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REVIEW

Mapping the Research Landscape of Polyphenols in Osteoarthritis: A Bibliometric Perspective

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Abstract: Polyphenols, a diverse group of plant-derived compounds known for their antioxidant and anti-inflammatory properties, have garnered increasing attention for their therapeutic potential in osteoarthritis (OA). However, a comprehensive bibliometric analysis of the research landscape in this field has been lacking. This study aimed to systematically evaluate global research trends, knowledge structure, and emerging hotspots related to polyphenols in OA. Publications from 2000 to 2025 were retrieved from the Web of Science Core Collection and analyzed using bibliometric tools such as VOSviewer and CiteSpace. A total of 1,436 publications were identified, demonstrating a steady rise in annual output, with China and the United States emerging as the most prolific contributors. Keyword co-occurrence and citation burst analyses revealed that curcumin, resveratrol, EGCG, inflammation, oxidative stress, and cartilage degeneration are central research themes. Notably, recent trends highlight increasing interest in ferroptosis, gut microbiota, and targeted drug delivery systems in the context of polyphenol-based OA therapies. This bibliometric analysis provides a comprehensive overview of the current status and developmental trajectory of polyphenol research in OA, offering valuable insights to guide future studies and foster interdisciplinary collaboration.

Keywords: polyphenols, osteoarthritis, bibliometric analysis, research trends, inflammation, oxidative stress

Introduction

Osteoarthritis (OA) represents the most prevalent form of degenerative joint disease, typified by progressive degradation of articular cartilage, remodeling of subchondral bone, synovial inflammation, and persistent pain.[1,2] The increasing prevalence of OA, driven by demographic aging, escalating obesity rates, and sedentary lifestyles, constitutes a substantial and growing public health burden, imposing significant demands on global healthcare systems.[3] Current therapeutic modalities predominantly target symptomatic relief without effectively modifying the underlying pathophysiological mechanisms, underscoring the critical need for safe and efficacious disease-modifying interventions.[4] Recent comprehensive analyses, such as the Global Burden of Disease Study, estimate that approximately 595 million individuals (95% uncertainty interval: 535–656 million) were affected by OA globally in 2020, reflecting the escalating magnitude of this health challenge.[5] The pathogenesis of OA is complex and multifactorial; beyond classical features of cartilage deterioration and subchondral bone alterations, accumulating evidence implicates metabolic dysregulation, chronic low-grade systemic inflammation, and immune system perturbations as pivotal factors in disease initiation and progression.[6–8] These advances in understanding underscore the necessity for integrative, multidisciplinary therapeutic strategies that concurrently address local joint pathology and systemic metabolic-inflammatory processes. Such approaches hold considerable promise for enhancing clinical outcomes and reshaping the therapeutic landscape of OA.

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Polyphenols, a large class of naturally occurring compounds found in fruits, vegetables, tea, and medicinal herbs, have attracted considerable attention due to their potent antioxidant, anti-inflammatory, and chondroprotective properties.[9–11] Notably, polyphenolic compounds such as curcumin, resveratrol, and epigallocatechin-3-gallate (EGCG) have demonstrated significant therapeutic potential in preclinical OA models by inhibiting pro-inflammatory cytokine production, reducing oxidative stress, and preventing extracellular matrix degradation in cartilage tissue.[12–14] In recent years, there has been a notable surge in studies exploring polyphenol-based interventions for OA, with emerging research focusing on novel mechanisms including ferroptosis, autophagy, and the gut–joint axis.[15–17]

Despite this expanding body of literature, a comprehensive bibliometric analysis of global research efforts, thematic development, and knowledge evolution in the field of polyphenols in OA remains absent. Bibliometric analysis is a powerful tool that enables quantitative and visual exploration of scientific output, revealing influential authors, institutions, and countries, while also uncovering research hotspots and emerging frontiers.[18,19] Therefore, the present study aims to conduct a systematic bibliometric assessment of the global research landscape on polyphenols in OA, with the goal of mapping current trends, collaborative networks, and future directions to inform and inspire more targeted and innovative studies in this growing interdisciplinary field.

Materials and Methods

Data Source and Retrieval Strategy

The Web of Science Core Collection (WoSCC) (https://www.webofscience.com/wos/) was selected as the primary data source for this bibliometric analysis due to its comprehensive coverage and multidisciplinary relevance. Research on polyphenols in OA spans pharmacology, molecular biology, and clinical medicine, making WoSCC's integrative indexing and accurate literature retrieval particularly valuable. Its robust citation data and built-in analytical tools facilitate the construction of knowledge networks and reliable identification of research trends.[20,21] Compared with other databases, WoSCC offers more precise classification, reducing bias and enhancing data consistency.[22,23] The inclusion of the Science Citation Index Expanded (SCIE) further enables dynamic tracking of publication trends in the polyphenol–OA field.[22,24–26] Additionally, its journal selection follows Bradford's and Garfield's laws, ensuring coverage of core literature and minimizing omissions of key studies. These features collectively make WoSCC a widely recognized and authoritative platform for bibliometric research.

A comprehensive search was conducted in WoSCC to identify original articles and reviews related to polyphenols in OA. Interest in polyphenols—natural compounds with antioxidant and anti-inflammatory properties derived from plants—began decades ago. Early studies highlighted compounds such as resveratrol, curcumin, and EGCG for their therapeutic potential in chronic inflammatory conditions, including OA.[27] Recent advances in pharmacology and molecular biology have deepened understanding of their roles in modulating oxidative stress, cartilage degradation, and inflammatory signaling pathways.[10] The expanding volume of research underscores the growing interest in polyphenol-based strategies for OA prevention and treatment.

To systematically investigate this research area, we searched the WoSCC for literature published between January 1, 2000, and May 1, 2025. The search strategy integrated both Medical Subject Headings (MeSH) and free-text keywords from two thematic areas: (1) osteoarthritis-related terms (eg, "Osteoarthritis", "Osteoarthritides") and (2) polyphenol-related terms (eg, "Polyphenolic Compounds", "Flavonoids", "Flavones"). These terms were combined using Boolean operator AND to specifically identify studies addressing the role of polyphenols in OA. To enhance accuracy and reduce irrelevant results, an initial manual screening was conducted, which helped refine the search terms. The final strategy was iteratively optimized by three independent researchers to achieve a balance between sensitivity and specificity. This approach was informed by prior bibliometric and systematic review methodologies,[28] with detailed search parameters provided in the Supplementary Table 1.

Inclusion and Exclusion Criteria

Only English-language original studies and reviews on polyphenols in OA were included. Exclusions covered unrelated topics, non-peer-reviewed sources, conference abstracts, and journals with unclear titles. Criteria were set by team consensus.

Data Analysis

Data for this study were retrieved from the WoSCC. Bibliometric analyses were conducted using VOSviewer (version 1.6.18, Leiden University, Netherlands) and CiteSpace (version 6.3.R1, Chaomei Chen, China). CiteSpace was used to map collaboration and co-citation networks and to identify the top 10 citation bursts across key categories.

Results and Discussion

Scientific Output

As shown in Figure 1A, research on polyphenols in OA has steadily increased, with 1,436 relevant publications identified between 2000 and 2025, averaging 55.2 articles per year. Significant growth spikes were observed in 2005 (266.7%),

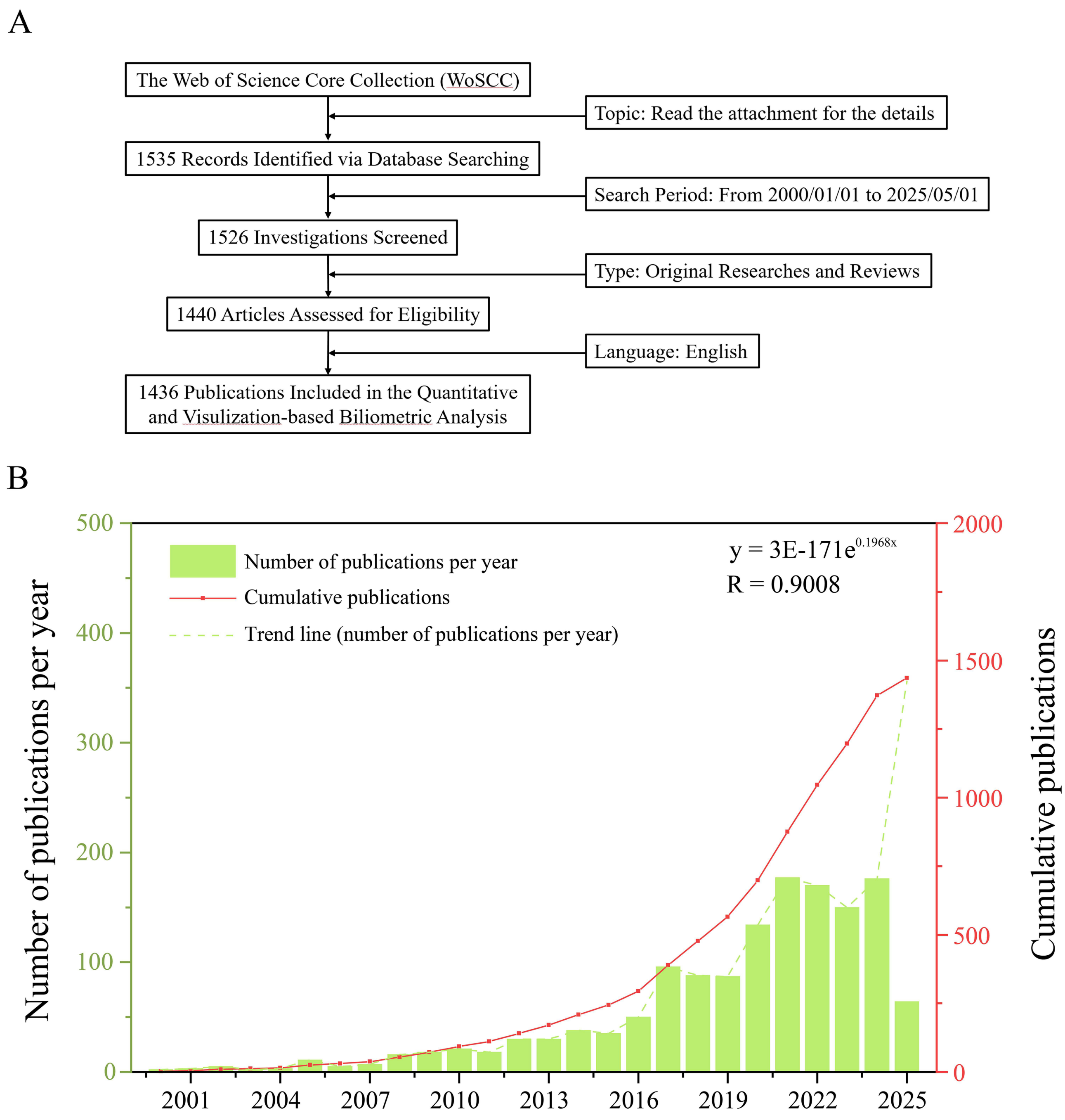

Figure 1 (**A**) A schematic overview of the literature retrieval and selection process. (**B**) Analysis of the publication trends for research on "polyphenol applications in osteoarthritis" from 2000 to 2025.

2008 (128.5%), and 2012 (66.6%). The publication trend fits an exponential growth model ($y = 3E\text{-}171e^{0.1968x}$) with a strong correlation (R^2 =0.9008) (Figure 1B), indicating a consistent rise in scholarly interest and suggesting continued expansion in this research domain.

The rapid increase in OA-related polyphenol studies, particularly the recent surge in publications, underscores the growing importance of this field. These findings can inform healthcare policymakers in developing frameworks that encourage innovation while ensuring safety, efficacy, and ethical compliance. Notable spikes in publication numbers, supported by a strong growth trend (R^2 = 0.9008), reflect significant scientific momentum. This expanding body of literature provides valuable data for identifying research patterns and gaps. The sustained rise in interest also highlights the commercial potential of polyphenol-based therapies, suggesting their future role in OA management and clinical translation.

Analysis of Research Performance

National and Regional Contributions

Polyphenol research in OA involves 81 countries/regions. As shown in Figure 2A, collaboration networks (≥10 publications per country) reveal global research distribution and highlight opportunities for international cooperation.[29] China leads with 605 publications, representing 36.55% of global output, more than seven times that of Italy, which ranks fifth. This emphasizes China's prominent role in driving progress in this research area. Over the past two decades, research on polyphenols in OA has expanded rapidly due to the combined influence of national health priorities, interdisciplinary collaboration, and technological innovation. Governments in countries such as China, the United States (US) and the member states of the European Union (EU) have promoted safe, long-term therapies for OA, with polyphenols emerging as promising candidates due to their anti-inflammatory and chondroprotective properties. Strategic initiatives like "Healthy China 2030" and the EU's Green Deal, along with funding from agencies such as the National Natural Science Foundation of China (NSFC) and the National Institutes of Health (NIH), have provided strong policy support. The field benefits from interdisciplinary efforts across pharmacology, molecular biology, traditional medicine, and nutraceutical science, with active contributions from leading institutions in China, India, and South Korea. However, disparities in infrastructure still limit participation from some developing regions. Technological advances—such as network pharmacology, molecular docking, and nanoformulations—have addressed key challenges like bioavailability, while novel drug delivery systems (eg, hydrogels and liposomes) have facilitated more effective therapeutic application. Although China, the US, and India dominate the field, emerging hubs in Southeast Asia, Eastern Europe, and South America are providing new insights, particularly through local resources and ethnobotanical knowledge. Looking forward, research is expected to shift toward functional foods, personalized nutrition, and clinical applications, supported by omics technologies and artificial intelligence (AI)-driven screening. Yet, despite encouraging experimental data, clinical translation remains limited, underscoring the need for standardized extraction methods, toxicity evaluation, and regulatory harmonization to fully realize the therapeutic potential of polyphenols in OA management.

The US and India are major contributors to polyphenol research in OA, with approximately 196 (11.8%) and 96 (5.8%) publications, respectively. Their high publication volume and international collaboration highlight their potential as emerging markets for polyphenol-based therapies. China and the US lead the field, reflecting strong national support, investment in biomedical research, and robust scientific infrastructure. High-income countries often focus on developing novel polyphenol derivatives and advanced delivery systems, while lower-income regions tend to emphasize epidemiological or traditional medicine studies due to resource constraints—creating disparities that may hinder equitable progress. Furthermore, bibliometric analysis shows that despite shared research interests, international collaboration remains limited. Expanding global cooperation is essential for standardizing experimental models, safety assessments, and clinical protocols. Strengthening cross-disciplinary and inclusive networks can enhance resource sharing, overcome translational challenges, and support the broader application of polyphenol-based interventions in OA, ultimately contributing to reduced global health disparities in OA care.

Citation bursts are valuable for identifying influential research trends, guiding institutions and industry in strategic planning, talent recruitment, and investment. As illustrated in Figure 2B, citation bursts in the top ten countries studying polyphenols in OA highlight periods of high academic impact. The US showed a strong citation surge from 2002 to 2010,

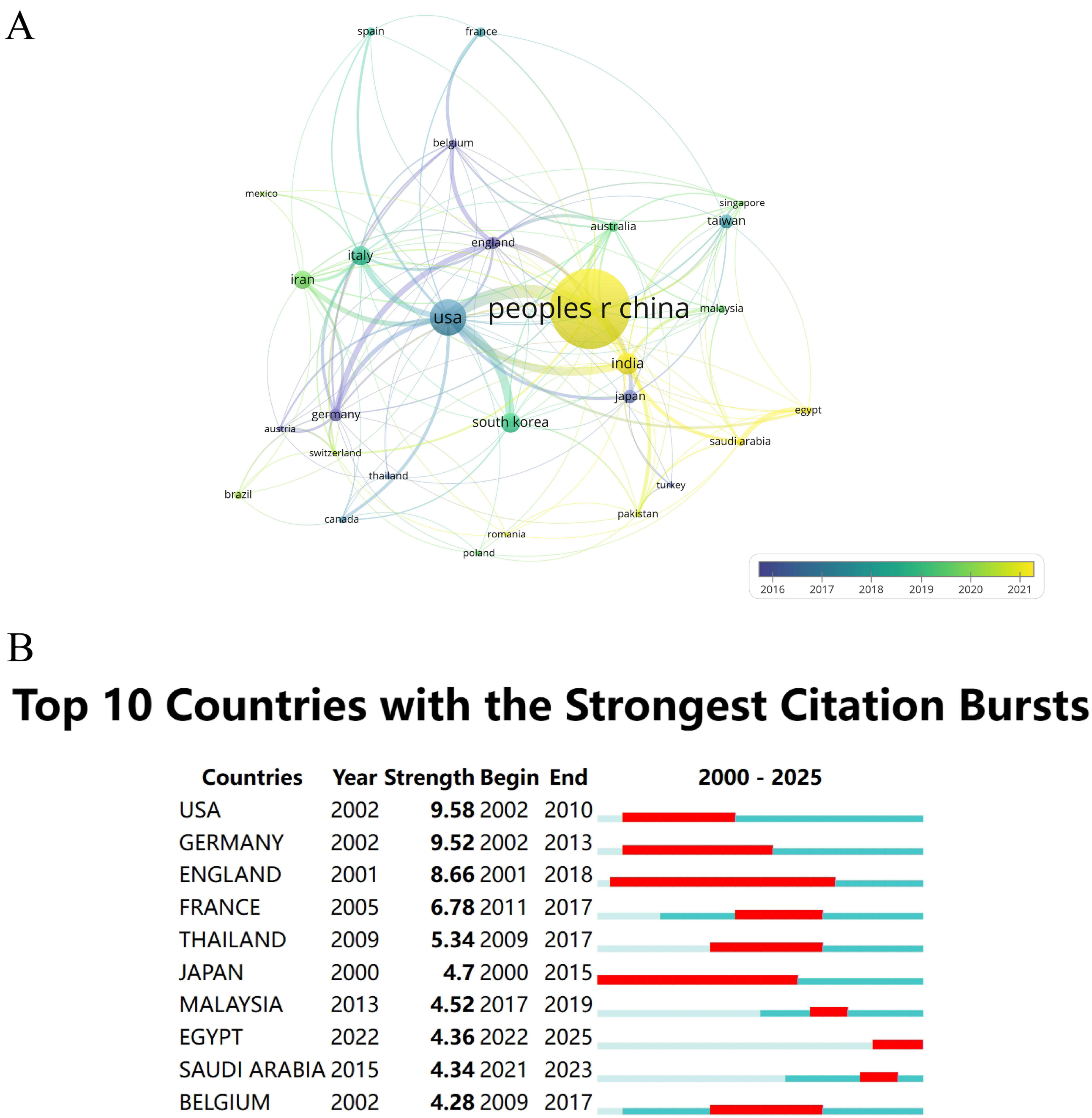

Figure 2 (**A**) A global map illustrating research on polyphenol applications in osteoarthritis, where sphere sizes correspond to the number of publications per country, and the thickness of connecting lines represents the intensity of international collaborations. (**B**) Publication trends of the top ten countries in this field, marked in red to highlight notable growth. "Burst" refers to a rapid rise in research activity, while "BurstBegin" and "BurstEnd" indicate the onset and conclusion of this surge, respectively.

with a peak burst strength of 9.58, indicating its early leadership in the field. England demonstrated the longest burst, spanning 18 years (2001–2018), reflecting sustained research activity. Overall, the most active citation burst periods occurred between 2000 and 2020, marking rapid development in areas such as oxidative stress modulation, cartilage protection, and nanocarrier-based polyphenol delivery. These trends reveal not only key breakthroughs but also shifts in global research leadership—from early dominance by North America and Europe to a growing influence from Asian countries, especially China. While this eastward shift signals strong regional growth, it also raises concerns about research centralization. Promoting global collaboration and methodological diversity is essential to ensure balanced innovation and the successful translation of polyphenol-based therapies into effective OA treatments.

China has become a leading force in polyphenol and OA research, driven by supportive national policies and interest in functional phytochemicals. However, the concentration of research output and institutional resources raises concerns about limited methodological diversity and underrepresentation of global perspectives. Despite its high publication volume, China's international collaborations remain modest, potentially restricting the integration of alternative approaches. Overreliance on a few dominant countries may hinder inclusive innovation. To ensure continued progress and broader impact, it is crucial to promote diverse research strategies and foster global partnerships—especially with regions offering unique traditional medicine insights. Strengthening international cooperation will enhance the translational potential of polyphenol-based therapies and support a more resilient, globally relevant research landscape.

Analysis by Research Institutions

Examining collaboration strength and institutional productivity helps researchers identify key partners and leading research institutions. This facilitates the formation of strategic partnerships, particularly those that bring together diverse areas of expertise and promote interdisciplinary innovation. Policymakers can leverage these insights to inform funding strategies and encourage international cooperation. Moreover, mapping the global and regional distribution of research efforts helps optimize the allocation of resources and supports initiatives aligned with specific healthcare priorities. From an industry standpoint, recognizing high-impact institutions allows for more targeted planning in areas such as product innovation, technology licensing, and joint research investment. Collaborating with top academic centers can greatly speed up the translation of polyphenol research into clinical applications for OA, promoting scientific progress and improving public health.

Over the past 26 years, research on polyphenol applications in OA has expanded significantly, involving 2,016 institutions worldwide (Figure 3A). Wenzhou Medical University leads with 51 publications (9.58%), followed by Zhejiang University with 29 (5.45%) and China Medical University with 28 (5.26%). Among the top 10 institutions by publication count, Mashhad University of Medical Sciences stands out with the highest average citations per paper at 89.17, followed by the University of Liège with 50.31. This reflects not only their substantial research output but also strong academic influence in the field. These institutions are well-positioned to act as key collaborators in future studies, facilitating joint projects and knowledge exchange. Notably, the University of Liège plays a central role in institutional collaborations, demonstrating a strong commitment to partnership-building, as evidenced by its extensive connections with other leading academic organizations.

Identifying institutions experiencing citation surges is critical for both researchers and industry stakeholders. By assessing the sustained impact and adaptability of research efforts, a comprehensive evaluation of an institution's scholarly contributions can be achieved.[30] Based on CiteSpace analysis (Figure 3B), this study identified institutions that demonstrated significant citation bursts. The top 10 institutions with the strongest citation bursts primarily emerged after 2016. Notably, Chinese institutions such as Wenzhou Medical University, Shanghai Jiao Tong University, Nanjing University of Chinese Medicine, and Zhejiang Chinese Medical University have shown sustained citation bursts extending into 2025, indicating continued academic influence and active engagement in the field of polyphenols in OA.

Author Analysis

Identifying prominent scholars and analyzing their collaboration networks is essential for pinpointing key influencers in the field.[31] Researchers with high citation counts and prolific publication records provide important guidance for future studies. A thorough author analysis in polyphenol research on OA revealed 7,737 contributors, with 65 authors publishing five or more papers each. These leading researchers have played a major role in shaping the field, and their collaborative networks offer opportunities for strategic partnerships moving forward. For early-career researchers, mapping these networks is crucial for identifying key collaborators and uncovering opportunities for interdisciplinary projects grounded in established expertise.

To analyze collaboration patterns in greater detail, VOSviewer was employed to create visual maps. In these maps, node size reflects an author's publication volume, and the thickness of connecting lines represents the intensity of their collaborations. Notably, as illustrated in Figure 4A, leading contributors such as Mobasheri, Ali (16 articles), Haqqi, Tariq M. (14 articles), Shakibaei, Mehdi (10 articles), Gu, Hailun (9 articles), and Liu, Li (9 articles) are prominent

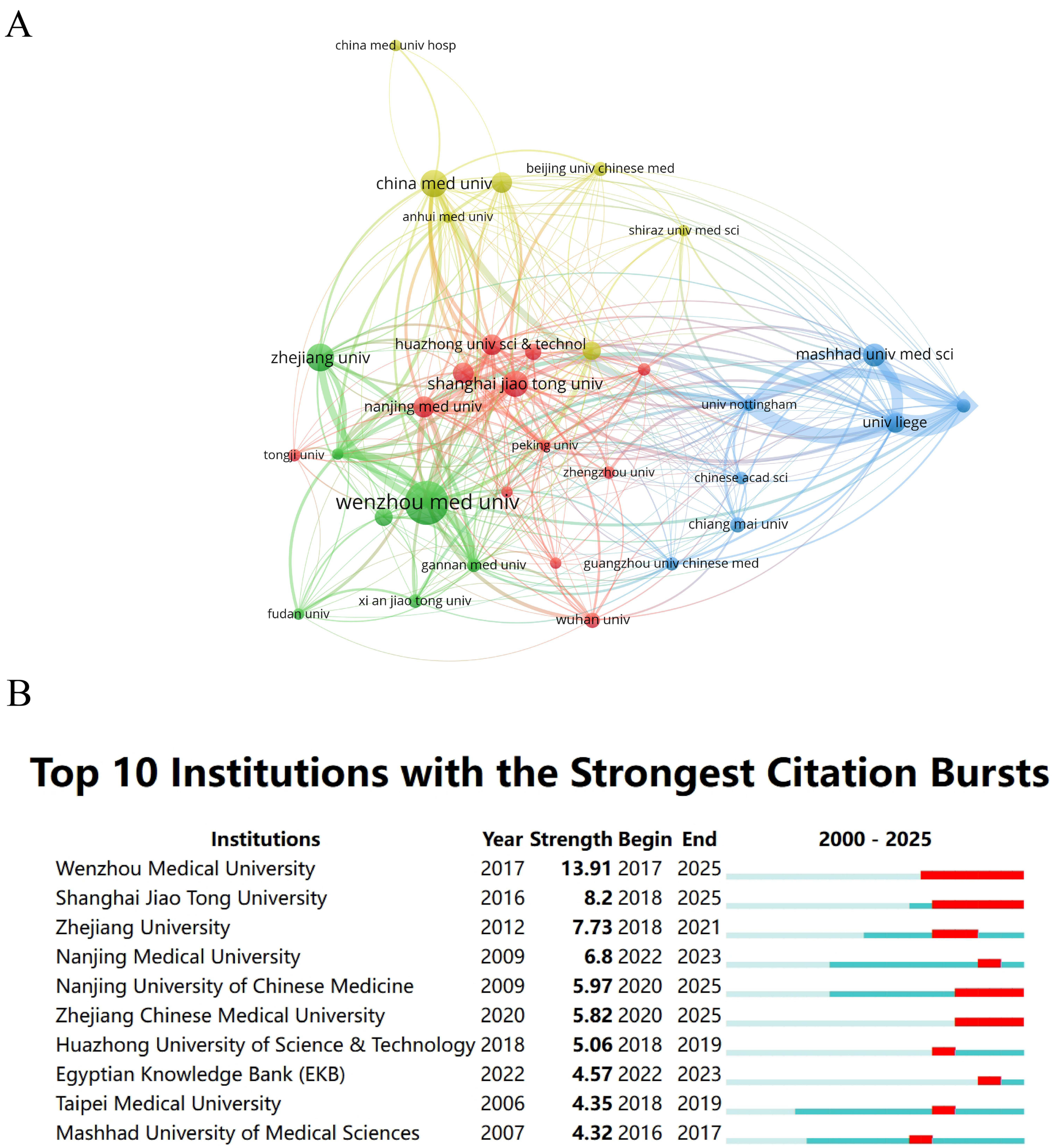

Figure 3 (**A**) A hierarchical clustering map showing research institutions based on co-citation networks. Clusters are color-coded, with thicker lines representing stronger collaborations and circle sizes corresponding to each institution's publication volume. (**B**) Citation bursts of the top ten institutions are shown, with red bars indicating periods of heightened citation impact. "Burst" signifies a sharp rise in attention, and "BurstBegin" and "BurstEnd" mark the beginning and end of these intervals, respectively.

figures in the field of polyphenols in OA and frequently engage in collaborative research. Their consistent output and close cooperation highlight their pivotal roles in driving progress in this research domain.

Citation burst analysis is a powerful method for evaluating the frequency at which an author is cited during specific time periods, reflecting their influence in a given academic field. Figure 4B highlights the top five authors with the most pronounced citation bursts in the field of polyphenols in OA. Notably, Haqqi, Tariq M saw a significant citation surge from 2009 to 2018, reaching a peak burst strength of 4.14. Moreover, he demonstrated the longest citation burst duration

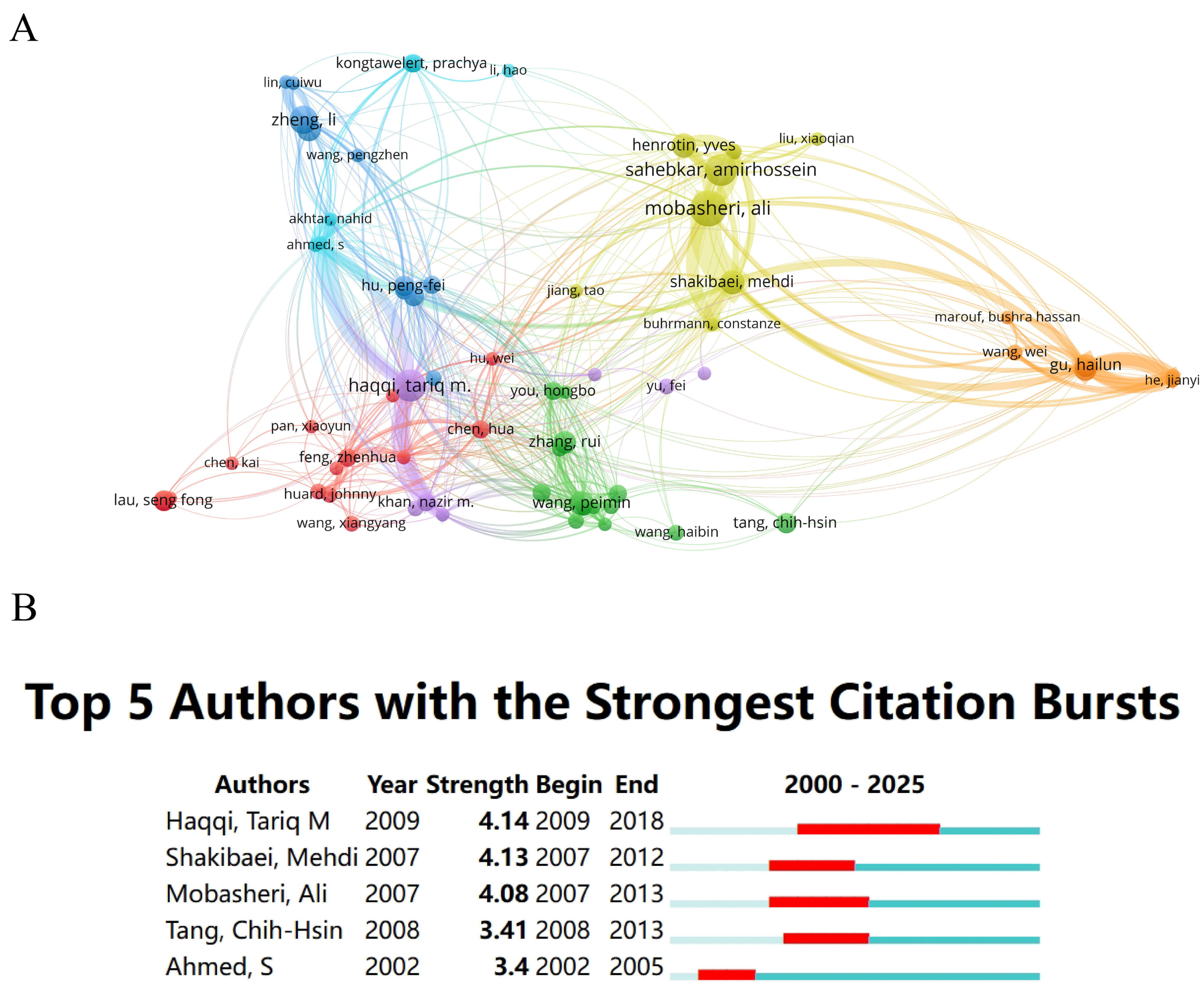

Figure 4 (**A**) Co-occurrence network of authors represented by labeled circles, color-coded to reflect distinct clusters. (**B**) The top ten authors with the strongest citation bursts in the field of "polyphenol applications in osteoarthritis". The term "Burst" denotes a rapid rise in research focus within a defined period, with "BurstBegin" and "BurstEnd" indicating the start and end of this increase, respectively.

—lasting a full 10 years—indicating sustained recognition of his contributions to the field. Ahmed, S was the earliest author to exhibit a citation burst, active between 2002 and 2005, suggesting his early involvement in this line of research. These citation bursts reveal promising directions for future studies, grounded in the foundational work of these leading scholars. By leveraging these insights, researchers can build on past achievements, pinpoint knowledge gaps, and expand the exploration of polyphenol applications in OA.

Journals, Disciplines, and Co-Citation Analysis

Journals and Associated Fields

The journal publication network visualization provides key insights into academic communication across 543 journals covering polyphenol research in OA. To accurately represent document distribution, a heat map based on a minimum threshold of five papers per journal was applied, with color intensity indicating publication volume (Figure 5A). This tool helps researchers identify suitable journals for submission. Frontiers in Pharmacology led with 36 articles and an average of 18.33 citations per paper, followed by International Journal of Molecular Sciences (31 papers, 17.61 citations) and International Immunopharmacology (29 papers, 31.55 citations). Among the top 10 journals by output, Biomedicine & Pharmacotherapy and Phytotherapy Research had the highest average citations per article, at 61.82 and 59.33,

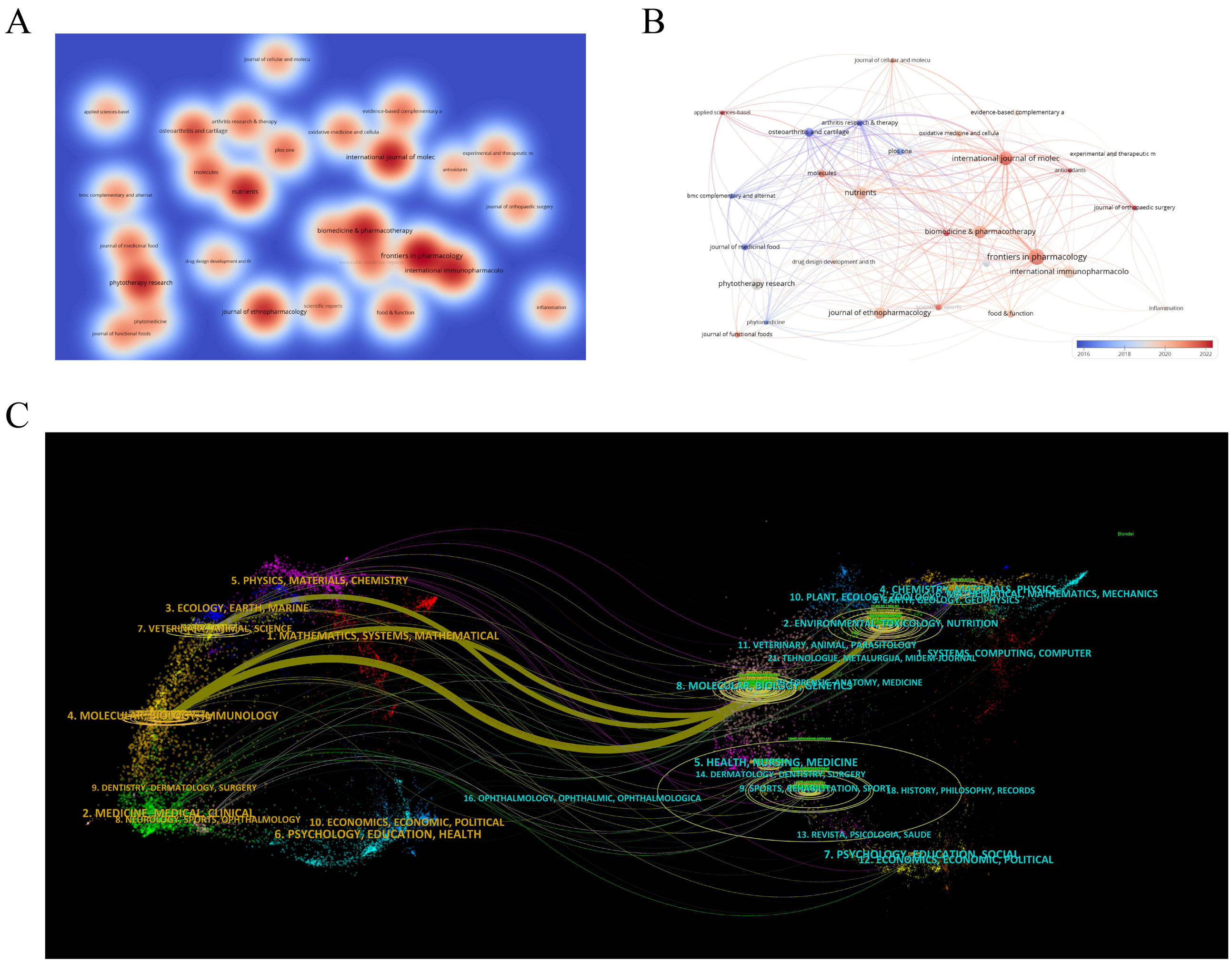

Figure 5 (**A**) Density heatmap illustrating journal citation frequencies, where color intensity corresponds to the volume of publications. (**B**) Journal distribution map based on average publication year, with blue indicating earlier and red indicating more recent publications; node size reflects keyword frequency, and the color gradient represents the publication period. (**C**) Dual-map overlay depicting citation networks among journals in polyphenol applications in osteoarthritis, with nodes representing journals and curved lines indicating citation relationships, emphasizing interdisciplinary connections and citation flows.

Notes: Journal of cellular and molecu (journal of cellular and molecular medicine); evidence-based complementary a (evidence-based complementary and alternative medicine); oxidative medicine and cellula (oxidative medicine and cellular longevity); experimental and therapeutic m (experimental and therapeutic medicine); international journal of molec (international journal of molecular sciences); international immunopharmacolo (international immunopharmacology); drug design development and the (drug design development and therapy); bmc complementary and alternat (bmc complementary and alternative medicine); journal of orthopaedic surgery (journal of orthopaedic surgery and research).

respectively, reflecting strong academic recognition for research in this field. However, citation counts should be viewed cautiously as they only quantify influence and may be skewed by practices like excessive self-citation aimed at inflating journal impact factors.[32,33] The academic community and research institutions are increasingly promoting responsible citation practices to uphold scientific integrity.

Figure 5B uses a color-coded scheme to show the average publication year for each journal, with each circle and label representing a journal node. The circle size reflects the number of publications, while the color—from blue to red—indicates the publication timeframe, with blue for older and red for more recent articles, as illustrated by the color scale at the bottom right. The data show that among the top 10 journals, Osteoarthritis and Cartilage and Phytotherapy Research have earlier average publication years, mostly before 2020. In contrast, articles in the field of "polyphenols in osteoarthritis" were more recently published, between 2020 and 2022, in journals such as Biomedicine & Pharmacotherapy, Food & Function, Frontiers in Pharmacology, International Immunopharmacology, International Journal of Molecular Sciences, Journal of Ethnopharmacology, Molecules, and Nutrients.

The dual-map overlay technique offers a clear visualization of evolving research hubs and journal classifications across academic fields.[34] The map labels represent the research areas covered by the articles. On the left are journals being cited, while on the right are journals citing them. Citation flows are shown by color-coded lines, with line thickness reflecting citation frequency based on z-scores.[22] This method highlights emerging trends and shifts in research focus, helping scholars adapt their priorities. As illustrated in Figure 5C, polyphenol research in OA spans multiple disciplines, including physics, materials science, chemistry, veterinary science, clinical medicine, molecular biology, and immunology. This interdisciplinary nature underscores the field's broad scientific impact by integrating diverse knowledge to tackle complex health issues. The citation patterns indicate growing momentum for polyphenol applications in OA across various domains, which could guide future research directions and innovations.

These insights are vital for stakeholders to strategically navigate the evolving field of polyphenol research in OA. They support the goal of maximizing research impact and translating scientific findings into improved health outcomes. Policymakers can use this data to understand research distribution, identify key journals, and guide funding and policy decisions. Awareness of emerging trends helps optimize resource allocation and focus on promising areas. For researchers, recognizing leading journals aids in targeting submissions effectively. By tracking citation trends and research themes, they can align their work with dominant topics and influential publication patterns. Industry players gain valuable understanding of active research areas and top journals, enabling Research and Development (R&D) teams to follow key interdisciplinary directions, foster innovation, and build collaborations with leading institutions in high-impact fields.

Co-Citation Analysis of References

Recognizing highly cited and influential publications helps researchers deepen their understanding and prioritize their work. Figure 6A presents a co-citation network of studies on polyphenols in OA from January 2000 to May 2025, analyzed via CiteSpace. The size of each sphere, arranged like tree rings, reflects co-citation frequency, with purple indicating earlier citations and red indicating more recent ones. Overlapping colors show citation periods. Lines between spheres represent co-citation links. The three most co-cited papers are Hunter (2019)[1] with 80 citations, Hu (2019)[35] with 45, and Ansari (2020)[10] with 44. Hunter (2019)[1] stands out for its high citation count, suggesting a central role in the network. Highlighting these key works allows researchers to grasp core concepts, track emerging trends, and target important future topics. The color overlaps also indicate that these publications maintain lasting influence over time.

The size of the overlapping spheres reflects the total co-citation strength over tree-ring-style timelines, with bigger spheres indicating more frequent co-citations. Color gradients reflect the citation timeline—purple denotes earlier citations, while red indicates more recent ones. The color overlaps illustrate the specific years during which articles were cited, and the connecting lines signify co-citation relationships between articles. CiteSpace evaluates the network's clustering performance using two key metrics: modularity (Q value) and silhouette score (S value). A Q value above 0.3 suggests a well-defined cluster structure, and an S value above 0.5 indicates high clustering reliability. In this analysis, the modularity is 0.6105 and the mean silhouette score is 0.8903, confirming both a significant and reliable clustering outcome. As shown in Figure 6B, the co-cited references are categorized into 14 clusters: #0 knee osteoarthritis, #1 oxidative stress, #2 meta-analysis, #3 NSAID, #4 expression, #5 interleukin-1 beta, #6 rheumatoid arthritis, #7 sulfation, #8 bone graft, #9 progression, #10 tissue inhibitor, #11 Th17 cell, #12 synergism, and #13 5-lipoxygenase.

The citation burst analysis of the top 10 publications on "polyphenols in osteoarthritis" from January 1, 2000, to May 1, 2025, was conducted using CiteSpace. A citation burst refers to a rapid rise in a publication's citation count over a certain period. Red segments mark the time frames when each article saw a notable spike in citations. As shown in Figure 6C, Hunter (2019)[1] exhibits the strongest citation burst, with an intensity of 29.62 during the period from 2020 to 2025. The top five references with the highest citation burst intensities are Hunter (2019),[1] Ansari (2020),[10] Panahi (2014),[36] Hu (2019),[35] and Haroyan (2018),[37] with burst intensities of 29.62, 20.25, 16.45, 14.77, and 14.77, respectively. The burst periods for all the top publications began after 2014, indicating that these papers have gained significant attention and become relatively popular in recent years within the field of "polyphenols in osteoarthritis". For researchers, detecting citation bursts provides important insights to refine their strategies and remain in step with emerging trends.

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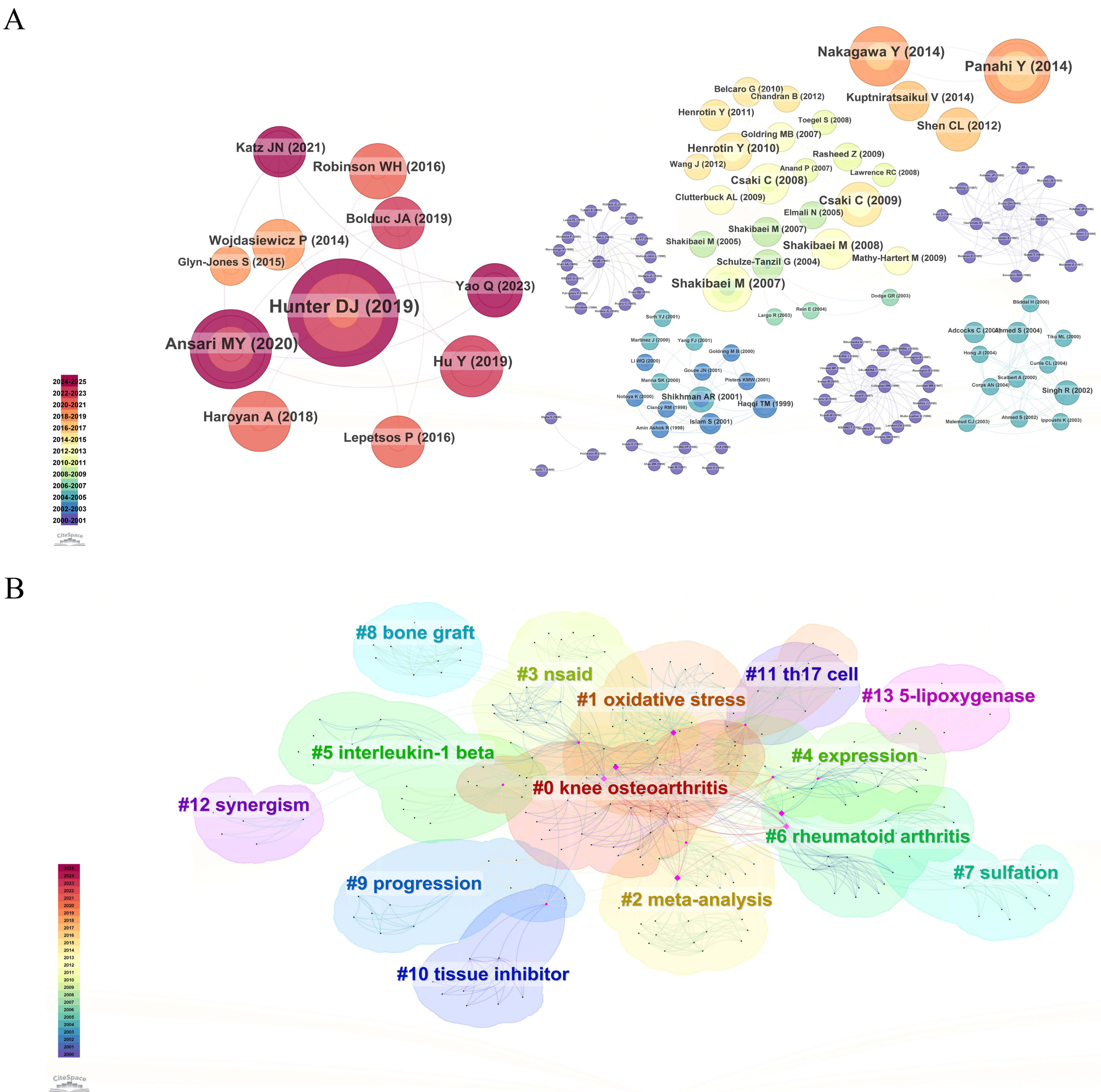

C

Top 10 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	2000 - 2025
Hunter DJ, 2019, LANCET, V393, P1745, DOI 10.1016/S0140-6736(19)30417-9, DOI	2019	**29.62**	2020	2025	
Ansari MY, 2020, BIOMED PHARMACOTHER, V129, P0, DOI 10.1016/j.biopha.2020.110452, DOI	2020	**20.25**	2022	2025	
Panahi Y, 2014, PHYTOTHER RES, V28, P1625, DOI 10.1002/ptr.5174, DOI	2014	**16.45**	2016	2019	
Hu Y, 2019, FREE RADICAL BIO MED, V145, P146, DOI 10.1016/j.freeradbiomed.2019.09.024, DOI	2019	**14.77**	2022	2023	
Haroyan A, 2018, BMC COMPLEM ALTERN M, V18, P0, DOI 10.1186/s12906-017-2062-z, DOI	2018	**14.77**	2020	2021	
Nakagawa Y, 2014, J ORTHOP SCI, V19, P933, DOI 10.1007/s00776-014-0633-0, DOI	2014	**14.05**	2016	2019	
Robinson WH, 2016, NAT REV RHEUMATOL, V12, P580, DOI 10.1038/nrrheum.2016.136, DOI	2016	**12.29**	2020	2021	
Wojdasiewicz P, 2014, MEDIAT INFLAMM, V2014, P0, DOI 10.1155/2014/561459, DOI	2014	**11.49**	2018	2019	
Lepetsos P, 2016, BBA-MOL BASIS DIS, V1862, P576, DOI 10.1016/j.bbadis.2016.01.003, DOI	2016	**11.07**	2020	2021	
Bolduc JA, 2019, FREE RADICAL BIO MED, V132, P73, DOI 10.1016/j.freeradbiomed.2018.08.038, DOI	2019	**10.62**	2022	2023	

Figure 6 (**A**) Co-citation network visualization featuring overlapping spheres that represent citations over specific years; sphere size corresponds to co-citation frequency. Early citations are colored purple, recent citations red, and blended hues indicate citations spanning multiple years. Lines connect co-cited papers, with key nodes highlighted in rose red. (**B**) Cluster map of co-cited literature where sphere size reflects annual citation counts and co-citation frequency. Colors follow the same pattern: purple for earlier, red for recent, and mixed shades for citations across time. (**C**) The top 20 references displaying significant citation bursts—periods of rapid increase in scholarly attention. "BurstBegin" and "BurstEnd" denote the start and end of these surges, respectively.

Concentrating on these emerging research areas helps scholars keep their work relevant and maximize its impact within the field of polyphenols in OA. This focused approach not only advances scientific progress but also improves the practical application of findings in clinical and policy settings. For industry professionals, analyzing citation and collaboration networks offers valuable guidance for investment decisions and innovation strategies. By staying aware of the latest trends, they can better capitalize on new opportunities and maintain a competitive advantage in the rapidly evolving field of polyphenol research in OA.

These research findings provide valuable guidance for stakeholders, promoting advancements in research, policy, and industry innovation concerning polyphenols in OA. Policymakers can leverage insights from collaboration patterns, citation networks, and bursts to pinpoint rapidly emerging areas that may require focused support or regulation, shaping health policies, funding decisions, and strategic plans. Researchers gain from identifying key publications and citation trends, enabling them to prioritize both foundational and novel topics that boost the significance and impact of their work. Similarly, industry professionals can utilize citation data and pivotal studies to steer R&D efforts toward technologies with strong clinical relevance and market potential, ensuring alignment with healthcare needs and business objectives.

Keywords

VOSviewer was used to conduct a keyword co-occurrence clustering analysis, extracting 5,335 unique keywords. Figure 7A presents the overlay visualization, where each circle represents a keyword—its size indicates frequency, and its color reflects the average year of appearance, ranging from blue (earlier) to yellow (more recent). Keywords like "osteoarthritis", "inflammation", "cartilage", "curcumin", "NF-kappa-B", and "chondrocytes" were most prominent between 2018 and 2020, suggesting these are emerging or intensifying areas of research.

Co-occurrence and citation burst analyses help researchers identify high-impact topics and potential collaboration opportunities in rapidly evolving fields. Figure 7B highlights the top ten keywords with the strongest citation bursts in "Polyphenol Research in Osteoarthritis" from January 1, 2000, to May 1, 2025, based on CiteSpace analysis. Red bars indicate the burst duration, alongside intensity, start, and end years. "Rheumatoid arthritis" showed the highest burst intensity (20.13) from 2009 to 2017, reflecting heightened interest during that period. "Gene expression" followed with a burst of 19.27 from 2012 to 2018, indicating growing attention to polyphenols' regulatory roles. Recent bursts in "oxidative stress", "apoptosis", and "inflammation" further emphasize increasing focus on the molecular mechanisms of OA.

Citation burst analysis is a powerful tool for identifying research frontiers. It guides researchers in selecting timely topics, helps policymakers target funding to high-potential areas, and enables industry professionals to align innovation strategies with current scientific priorities, enhancing both clinical impact and commercial relevance. Analyzing trends and key areas in polyphenol research related to OA is crucial for guiding funding decisions and fostering collaborations aligned with current research priorities. Figure 7C shows a timeline visualization of clustered keywords, where sphere size corresponds to keyword frequency, and connecting lines indicate co-occurrence. Colors range from purple (early) to red (recent), with overlapping hues marking periods of peak activity. Rose red nodes represent high-centrality keywords, underscoring their pivotal roles in the network. Keywords within each cluster appear on the same horizontal line, with their first appearance indicated near the top and progressing chronologically. The number of keywords per cluster reflects the importance of each research area. Fourteen clusters were identified, including #0 and #1 knee osteoarthritis, #2 meta-analysis, #3 NSAID, #4 expression, #5 interleukin-1 beta, #6 rheumatoid arthritis, and others. These findings offer valuable insights for researchers and industry stakeholders by revealing emerging directions and investment opportunities. The keyword analysis highlights evolving scientific focus areas, providing a foundation for shaping research agendas, informing policy, and aligning industry strategies with the field's most impactful developments.

Strengths and Limitations

Unlike previous studies that mainly used meta-analyses or narrative reviews, this research applies bibliometric methods to offer a more comprehensive and systematic understanding of evolving trends and key research areas in the field. As one of the first bibliometric analyses focused on "polyphenols in osteoarthritis", it presents a detailed knowledge

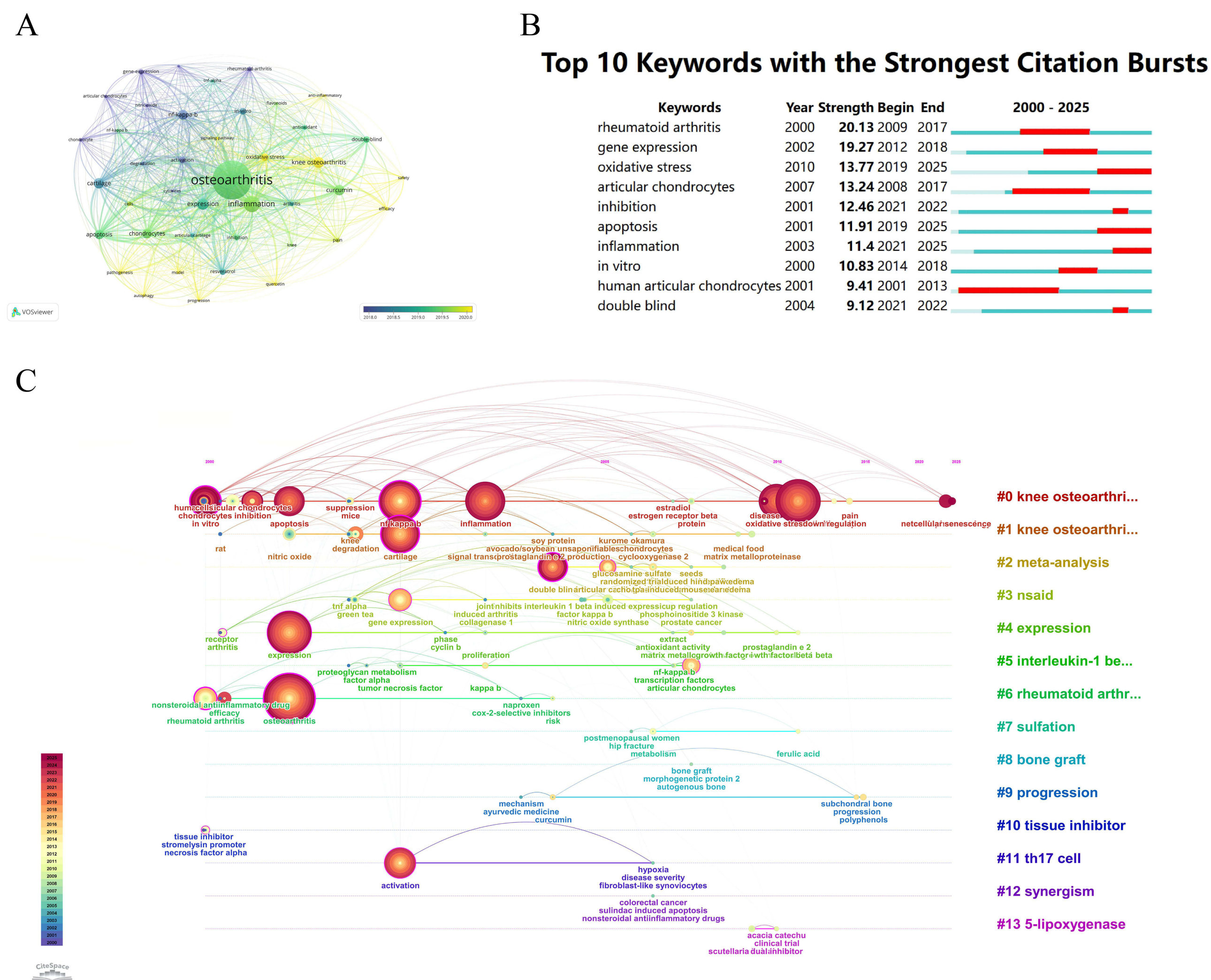

Figure 7 (**A**) Temporal map of keyword prominence, where node size reflects keyword frequency. The color gradient from purple to red indicates the transition from earlier to more recent keywords, highlighting emerging research trends. (**B**) The top 10 keywords with the strongest citation bursts identified by CiteSpace. A "burst" signifies a rapid rise in topic prominence, with "BurstBegin" and "BurstEnd" marking the start and end of this surge. (**C**) Timeline cluster analysis of keywords, with sphere size proportional to annual keyword frequency and connecting lines representing co-occurrence relationships. Colors correspond to time periods—purple for early, red for recent, and mixed shades for sustained relevance. Key central nodes are emphasized in rose red. Keywords within each cluster are arranged horizontally from earliest (left) to latest (right), illustrating their volume and temporal distribution, underscoring their significance and persistence.

Notes: Knee osteoarthri… (knee osteoarthritis); interleukin-1 be. (interleukin-1 beta); rheumatoid arthr. (rheumatoid arthritis).

framework. Despite certain limitations, the study serves as an objective reference to guide future research and advance progress in this area.

Several limitations deserve attention. First, the analysis relies solely on data from the WoSCC accessed via CiteSpace, which may cause selection bias and limit data coverage. The choice of database greatly affects bibliometric outcomes, especially in emerging fields. While Scopus offers broader coverage of engineering and regional journals, and PubMed focuses on biomedical literature, future studies would benefit from integrating multiple databases such as Scopus and PubMed for wider representation. Second, citation-based metrics used to assess publication influence can be influenced by confounding factors.[38] Including a large volume of publications may reduce the depth of analysis on specific studies or subtopics, impacting the overall detail of the results. Additionally, incorporating natural language processing (NLP) in bibliometric analyses may introduce bias.[39] The exclusive focus on English-language publications can also lead to publication bias.[30] Although English dominates scientific communication globally, incorporating multilingual databases such as China National Knowledge Infrastructure, SinoMed, Wanfang, and VIP would better capture regional and non-English research outputs. Another challenge is the potential omission of recent key studies or terms due to incomplete bibliographic data. Current bibliometric tools also struggle to accurately determine whether specific entities—like countries, institutions, or researchers—are truly engaged in polyphenol research related to OA or to precisely classify their research focus (eg, diseases, compounds, or applications). Methodological improvements are needed to enhance such granularity. Although keyword selection was carefully conducted, emerging terms may have been missed. Future analyses should adopt dynamic keyword strategies combining MeSH terms with AI-driven semantic techniques to better capture evolving terminology and interdisciplinary trends.[40] Finally, a major limitation of bibliometrics is its inability to track translational outcomes such as patents, clinical trials, or commercial applications. Academic databases like WoSCC primarily index peer-reviewed publications, while patent and clinical trial data are stored in separate repositories like the US Patent and Trademark Office and ClinicalTrials.gov. Though this study identified 1,436 publications on polyphenols in OA from 2000 to 2025, it could not assess how many led to patents or clinical trials. Future bibliometric research should integrate patent and clinical trial databases to offer a more complete view of translational impact.

Conclusion

This bibliometric study covering 2000 to 2025 highlights the growing academic interest and swift progress in the field of polyphenols research related to OA. China has become a dominant force in this area, showing a consistent rise in scientific contributions. Initially, studies focused on the antioxidant and anti-inflammatory effects of polyphenols, but the scope has since broadened to include their regulation of chondrocyte metabolism, suppression of synovial inflammation, reduction of oxidative stress and apoptosis, and more recently, modulation of ferroptosis pathways. These findings highlight the multi-targeted, low-toxicity nature and translational promise of polyphenols for OA therapy. Chinese research groups have driven this progress through multi-center collaborations and interdisciplinary approaches, advancing from compound screening and mechanistic exploration to drug delivery innovations.

These developments not only bolster the advancement of natural product-based OA treatments but also contribute to the modernization of traditional Chinese medicine and the progress of precision orthopedics. Looking ahead, researchers are encouraged to optimize the structural and pharmacological properties of polyphenols while integrating them with innovative delivery platforms—such as hydrogels and nanoparticles—to enhance applications in tissue repair and immune regulation. Policymakers should support the creation of integrated platforms for natural product screening, high-throughput analyses, and animal model testing to accelerate preclinical development. Meanwhile, industry efforts should emphasize sustainable sourcing, large-scale extraction, formulation refinement, and exploration of personalized OA treatments.

Future research priorities include: (1) multi-targeted regulation and systems biology approaches utilizing multi-omics to unravel polyphenols' systemic effects on OA's complex pathology; (2) co-development with advanced delivery systems—like pH-responsive carriers, hydrogels, and microneedles—to improve bioavailability and targeting; (3) standardized clinical translation pathways covering active ingredient isolation, formulation design, and pharmacokinetic/pharmacodynamic evaluation; and (4) fostering international collaboration and harmonization in natural product research, data sharing, and clinical trial protocols to accelerate industrialization and global adoption of polyphenol-based OA therapies.

By pursuing these forefront directions and aligning with global trends in natural product interventions for OA, polyphenols are positioned to play a crucial role in future integrative OA treatments, offering novel strategies that emphasize precision, sustainability, and therapeutic efficacy in OA management.

Data Sharing Statement

All the data used in this article are available from the corresponding author Fei Yu.

Author Contributions

Jian Weng and Fei Yu contributed equally to this work and share the last authorship. All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

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

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