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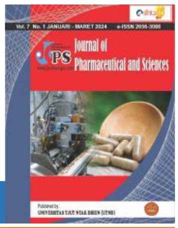

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Scientific Mapping of *Brassicaceae* Plants' Potential for Anti-inflammatory Applications: A Bibliometric Analysis Covering the Period 2003–2024

Pemetaan Saintifik terhadap Potensi Tanaman *Brassicaceae* sebagai Anti-inflamasi: Analisis Bibliometrik Periode Tahun 2003–2024

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Abstract

The *Brassicaceae* family is recognized for its antioxidant and anti-inflammatory properties. Due to its widespread distribution, it serves as a prominent source of bioactive phytochemicals, attracting considerable research interest. Brassicaceae plants contain several secondary metabolites, including glucosinolates, which are precursors to bioactive compounds like isothiocyanates (e.g., sulforaphane) that have demonstrated anti-inflammatory effects. This study aims to investigate keywords, countries, number of publications, institutions, authors, and journals related to Brassicaceae plants as anti-inflammatory agents during the period 2003–2024 using a comprehensive bibliometric analysis method. Information was collected using the Scopus database, followed by data analysis using the Biblioshiny R Package and VOSviewer. A total of 760 articles meeting the inclusion criteria were analyzed. The results indicate that 2023 saw the largest increase in research publications, with China emerging as the leading contributor, while the USA had the highest citation count. The International Journal of Molecular Sciences was identified as the most popular publishing journal. Kyung Hee University was designated as the most productive institution, with *Li Y* as the author with the highest contribution. Bibliometric data also highlighted several therapeutic target molecules, including cytokines, nitric oxide, cyclooxygenase-2, and Nrf2, which play crucial roles in the action mechanisms of signature metabolites from Brassicaceae plants, including sulforaphane, isothiocyanates, glucosinolates, and flavonoids, for therapeutic purposes as anti-inflammatory, antioxidant, antimicrobial, and chemopreventive agents. These findings highlight the significant potential of Brassicaceae medicinal plants for various therapeutic mechanisms and provide recommendations for future research in the pharmacy field.

Keywords:* *Anti-inflammatory, Bibliometrics, Biblioshiny R Package, Brassicaceae, VOSviewer.

Abstrak

Brassicaceae adalah famili tanaman yang dikenal dengan aktivitas antioksidan dan anti-inflamasinya. Distribusi yang luas membuat tanaman ini berperan sebagai sumber fitokimia bioaktif yang penting, sehingga menarik minat penelitian yang signifikan. Tanaman Brassicaceae mengandung beberapa metabolit sekunder, termasuk glukosinolat, yang merupakan prekursor senyawa bioaktif seperti isotiosianat (misalnya sulforafan) yang telah terbukti memiliki efek anti-inflamasi. Penelitian ini bertujuan untuk menyelidiki kata kunci, negara, jumlah publikasi, institusi, penulis, dan jurnal penerbit yang terkait dengan tanaman Brassicaceae sebagai anti-inflamasi pada periode tahun 2003–2024 menggunakan metode analisis bibliometrik yang komprehensif. Informasi dikumpulkan menggunakan basis data Scopus, diikuti dengan analisis data menggunakan Biblioshiny R Package dan VOSviewer. Total publikasi sebanyak 760 artikel yang memenuhi kriteria inklusi kemudian dianalisis. Hasil analisis menunjukkan bahwa tahun 2023 mengalami peningkatan terbesar dalam publikasi penelitian, dengan negara China muncul sebagai kontributor utama, sementara USA memiliki jumlah sitasi tertinggi. International Journal of Molecular Sciences diidentifikasi sebagai jurnal penerbit yang terpopuler. Kyung Hee University ditetapkan sebagai institusi terproduktif, dengan *Li Y* sebagai penulis yang memberikan kontribusi tertinggi. Data bibliometrik juga menggambarkan beberapa molekul target terapeutik termasuk sitokin, oksida nitrit, siklooksigenase-2, dan Nrf2 yang berperan penting terhadap mekanisme aksi senyawa metabolit khas tanaman Brassicaceae seperti sulforafan, isotiosianat, glukosinolat, dan flavonoid untuk tujuan terapeutik sebagai anti-inflamasi, antioksidan, antimikrobial, dan kemopreventif. Temuan ini menekankan potensi signifikan pengembangan tanaman obat Brassicaceae untuk berbagai mekanisme terapeutik dan memberikan rekomendasi untuk penelitian di masa depan dalam bidang farmasi.

Kata Kunci: Anti-inflamasi; Bibliometrik; Biblioshiny R Package; Brassicaceae; VOSviewer.

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Introduction

Inflammation is a vital biological response for protecting the body against infection and injury [1]. Although acute inflammation plays a critical role in the healing process and tissue repair, chronic, uncontrolled inflammation can contribute to the pathogenesis of various degenerative diseases such as arthritis, cardiovascular disease, diabetes, and cancer [2–4]. Consequently, searching for effective and safe anti-inflammatory agents is paramount in developing medical therapies [5]. Conventional anti-inflammatory drugs, such as nonsteroidal anti-inflammatory drugs (NSAIDs), have been widely used, but their long-term use is often associated with gastrointestinal and cardiovascular side effects, highlighting the need for safer alternatives [6]. This has prompted research efforts to explore safer, plant-based alternatives that exhibit minimal adverse effects while retaining efficacy in combating inflammation [7].

The Brassicaceae family, a group of plants encompassing various crops such as cabbage, radish, mustard, and kale, has long been recognized in traditional medicine for its constituent bioactive compounds, some exhibiting anti-inflammatory potential [8,9]. These plants contain glucosinolates, flavonoids, terpenoids, and phenolic compounds, which have been demonstrated to inhibit inflammatory pathways by modulating various molecules involved in the host immune response [10,11]. Modern scientific research supports using Brassicaceae species as anti-inflammatory agents, evidenced by their capacity to reduce levels of pro-inflammatory cytokines and inhibit the activity of enzymes integral to the inflammatory process [12,13].

Concurrent with the increasing interest in plant-based therapies, particularly within the context of inflammation, numerous studies have explored the anti-inflammatory potential of Brassicaceae [14,15]. Despite numerous studies have explored the anti-inflammatory potential of Brassicaceae plants, a systematic bibliometric analysis that examines research trends, international collaboration, and evolving research themes is still underrepresented in the literature. Therefore, this article aims to provide a comprehensive bibliometric analysis of the research landscape concerning the anti-inflammatory activities of Brassicaceae. This analysis will focus on identifying publication trends, mapping collaborations between countries and institutions, and elucidating the major research themes emerging within the relevant literature.

Employing a bibliometric approach utilizing software tools such as the Biblioshiny R Package [16] and VOSviewer [17], this study analyzes over 700 publications indexed in the Scopus database from 2003 to 2024. The findings derived from this analysis are expected to provide clearer insights into the developmental trajectory of research within this domain and identify future research directions. This research will further explore the contributions of principal countries, evolving thematic clusters, and the potential applications of Brassicaceae-derived therapies for managing inflammatory conditions. Through this methodology, it is anticipated that novel perspectives on the existing body of research will be generated, thereby offering guidance for subsequent studies to develop more efficacious and sustainable plant-based therapeutic strategies.

Experimental Section

Data Source

The Scopus database (accessed in December 2024) was utilized to extract relevant published articles for this research. This database was selected in preference to other databases, such as PubMed and Google Scholar, owing to its broader catalog coverage and established significance [18]. Furthermore, this database offers features including sorting options by country, author, journal, and institution, as well as document citation counts, which function as a metric of scholarly impact [19].

Bibliometric Indicators

This research investigates several key bibliometric indicators: publication development trends; commonly utilized author keywords; citation analysis, encompassing highly cited articles; the top ten most productive organizations, alongside the most frequently cited countries; and the ten leading publishing journals [20,21]. The study sourced citations and country productivity data from the Scopus database, which tracks publication citations and annual article output per country.

Keywords and Search Strategy

The literature search focused on publications from 2003 to 2024, encompassing a period deemed relevant to the evolving research trends within this field. This timeframe was selected based on the assessment that significant scholarly output in this domain began to escalate around the start of this period. The literature search was conducted to identify publications on Brassicaceae plants' anti-inflammatory activities, utilizing Scopus as the primary database. The search strategy integrated keywords relevant to two principal themes: anti-inflammation and Brassicaceae. The search was performed using the following query:

(TITLE-ABS-KEY ("anti-inflammatory activity" OR "anti-inflammatory" OR "anti-inflammation" OR "antiinflammatory" OR "antiinflammation" OR "anti-inflammatory effects") AND TITLE-ABS-KEY ("brassicaceae" OR "brassicaceae plants" OR "brassicaceae family" OR "brassica" OR "cruciferous" OR "cruciferous plants" OR "cruciferous family" OR "cruciferous vegetables"))

This search strategy ensured that only articles directly addressing anti-inflammatory activities in Brassicaceae were included in the analysis, thereby guaranteeing the relevance of the resulting dataset to the core research topic [22].

Data Extraction and Bibliometric Parameters

The data utilized in this bibliometric analysis were obtained from the Scopus database in two primary formats: Research Information System (RIS) and Comma Separated Values (CSV). These formats provided crucial information, including bibliographic data, abstracts, and keywords, necessary for the subsequent analysis [23]. These formats enabled extracting key data elements, such as citation counts, author names, document titles, publication years, document sources (e.g., journals, proceedings), publishers, and publication types.

This study employed various bibliometric parameters to assess publications' quantity, distribution, and ranking. These parameters included annual publication output, the distribution of publications across scientific fields, and the ranking of contributing authors based on their publication volume. Additionally, the study identified highly cited articles and analyzed the distribution of publications by country and institutional affiliation. The research also explored document types, predominant publication languages, and overall distribution patterns. All essential publication metadata, including titles, authors, affiliations, abstracts,

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keywords, journal names, publication years, and citation counts, were downloaded during the data extraction [24,25].

Inclusion and Exclusion Criteria

The inclusion criteria encompassed articles from 2003 to 2024, a period selected to capture the surge in research related to the anti-inflammatory properties of Brassicaceae plants, particularly as advanced pharmacological and biochemical analysis methods gained prominence. Included publications must be published in English, given the predominance of international scholarly literature available in this language within the field [26]. Furthermore, only documents classified as research articles ('article') and review articles ('review') were incorporated, as these document types are considered to provide the most relevant and in-depth scientific information regarding primary research findings and comprehensive overviews related to the anti-inflammatory activity of Brassicaceae.

Conversely, the exclusion criteria comprised articles deemed irrelevant to anti-inflammatory activity in Brassicaceae, such as those not discussing the bioactive compounds within these plants or those unrelated to anti-inflammatory mechanisms. Articles unavailable in full-text format or those published in languages other than English were also excluded from this analysis [27,28]. Additionally, documents not classified as research or review articles—such as conference papers, editorials, or other document types lacking substantial scientific contribution to the analysis—were excluded from the literature search and subsequent study [29].

Data Analysis

Data management and analysis were conducted utilizing the Biblioshiny R Package [30] and VOSviewer version 1.6.16 [31], freely available software tools for creating and visualizing bibliometric maps. These methodologies facilitate the generation of a comprehensive overview of the current research landscape, including identifying co-authorship networks, keyword co-occurrence patterns, and citation trends [28,32]. The Biblioshiny R Package was employed to generate specific indicators, encompassing annual scientific production, the top ten contributing authors, country-based publication distribution, affiliation-based publication distribution, and the visualization of international collaboration networks among countries [33,34]. VOSviewer was utilized to produce several indicators, such as author distribution visualizations and network visualization maps of the most frequent author keywords [35–37].

Results and Discussion

Analysis of Document Types in Publications

A total of 760 documents published between 2003–2024 were extracted from the Scopus database, originating from 391 sources and involving contributions from over 4,300 authors globally. Analysis of document types revealed a predominance of research articles and review articles, with an average annual growth rate (AAGR) of 18.99%. The average number of citations per document was 6.15, suggesting that research on this topic remains relevant and is actively evolving. Considering an average annual citation rate of 33.61 per document and a total of 48,011 cited references within the corpus, it can be inferred that research concerning the anti-inflammatory activity of Brassicaceae possesses substantial academic impact.

Research articles (557 documents, 73.29%) and review articles (203 documents, 26.71%) comprised the majority of analyzed document types. The predominance of research articles underscores the focus on exploring novel findings, whereas review articles provide an essential synthesis of existing literature and help guide future research directions. The substantial volume of review articles further indicates that this topic has garnered significant academic attention, particularly in assessing the relevance of Brassicaceae within the context of inflammation. Detailed data regarding the extracted documents are presented in Table 1.

Overall, this research indicates that the anti-inflammatory activity of Brassicaceae plants represents a rapidly evolving field possessing significant academic and clinical relevance. The insights derived from this analysis can be utilised to delineate major research themes, uncover global collaboration patterns, and provide perspectives on future research trends. Through continuously increasing contributions from the international scientific community, this topic holds substantial potential to impact chronic inflammation management through plant-based approaches significantly.

Table 1. Main Information of Scientific Publications Associated to the Anti-inflammatory Activity of Brassicaceae.

Description	Results
Main information about data:	
Timespan	2003–2024
Sources (journal, book, etc.)	391
Documents	760
Annual growth rate (%)	18.99
Document average age	6.15
Average citations per doc	33.61
References	48,011
Document contents:	
Keywords Plus (ID)	10,393
Author's Keywords (DE)	2,160
Authors:	
Authors	4,322
Authors of single-authored docs	20
Authors colaboration:	
Single-authored documents	20
Co-authors per doc	6.89
International co-authorship (%)	22.37
Document types:	
Article	557
Review	203

Analysis of Global Publication Trends

Analysis shows a steady rise in research publications on Brassicaceae's anti-inflammatory properties, with a notable peak after 2010, reflecting advancements in plant-based therapeutic research. Figure 1 presents the annual publication trends on the anti-inflammatory activity of Brassicaceae plants, which reveals the growing interest and research output in this area over the past decade.

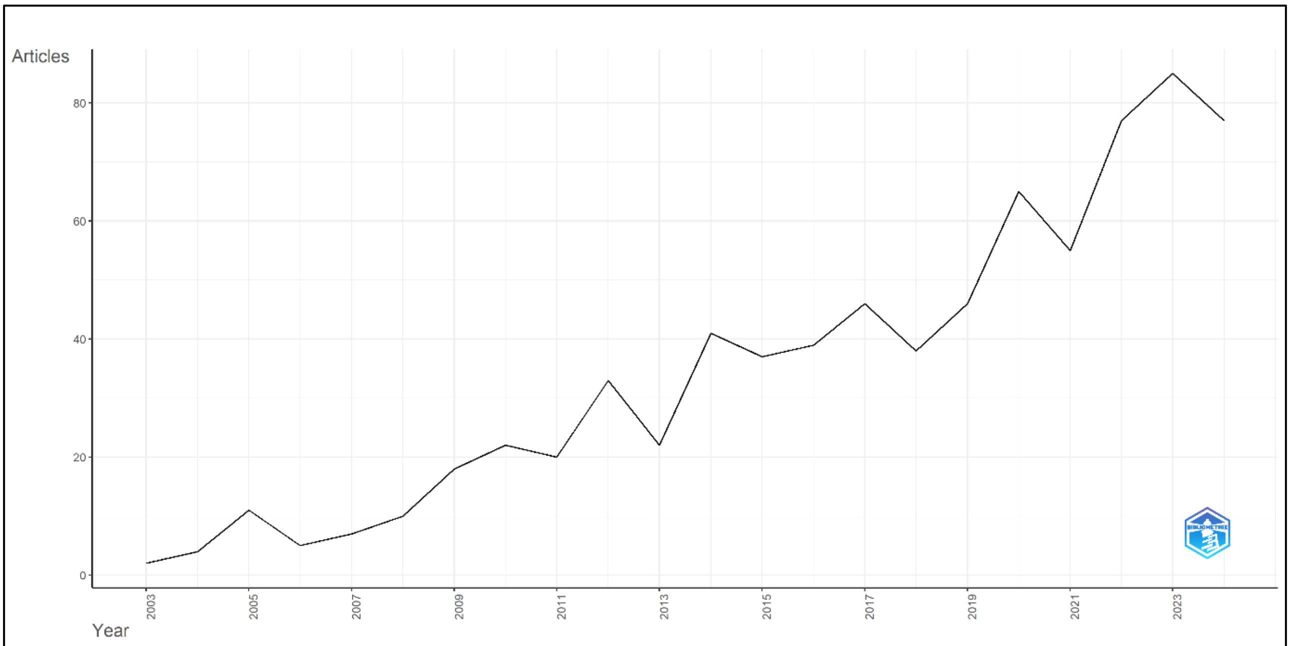

Figure 1. Annual Scientific Publication Trend on the Anti-inflammatory Activity of Brassicaceae (2003–2024).

Publication volume peaked in 2022, followed by a slight decline in the subsequent two years (2023–2024). This decrease may be attributed to a saturation effect within specific research themes or a shift in focus towards other aspects of the biological activities of Brassicaceae plants. The substantial increase in publications

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from 2011 to 2020 coincides with intensified international collaboration and breakthroughs in biochemical analysis, as well as technological advancements enabling new understanding of the molecular mechanisms of bioactive compounds and the growing interest in plant-based compounds, such as sulforaphane and isothiocyanates, for therapeutic purposes. This trend reflects the relevance and impact of research on Brassicaceae plants in managing chronic inflammatory diseases.

Future research is expected to focus on clinical validation, enhanced international collaboration, and diverse research themes to explore novel bioactive compounds and their applications in plant-based therapies. With ongoing development, this field can significantly contribute to developing innovative and sustainable therapies.

Analysis of Author Publications Associated with Country and Institutional Affiliation

The association among the countries of origin of authors, principal authors, and institutional affiliations within the research on the Brassicaceae's anti-inflammatory effects can be observed in Figure 2.

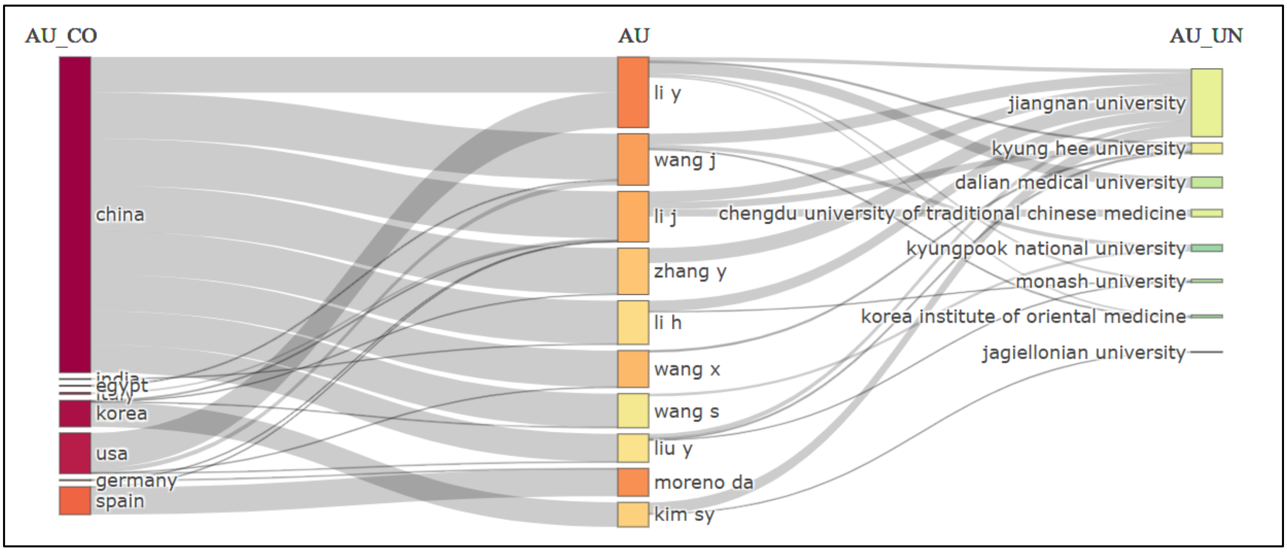

Figure 2. Relationship Network of Authors, Countries, and Institutional Affiliations concerning Anti-inflammatory Activity in Brassicaceae (2003–2024). Key: AU_CO: Author Country, AU: Author, AU_UN: Author University.

Based on the analysis, this field is dominated by authors from China, emerging as the primary contributors in terms of publication count, followed by the United States (USA), Korea, as well as other countries including Spain, India, Egypt, and Germany. Prolific authors, such as *Li Y*, *Wang J*, and *Li J*, demonstrate significant contributions within this domain, reflecting high levels of individual productivity within the associated scientific community. Furthermore, institutions like Jiangnan University, Kyung Hee University, and Dalian Medical University emerge as key research hubs, highlighting these institutions' crucial role in facilitating high-quality research in this field.

Figure 3 indicates that the USA ranks as the country with the highest total number of citations (4,173 citations) in publications concerning the anti-inflammatory potential of the Brassicaceae plant, followed by China (3,214 citations) and South Korea (2,170 citations). This finding underscores the dominance of countries with well-established research infrastructures in producing and disseminating scientific knowledge within this field. Notably, the United Kingdom (UK) exhibits an exceptionally high average number of citations per document (268.2), suggesting its publications' high quality or impact, despite having a lower total citation count than the USA and China.

Despite the USA leading in total citations (4,173), this metric reflects not only volume but also the foundational impact of its research on elucidating Brassicaceae's anti-inflammatory mechanisms. Key studies from USA-affiliated institutions have been instrumental in characterizing bioactive compounds and their molecular targets. USA contributions often emphasize mechanistic depth, such as defining the Nrf2 signaling (e.g., Harvey et al. 2011 from Johns Hopkins University, Baltimore, USA) and NF-κB inhibition (e.g., Guerrero-Beltrán et al. 2012 from National Institutes of Health, Bethesda, USA) by the phytochemical sulforaphane, which underpin the anti-inflammatory properties of Brassicaceae metabolites. Similarly, research led by Yanaka et al. (2009) [46] in authorship collaboration with Johns Hopkins University (Baltimore, Maryland,

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USA), demonstrated the clinical efficacy of sulforaphane-rich broccoli sprouts in attenuating Helicobacter pylori-induced gastritis in humans, bridging preclinical findings with therapeutic applications. This focus on molecular pathways and translational validation has positioned USA research as a cornerstone for advancing the field beyond observational studies toward targeted therapeutic strategies.

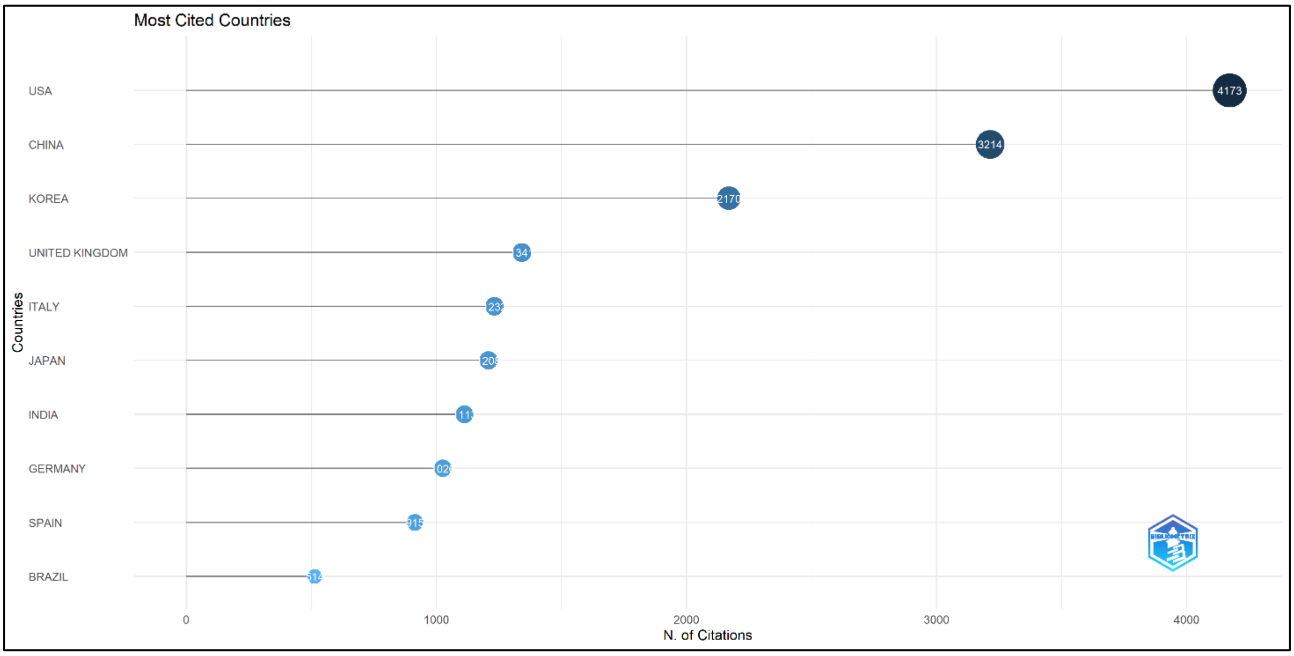

Figure 3. Distribution of the Top Ten Most Cited Countries in Research on the Anti-inflammatory Activity of Brassicaceae (2003–2024).

Other countries (e.g., Italy, Japan, India) contributed fewer publications but demonstrated niche research foci. For example, Italian studies often emphasized the synergistic effects of Brassicaceae-derived polyphenols in Mediterranean diets (e.g., *Brassica oleracea* in cardiovascular health), while Indian research frequently explored traditional ethnopharmacological uses of local species like *Brassica juncea* in Ayurvedic medicine. Japan's contributions leaned toward isolating novel isothiocyanate derivatives from *Wasabia japonica*, reflecting region-specific agricultural and biotechnological interests. These niche foci enrich the global discourse by addressing context-specific health challenges and cultural practices, despite their smaller publication volumes. The current citation distribution suggests that while research on Brassicaceae has an international presence, it is primarily concentrated within countries possessing superior research capabilities. A high number of citations can signify recognition of a publication's relevance and scientific impact, thus serving as an essential indicator for mapping international research strengths [38]. Notably, the United Kingdom (UK) exhibits an exceptionally high average number of citations per document (268.2), suggesting its publications' high quality or impact, despite having a lower total citation count than the USA and China.

Figure 4 indicates that Kyung Hee University is the most productive institution based on author affiliation, having published 65 articles from 2003 to 2024. This ranking highlights the institution's strong commitment towards advancing research in phytopharmacology, particularly concerning traditional and molecular therapeutic approaches. It is followed by Jiangnan University (40 articles) and Chengdu University of Traditional Chinese Medicine (38 articles). The dominance of educational and research institutions from Asia, particularly China and South Korea, is particularly striking in this context.

Additionally, institutions including Gachon University, Dalian Medical University, and the Korea Institute of Oriental Medicine further bolster the regional contribution to this research area. The presence of Monash University (Australia) and the University of Maine (USA) among these leading institutions demonstrates that research on Brassicaceae also garners interest from research institutions outside of Asia. These findings suggest that international collaboration and interdisciplinary approaches are crucial for broadening the understanding and utilization of Brassicaceae plants as evidence-based anti-inflammatory agents. Therefore, mapping these affiliations is essential for establishing more strategic global research networks.

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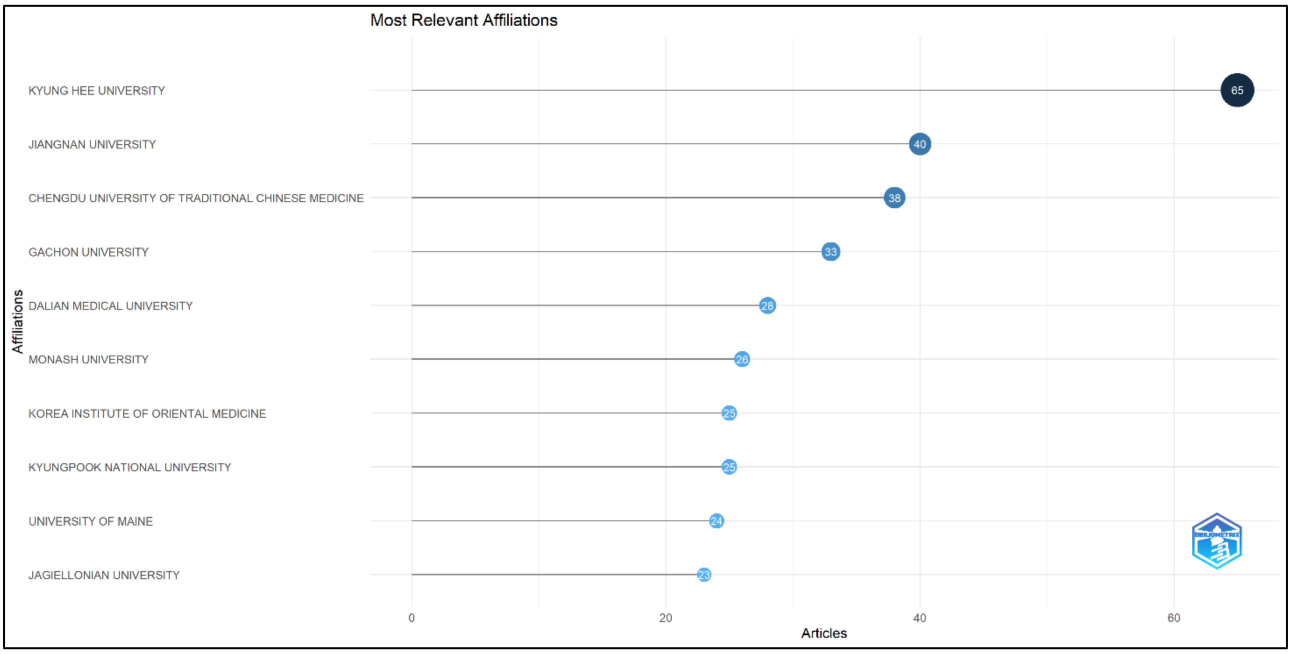

Figure 4. Distribution of the Top Ten Most Productive Institutions (Based on Author Affiliation and Number of Articles) in Research on the Anti-inflammatory Activity of Brassicaceae (2003–2024).

Figure 5 indicates that the most productive author in research concerning the anti-inflammatory potential of Brassicaceae plants is *Li Y*, with 17 scientific documents published. This count significantly surpasses that of other leading authors, such as *Moreno DA* (12 documents) and *Wang J* (11 documents). This suggests that *Li Y* is central and consistent in developing research within this domain. The prevalence of researcher names from Asia, particularly China and South Korea, further strengthens the earlier finding that research concerning Brassicaceae is predominantly conducted in this region.

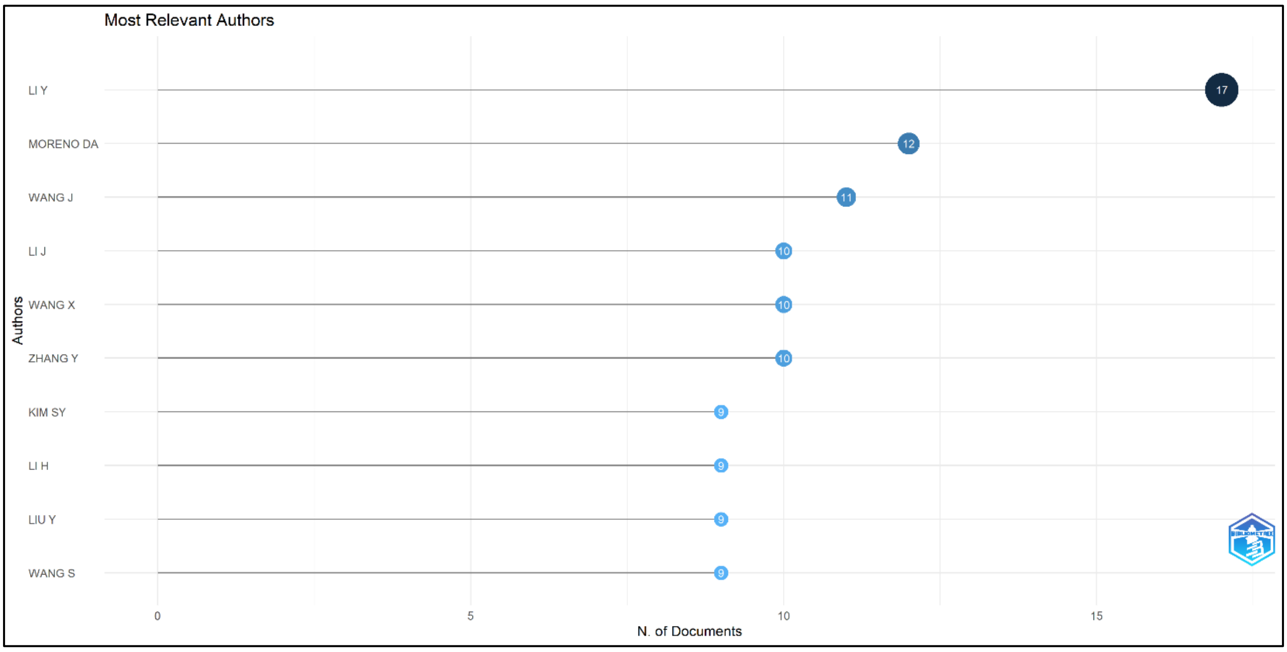

Figure 5. Distribution of the Top Ten Most Productive Authors (by Number of Publications) in Research on the Anti-inflammatory Activity of Brassicaceae (2003–2024).

It is noteworthy that although several authors share the same total number of publications, including *Li J*, *Wang X*, and *Zhang Y* (10 documents each), their fractional contributions differ—indicating varying levels of involvement across their respective publications. Fractional counting is essential in bibliometrics as it offers a more equitable assessment of the distribution of scholarly contributions within collaborative teams. Overall, this ranking is valuable not only for identifying the most active researchers but also serves as a reference for establishing academic collaboration networks and mapping expertise within Brassicaceae anti-inflammatory research.

Analysis of Publication Sources

The most relevant journals concerning research on the anti-inflammatory activity of Brassicaceae plants are presented in Figure 6.

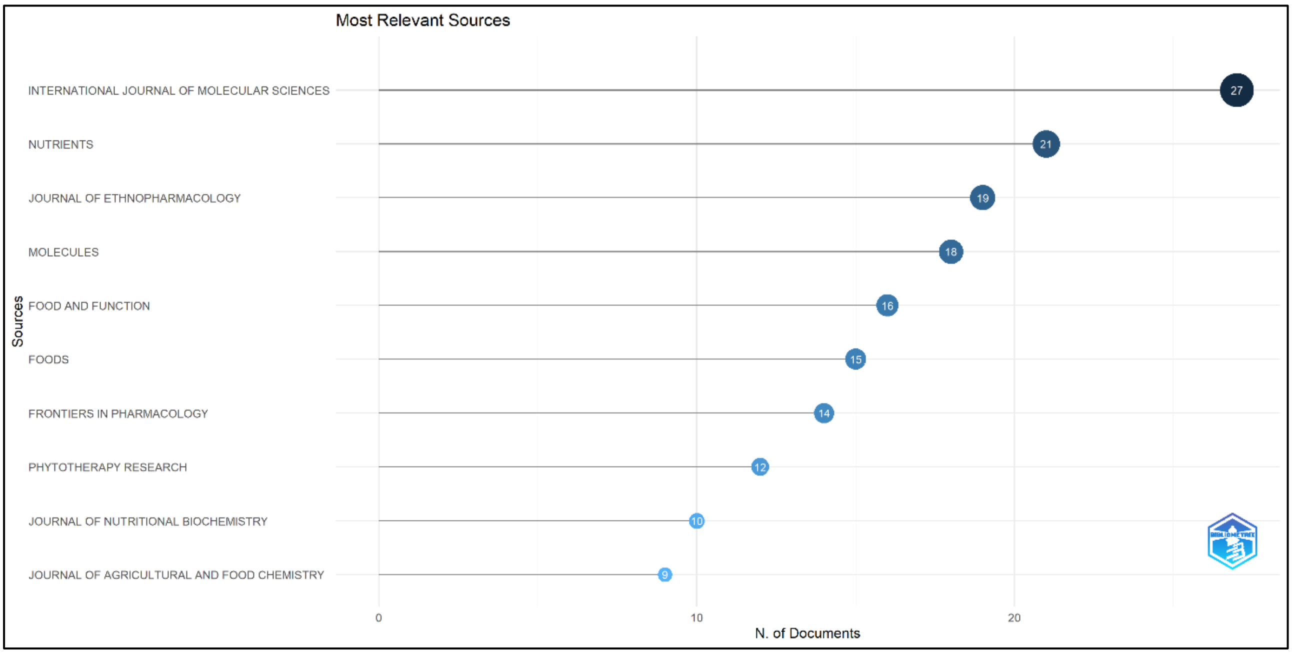

Figure 6. Distribution of the Top Ten Journals (by Number of Documents) in Publishing Research on the Anti-inflammatory Activity of Brassicaceae (2003–2024).

The journal with the highest publication output is the International Journal of Molecular Sciences, leading with 27 documents, reflecting the research focus on the molecular mechanisms and bioactive compounds of Brassicaceae plants. Subsequently, the journal Nutrients ranks second with 21 documents, highlighting the strong connection between anti-inflammatory compounds in Brassicaceae and nutritional health aspects. Other journals, such as the Journal of Ethnopharmacology (19 documents) and Molecules (18 documents), indicate the role of ethnopharmacological and organic chemistry approaches in this research. Furthermore, journals such as Food and Function, Foods, and Frontiers in Pharmacology underscore research diversification into nutrition, food function, and pharmacology. Meanwhile, contributions from journals such as Phytotherapy Research, the Journal of Nutritional Biochemistry, and the Journal of Agricultural and Food Chemistry focus on plant-based therapies, biochemical analysis, and agricultural applications. The diversity of these journals reflects the multidisciplinary nature of research on Brassicaceae plants, encompassing fields such as pharmacology, nutrition, ethnopharmacology, and biochemistry, while simultaneously highlighting the practical relevance of this research in human health and food consumption.

Analysis of Substantially Impacted Publications

Based on the number of citations, the top 10 most impactful publications in Brassicaceae anti-inflammatory research are presented in Table 2.

The most highly cited studies in Table 2 reflects essential contributions to research on the health benefits of bioactive compounds in Brassicaceae plants, particularly concerning anti-inflammatory activity and chemoprevention. Table 2 also highlights the significant contribution of specific metabolites in Brassicaceae plants to human health, such as sulforaphane, glucosinolates, isothiocyanates, and sinapic acid. These compounds possess antioxidant, anti-inflammatory, and anticancer properties, supporting the body's protective mechanisms by activating molecular pathways such as Nrf2 and the AhR receptor.

Highly cited articles, such as Juge et al. (2007) [39] and Dinkova-Kostova et al. (2012) [40], highlight the vital role of sulforaphane in chemoprevention and the reduction of oxidative stress, while other studies, such as Yanaka et al. (2009) [46] and Deng et al. (2017) [44], examine the benefits of sulforaphane for treating specific conditions like *Helicobacter pylori*-induced gastritis and colitis. This underscores the importance of a diet rich

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in cruciferous vegetables, such as broccoli and cabbage, for supporting overall health, including preventing chronic diseases and their potential use as natural therapies within healthcare. This body of research serves as the scientific basis for developing nutraceutical and pharmaceutical applications based on natural ingredients.

Table 2. Most Impactful Publications Based on Citation Count.

No.	Authors	Title	Year	Journals	Total Citations	Ref.
1	Juge, N., Mithen, R. F., & Traka, M.	Molecular basis for chemoprevention by sulforaphane: a comprehensive review	2007	Cellular and Molecular Life Sciences	622	[39]
2	Dinkova-Kostova, A. T., & Kostov, R. V.	Glucosinolates and isothiocyanates in health and disease	2012	Trends in Molecular Medicine	510	[40]
3	Hubbard, T. D., Murray, I. A., & Perdew, G. H.	Indole and Tryptophan Metabolism: Endogenous and Dietary Routes to Ah Receptor Activation	2015	Drug Metabolism and Disposition	463	[41]
4	Nićiforović, N., & Abramovič, H.	Sinapic Acid and Its Derivatives: Natural Sources and Bioactivity	2014	Comprehensive Reviews in Food Science and Food Safety	381	[42]
5	Ksouri, R., Ksouri, W. M., Jallali, I., Debez, A., Magné, C., Hiroko, I., & Abdelly, C.	Medicinal halophytes: potent source of health promoting biomolecules with medical, nutraceutical and food applications	2012	Critical Reviews in Biotechnology	317	[43]
6	Deng, Z., Rong, Y., Teng, Y., Mu, J., Zhuang, X., Tseng, M., Samykutty, A., Zhang, L., Yan, J., Miller, D., Suttles, J., Zhang, H	Broccoli-Derived Nanoparticle Inhibits Mouse Colitis by Activating Dendritic Cell AMP-Activated Protein Kinase	2017	Molecular Therapy	299	[44]
7	Lin, W., Wu, R. T., Wu, T., Khor, T. O., Wang, H., & Kong, A. N	Sulforaphane suppressed LPS-induced inflammation in mouse peritoneal macrophages through Nrf2 dependent pathway	2008	Biochemical Pharmacology	288	[45]
8	Yanaka, A., Fahey, J. W., Fukumoto, A., Nakayama, M., Inoue, S., Zhang, S., Tauchi, M., Suzuki, H., Hyodo, I., Yamamoto, M.	Dietary Sulforaphane-Rich Broccoli Sprouts Reduce Colonisation and Attenuate Gastritis in Helicobacter pylori–Infected Mice and Humans	2009	Cancer Prevention Research	239	[46]
9	Manchali, S., Murthy, K. N. C., & Patil, B. S.	Crucial facts about the health benefits of popular cruciferous vegetables	2012	Journal of Functional Foods	217	[47]
10	Zhou, Y., Li, Y., Zhou, T., Zheng, J., Li, S., & Li, H. B.	Dietary Natural Products for Prevention and Treatment of Liver Cancer	2016	Nutrients	215	[48]

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Analysis of Countries' Productivity and Visualization of Cross-Country Collaboration

The distribution of the most productive countries publishing research related to the Brassicaceae's anti-inflammatory properties is shown in Figure 7.

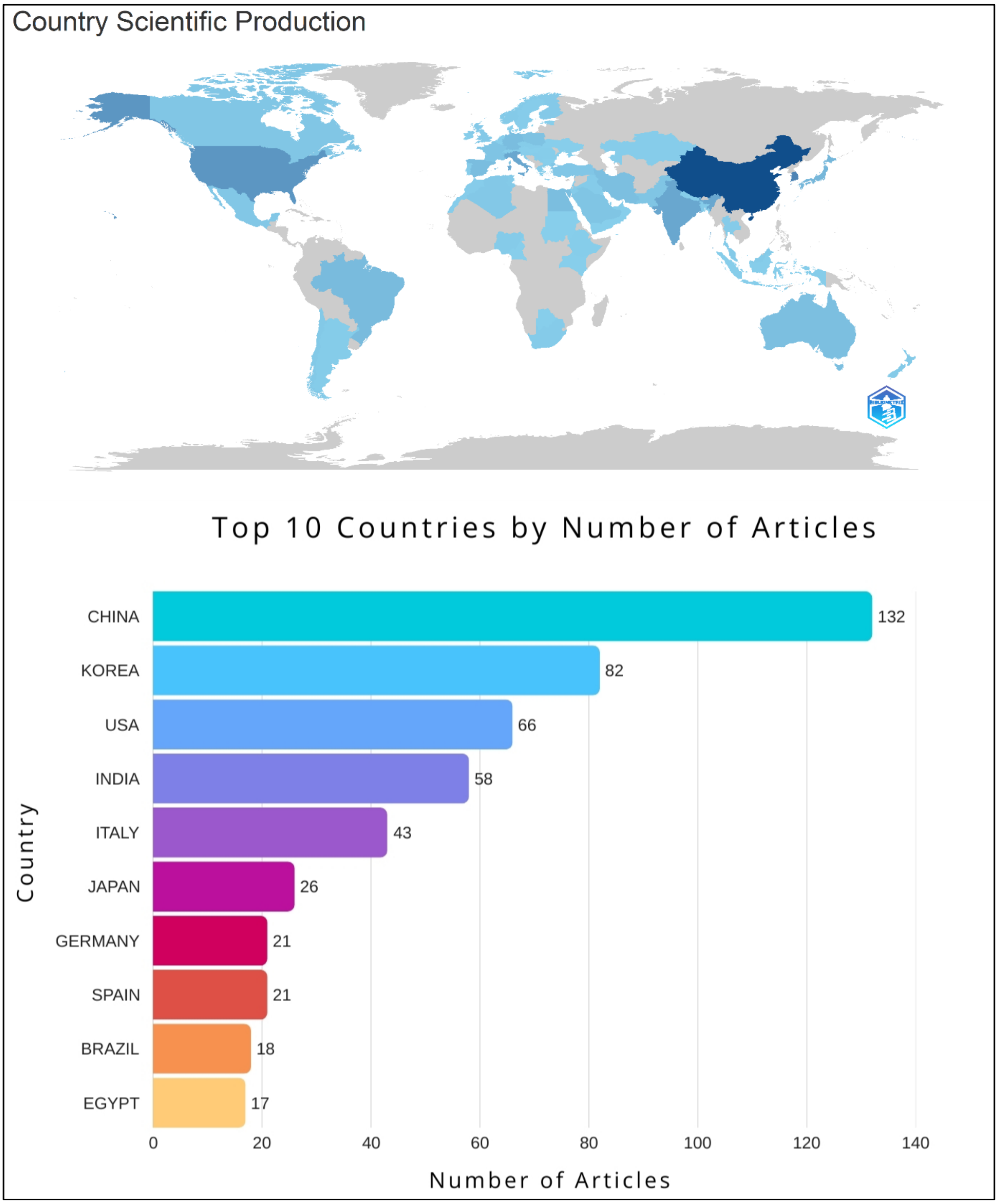

Figure 7. Publication Distribution by Country Concerning Research on the Anti-inflammatory Activity of Brassicaceae (2003–2024).

According to the data collected, research concerning the anti-inflammatory properties of Brassicaceae plants exhibits a notable distribution pattern across various countries. China leads with the highest number of articles (132 articles), followed by Korea (82 articles), and the USA (66 articles). China's dominance stems from its strong investment position in traditional medicine (TCM) research and extensive cultivation of Brassicaceae crops. TCM, including herbal medicine, has a long history in China and is still practiced [49]. Despite China's dominance in publication count, most of its publications are single country publications (SCP), suggesting that the country engages more in domestic research than international collaboration (see

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Figure 8). Korea exhibits a similar trend, with 77 publications classified as SCP out of 82 articles, while its percentage of multiple country publications (MCP) remains notably low (6.1%).

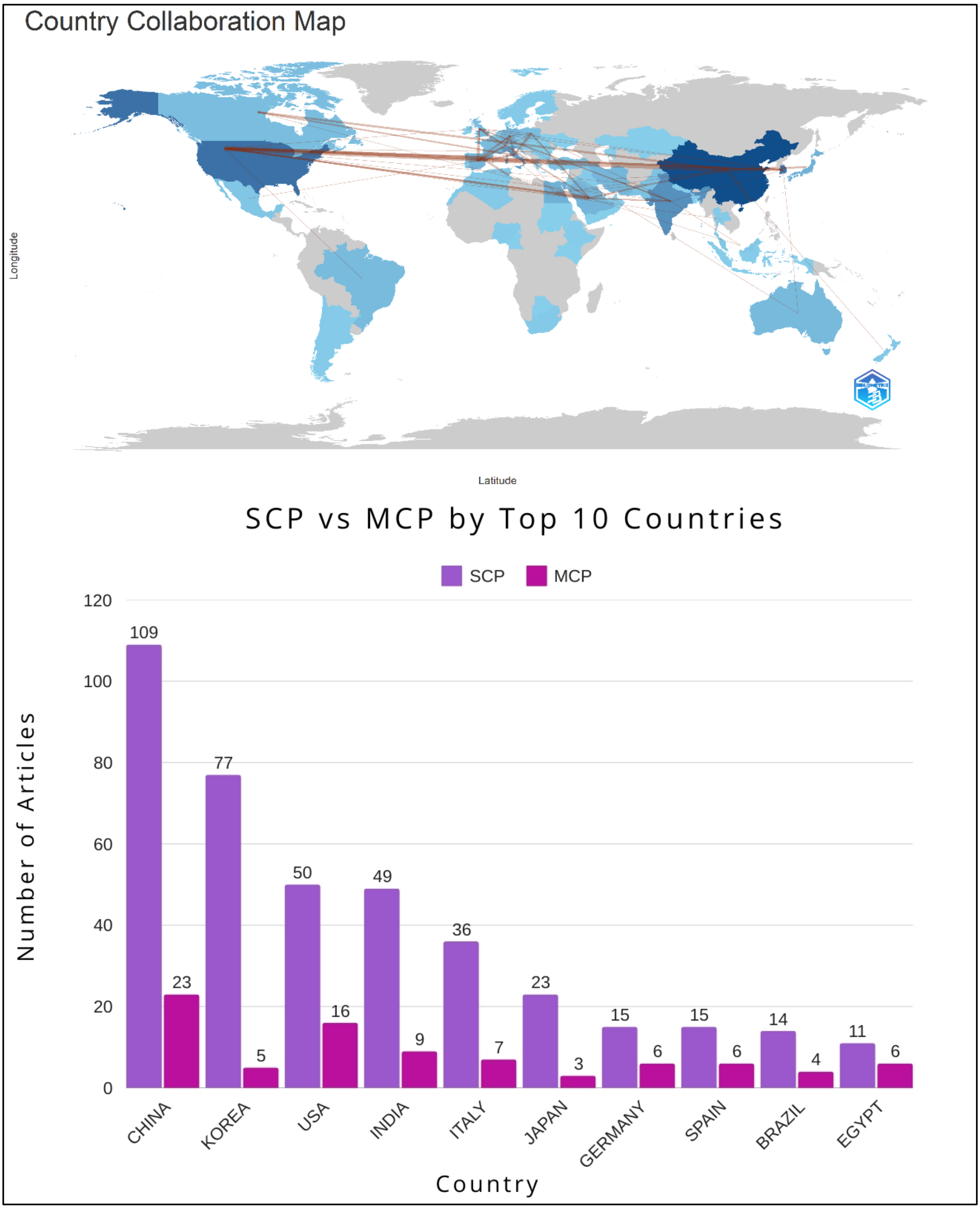

Figure 8. Visualisation of Inter-country Collaboration Networks concerning Research on Anti-inflammatory Activity in Brassicaceae (2003–2024). SCP: Single Country Publications, MCP: Multiple Country Publications.

In contrast, the USA demonstrates high international collaboration, with 24.2% of its total articles classified as MCP. This indicates that a significant portion of USA-based research involves collaboration with other countries, highlighting the importance of international cooperation for scientific research advancement. Countries such as India, Italy, Germany, and Spain also contribute significantly to this field, although most of their publications are SCP. Italy, for instance, has 16.3% MCP, while Germany and Spain exhibit higher MCP rates at 28.6% each, signifying their involvement in international research.

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Furthermore, developing countries such as Brazil, Egypt, and Iran also participate in this research area, despite having lower publication volumes than the leading nations. Brazil and Egypt exhibit significant MCP percentages, at 22.2% and 35.3% respectively, indicating active international collaboration despite their smaller overall publication output. International collaboration in this field is crucial as it accelerates research progress, particularly in developing plant-derived drug candidates, necessitating knowledge and technological exchange between countries.

The implications of these findings encompass two main aspects: the dominance of countries possessing robust research infrastructure and the critical role of international collaboration. The dominance of China, Korea, and the USA underscores the importance of Government support, funding, and access to cutting-edge technology in driving research productivity. Meanwhile, the high level of international collaboration observed in countries like Egypt, Germany, and Spain suggests that global cooperation can effectively offset resource limitations. However, the uneven distribution of research contributions, with 36.15% of publications originating from outside the top 10 countries, underscores the necessity of initiatives to foster equitable access to research resources, particularly for developing nations.

Overall, this analysis underscores that research on the Brassicaceae's anti-inflammatory effects continues to be dominated by nations possessing robust independent research capabilities. At the same time, international collaboration serves as a key strategy for countries with more limited resources. These findings not only reflect the current research landscape but also offer insights for strengthening global networks and reducing disparities in scientific productivity.

Analysis of Prominent Terms According to Author Keywords

VOSviewer was employed to visualize the keywords extracted from the 760 Scopus documents of the research topic of the anti-inflammatory activity of Brassicaceae plants. This approach aids in identifying emerging research fronts within the related domain. By default, the visualisation depicts keywords as circles (see Figure 9). The diameter of each circle represents the frequency and significance of the keyword. Each circle is colour-coded according to its respective cluster assignment for improved visual distinction [31,50]. The initial search yielded 2,161 keywords. Subsequently, a minimum occurrence threshold of five was applied, resulting in 95 keywords meeting the inclusion criteria for analysis. Following the analysis, seven distinct thematic clusters were identified, representing key research trends related to the Brassicaceae's anti-inflammatory properties, with each cluster denoted by a unique colour. The network visualisation depicting these seven clusters and their interconnections within the researched domain is presented in Figure 9(a). Each cluster comprises numerous keywords exhibiting a high degree of relatedness within the network structure, representing keywords frequently employed by authors in this field. High-frequency keywords within each cluster indicate research themes previously investigated in those areas. The seven clusters, characterised by their most frequently occurring keywords, were analysed further.

The first cluster (red) includes the following terms: anti-inflammatory (64 occurrences), brassicaceae (47 occurrences), antioxidant (46 occurrences), medicinal plants (20 occurrences), and antimicrobial (10 occurrences). Subsequently, the second cluster (green) consists of terms such as: sulforaphane (117 occurrences), oxidative stress (39 occurrences), apoptosis (22 occurrences), Nrf2 (21 occurrences), and indole-3-carbinol (20 occurrences). The third cluster (blue) includes the terms: Glucosinolates (38 occurrences), polyphenols (18 occurrences), flavonoids (13 occurrences), bioactive compounds (9 occurrences), and diabetes (8 occurrences). Furthermore, the fourth cluster (yellow) consists of terms such as isothiocyanates (39 occurrences), chemoprevention (20 occurrences), phytochemicals (15 occurrences), anticancer (13 occurrences), and rheumatoid arthritis (8 occurrences). The fifth cluster (purple) includes the following terms: broccoli (22 occurrences), *Brassica rapa* (11 occurrences), gut microbiota (9 occurrences), glucoraphanin (8 occurrences), and ulcerative colitis (7 occurrences). Meanwhile, the sixth cluster (light blue) consists of three terms: cytokines (10 occurrences), nitric oxide (8 occurrences), and LPS (5 occurrences). Finally, the seventh cluster (orange) comprises only one term of *Isatis tinctoria* (7 occurrences). Detailed information regarding the cluster analysis results is presented in Table 3.

Moreover, the colour gradient in Figure 9(b) represents term temporality, with brighter colours indicating terms associated with more recent publications and darker colours representing terms related to earlier publications. This suggests that terms such as cytokines, NF-κB, cyclooxygenase-2 (COX-2), MAPK, and TNF-α emerged earlier within the research timeline. Conversely, terms such as antimicrobial, gut microbiota, antioxidant, anti-inflammatory, and glucosinolates represent themes associated with more recent publication trends.

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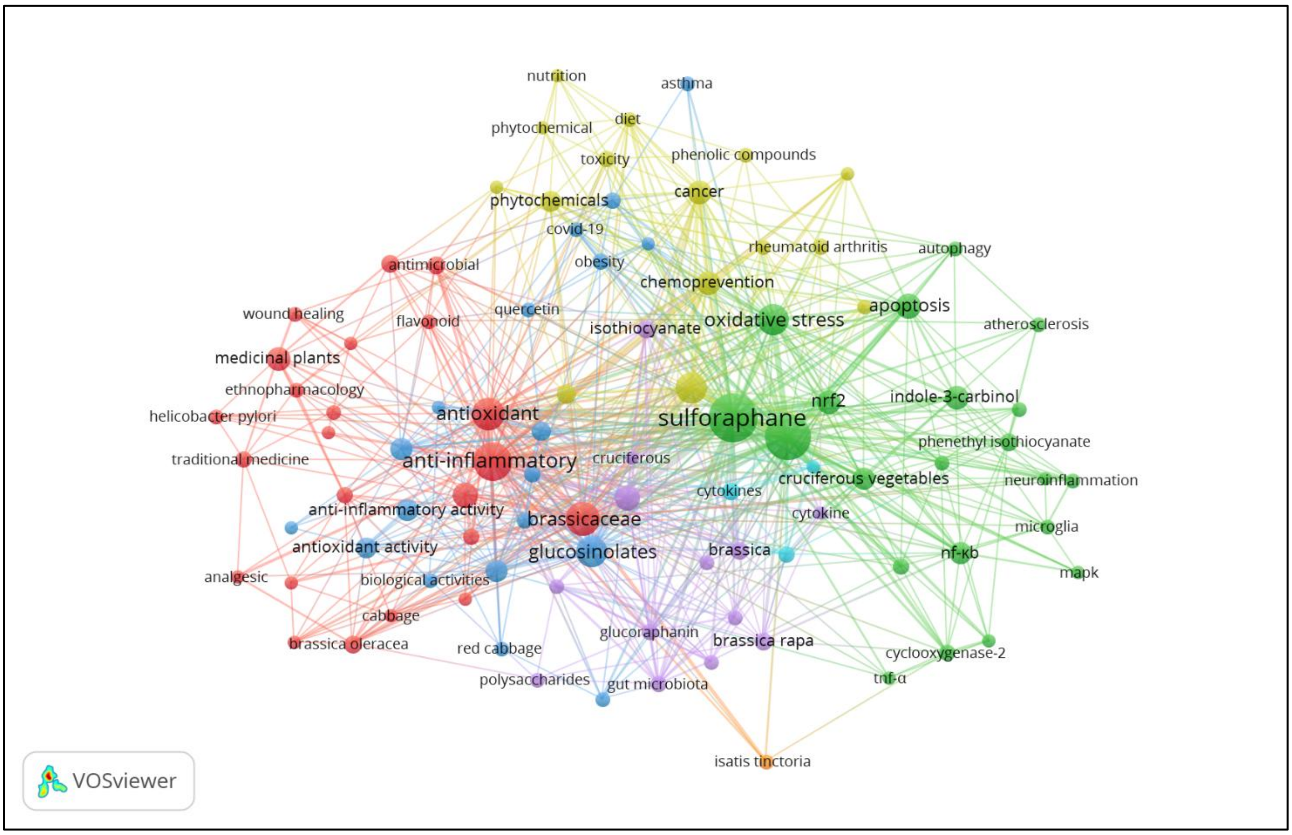
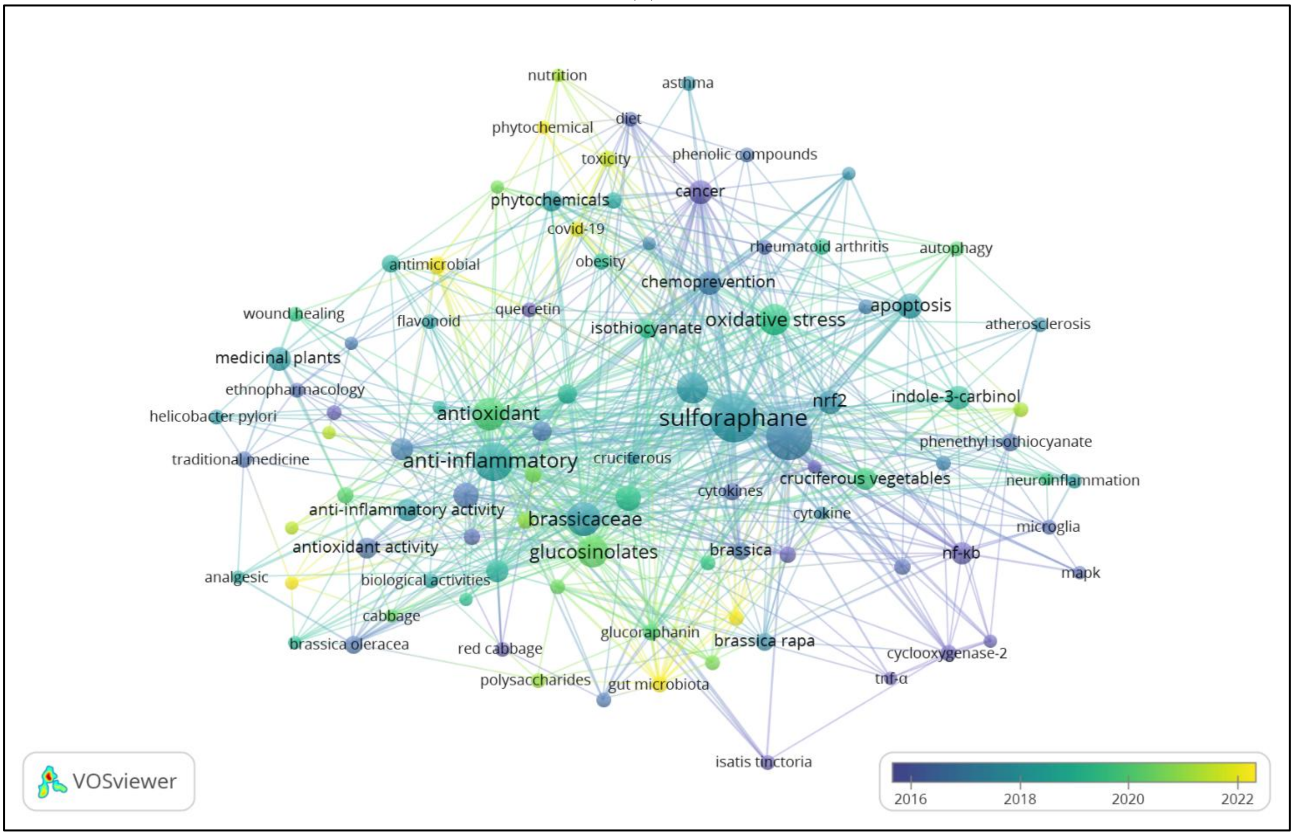


(a)



(b)

Figure 9. Visualisation of Author Keywords Related to Anti-inflammation and Brassicaceae: (a) Network Visualization; (b) Overlay Visualization.

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Table 3. Analysis of Clusters Based on Keyword Frequency.

Clusters	Most Frequent Author Keyword	Other Keywords
Red – 23 term	Anti-inflammatory (64)	Brassicaceae (47); antioxidant (46); anti-inflammation (22); medicinal plants (20); antimicrobial (10); *brassica oleracea* (10); natural products (10); cytotoxicity (9); phytochemistry (8); traditional medicine (8); ethnopharmacology (7); medicinal plant (7); wound healing (7); flavonoid (6); *helicobacter pylori* (6); analgesic (5); atopic dermatitis (5); bioavailability (5); cabbage (5); lactic acid bacteria (5); pharmacological activity (5); phytotherapy (5).
Green – 21 term	Sulforaphane (117)	Inflammation (102); oxidative stress (39); apoptosis (22); nrf2 (21); indole-3-carbinol (20); cruciferous vegetables (18); nf-κb (16); phenethyl isothiocyanate (10); lipopolysaccharide (9); cyclooxygenase-2 (8); atherosclerosis (7); microglia (7); allyl isothiocyanate (6); autophagy (6); benzyl isothiocyanate (6); neuroinflammation (6); inducible nitric oxide synthase (5); mapk (5); neuroprotection (5); tnf-α (5).
Blue – 19 term	Glucosinolates (38)	Polyphenols (18); anti-inflammatory activity (17); antioxidants (16); antioxidant activity (14); flavonoids (13); bioactive compounds (9); diabetes (8); kale (8); obesity (8); biological activities (7); colitis (7); quercetin (7); asthma (6); covid-19 (6); red cabbage (6); gc-ms (5); insulin resistance (5); nutraceuticals (5).
Yellow – 15 term	Isothiocyanates (39)	Cancer (20); chemoprevention (20); phytochemicals (15); anticancer (13); rheumatoid arthritis (8); toxicity (8); phenolic compounds (7); diet (6); glutathione (6); reactive oxygen species (6); epigenetics (5); nanoparticles (5); nutrition (5); phytochemical (5).
Violet – 13 term	Broccoli (22)	Brassica (11); *brassica rapa* (11); isothiocyanate (11); gut microbiota (9); glucoraphanin (8); glucosinolate (7); ulcerative colitis (7); broccoli sprouts (6); inflammatory bowel disease (6); polysaccharides (6); cruciferous (5); cytokine (5).
Light blue – 3 term	Cytokines (10)	Nitric oxide (8); LPS (5).
Orange – 1 term	–	*Isatis tinctoria* (7).

We conducted further investigations to elucidate trends and research novelty regarding the Brassicaceae's anti-inflammatory effects. The analysis of specific relationships among variables revealed interesting associations. Figure 10 illustrates the association between the keyword "brassicaceae" and specific domains related to its therapeutic effects, including terms such as "anti-inflammatory", "antioxidant", "antimicrobial", and "chemoprevention".

Moreover, the keyword "brassicaceae" is also associated with a specific domain related to characteristic plant metabolites, including terms such as: "sulforaphane", "isothiocyanates", "Glucosinolates", and "flavonoid". Additionally, the keyword "brassicaceae" is associated with another specific domain concerning molecular therapeutic targets, including terms such as: "cytokines", "nitric oxide", "cyclooxygenase-2 (COX-2)", and "Nrf2".

Isothiocyanates represent a class of phytochemicals possessing the highly reactive, electrophilic −N=C=S functional group. These compounds are stored within plant tissues as precursor molecules known as glucosinolates. Upon tissue disruption (e.g., chewing, cutting), these are hydrolysed by the endogenous enzyme myrosinase, yielding isothiocyanates along with other breakdown products. Sulforaphane, isolated

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from broccoli (*Brassica oleracea* var. *italica*), is the most extensively studied isothiocyanate known for its antioxidant properties. Its principal mode of action involves the induction of the transcription factor Nuclear factor erythroid 2-related factor 2 (Nrf2), which subsequently enhances the expression of genes encoding antioxidant proteins [51]. The prominence of sulforaphane in keyword clusters aligns with its well-documented role in Nrf2 activation, as evidenced by Lin et al. (2008) [45]. Sulforaphane has also been reported to exhibit anti-inflammatory properties, attributed to its ability to downregulate the expression of pro-inflammatory cytokines (such as IL-1β and TNF-α), chemokines (like MCP-1 and CXCL-1), adhesion molecules (particularly on endothelial cell and leukocyte surfaces), cyclooxygenase-2 (COX-2), and inducible nitric oxide synthase (iNOS). Furthermore, the anti-inflammatory mechanisms of sulforaphane are also linked to its effects on other signalling pathways, including nuclear factor kappa B (NF-κB), activator protein 1 (AP-1), sirtuin 1 (SIRT1), as well as microRNAs. [51]. These anti-inflammatory mechanisms are frequently attributed to direct interactions with sulfhydryl (-SH) groups on cysteine residues in key proteins and enzymes [52–54].

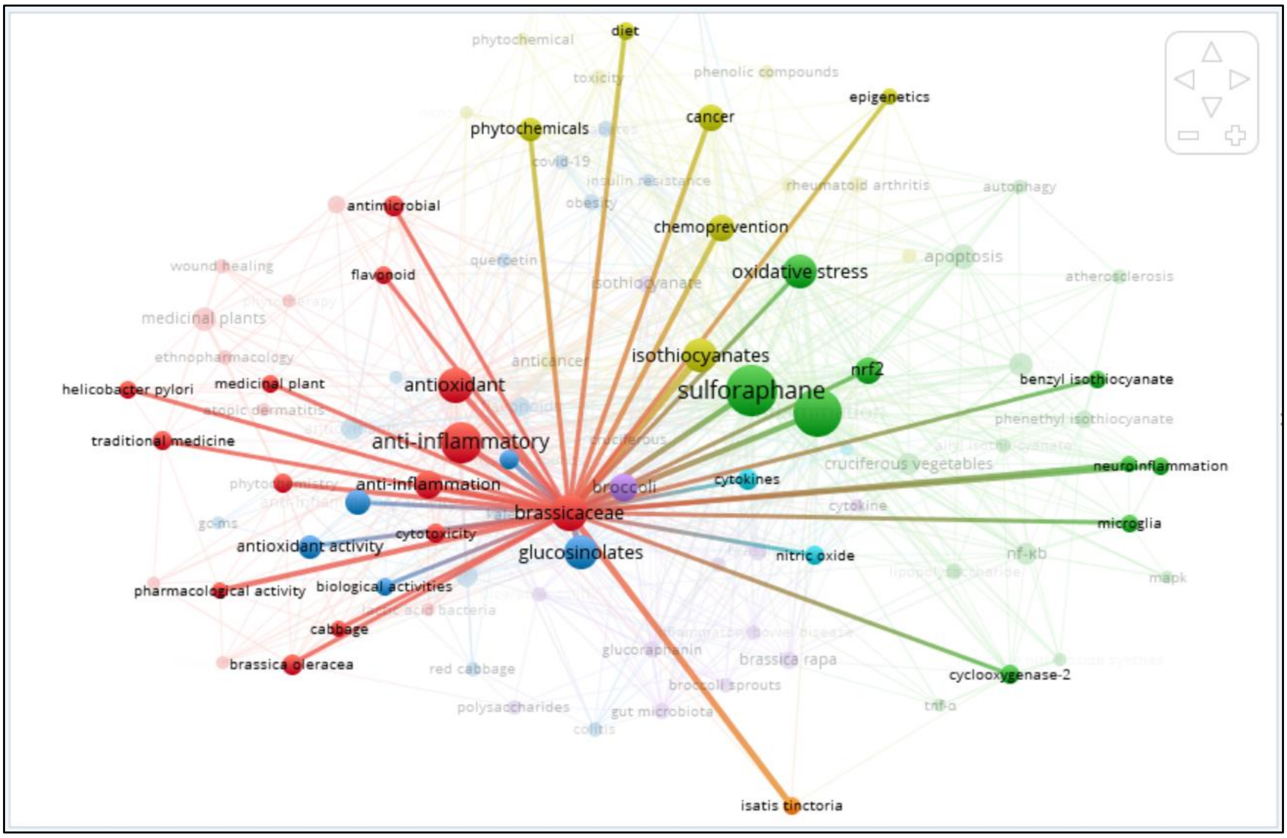

Figure 10. Visualisation of the relationship between the keyword "brassicaceae" and thematic domains of therapeutic effects and metabolite compounds from Brassicaceae plants.

Research Gaps and Future Challenges

Despite the prolific research output documented in this bibliometric analysis, several critical gaps impede the translation of Brassicaceae-based therapies into clinical practice. First, while in vitro and preclinical studies robustly demonstrate the anti-inflammatory mechanisms of key compounds (e.g., glucosinolates, isothiocyanates, sulforaphane), human clinical data remain scarce and fragmented. Few trials have systematically evaluated the pharmacokinetics and bioavailability of these compounds in humans, particularly regarding dose-dependent efficacy and inter-individual variability influenced by factors such as gut microbiota composition, food matrix interactions, and genetic polymorphisms in metabolic enzymes (e.g., GST isoforms). Second, the bioavailability of sulforaphane—a cornerstone metabolite—exhibits significant variability across Brassica cultivars and preparation methods, complicating dose standardization and reproducibility in therapeutic applications. Third, the field lacks consensus on clinical trial methodologies, including optimal biomarkers for assessing anti-inflammatory efficacy in chronic diseases, patient stratification criteria, and long-term safety monitoring.

Future research must prioritize translational studies to bridge these gaps, including: 1. Well-designed human trials validating dose-response relationships, safety profiles, and clinical endpoints for specific

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inflammatory conditions (e.g., IBD, arthritis); 2. Standardization of extracts via advanced cultivation and processing techniques to ensure consistent bioactive compound delivery; 3. Exploration of synergistic interactions between Brassicaceae compounds (e.g., sulforaphane-flavonoid combinations) or with conventional therapeutics (e.g., NSAIDs) to enhance efficacy while mitigating side effects. Such synergy could leverage multi-target mechanisms (e.g., simultaneous Nrf2 activation and NF-κB inhibition) to address complex inflammatory pathways.

Conclusions

A bibliometric analysis was conducted on 760 published articles from the Scopus database to examine research trends concerning the anti-inflammatory properties of Brassicaceae plants from 2003 to 2024. The study aimed to identify the most productive countries/regions, leading publishing journals, key authors, and emerging research themes within this domain. The findings revealed that 2023 exhibited the most substantial growth, China emerged as the most productive country regarding article publication, while the USA was the most cited country. Kyung Hee University was ranked as the most productive institution based on author affiliation, and the International Journal of Molecular Sciences was identified as the leading publishing journal in this domain. Furthermore, *Li Y* was recognised as the author providing the most significant research contribution. The role of compounds such as sulforaphane, isothiocyanates, glucosinolates, and flavonoids, as characteristic metabolites in Brassicaceae plants influencing their various pharmacological activities, warrants further comprehensive investigation. The bibliometric findings offer valuable insights that can guide future studies, especially those investigating molecular targets like cytokines, nitric oxide, cyclooxygenase-2 (COX-2), and Nrf2, which are crucial in the anti-inflammatory mechanisms of Brassicaceae compounds. This bibliometric analysis complements previous studies by systematically mapping the global research landscape and identifying critical gaps that have not been sufficiently addressed. Despite existing literature predominantly emphasizing *in vitro* and preclinical investigations into the anti-inflammatory mechanisms of Brassicaceae metabolites, our analysis highlights a notable scarcity of clinical trials validating these findings in human subjects, indicating the importance of translational research to bridge the gap between laboratory discoveries and therapeutic implementations. Addressing this gap could accelerate the development of evidence-based herbal therapies and strengthen the scientific foundation for utilizing Brassicaceae in clinical applications, while also facilitating the development of Brassicaceae as medicinal plants and promoting their wider utilization.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Supplementary Materials

No supplementary materials are available for this paper.

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