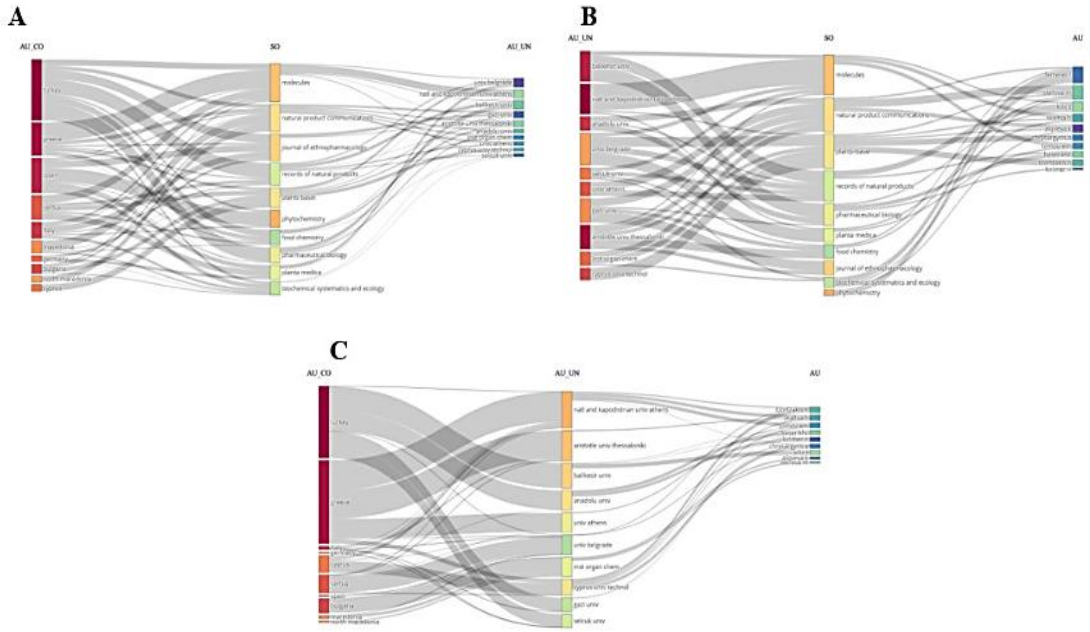

Figure 11: Tree field plot

While the findings support the pharmacological potential of *Sideritis* species, some limitations in the reviewed studies must be acknowledged. Significant differences in the chemical composition of different *Sideritis* species due to factors such as geographic origin, harvest time, and extraction techniques lead to heterogeneity, making it difficult to compare and generalize pharmacological results. Furthermore, the majority of existing studies have been conducted only in vitro, leaving limited in vivo validation. Methodological inconsistencies and the lack of detailed quantitative data in some publications further undermine the reproducibility and scientific rigor of the findings.

Another significant gap in the literature is the lack of comprehensive toxicological and pharmacokinetic data on *Sideritis* species. Few studies have evaluated acute or chronic toxicity in animal models, and critical parameters such as LD_{50} values, bioavailability, metabolic pathways, and elimination pathways of the main bioactive compounds have been largely unstudied. This lack of standardized data limits the ability to assess the safety and optimal dosage of *Sideritis*-based products, particularly for long-term or clinical use. Future studies should address these shortcomings through systematic toxicological and pharmacokinetic evaluations to ensure the safe and effective therapeutic use of *Sideritis* species.

4. Conclusion

In this study, based on 414 scientific publications published in the Web of Science (WoS) database between 1983 and 2025, research on phytochemical constituents and pharmacological effects of *Sideritis* species were analyzed by bibliometric methods. The data obtained reveal that *Sideritis* species are particularly prominent with their antioxidant activity and that this effect is directly related to the phytochemical content. Bibliometric findings show that the words such as "antioxidant activity", "essential oil", "flavonoids" and "antimicrobial activity" are frequently used in the studies. This suggests that *Sideritis* species are being considered in the context of potential health benefits and are being intensively investigated for relevant biological activities. However, studies on the detailed analysis of specific phytochemical compounds are still limited. This indicates an important research gap in terms of the effective use of the plant in the pharmaceutical and food industry. Future studies in areas such as molecular biology, biotechnological production and metabolomic analysis will expand the potential uses of *Sideritis* species. Interdisciplinary research in this direction will contribute to a more effective and sustainable utilization of the plant in the health, food and pharmaceutical sectors.

Declaration of Competing Interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding Declaration

The study was not funded by any organization or individual.

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