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REVIEW PAPER

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ADVANCING HORTICULTURAL KNOWLEDGE OF *Asparagus officinalis* L. A COMPREHENSIVE BIBLIOMETRIC AND THEMATIC ANALYSIS (1853–2025)

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ABSTRACT

Background/Aim: *Asparagus officinalis* L. has attracted increasing scientific interest because of its agricultural, genetic, and pharmacological significance. This study aimed to systematically map intellectual and conceptual structures, growth patterns, and emerging trends in *A. officinalis* research from 1853 to 2025.

Methods: A bibliometric and conceptual analysis was conducted using the Scopus database following the PRISMA 2020 guidelines. A total of 1,065 original research articles were retrieved and analyzed. Bibliometric indicators, keyword mapping, co-citation clustering, and citation burst analyses were performed using Bibliometrix (RStudio), VOSviewer and CiteSpace.

Results: Scientific production exhibited a steady increase with notable surges after 2000. Japan, China, and the USA have emerged as leading contributors. Core journals were identified according to Bradford's law and key scholars were ranked by their local H-index. Thematic evolution revealed two major shifts in knowledge around 2001 and 2017, highlighting a transition toward molecular biology, genomics, and health-related studies. Eleven conceptual clusters were detected, with high Silhouette values indicating strong clustering quality. Emerging research hotspots include metabolomics, transcriptomics, and medicine.

Conclusion: This comprehensive bibliometric analysis revealed the dynamic growth and conceptual diversification of *A. officinalis* research, offering valuable insights into historical developments, current trends, and future research directions.

Keywords: *Asparagus officinalis*, bibliometric analysis, conceptual structure, thematic evolution, citation analysis

Abbreviations: ACE: angiotensin-converting enzyme; IMS: imaging mass spectrometry; PRISMA: preferred reporting items for systematic reviews and meta-analyses; RAPD: random amplified polymorphic DNA; SSR: simple sequence repeat; STS: sequence tagged site; SVG: scalable vector graphics; TLS: total link strength

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INTRODUCTION

Asparagus (*Asparagus officinalis* L.) is a perennial horticultural crop of significant economic and nutritional value, cultivated globally for its edible young shoots or spears. With a rich cultivation history spanning ancient civilizations – such as the Egyptians, Greeks, and Romans – its early use is evidenced in art and literature, though its exact applications during antiquity remain partially speculative [Moreno-Pinel et al. 2021]. The depiction of its presentation as an offering on an ancient Egyptian frieze serves as an initial indication of its utilization, although it remains ambiguous whether the plant was employed for culinary or therapeutic purposes during that period. Several literature sources have discussed its application in herbal medicine during the ancient periods of Greece and Rome [Prasad et al. 2024, Wen et al. 2024, Yadav et al. 2024]. Today, it is used by people worldwide. Furthermore, its medicinal value has been recognized in Traditional Chinese Medicine [Zhu et al. 2024].

Asparagus officinalis spears are rich in vitamins and antioxidants, and powerful in fiber, but relatively low in calories; its consumption greatly improves a healthy diet [Fang et al. 2024]. In addition, due to the presence of potassium in asparagus, some patient groups, particularly those with hypertension, can benefit from its mineral composition [Prasad et al. 2024, Wen et al. 2024]. *Asparagus* spp. has long been used in China and Korea as a source of herbal remedies. For example, vegetables are used in the management of urinary pathologies because of their diuretic properties [Kumar et al. 2010, Olas 2024]. In India, asparagus root preparations have been traditionally used to treat women's reproductive health, promote conception, and increase breast milk production [Pahuja et al. 2024]. In ancient Eastern and Greek medicine, asparagus extracts were administered as a tonic for the prevention and treatment of a myriad of illnesses, including rheumatism, liver disease, asthma, cancer, and kidney and bladder [Fang et al. 2024, Jana et al. 2025, Olas 2024, Pahuja et al. 2024, Prasad et al. 2024, Zhu et al. 2024]. Despite traditional uses, there is a lack of robust clinical data to support *A. officinalis*'s pharmacological applications, as highlighted by Olas [2024], who notes limited clinical trials for its health benefits, and Fang et al. [2024], who call for further clinical validation of its anti-proliferative effects in endometrial cancer. Traditional uses of *A. officinalis* lack robust clinical data, limiting FDA endorsement and restricting its pharmacological applications to traditional medicine [Fang et al. 2024, Zedan et al. 2025].

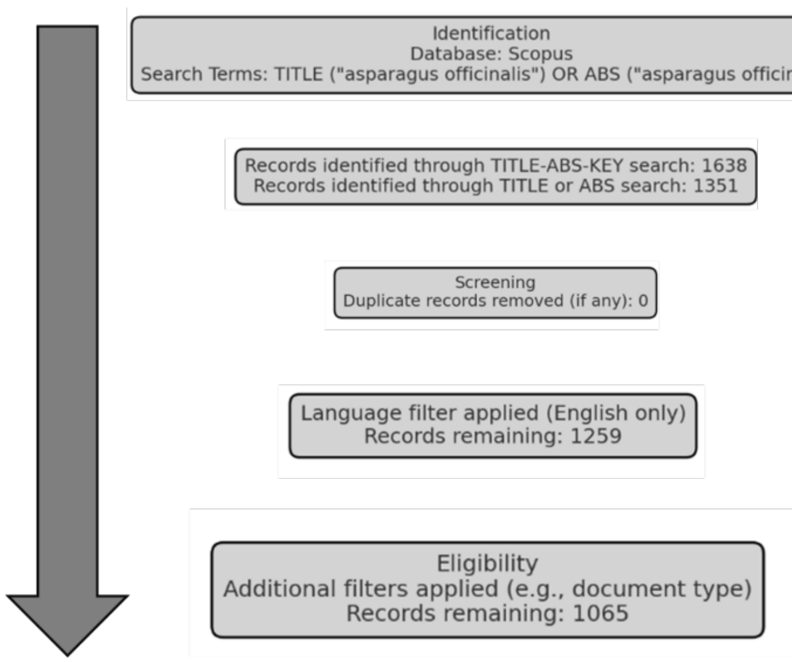
In the context of horticultural science, understanding the evolution of asparagus research is crucial for advancing cultivation practices, genetic improvement, and utilization strategies. Bibliometric analysis – an established method for quantitatively mapping scientific output – offers a powerful tool to evaluate global research dynamics, highlight knowledge gaps, and forecast emerging trends [Alkhammash 2023]. In the context of horticultural science, understanding the evolution of asparagus research is crucial for advancing cultivation practices, genetic improvement, and utilization strategies. Bibliometric analysis – an established method for quantitatively mapping scientific output – offers a powerful tool to evaluate global research dynamics, highlight knowledge gaps, and forecast emerging trends.

MATERIALS AND METHODS

Data source and search strategy

A systematic approach using the Scopus database was employed to identify relevant studies on *Asparagus officinalis*, following PRISMA 2020 guidelines [Sarkis-Onofre et al. 2021] to ensure transparency, reproducibility, and methodological rigor (Figure 1). The search term "*Asparagus officinalis*" was used in two complementary searches to maximize retrieval of relevant articles while maintaining precision. The first search, using the TITLE-ABS-KEY field (covering title, abstract, and keywords), returned 1,638 records, capturing a broad range of studies, including those with the term in author-provided keywords. The second search, limited to TITLE or ABSTRACT fields, returned 1,351 records, focusing on articles where the term was explicitly mentioned in these fields to enhance specificity. Results from both searches were merged, and duplicate records were removed during the screening phase, yielding 1,259 records after applying a language filter to include only English-language studies. This filter was applied to ensure compatibility with bibliometric tools (e.g., Bibliometrix, VOSviewer, CiteSpace), which are optimized for English metadata, though this may introduce language bias by potentially excluding relevant non-English studies from regions like China or Japan; this limitation is acknowledged in the discussion section. During the eligibility phase, additional filters (e.g., restriction to original articles) were applied, resulting in 1,065 eligible records for bibliometric analysis. Data extracted on 31.03.2025.

Figure 1. PRISMA flow diagram illustrating the search and selection process for studies *on Asparagus officinalis* identified in Scopus, including identification, screening, eligibility assessment, and final inclusion



Data analysis

This study employed a multi-step bibliometric methodology to analyze *Asparagus officinalis* research from 1853 to 2025. Metadata were extracted from Scopus and processed in BibTeX and CSV formats. The year 1853 marks the earliest indexed publication on this species in the Scopus database, providing a foundational point for bibliometric analysis. Including data up to 2025 ensures the incorporation of the most recent studies and preprints available at the time of data extraction (May 2024), allowing for a forward-looking perspective on emerging trends. By covering over 170 years, the analysis provides a robust and contextualized understanding of how scientific interest, methodologies, and applications of *A. officinalis* have transformed over time, highlighting both historical contributions and current frontiers in horticultural science. Descriptive statistics, including publication trends, co-authorship, international collaboration, and citation metrics, were analyzed using Bibliometrix in RStudio. Global research contributions were visualized through world maps and bar-line charts. Core journals were identified via Bradford's Law, and influential authors were ranked using the local H-index. Keyword co-occurrence networks and thematic evolutions were mapped using VOSviewer and Bibliometrix, while CiteSpace enabled co-citation clustering, burst detection, and conceptual mapping. Eleven major research clusters were identified with high silhouette values (0.831–0.997), indicating strong thematic cohesion. Together, these tools provided an integrated view of publication growth, research hotspots, collaboration patterns, and evolving themes in *A. officinalis* studies.

RESULTS

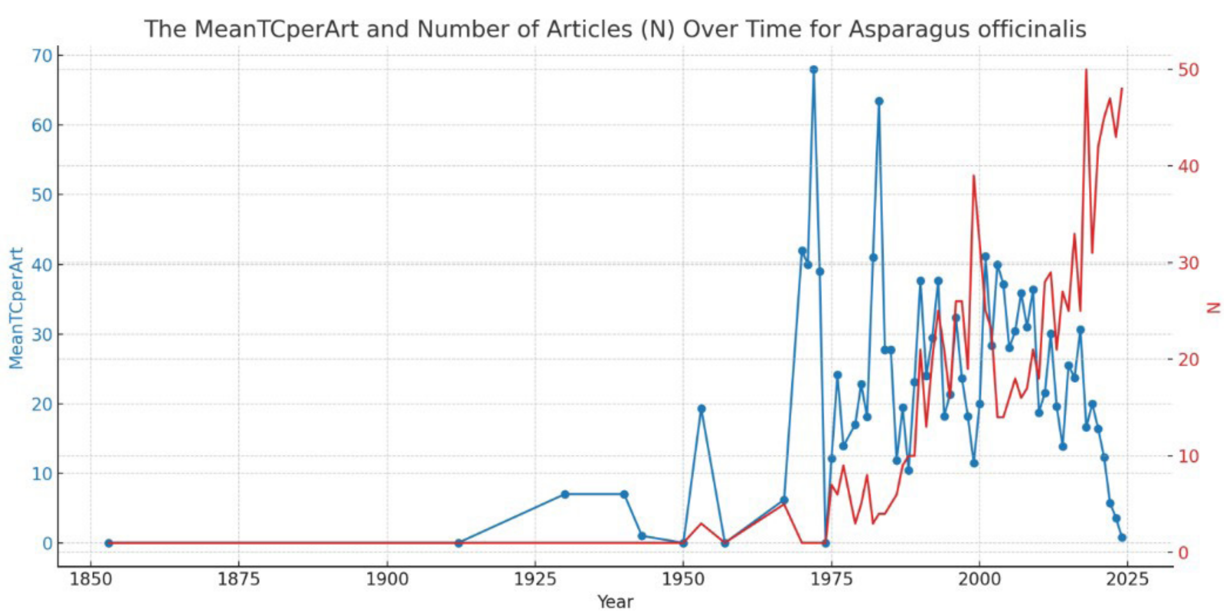
Descriptive bibliometrics

Descriptive bibliometric statistics for *A. officinalis* research were extracted from the Scopus database (1853–2025). A total of 1,065 documents authored by 2,962 researchers were analyzed across 416 sources, with an annual growth rate of 2.29%. The international co-authorship rate was 16.49% and the average number of citations per document was 21.01. Additional metrics included an average of 4.49 co-authors per document and 2,748 author keywords, reflecting a collaborative and expanding research landscape.

Growth and impact

The growth of research on *A. officinalis* has demonstrated a clear upward trajectory, particularly since the early 1990s (Figure 2). Although publication activity was sporadic and limited before 1980, a steady increase in the number of articles became evident from the late 20th century onward, with notable surges after 2000. This trend indicates rising scientific interest in the agricultural, genetic, and pharmacological properties of plants. Citation analysis revealed that earlier studies, particularly those published between the 1970s and the early 2000s, achieved higher average citations per article, suggesting their foundational influence on the field. However, in recent years (post-2017), although the volume of publications has increased, the mean total citations per article has declined, reflecting the time lag in citation accumulation, as newer publications require several years to accrue significant citations. Overall, this pattern highlights both the maturation of research on *A. officinalis* and emergence of new investigative directions (Figure 2).

Figure 2. Trends in the scientific research on *Asparagus officinalis* from 1853 to 2025. The blue line represents the mean total citations per article (MeanTCperArt), while the red line indicates the number of publications (N) per year



Frontier countries

The scientific production of *A. officinalis* exhibits notable geographical variation, with Japan emerging as the most prolific contributor (470 documents), followed by China (354), the USA (198), Germany (149), and Italy (127). Other countries, such as New Zealand, Spain, Poland, and South Korea, also demonstrated significant research output. Countries from Europe, North America, and Asia dominate the scientific landscape, whereas contributions from Africa, South America, and Oceania remain comparatively limited. The global distribution illustrated in Figure 3 shows dense research activity concentrated in technologically advanced and agriculturally significant nations, reflecting both the research capacity and agricultural importance of *A. officinalis* worldwide.

Figure 3. Global distribution of scientific publications on *Asparagus officinalis* research. Countries are shaded according to their publication output, with darker colors representing higher numbers of documents. Japan, China, and the USA are the top contributors, reflecting major centers of research activity on *A. officinalis*. Map created using Bibliometrix

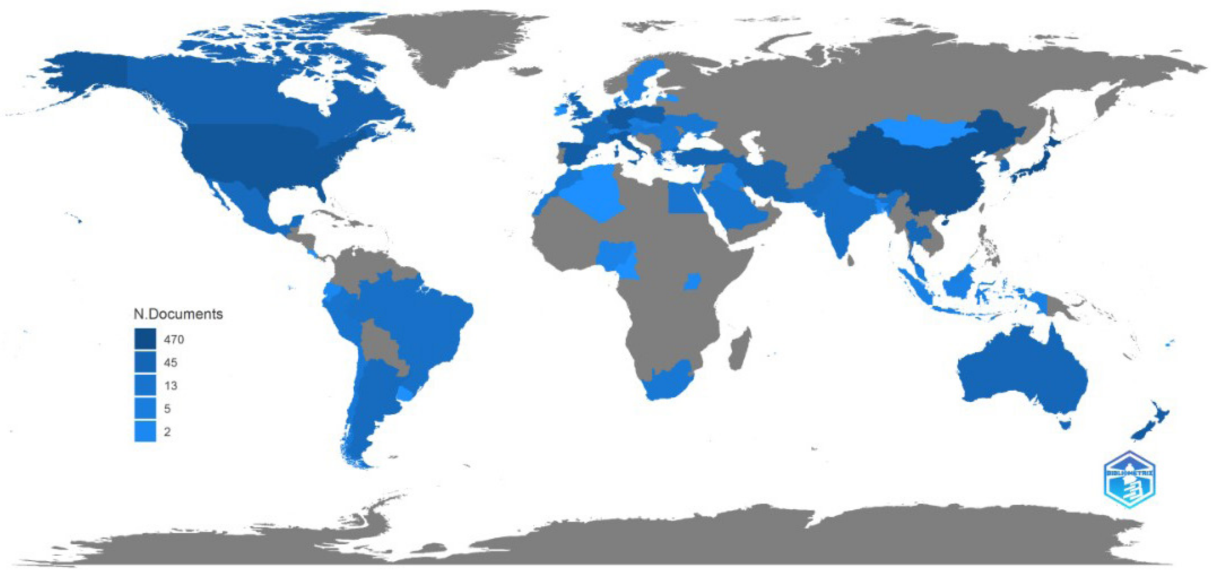
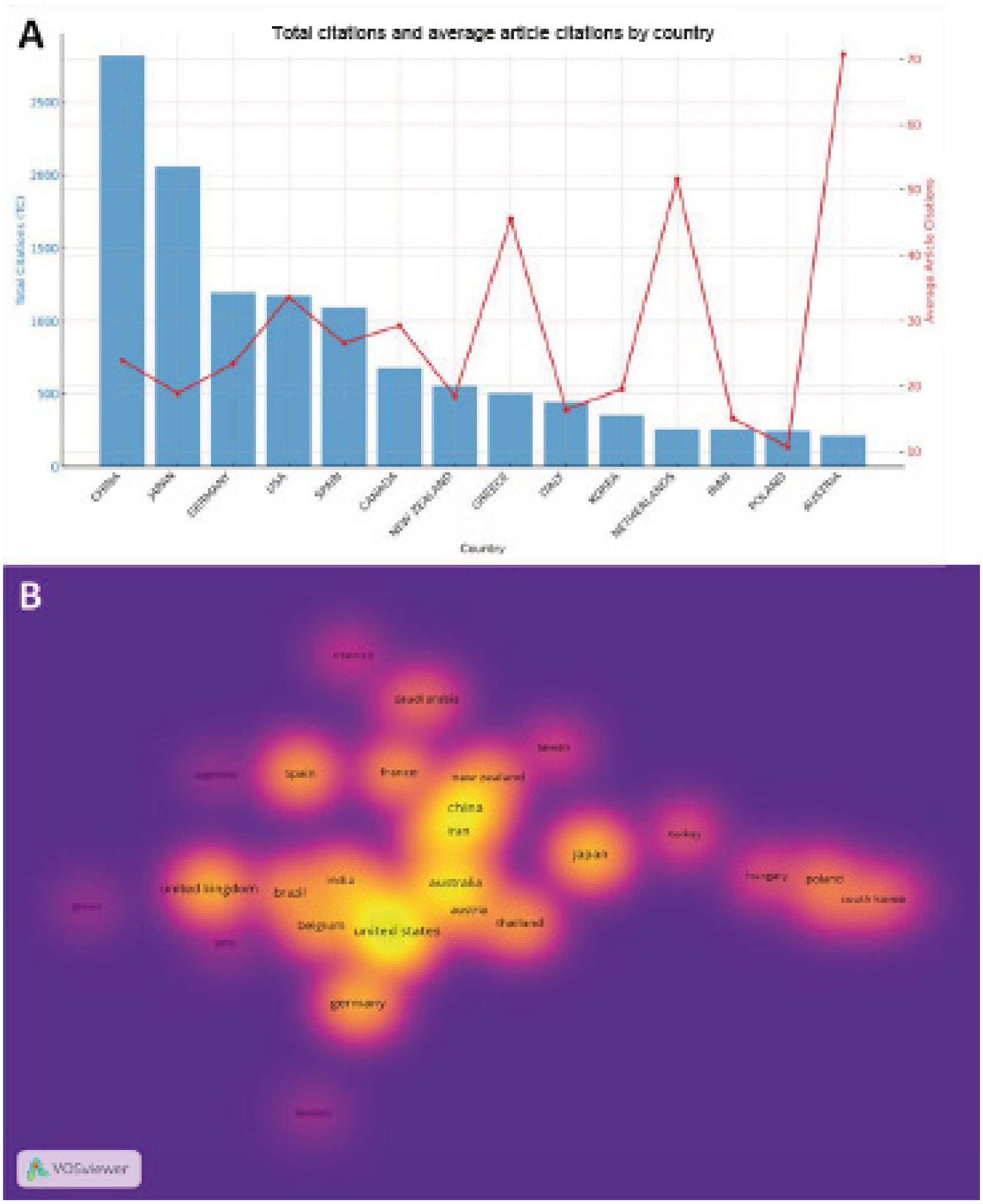


Figure 4A shows total citations and average article citations for *A. officinalis* research across 14 countries. China leads in total citations, followed by Japan, Germany, and the USA, while Austria has the highest citation impact per article (70.7), indicating strong academic influence despite lower output. Other high-impact countries include the Netherlands, Greece, and the USA. Figure 4B, a VOSviewer density map, highlights top collaborative nations based on total link strength (TLS), with the USA (TLS = 76), China (66), Australia (49), and Japan (46) leading. European countries like Germany, the UK, and the Netherlands also show strong research networks, along with Canada and Thailand. This underscores the central role of North America, East Asia, and Europe in global asparagus research collaboration.

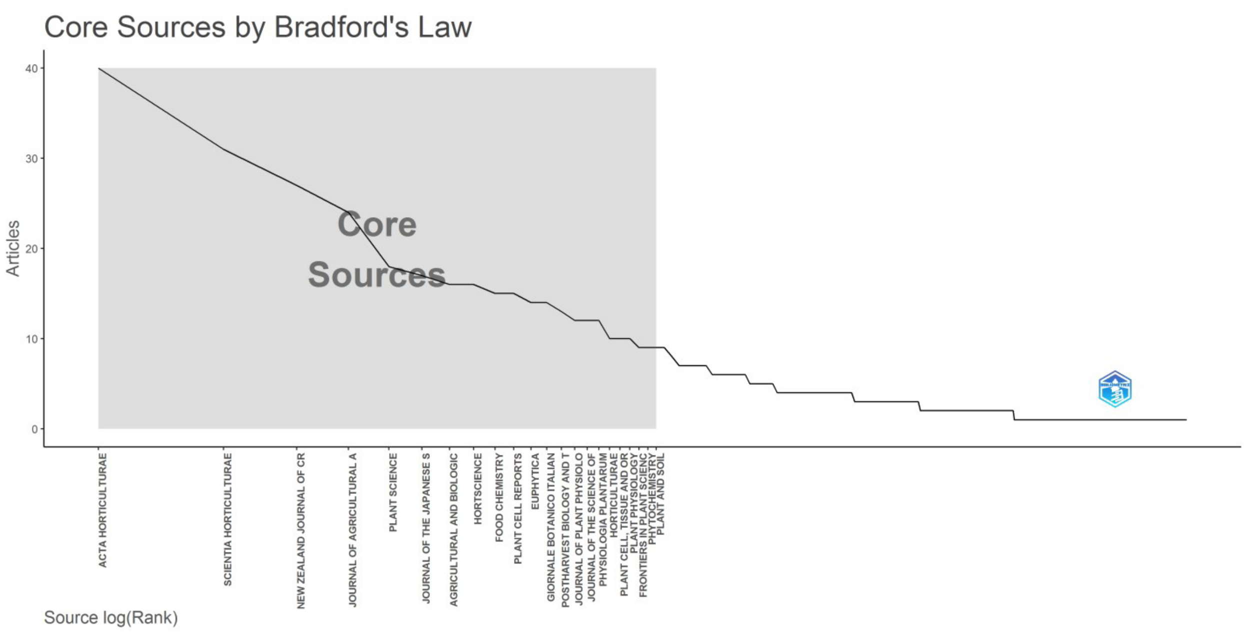
Figure 4. A: Total citations (blue bars) and average article citations (red line) for *Asparagus officinalis* research across leading countries, generated using Bibliometrix from Scopus data. B: Density visualization of international collaboration in *A. officinalis* research, generated using VOSviewer from Scopus data, with halo intensity representing total link strength (TLS**)**. Warmer colors indicate higher TLS values, reflecting greater international research connectivity



Core journals based on Bradford's law

The distribution of sources related to *A. officinalis* research follows Bradford's Law of Scattering, classifying the journals into three distinct zones (Figure 5). Zone 1 included 22 core journals that collectively accounted for a substantial portion of published articles. "Acta Horticulturae" ranked first with 40 articles, followed by "Scientia Horticulturae" (31 articles), and the "New Zealand Journal of Crop and Horticultural Science" (27 articles). Zone 2 comprised 94 journals with a moderate number of articles per source, such as "Sexual Plant Reproduction and Theoretical" and "Applied Genetics". Zone 3 contains the remaining 300 journals, each contributing a small number of documents, such as "European Food Research" and "Technology and Food Science" and "Nutrition". Overall, out of the 416 sources analyzed, a small core group was responsible for a disproportionately large share of the scientific output, highlighting the concentration of asparagus research in specialized journals.

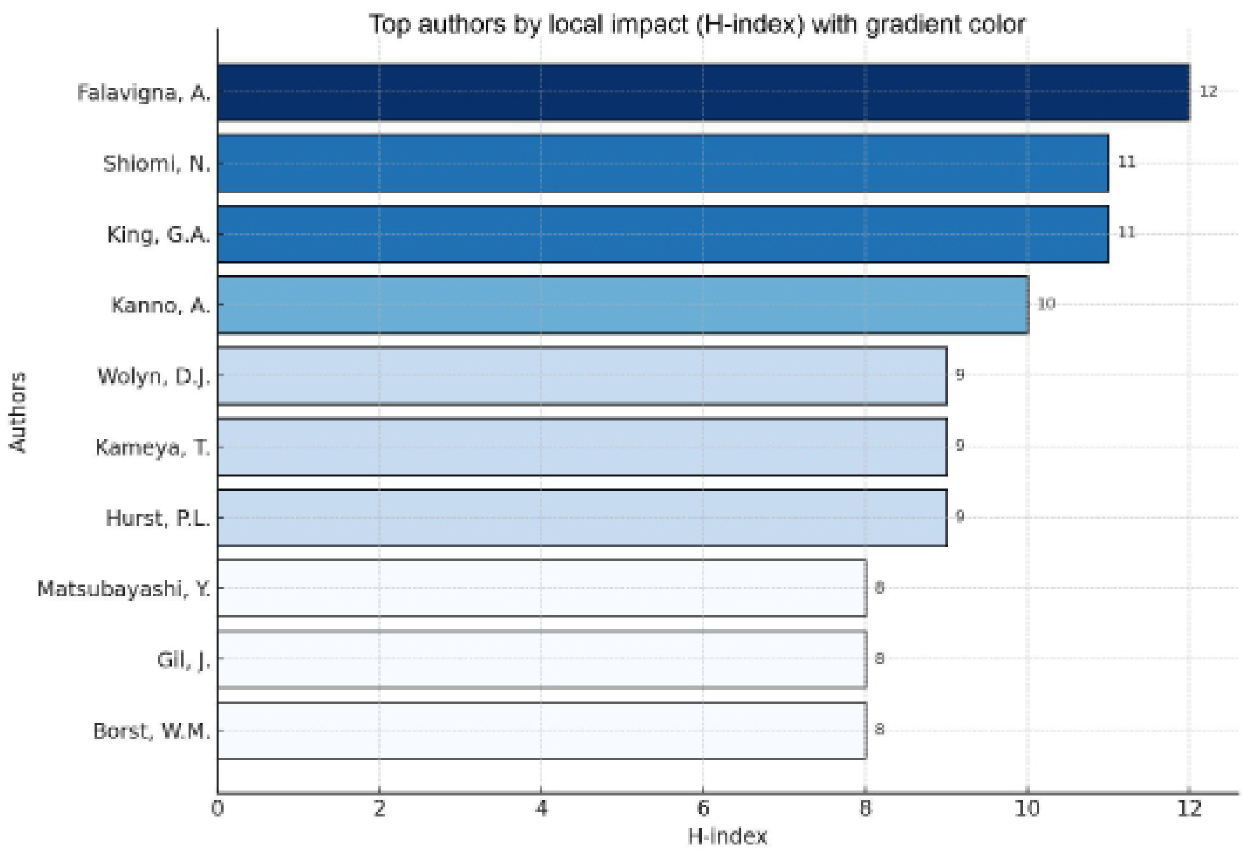
Figure 5. Bradford's Law distribution of core journals publishing *Asparagus officinalis* research. The plot identifies three zones: a small group of highly productive core journals (Zone 1), a moderate group (Zone 2), and a large group with fewer publications (Zone 3). Analysis based on 416 sources using Bibliometrix



Most impactful scholars based on local H-index

Figure 6 shows the most important scholars based on their local H-index values. The H-index is a composite metric that measures both the productivity and citation impact of an author's publications; an H-index of h means that the author has h papers, each cited at least h times. In this analysis, Falavigna, A. achieved the highest local H-index (12), followed by King, G.A. and Shiomi, N. (both with 11). Kanno, A. ranked fourth with an H-index of 10, whereas several other researchers, including Hurst, P.L., Kameya, T., and Wolyn, D.J., demonstrated a strong impact with scores of 9. The gradient color scheme represents the relative strength of each author's influence, with darker shades indicating higher H-index values (Figure 6).

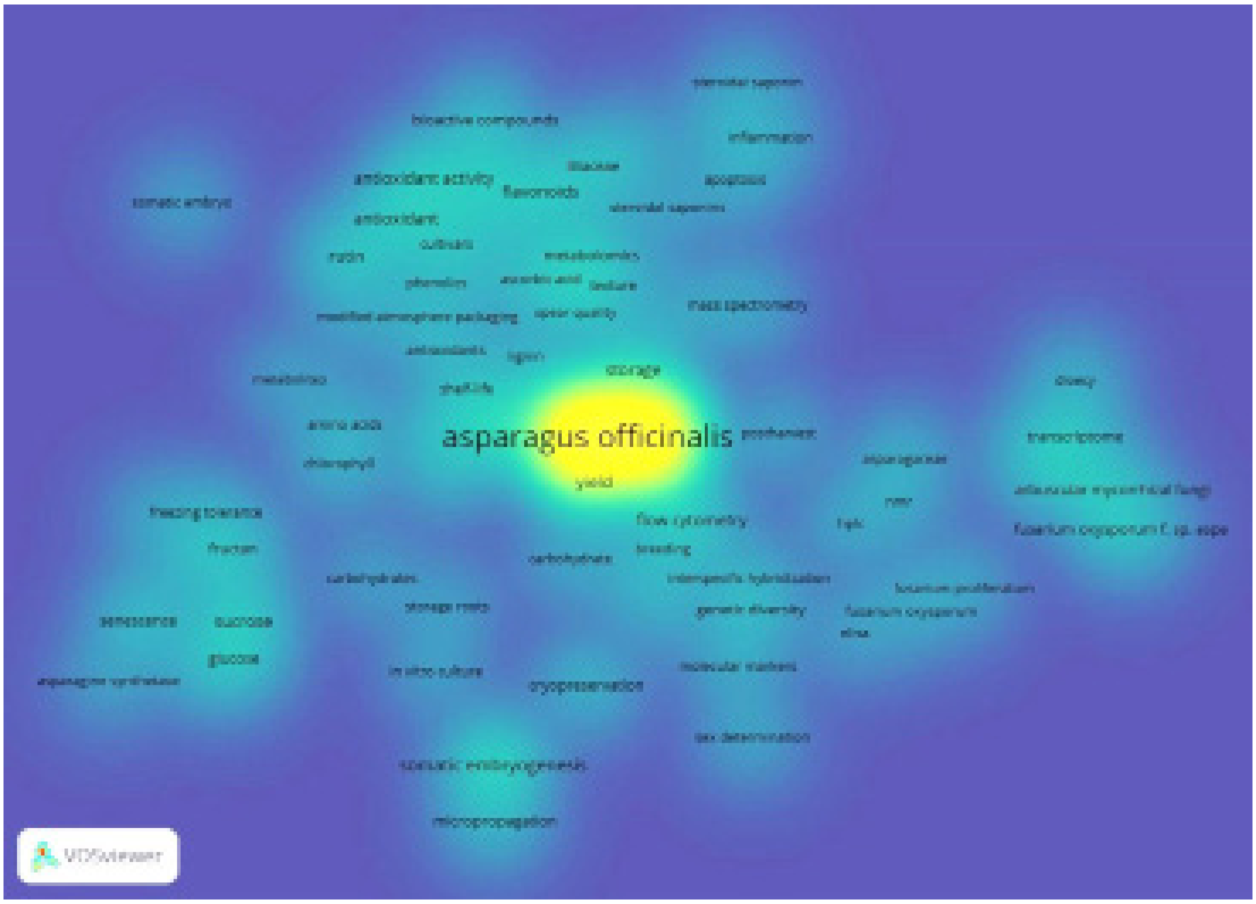
Figure 6. The figure illustrates the local impact of top authors in *Asparagus officinalis* research, measured by their H-index. Authors' names are presented in the format "Surname, Initial." The length of each bar corresponds to the H-index value, while the gradient blue color intensity reflects the magnitude of scholarly impact, with darker bars indicating higher values. Falavigna, A. achieved the highest H-index (12), followed closely by King, G.A. and Shiomi, N. (both with 11). The visualization highlights variations in research productivity and influence among key contributors in the field



Keywords co-occurrence: most frequent author's keywords

The density visualization map generated using VOSviewer highlighted the most frequently occurring author's keywords in *A. officinalis* research (Figure 7). The keyword "*Asparagus officinalis*" dominates the map and is surrounded by a dense cluster of related terms. Other prominent keywords include "yield," "antioxidant activity," "storage," "flow cytometry," and "genetic diversity," indicating the major thematic areas within the field. Additionally, keywords such as "somatic embryogenesis," "metabolomics," "sucrose," "cryopreservation," and "transcriptome" emerge, reflecting research directions related to plant development, molecular biology, and biochemical profiling. The color intensity in the visualization corresponds to the frequency of occurrence, with warmer colors (yellow) indicating higher concentrations of research focus and cooler colors (blue) signifying less-frequent topics. This density map underscores the diverse yet interconnected nature of asparagus research spanning agricultural, genetic, and phytochemical domains.

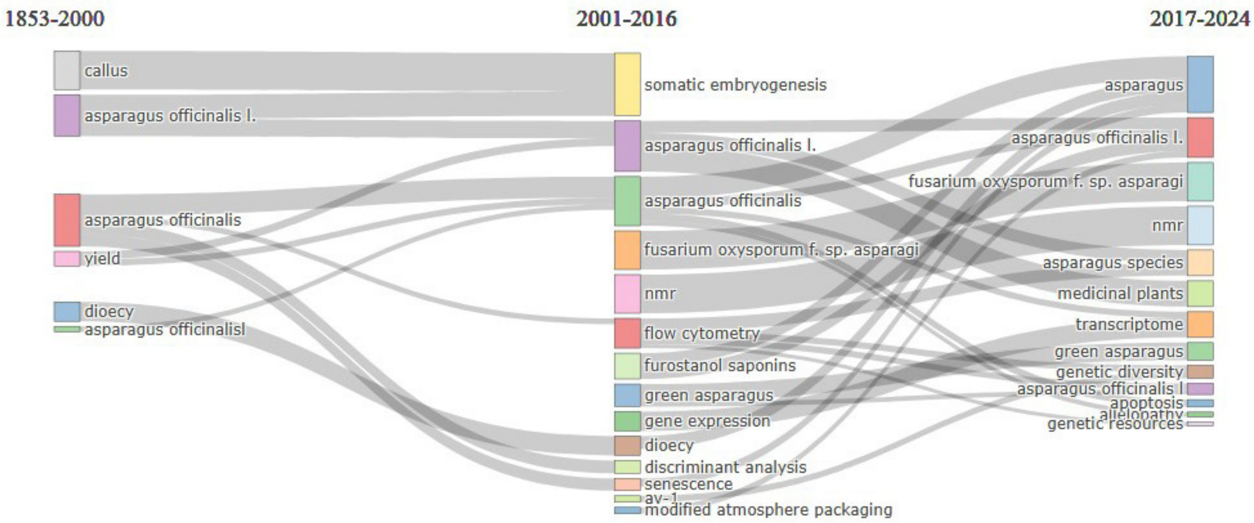
Figure 7. Density visualization of the most frequent author's keywords related to *Asparagus officinalis* research, generated using VOSviewer. Phrases like, "*Asparagus officinalis,*" "yield," "antioxidant activity," "storage," and "flow cytometry" illustrate balancing levels of attention towards specific areas of research. The strength of shading indicates the value of the keyword's frequency



Thematic evolution

Chronological changes in research topics associated with *A. officinalis* demonstrate multidisciplinary diversity and its traditional branches from 1853 to 2025, as illustrated in Figure 8. This figure captures the gradual accumulation of knowledge in this area, which is tailored by two major turning points. The first turning point appeared around year 2001, where beginnings concepts like "callus," "yield," and "dioecy" transformed into expansionist monoculturalism "somatic embryogenesis," "fusarium oxysporum," "flow cytometry," and "gene expression" indicating increased focus towards plant biotechnology and pathogen relationships. The second major shift emerged in 2017, signalling an advanced phase with research expanding toward "transcriptome," "medicinal plants," "genetic diversity," and "apoptosis," indicating the integration of molecular biology, genomics, and applied health sciences into *A. officinalis* studies. This conceptual dynamics analysis underscores the continuous broadening and deepening of asparagus research, driven by technological innovations and evolving scientific priorities.

Figure 8. Thematic evolution of *Asparagus officinalis* research from 1853–2025. This figure, produced with Bibliometrix alongside a BibTeX file sourced from Scopus, showcases the most prominent changes in the focus of research over three periods, particularly emphasizing two important shifts in 2001 and 2017 that transformed the scientific frontier



Top 25 cited authors with the strongest citation bursts

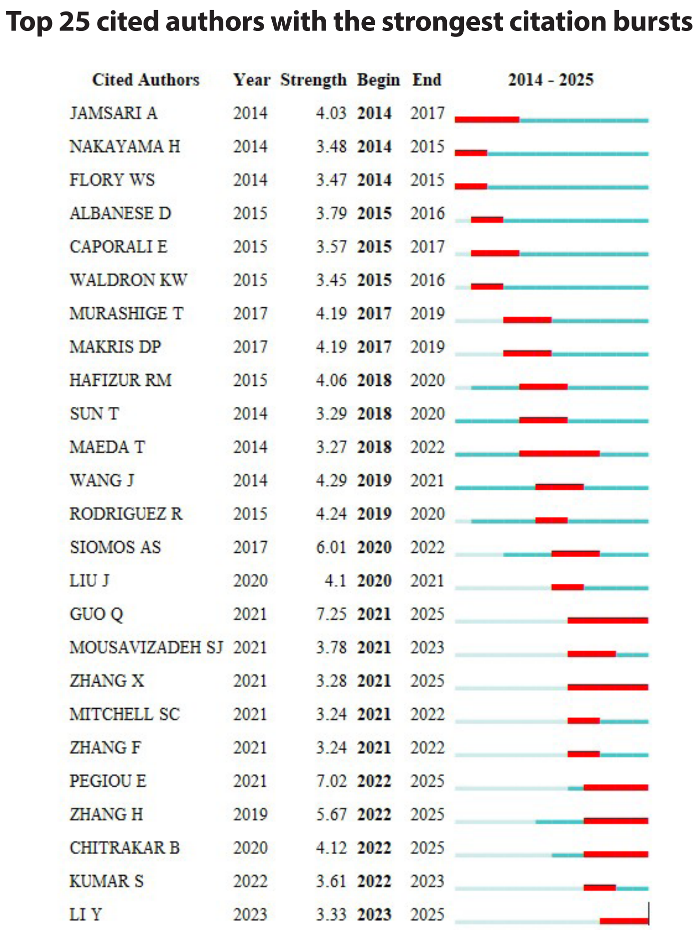
Figure 9 illustrates the top 25 most cited authors with the strongest citation bursts in *A. officinalis* research from 2014 to 2025. A citation burst indicates the period during which an author's work has received a significant increase in citations. The figure shows that authors such as Guo, Q. (7.25), Pegiou, E. (7.02), and Siomos, A.S. (6.01) exhibited the strongest citation bursts, as reflected by their high strength values. Early bursts were noted by authors such as Jamsari, A., and Nakayama, H., beginning around 2014–2015. In contrast, more recent bursts were observed for authors such as Liu, J., Mousavizadeh, S.J., and LiI, Y., suggesting emerging influential contributions in the latest research period. The red bars represent the active burst period, highlighting shifts in author influence over time.

Conceptual structure and clustering of *Asparagus officinalis* research

The CiteSpace-generated conceptual map (Figure 10) visualizes the knowledge structure of *Asparagus officinalis* research, identifying 11 major clusters characterized by distinct themes and research directions. The clustering quality was high, with silhouette values ranging from 0.831 to 0.997, reflecting strong homogeneity within the clusters.

Cluster #0, titled "Antioxidant Activity," was the largest with 71 members and an average of 2017. This cluster focuses on the antioxidant properties and health-promoting phytochemicals found in *A. officinalis*, with key contributions from Conversa, G. (2019) and Shahrajabian, M.H. (2022). Prominent authors in this area include Fuentes-Alventosa, J.M., Rodriguez, R., and Wang, J. Cluster #1, "Salt Tolerance," also comprises 71 members and centers on mechanisms of salt stress resistance, particularly the role of mycorrhizal associations and saponin biosynthesis, with important studies by Zhang, X. (2021) and Ying, J. (2024). The leading figures include Zhang, Y., Zhang, J., and Wang, Y. Cluster #2, "SSR Marker and Genetic Diversity," involves 58 members and highlights efforts in genetic mapping and breeding programs. Influential papers by Harkess, A. (2017) and Mercati, F. (2015) define this area, supported by key authors such as Knaflewski, M. and Kubota, S. Cluster #3, focusing on "Antibacterial Properties," encompassed 40 members, and emphasized the antimicrobial potential of asparagus extracts,

Figure 9. Top 25 cited authors with the strongest citation bursts in *Asparagus officinalis* research from 2014 to 2025. The figure, generated using CiteSpace, highlights periods of significant citation increases (red bars). Authors such as Guo, Q. (7.25), Pegiou, E. (7.02), and Siomos, A.S. (6.01) exhibited the most prominent bursts during the analyzed timeframe



Cited Authors	Year	Strength	Begin	End
JAMSARI A	2014	4.03	**2014**	2017
NAKAYAMA H	2014	3.48	**2014**	2015
FLORY WS	2014	3.47	**2014**	2015
ALBANESE D	2015	3.79	**2015**	2016
CAPORALI E	2015	3.57	**2015**	2017
WALDRON KW	2015	3.45	**2015**	2016
MURASHIGE T	2017	4.19	**2017**	2019
MAKRIS DP	2017	4.19	**2017**	2019
HAFIZUR RM	2015	4.06	**2018**	2020
SUN T	2014	3.29	**2018**	2020
MAEDA T	2014	3.27	**2018**	2022
WANG J	2014	4.29	**2019**	2021
RODRIGUEZ R	2015	4.24	**2019**	2020
SIOMOS AS	2017	6.01	**2020**	2022
LIU J	2020	4.1	**2020**	2021
GUO Q	2021	7.25	**2021**	2025
MOUSAVIZADEH SJ	2021	3.78	**2021**	2023
ZHANG X	2021	3.28	**2021**	2025
MITCHELL SC	2021	3.24	**2021**	2022
ZHANG F	2021	3.24	**2021**	2022
PEGIOU E	2021	7.02	**2022**	2025
ZHANG H	2019	5.67	**2022**	2025
CHITRAKAR B	2020	4.12	**2022**	2025
KUMAR S	2022	3.61	**2022**	2023
LI Y	2023	3.33	**2023**	2025

including nanoparticle-mediated approaches. Noteworthy works include those by Nguyen, G.T.N. (2024) and Esfanddarani, H.M. (2025), with Guo, Q., Pegiou, E., and Zhang, H. as major contributors.

The "Chemical Change" cluster (#4), with 38 members, concentrates on postharvest physiology, storage, and quality preservation strategies, as seen in studies by Techavuthiporn, C. (2016) and Mastropasqua, L. (2016). Cluster #5, "Young Y Chromosome," contains 37 members and explores the evolution and genetics of sex chromosomes in asparagus, as highlighted by Harkess, A. (2017) and Murase, K. (2017).

Cluster #6, "Root Distribution," composed of 28 members, investigates the root architecture and varietal differences under diverse conditions, with Drost D (2023) as a leading figure. "Asparagus Decline Syndrome" forms cluster #7 with 19 members, concentrating on the pathology and management of viral and fungal diseases, led by studies such as those by López-Moreno FJ (2025) and Farahani-Kofoet RD (2020). Cluster #8, "Heavy Metal Content," includes 18 members and assesses the accumulation of toxic elements in asparagus grown in contaminated soils, as addressed by Conversa, G. (2019).

Figure 10. Conceptual Structure and Major Research Clusters in *Asparagus officinalis* Studies (2014–2025). This figure presents a cluster visualization of the conceptual structure of *Asparagus officinalis* research, based on co-citation analysis using CiteSpace (SVG format). Each color represents a distinct research cluster, with labels highlighting the dominant themes such as "Antioxidant Activity," "Salt Tolerance," "SSR Marker," and others. Node size reflects the frequency of citation, while the spatial proximity of clusters indicates thematic similarity. Data were extracted from studies published between 2014 and 2025

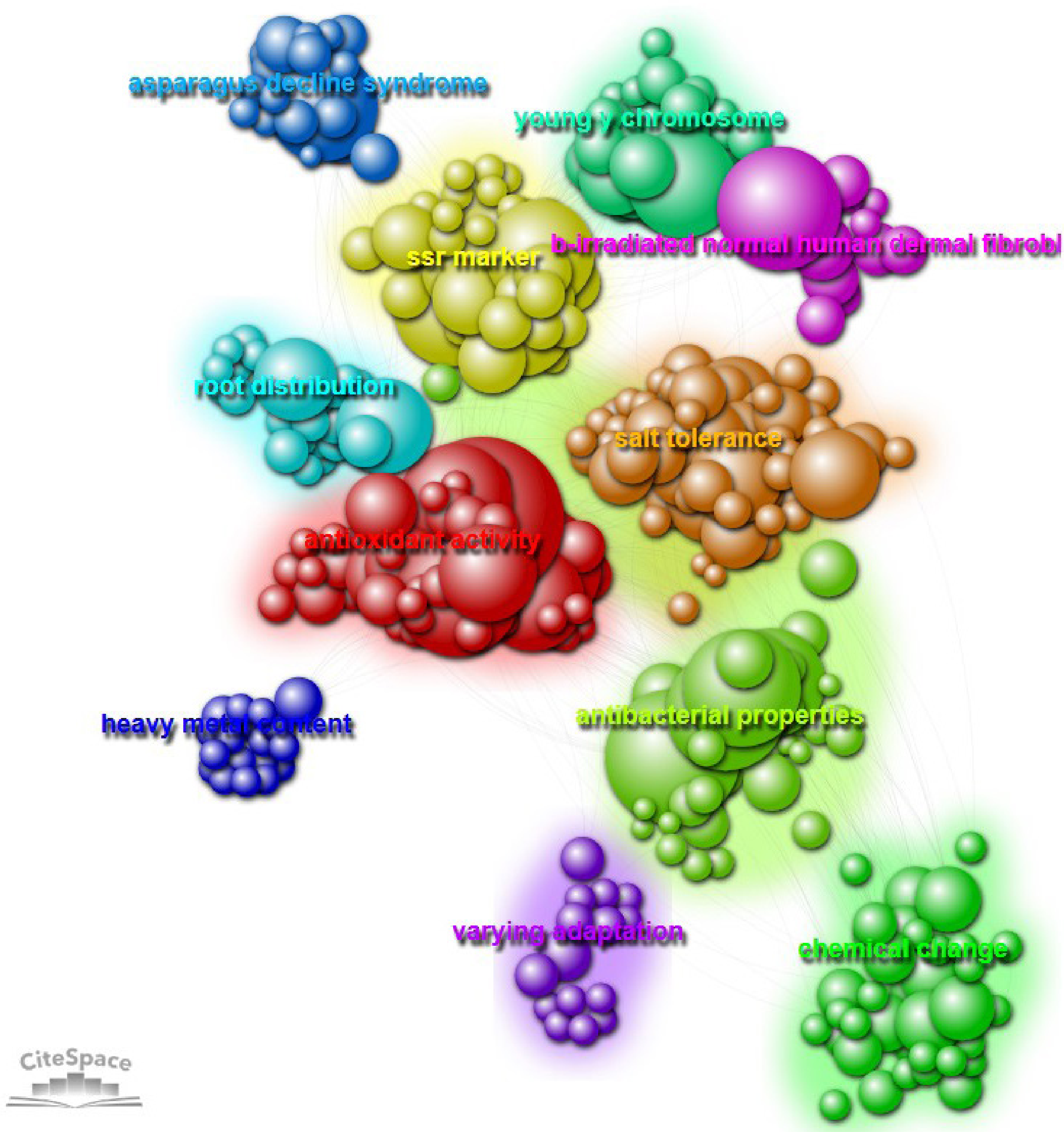


Table 1. Conceptual structure and major research clusters in *Asparagus officinalis* studies (2014–2025)

Cluster	Size	Average year	Silhouette value	Focus
#0: Antioxidant Activity	71	2017	0.848	antioxidant properties and phytochemicals
#1: Salt Tolerance	71	2022	0.823	salt stress resistance and saponin biosynthesis
#2: SSR Marker and Genetic Diversity	58	2017	0.866	genetic mapping, diversity analysis, breeding
#3: Antibacterial Properties	40	2023	0.858	antimicrobial potential and nanoparticle applications
#4: Chemical Change	38	2016	0.831	postharvest physiology and quality retention
#5: Young Y Chromosome	37	2016	0.919	sex chromosome evolution and genetics
#6: Root Distribution	28	2020	0.972	root architecture and varietal differences
#7: Asparagus Decline Syndrome	19	2017	0.962	asparagus virus 1 and fusarium-induced decline
#8: Heavy Metal Content	18	2018	0.997	heavy metal accumulation in contaminated soils
#9: Varying Adaptation	15	2019	0.993	adaptation to environmental stresses
#10: B-Irradiated Normal Human Dermal Fibroblast	12	2019	0.962	bioactivity on human cells and anti-inflammatory effects

*The Silhouette Value is a measure used in clustering analysis to assess how well each object lies within its cluster, indicating how good or strong the clustering is. All Silhouette Values were high (approximately 0.83 to 0.99). This indicates that the clusters are well-separated, and the themes like "antioxidant activity," "salt tolerance," etc., are very cohesive and distinct.

The smaller Cluster #9, "Varying Adaptation," with 15 members, explores adaptation strategies to environmental stresses, such as freezing, as represented by Panjtandoust, M. (2016). Finally, Cluster #10, "B-Irradiated Normal Human Dermal Fibroblast," consisting of 12 members, examined the biomedical effects of asparagus extracts on human cells, particularly their anti-inflammatory properties, as discussed in studies by Shirato, K. (2018, 2021).

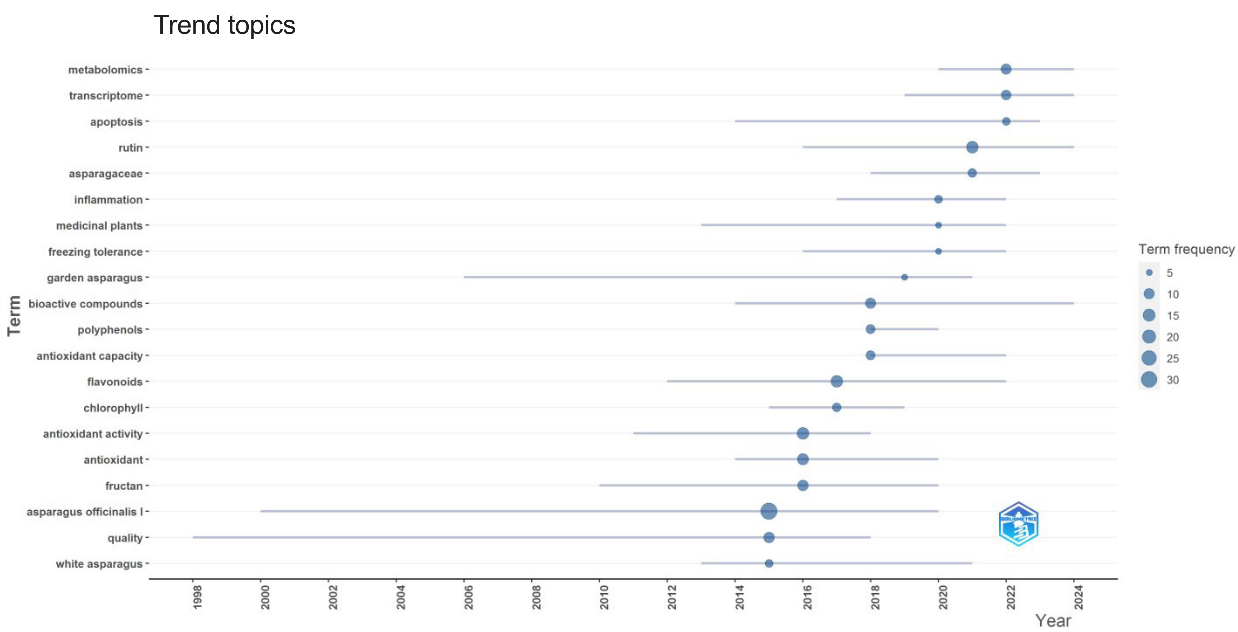
Trending topics in *A. officinalis* research

The trending topic analysis, generated through text mining using Bibliometrix, highlights the evolution of research interest in *A. officinalis* over time (Figure 11). Earlier topics such as "white asparagus," "antioxidant," and "quality" quality began to emerge in the early 2000s. More recent and emerging topics include "metabolomics," "transcriptome," "apoptosis," and "medicinal plants," reflecting a shift toward molecular biology, omics technologies, and health-related research. "Antioxidant capacity," "bioactive compounds," and "polyphenols" have maintained steady attention, linking asparagus research to food quality, health benefits, and nutritional analysis. Overall, visualization emphasizes a transition from agricultural and physiological studies toward biochemical and therapeutic investigations in recent years.

From the citation analysis, Fuentes-Alventosa, J.M. emerged as the most cited scholar (Cluster #0), whereas Guo, Q. (Cluster #3) recorded the highest citation burst. The highest degree centrality was attributed to Castro, P. (Cluster #2), whereas Fuentes-Alventosa, J.M. (Cluster #0) showed the highest betweenness centrality, underscoring the pivotal role of their work within the network. Notably, Wang, J. (Cluster #0) achieved the highest Sigma score, indicating a strong combined influence of citation bursts and network centrality.

In conclusion, the research landscape of *A. officinalis* has evolved dynamically, moving from initial studies focused on antioxidant properties to advanced explorations of molecular genetics, stress adaptation, and biomedical applications. Dominant intellectual structures are anchored in clusters, such as "Antioxidant Activity," "Salt Tolerance," "SSR Marker and Genetic Diversity," while recent trends indicate a shift towards postharvest biotechnology and human health-related investigations.

Figure 11. Trending topics in *Asparagus officinalis* research. Using text mining in Bibliometrix, this illustration illustrates trending topics over time. Horizontal lines represent the lifespan of terms, while circle size indicates their frequency. Early research focused on "white asparagus," "antioxidant," and "quality," whereas recent attention has shifted toward "metabolomics," "transcriptome," and "medicinal plants," reflecting growing interest in molecular and health-related aspects



DISCUSSION

This research applied bibliometric and conceptual analyses to chronologically study asparagus research from 1853 to 2025. It highlights important constituents and sheds light on new themes in the study, describing the state of the art in the field for the first time. The study, with the help of Bibliometrix, VOSviewer, and CiteSpace, discovers indicators of development, key journals, principal authors, and changes in themes. These results are important for formulating strategies for further research in plant science, biotechnology, and environmentally friendly agriculture.

The increase in research on *A. officinalis* since the early 90s can be linked to improvements in plant biotechnology, greater recognition of asparagus as a functional food, and interest in sustainable agriculture globally [Yu and Fan 2021]. Early sporadic activity prior to 1980 appears to have resulted from a combination of limited technological capacity and relatively peripheral agricultural interests. The surge after 2000 aligns with advances in genomics, molecular breeding programs, and greater appreciation for the antioxidant and phyto-pharmaceutical properties of plants [Cui et al. 2024]. Earlier studies achieved higher average citations, implying their primary character in influencing the focus of later research, whereas lower mean citations in more recent studies are a consequence of the inevitable citation time lag [Aksnes et al. 2019]. Overall, the increasing research output (Figure 2) reflects both technological advancements and broader societal emphasis on crop improvement, nutritional health, and bioactive compound discovery [Saleh et al. 2019].

Kanno and collaborators have made significant contributions to *Asparagus officinalis* research, particularly in the areas of sex determination, genetic mapping, molecular breeding, and interspecific hybridization. Early work clarified phylogenetic relationships within the genus using chloroplast DNA analysis [Lee et al. 1997] and investigated floral developmental genes, such as AODEF and GLOBOSA-like genes, refining the understanding of floral organ specification [Park et al. 2003, 2004]. Kanno et al. [2014] pioneered the development of sex-linked molecular markers, notably by converting a male-specific RAPD marker into an STS marker for early gender identification [Nakayama et al. 2006]. They also produced interspecific hybrids between *A. officinalis* and related species such as *A. schoberioides* and *A. kiusianus* to introduce disease-resistance and stress-tolerance traits [Ito et al. 2011, Kanno et al. 2014]. More recently, Kanno has contributed to transcriptomic studies revealing disease resistance mechanisms [Abdelrahman et al. 2017] and investigations into the evolution of the asparagus Y chromosome and male-specific genes [Harkess et al. 2017b, Murase et al. 2017]. Overall, Kanno's work has substantially advanced both fundamental knowledge and applied breeding strategies to asparagus research.

The conceptual structure of *A. officinalis* research revealed a well-defined and mature intellectual landscape, as evidenced by high silhouette values (0.831–0.997) across 11 distinct clusters (Figure 10, Table 1). The largest clusters, "Antioxidant Activity," "Salt Tolerance," "SSR Marker and Genetic Diversity," reflect historical and emerging research priorities in the field. Early studies have focused on the health-promoting phytochemicals of asparagus [Conversa et al. 2019, Shahrajabian and Wenli 2022], while more recent trends emphasize molecular breeding, stress adaptation, and genetic mapping [Harkess et al. 2017a, Zhang et al. 2024a]. The identification of antibacterial properties [Giang and Van Khai 2024] and investigations of postharvest physiology [Techavuthiporn and Boonyaritthongchai 2016] further demonstrate the diversification of research topics. Notably, advanced topics, such as sex chromosome evolution [Murase et al. 2017] and biomedical applications, including anti-inflammatory effects on human cells [Shirato et al. 2018], indicate the field's expansion into genomics and translational research. Citation network metrics highlight Fuentes-Alventosa, J.M. as the most influential scholar and Wang, J. as a major knowledge integrator with the highest sigma score, underscoring the central role of antioxidant studies in shaping the discipline. Overall, conceptual mapping illustrates how *A. officinalis* research has evolved from traditional phytochemical studies to cutting-edge biotechnological and biomedical investigations.

This bibliometric and conceptual analysis of *A. officinalis* research provides critical insights that directly inform horticultural practices and strategic crop development. The identification of key research clusters – such as salt tolerance, genetic diversity, root architecture, and postharvest physiology – highlights the evolving priorities in improving stress resilience, optimizing yield, and extending shelf life. Findings related to salt stress mechanisms and mycorrhizal associations (Cluster #1) can guide breeding programs aimed at developing cultivars better suited for saline or marginal soils. The prominence of SSR markers and genomic mapping efforts (Cluster #2) suggests accelerating potential in marker-assisted selection for desirable agronomic traits. Additionally, trends in root system studies (Cluster #6) and disease management (Cluster #7) support the refinement of cultivation techniques and integrated pest management. Finally, the increasing focus on phytochemical and metabolomic profiling offers opportunities to enhance the nutritional and functional value of asparagus through targeted breeding. Together, these findings contribute a roadmap for advancing sustainable cultivation, genetic improvement, and value-added utilization of *A. officinalis* in horticultural systems.

Metabolomics has emerged as a major trending topic in *A. officinalis* research, reflecting a shift toward understanding the complex biochemical and physiological processes of plants. Recent studies have demonstrated the critical role of metabolomics in identifying bioactive compounds and stress responses. Nakabayashi et al. [2015] first applied targeted metabolomics to identify asparaptine, a sulfur-containing metabolite with angiotensin-converting enzyme (ACE) inhibitory activity. Further advancing the field, Nakabayashi et al. [2021] used spatial metabolomics via imaging mass spectrometry to localize asparaptine A within asparagus tissues, linking metabolite distribution to specific developmental structures [Nakabayashi et al. 2021, Nakabayashi et al. 2015]. Creydt et al. [2018] optimized extraction protocols to enhance metabolite profiling in asparagus, enabling more comprehensive untargeted metabolomic studies [Creydt et al. 2018]. Recently, integrated metabolomics and transcriptomics approaches have provided insights into the regulation of bioactive compounds, such as steroidal saponins [Cheng et al. 2023], and stress adaptation mechanisms under drought conditions [Zhang et al. 2024b]. Collectively, these studies underscore how metabolomics advances both fundamental knowledge of *A. officinalis* biology and its applications in breeding for improved nutritional and stress-resilient traits (Figure 11).

The "SSR Marker and Genetic Diversity" clusters represent a critical research focus in *A. officinalis* studies, emphasizing molecular breeding, genetic mapping, and population diversity. Simple Sequence Repeats (SSRs), also known as microsatellites, are widely used as markers because of their high polymorphism, co-dominant inheritance, and reproducibility. Studies in this area aim to assess genetic variability within and between *Asparagus* populations, facilitate the construction of linkage maps, and support marker-assisted selection (MAS) in breeding programs. Notable contributions, such as those by Harkess et al. [2017b] and Mercati et al. [2015], have advanced our understanding of genome structure and diversity, including interspecific hybrids and wild relatives. Kanno et al. have helped define the gene pools available for cultivar improvement (Kanno et al. 2014). This cluster underpins efforts to enhance disease resistance, stress tolerance, and yield traits in *A. officinalis*, making it central to the long-term sustainability and genetic improvement of this species.

Authors such as Guo, Q. (7.25) and Pegiou, E. (7.02) exhibited strong citation bursts due to their influential work in Cluster #3 (Antibacterial Properties), focusing on the antimicrobial potential of *A. officinalis* extracts, particularly through nanoparticle-mediated approaches [Francis et al. 2024]. These contributions align with emerging trends in bioactive compound research and their applications in food safety and biomedicine, driving rapid citation increases

This study had several limitations. This study focused only on the Scopus database and failed to include relevant research found in Web of Science or PubMed. They may also have suffered from bias by only accepting articles in English. Recent publications on lesser-cited works might contain perception bias. Working papers and conference proceedings were excluded, potentially omitting unpublished research. Finally, the restrictions posed by Bibliometrix, VOSviewer, and CiteSpace limit algorithmic clustering and clustering of repetitively identical keywords, leading to ambiguous theme labeling.

CONCLUSIONS

This research maps the intellectual structure of *Asparagus officinalis* research and its thematic evolution from 1853 to 2025, which has not been done before. It also contains a comprehensive bibliometric and conceptual analysis of research. It is clear that the field of asparagus research is developing with the help of biotechnology, phytochemistry, and genomic advances. Fundamental studies by Is it Kanno et al. [2014] and other scholars have advanced the foundational components of genetic research pertaining to sex determination and breeding. Attention is shifting toward molecular and biomedical applications, particularly in metabolomics. Achievements in human health research have been made by integrating multi-omics, climate-resilient approaches, and large translational studies; however, gaps remain. Global efforts to tackle these liminal areas are essential, along with a focus on international collaboration to promote rigorous longitudinal field experiments and shift the focus to standardized multi-omics platforms. Addressing these gaps will increase the significance of research on *A. officinalis*. These actionable insights will advance the emerging importance of *A. officinalis* as a functional crop and further highlight the significance of fundamental and applied research.

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