Nanomaterials for cancer treatment: A scientometric analysis

Nanomateriales para el tratamiento del cáncer: un análisis cienciométrico

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Abstract

The use of nanomaterials has emerged as a potential tool in cancer therapy given their capacity to selectively target cancer cells, offering targeted drug delivery, reduced toxicity, and enhanced efficacy, which can improve survival and quality of life. However, there are overall challenges in the academic subject regarding biocompatibility and clinical translation. Ongoing research suggests that nanomaterials will contribute to improving cancer treatment in terms of viability and clinical trials. On the other hand, there is also a void in the scientometric aspect of this research field, as there are mostly experimental articles and a few reviews regarding the scientific and biological side of the field, which do not offer deep information about publication patterns, research hotspots, or collaboration networks typical of scientometric studies. Therefore, this work offers a scientometric analysis with valuable insights into the global picture of this field. To do this, databases like Web of Science (WoS) and Scopus were used, as well as the PRISMA algorithm workflow to analyze the search results. The results showed an overall accelerated production with a three-phase evolution going from emerging research focus (2015-2017) with a total of 113 papers (12.9% of total production), through consolidation and recognition (2018-2020) with 203 total papers (23.1% of total production), to high productivity and market maturity (2021-2022) reaching 220 total papers (25% of total production).

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*Artículo inédito: "Aporte técnico y ambiental a la gerencia integral de proyectos de obra en Boyacá con el uso de adoquines compuestos por materiales residuales".

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Research efforts mainly established in the Western-Eastern collaborations, mirrored by articles published in journals, and authors from countries such as China, USA, or India. In practical terms, the results could be used to give a vision of the optimum integration of nanomaterials, so the resources are strategically invested for cancer therapy in the years to come, as well as for further experimental research and efforts in clinical translation.

Keywords
Cancer, Nanomaterials, Treatment, Scientometrics, Networking, Collaboration

Resumen

El uso de nanomateriales ha surgido como una herramienta potencial en la terapia contra el cáncer dada su capacidad para dirigirse selectivamente a las células cancerosas, ofreciendo una administración dirigida de fármacos, toxicidad reducida y una eficacia mejorada, lo que puede mejorar la supervivencia y la calidad de vida. Sin embargo, existen desafíos generales en el ámbito académico con respecto a la biocompatibilidad y la traducción clínica. La investigación en curso sugiere que los nanomateriales contribuirán a mejorar el tratamiento del cáncer en términos de viabilidad y ensayos clínicos. Por otro lado, también existe un vacío en el aspecto cienciométrico de este campo de investigación, ya que en su mayoría hay artículos experimentales y pocas revisiones sobre el lado científico y biológico del campo, que no ofrecen información profunda sobre los patrones de publicación, los puntos clave de investigación o las redes de colaboración típicas de los estudios cienciométricos. Por lo tanto, este trabajo ofrece un análisis cienciométrico con valiosos conocimientos sobre el panorama global de este campo. Para ello, se utilizaron bases de datos como Web of Science (WoS) y Scopus, así como el flujo de trabajo del algoritmo PRISMA para analizar los resultados de la búsqueda. Los resultados mostraron una producción general acelerada con una evolución en tres fases que van desde el enfoque de investigación emergente (2015-2017) con un total de 113 artículos (12.9% de la producción total), pasando por la consolidación y el reconocimiento (2018-2020) con 203 artículos en total (23.1% de la producción total), hasta la alta productividad y madurez del mercado (2021-2022) alcanzando 220 artículos en total (25% de la producción total). Los esfuerzos de investigación se establecieron principalmente en las colaboraciones Occidente-Oriente, reflejadas en artículos publicados en revistas y autores de países como China, EE. UU. o India. En términos prácticos, los resultados podrían utilizarse para dar una visión de la integración óptima de los nanomateriales, de modo que los recursos se inviertan estratégicamente para la terapia contra el cáncer en los próximos años, así como para futuras investigaciones experimentales y esfuerzos en la traducción clínica.

Palabras clave: Cáncer, Nanomateriales, Tratamiento, Cienciometría, Networking, Colaboración

1. Introduction

The integration of nanomaterials is a highly promising and growing approach in modern cancer therapy [1]. They have emerged as promising tools in cancer therapy, offering targeted drug delivery, reduced toxicity, and enhanced efficacy, which can improve survival and quality of life [2], [3], [4]. Their ability to selectively target and specifically kill cancer cells makes nanomaterial-based approaches a significant advance in the treatment of various cancers, with ongoing research focusing on the optimization of nanoparticle design and clinical translation [5], [6]. These types of approaches are promising since traditional treatments such as surgery, chemotherapy, and radiotherapy, despite having increased overall survival, are often limited by recurrence, side effects, and incomplete tumor eradication [7], [4]. Combination therapies using nanomaterials—such as integrating chemotherapy with phototherapy or immunotherapy—are being developed to overcome resistance and recurrence, further improving survival prospects [2], [4]. While challenges remain, including biocompatibility and clinical translation, ongoing research suggests that nanomaterials will play a key role in advancing cancer treatment and improving survival rates across multiple cancer types [2], [4], [8].

Nanomaterial studies for cancer treatment, although on the rise, are likely to face certain specific challenges and pose certain specific opportunities. Studies from countries like Mexico [9], [10], Cuba [11], Brazil [12], [13], [14] and Chile [15], [16], have made contributions towards fundamental studies on the synthesis of various nanomaterials including magnetic nanoparticles and studying their *in vitro* and *in vivo* activity application against various cancers. These contributions represent the basis of regional experience and development of such technologies. However, there is a significant gap in the transfer of these encouraging preclinical results to mass clinical trials and conventional therapeutic use [17]. Regulatory hurdles, a lack of specialized manufacturing facilities, and inadequacies in large-scale clinical infrastructure generally hinder this crucial phase, at least in South America [18]. Most of this ongoing research is focused on material synthesis, characterization, and early *in vitro* testing, reflecting the scientific capability underlying, but showing that further advanced, translational studies are needed. This context brings about an important void, as there is a need for research that closes the gap between preliminary laboratory findings and clinically relevant findings. Such an investigation would not only contribute to the identification of novel data that is appropriate to the country-specific needs and patient populations but also be a significant step towards establishing a robust translational research pipeline for advanced cancer treatments.

On the other hand, while there are several comprehensive reviews on the use of nanomaterials for cancer treatment [19], [20], [21], [22], none of them specifically identify themselves as scientometric or bibliometric reviews, which systematically analyze publication trends, citation networks, or research impact in this field. As mentioned earlier, most available reviews focus on summarizing advances in nanomaterial types, mechanisms, and clinical translation challenges for cancer therapy, including discussions of functionalized nanomaterials, smart nanomaterials, and their roles in precision medicine, imaging, and drug delivery. These reviews highlight the rapid growth and diversity of research, the promise of nanomaterials for targeted and less toxic therapies, and the ongoing challenges in clinical translation and safety assessment. However, they do not provide quantitative analyses of publication patterns, research hotspots, or collaboration networks typical of scientometric studies. Therefore, the rising field of nanomaterials used in cancer treatment requires an urgent need for scientometric analysis to illuminate follow-up research and development.

This scientometric work offers valuable insights into the global situation of this area of research, mapping out areas of potentiality, potential gaps, and areas of investment. Knowledge of citation and co-authorship trends, for instance, particularly in terms of new methodologies, is crucial to drive clinical translation forward. Furthermore, a proper analysis of trends, as can be seen in recent research into stimuli-responsive nanomaterials for targeted therapy [23] or artificial intelligence application in nanomedicine for cancer [24], would allow researchers and policymakers to identify upcoming technologies and form interdisciplinary collaborations. It would not only reflect the state of the art today but also provide a vision of the use of nanomaterials so the resources could be utilized to the maximum for cancer therapy in the years to come [25], [26].

2. Methodology

This study employs a scientometric analysis to systematically map the intellectual structure, research trends, and collaboration patterns within the field of nanomaterials for cancer treatment. The methodology was designed to be transparent and reproducible, following a structured workflow from data collection to analysis. The primary databases for this review were WoS and Scopus, based on similar methodological approaches that have been adopted by other researchers who have utilized this databases to conduct comprehensive bibliometric analyses across various cancer nanotechnology domains [27], [28], [29], and selected for their comprehensive coverage of high-impact, peer-reviewed scientific literature and their widespread use in academic research [30].

The bibliographic search was conducted on April 3, 2025, covering a ten-year period from 2015 to 2025 to capture the most recent advancements in the field. The search was limited to documents classified as "Article" to focus on original research contributions. The query was constructed using the keywords "Nanomaterials" and "Cancer" within the title, abstract, and keyword fields to ensure a broad yet relevant retrieval of publications. The specific search parameters and the number of documents retrieved from each database are detailed in Table I.

Table I. Search parameter used in both Scopus and WoS databases.

Parameter	Web of Science	Scopus
Range	2015-2025	
Date	April 3, 2025	
Document Type	Article	
Words	Nanomaterials, Cancer	
Results	379	762
Total (Wos+Scopus)	879	

The data collection and filtering process followed the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement, as illustrated in the workflow diagram in Figure 1. The initial search yielded 379 articles from WoS and 762 from Scopus. These records were merged, and after removing 262 duplicate entries, a final dataset of 879 unique articles was established. This dataset underwent a preprocessing stage using part of the ToS tool that involved text mining and web scraping to standardize and clean the bibliographic information, including author names, affiliations, and citation data, resulting in a comprehensive master file for analysis [31].

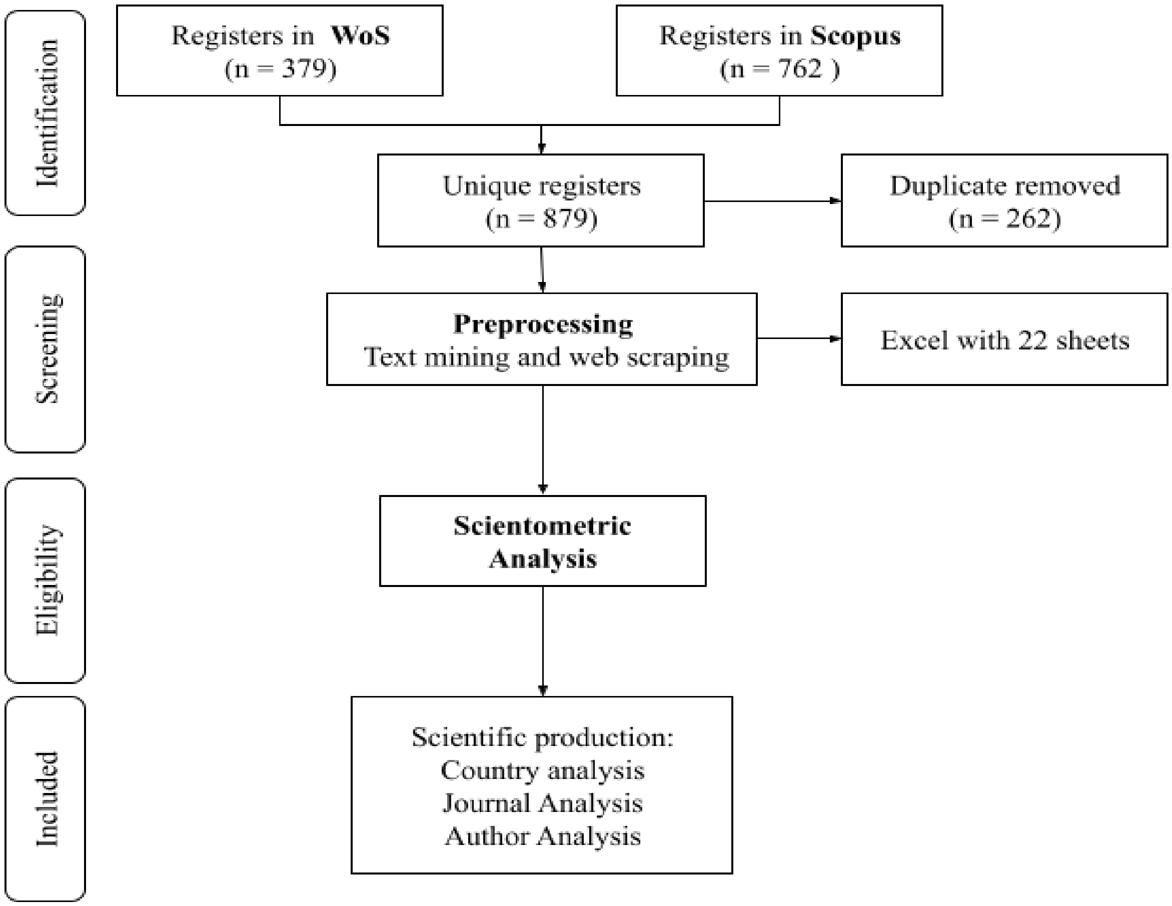

Figure 1. Scientometric search workflow according to the PRISMA algorithm

Once the search results from each database were obtained, the analysis was conducted in a quantitative scientometric analysis performed to evaluate scientific production and impact. This included examining publication trends over time and analyzing the contributions and collaborative networks of the most productive countries, journals, and authors. This approach provides a comprehensive overview of the evolution and current state of research on nanomaterials in cancer therapy.

3. Results

Annual Scientific Production

The overall trends in Figure 2 depict the oscillating output of publications, where the red line of "Total Publications" (not the sum of publications across databases) exhibits a comparatively oscillating but overall rising trend, reaching its highest point in 2022 and then dipping. It does show a dip in 2016 and 2019, but there was a strong growth between 2019 and 2022. By contrast, the purple line, which represents "Total Citations", indicates generally decreasing trends reflecting declining citations, especially following a peak in 2020. It further indicates a sharp decrease in citations for 2023, 2024, and most of all 2025, yet this is typical with recent scientific studies because most papers experience a rise in citations for a few years post-publication, peaking and then declining—a process known as "attention decay" [32]. This decline is becoming faster over time, largely because the number of new papers is growing rapidly, making it harder for any single study to maintain attention. The rate of decay is more closely tied to the number of new publications than to the passage of time itself [33]. The decrease in citation rates over time does not necessarily mean a paper is obsolete or unimportant; it is a typical pattern observed across disciplines [34], [35]. Also, the topic of *Nanomaterials applied in cancer treatment* may be worth watching for a turning point since the 2022 peak of publications, which might indicate an intense level of research interest, but the dip that followed could indicate saturation of some research streams or diversion of interest to other streams of research within nanomaterials or cancer treatment.

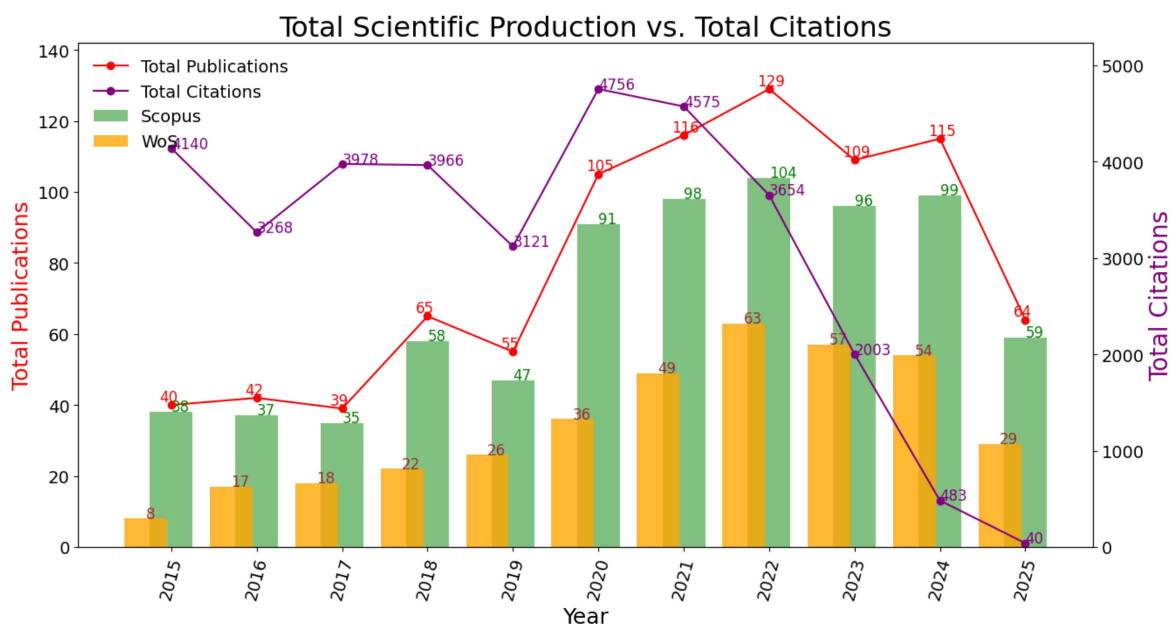

Figure 2. Annual and total scientific production by database

Throughout the decade, the frequent dominance in quantity of published works of Scopus (green bars) over WoS (orange bars), demonstrates a clear preference or wider inclusion of relevant journals in the Scopus database for this specific research area, and the difference between the rising number of published works (up to 2022) and falling number of citations (after 2020) could be a cause for concern over the mean quality or close-on effect of the increasing number of published works. Yet again, as mentioned earlier, the recency factor is pivotal, and thus the estimated tendencies for 2025 must be taken with caution, considering that the noticeable decline in publications and citations could be an initial estimate or perhaps indicate a slowing pace of research work in this niche.

More specifically, the scientific production demonstrates a three-phase evolution pattern commonly observed in emerging research areas, with each phase characterized by a distinct research focus and citation dynamics.

Phase 1: Emerging Research Focus (2015-2017)

This period spans from 2015 to 2017, during which 113 articles were published, representing 12.9% of the total output. During these years, scientific production was modest but steady, showing consistent growth as the field established its theoretical foundations. The most cited article from this period is Shen et al. [36], which introduced the revolutionary concept of switching from traditional apoptosis to ferroptosis through metal-organic networks, leveraging p53-mediated oxidative stress regulation and Fenton reactions for high-efficiency anticancer therapy.

Another pivotal work from this phase includes foundational studies on graphene-based biosensors and purpurin-peptide conjugates that established key methodological frameworks for nanomaterial synthesis and characterization. This study marked a paradigm shift in cancer cell death mechanisms and established ferroptosis as a viable therapeutic target. Taken together, this stage laid the groundwork for advanced nanomedicine approaches, marking the beginning of sophisticated therapeutic mechanism exploration in nanomaterials-based cancer treatment.

Phase 2: Research Consolidation and Recognition (2018-2020)

Between 2018 and 2020, 203 articles were published, representing 23.1% of total production. This period experienced initial growth followed by consolidation dynamics, with 2019 showing a temporary dip before strong recovery in 2020. The most cited article during this period is Jiang et al. [37], which established the foundation for dual-peak near-infrared photothermal therapy by demonstrating superior therapeutic potential of the second NIR window (1000-1700 nm) compared to the conventional first NIR window (650-950 nm), achieving enhanced tissue penetration and reduced photon scattering for cancer treatment.

The second most influential work is Liu et al. [38], which pioneered the use of self-assembling endogenous biliverdin as a versatile near-infrared photothermal nanoagent for cancer theragnostic, addressing critical clinical translation challenges by leveraging naturally occurring biomolecules for multimodal imaging and therapeutic functions. This research represented a crucial shift toward biocompatible nanomaterials with enhanced clinical applicability. This consolidation period established nanomedicine as a mature research discipline with clear therapeutic applications and clinical translation pathways.

Phase 3: High Productivity and Market Maturity (2021-2022)

From 2021 to 2022, 220 articles were published, representing 25.0% of total output and demonstrating the field's transition to high-productivity research. Annual production consistently exceeded 100 articles, peaking in 2022 with 116 publications, indicating intense research activity driven by regulatory approvals and clinical breakthrough developments. The most cited article from this period is Tang et al. [39], which demonstrated how glutathione depletion enhances ROS-based therapy, ferroptosis, and chemotherapy by targeting cellular antioxidative systems, representing a sophisticated understanding of cancer cell resistance mechanisms and multi-modal therapeutic enhancement.

The high citation density during this brief but productive period demonstrates the maturation of nanomedicine toward clinically translatable technologies. This phase reflects the field's evolution from fundamental discovery to application-focused research, establishing nanomaterials in cancer treatment as a mature discipline with clear clinical implementation pathways.

The divergent trajectories between publication volume and citation impact after 2020 reflect field specialization rather than declining relevance. The sustained high citations of breakthrough studies across all phases indicate that core innovations continue to drive research directions, while the proliferation of publications likely reflect diversification into specialized applications and clinical implementation studies. This pattern suggests healthy research maturation where emphasis shifts from discovery to optimization and clinical translation, requiring new metrics beyond traditional bibliometric measures to assess scientific and societal impact.

Country Analysis

A landscape dominated by some nations that are driving the research for nanomaterials in cancer therapy is detailed in Table II. It provides a comprehensive overview of national contributions by quantifying production in terms of total article count and percentage, impact with total citations and percentage, and quality through distribution of publications across journal quartiles Q1-Q4.

Table II. Scientific production and impact by country

Country	Production		Citation		Quality			
	Count	%	Count	%	Q1	Q2	Q3	Q4
China	408	44.3	12380	43.59	276	34	13	22
Usa	92	9.99	3921	13.81	71	5	2	2
India	87	9.45	2052	7.23	39	20	8	4
Italy	38	4.13	1059	3.73	24	9	0	0
Korea	29	3.15	1310	4.61	19	7	1	0
Brazil	18	1.95	339	1.19	13	3	1	0
Iran	16	1.74	361	1.27	5	3	1	2
France	14	1.52	530	1.87	10	0	0	0
Portugal	14	1.52	285	1.0	13	1	0	0
Poland	13	1.41	150	0.53	8	3	0	0

China stands as the leader in the metrics. Chinese researchers have published 408 articles, making up 44.3% of the total publications in the field. This count is mirrored by its impact as Chinese studies have been cited 12,380 times, with 43.59% of all citations. Secondly, the quality of its production is very high, since 276 of its publications are in high-quality (Q1) journals, indicating highly influential research. The United States follows with a count of 92 publications (9.99%), and even though its production is less than a quarter of China, its research remains highly impactful with 3,921 citations (13.81%) and a great record of high-impact research, with 71 out of 92 articles being published in Q1 journals.

India completes the top three of production, with 87 articles (9.45%) and 2,052 citations (7.23%), which reflects a decent research presence with a considerable number of publications (39) in Q1 journals. Some other countries, such as Korea, Italy, and Brazil, also make notable contributions on a smaller scale. For instance, Italy has authored 38 Q1 articles, and Korea has a high citation impact relative to the number of publications. This distribution indicates a global effort in research highly concentrated in Asia and North America, underlining the crucial role these trend-setting countries must play in advancing the field.

Similarly, Figure 3 illustrates schematically how scientometric tools can portray the map of a specific research field, revealing main actors, their relations, and time trends, crucial for planning policy and research funding. China, USA, and India are clearly the leading nations in collaborative activity within nanomaterials in cancer therapy. They are significant hubs that link dozens of other countries. Regarding structural community, research collaborations are not entirely random because they form different communities most likely based on geographical location, shared scientific interests, funding initiatives, or previous affiliations, for instance, the ubiquitous dominance of Community 1 (blue) is indicative of a general Western-Eastern collaborative axis, and the same applies to the other communities.

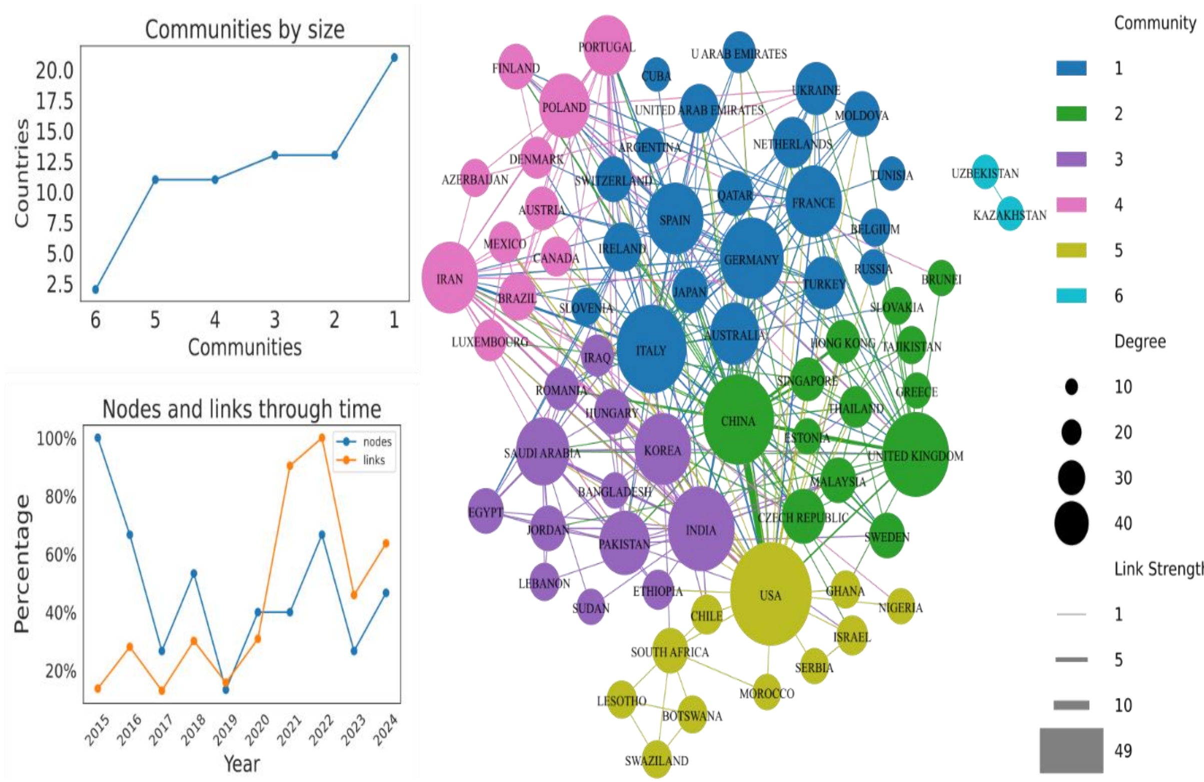

Figure 3. Global collaboration network

Just to mention some of the advances in the subject of nanomaterials in cancer treatment in some of the main countries, one study in China found that Zinc-iron-based nanomaterials synthesized via Prussian blue analogs show high drug loading capacity of Capsaicin and Tetracycline, controlled release 86.3% and 90% in PBS respectively, and strong antibacterial and anticancer effects, with promising safety profiles. These features position them as valuable candidates for future medical and pharmaceutical applications, especially in targeted drug delivery and combination therapies [40]. Another study in the United States (USA) provided a detailed, real-time view of how RNA-liposome nanoparticles assemble, revealing a two-step process influenced by RNA orientation. The researchers used multi-color fluorescence microscopy to observe the assembly of RNA and liposomes simultaneously, allowing for real-time, high-throughput, and model-independent tracking of the process. The imaging method used can be applied to study other complex nanomaterial assemblies, potentially advancing the design of more effective nanoparticle-based therapies [41].

In Brazil, researchers developed novel nanostructures by biofunctionalizing chitosan, a biocompatible polymer, with antibodies targeting CD19 and CD20—proteins commonly overexpressed on NHL (B-cell non-Hodgkin lymphoma) cells, a common and aggressive blood cancer that can invade the central nervous system, making diagnosis and treatment challenging. These nanoconjugates also incorporate fluorescent quantum dots, which act as fluorescent probes for bioimaging and as immunotherapeutic agents, selectively killing NHL cells while sparing healthy cells, allowing them to serve both as imaging agents for tracking or diagnosis, and targeted therapies [42].

Journal Analysis

The subject of nanomaterials for cancer treatment is mostly published in a small set of high-impact journals listed in Table III. Out of the ten most cited journals, all ten are classified in Quartile 1 (Q1), i.e., they constitute 25% of top-notch journals in their respective field with regard to parameters like impact factor, citation rate, and overall standing. Attention within the journals validates the impression that research into nanomaterials for cancer therapy is of high scientific relevance and quality.

Table III. Scientific production by leading journals

Journal	Wos	Scopus	Total	ISSN	SJR	Quartil	H-Index
Acs Applied Materials And Interfaces	0	49	49	19448244, 19448252	1.921	Q1	334
Acs Nano	22	24	28	19360851, 1936086X	4.497	Q1	504
Biomaterials	19	20	27	01429612, 18785905	2.998	Q1	451
Advanced Materials	17	21	24	09359648, 15214095	8.851	Q1	675
Nanomaterials	23	18	24	20794991	0.811	Q1	151
International Journal Of Nanomedicine	0	20	20	11769114, 11782013	1.306	Q1	193
Advanced Functional Materials	16	17	20	1616301X	5.439	Q1	428
Small	10	18	20	16136810, 16136829	3.301	Q1	313
Advanced Healthcare Materials	11	14	18	21922640, 21922659	2.328	Q1	159
Biosensors And Bioelectronics	0	16	16	09565663, 18734235	2.007	Q1	254

ACS Applied Materials & Interfaces, focusing on the real-world application of new materials, is the publication leader with 49 articles. A sample study shows the use of fluorescent covalent organic frameworks with highly conjugated structures for combined starvation and gas therapy approaches [43], showing evidence of the emphasis of the journal on new methods of therapeutic delivery. Ranking next to *ACS Applied Materials and Interfaces*, are journals like *ACS Nano* (28 articles) and *Biomaterials* (27 articles). *ACS Nano* is a top journal for emerging nanotechnology, publishing advanced and innovative systems like supramolecular aggregation-induced emission nanodots with programmed tumor microenvironment responsiveness for image-guided orthotopic pancreatic cancer therapy [44]. Similarly, *Biomaterials* is a top journal for materials in biological interaction, publishing articles with subjects like harnessing nanomaterials for copper-induced cell death [45], highlighting its focus on biocompatible and bio-inspired treatment systems.

In terms of scholarly influence, *Advanced Materials* stands as the top journal with an H-Index of 675 and the most superior SJR of 8.851, although it has the least number of publications with 24 articles. It is renowned for publishing pioneering research, such as the development of nanomaterial-based organelles that protect normal cells against chemotherapy-induced cytotoxicity [46]. Similarly, *Advanced Functional Materials* (H-Index 428) stands out for its focus on "smart" materials with outstanding research involving engineering DNA-grafted quatsomes as stable nucleic acid-responsive fluorescent nanovesicles [47].

Similar leading journals play equally crucial roles, e.g., *The International Journal of Nanomedicine* (20 articles), whose area of specialty is translational research with emphasis on systems like acid-unlocked two-layer Ca-loaded nanoplatforms to interfere with mitochondria for synergistic tumor therapy [48]. *Nanomaterials* (24 articles) is a broad platform for the field, often reporting on facile photochemical syntheses of conjoined nanotwin gold-silver particles within biologically-benign chitosan polymers [49] [50]. Finally, journals like *Small* and *Advanced Healthcare Materials* on key areas such as nanoparticle-based nanomedicines to promote cancer immunotherapy [51] and supramolecular nanofibers of drug-peptide amphiphile and affibody systems that suppress HER2-tumor growth [52], respectively. *Biosensors and Bioelectronics* is leading the field in diagnostics with peptide-based fluorescent probes for tumor diagnosis and image-guided surgery [53].

The H-Index in the table is a robust indicator of long-term scientific influence, and *Advanced Materials* (675), *ACS Nano* (504), *Biomaterials* (451), and *Advanced Functional Materials* (428) possess the highest H-Index, meaning that they lead in the core knowledge area of this subject. Due to their frequent publication and highly cited articles, they are the most influential and high-profile journals for nanomaterials in cancer treatment research.

This list of core high-impact journals, that are at the forefront of publishing research on nanomaterials for cancer treatment, top-level journals in nanoscience, materials science, chemistry, and biomedicine, is graphically shown in Figure 4. There are also several communities, from general nanotechnology to biomaterials to medical/cancer-specific journals, indicating the interdisciplinary nature of this area of research, where researchers from a wide range of backgrounds publish in this area. The very connected network with numerous thick links indicates dense co-citation patterns and a highly networked body of literature, which is indicative of extensive cross-referencing and collaboration among authors who publish in these journals.

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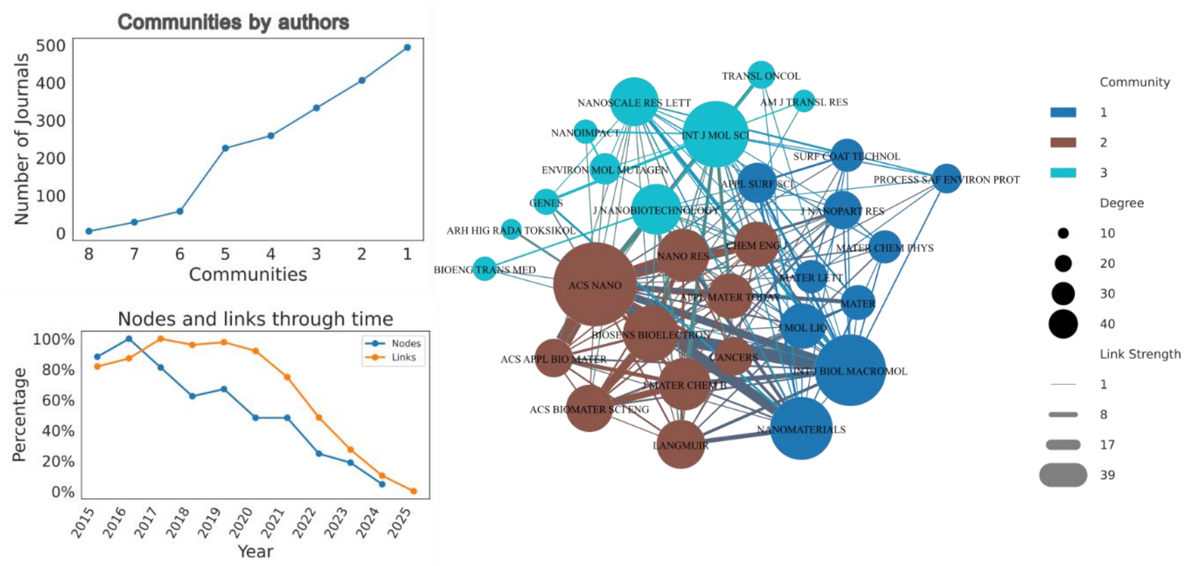

Figure 4. Network of the principal journals in the field of nanomaterials for cancer treatment

It is also of interest to observe that the most striking feature of the "Nodes and links through time" plot is the drastic decline in nodes and links from 2018 to 2025. This is highly atypical for an emerging and active research field like nanomaterials for cancer treatment. It is extremely suggestive of a data artifact, i.e., lack of data for current years, in which the data set might not be complete for current years (i.e., 2022-2025), which would lead to underrepresentation of current journals and their connections. A second cause for this is a filtering criteria change, where the procedure for selecting journals or the meaning of "active" might have changed, leading to a reduction in the set included. While the journal network provides a helpful picture of the key publication venues and their interconnections in nanomaterials for cancer treatment, the temporal trend plot must be viewed carefully. The plot is as likely to reflect data limitations as it is to signify an actual decline in either the extent or collaborative intensity of the field.

Author Analysis

Table IV provides a general idea of the top authors in the field of *Nanomaterials for cancer treatment* with their respective strengths in terms of productivity, impact, and collaborative research approach. Considering the overall productivity and impact, there is high productivity, high citation numbers, and a favorable H-Index. All authors mentioned have remarkable contributions to the field, with a total of papers between 26 and 44, indicating a very active and productive field of study. LIU Y stands out as the first author with the highest number of papers (44) as a metric of prolific publishing. The total citations column indicates the research activities of the authors as highly cited between 741 and 1607. This indicates their high influence and impact on the research community. ZHANG X has the highest total citations (1607), reflecting that their work has had the highest impact and visibility. WANG X (1162) and LIU X (1154) have very high totals of citations as well. Their "H-Index," measuring productivity alongside citation impact [54], is between 13 and 19, further solidifying their position as outstanding researchers in this area. LIU X has the highest H-Index of 19, which reflects a very good balance of productivity and highly cited papers. Following with LIU X, LIU Y (18) and LI Y (17) having very robust H-indices.

Table IV. Principal authors in *Nanomaterials for cancer treatment* subject

Author	Papers Total	Total Citations	H-Index	Network Size	Effective Size	Constraint	CDI
Liu Y	44	1026	18	2165	2067.54	0.002645	0.010157
Li Y	40	1153	17	2165	2063.91	0.002598	0.009796
Wang Y	37	1091	16	2575	2480.90	0.002285	0.010515
Wang X	36	1162	16	2014	1913.29	0.002795	0.009832
Liu X	35	1154	19	1617	1516.88	0.00332	0.009889
Zhang Y	34	1214	16	2578	2487.86	0.002254	0.010972
Zhang X	31	1607	16	1924	1815.76	0.002933	0.009154
Chen X	27	893	14	1587	1482.70	0.003383	0.009497
Wang J	27	962	15	2131	2035.23	0.002663	0.010334
Wang Z	26	741	13	1587	1484.406427	0.003378	0.009653

The following metrics provide a hint at the coauthoring behaviors of the authors. In terms of network size, or the number of unique collaborators one has [55], WANG Y and ZHANG Y have the largest network sizes (2575 and 2578 respectively), which means they coauthored with a very big team of researchers. This can be beneficial to interdisciplinarity and broader exposure of work. In general terms, the range of network sizes is quite broad (1587 to 2578), reflecting the differing cooperative styles of these top writers. On the other hand, the effective size shows the non-overlapping ties in the network of an author, and this represents the richness of various sources of different information that can be accessed by an author [56] as it can be noticed with WANG Y (2480.90) and ZHANG Y (2487.86) having the largest effective sizes, which indicate their ability to connect various research communities and access various knowledge. A greater effective size, as shown here, goes along with more creative studies and being introduced to new ideas.

Furthermore, the constraint column refers to the extent to which a network of an author is "constrained" by overlapping ties (e.g., working repeatedly with the same people) [57], therefore a smaller constraint will signify a broader and more varied network. This is confirmed with WANG Y (0.002285) and ZHANG Y (0.002254) having the smallest constraint values, which corresponds with their effective size numbers. This indicates they are successfully utilizing varied connections instead of being trapped in highly redundant collaborative loops. In contrast, LIU X (0.00332), CHEN X (0.003383), and WANG Z (0.003378) have comparatively higher constraint values, which may indicate their collaborations are more focused within specific groups.

The last measure, "CDI" (Cognitive Diversity Index), quantifies the diversity of research topics or perspectives an author publishes on [58]. Though the scale is limited, minor fluctuations can still be meaningful in such an index. For example, even if ZHANG Y has the highest CDI (0.010972), indicating that they are doing more topics of sub-topics of nanomaterials in combating cancer, ZHANG X has the lowest CDI (0.009154), revealing that they have a more specialized research topic in the area.

There is an equilibrium between quantity and influence, as LIU Y has the highest number of papers and ZHANG X has the highest number of citations. This serves to indicate that high output does not necessarily translate into the maximum citation rate and vice versa, as it can be impacted by fewer, very influential papers. It is also worth noting that between network and H-Index, there is no linear proportion, for example, WANG Y has a very large and powerful network but an H-index of 16, while LIU X has a less large network but the maximum H-index of 19. This suggests diversified strategies to create impact, some authors may shine at large-scale collaboration, while others may focus on deep, specialty inputs in a small network. Lastly, top-cited scholars with high H-indices and large/influential networks (ZHANG X, LIU X, WANG Y, ZHANG Y) will likely be the trendsetters and leaders that establish future directions.

Conclusions

The field of nanomaterials in cancer treatment has seen noticeable global progress, marked by rapid growth in the rate of publications since 2015. This progress is a three-stage development with an early nascent research focus (2015-2017), setting theoretical foundations, an intermediate period of research standardization and acclaim (2018-2020) with important milestones, and a phase of high productivity and market maturity (2021-2022) driven by regulatory approvals and clinical breakthroughs. Leading nations like China, the USA, and India have dominated scientific production and citation impact, and a huge proportion of their publications are in the leading Q1 rank of journals. This science is predominantly published in a small group of high-impact Q1 journals, such as *ACS Applied Materials & Interfaces*, *ACS Nano*, and *Biomaterials*, attesting to the scientific importance and excellence of the field.

Despite this overall progress and high productivity in the field, there are voids in publication trends, frontier research, and coauthorship networks systematically, since there is an overall post-2020 trend of citations diminution. This behavior is associated with "attention decay" since this field is rapidly evolving, which can be problematic to the long-term impact of single studies among a deluge of new publications. Also, differences in high output and citation rates, or network size and H-index of the principal authors, suggest varied strategies for impact and reveal that high output is not necessarily accompanied by the highest citation rates.

For the future, research opportunities lie in strategic investments, which can synchronize international cooperation and concentrate research in areas with developing potential, since cancer is an international public health concern. While the familiarity of Western-Eastern collaborations is high, research support needs to be augmented in developing nations with incipient scientific capabilities, such as in Latin America, to make the global research environment more diverse and balanced. It entails support for research into material synthesis, characterization, and preliminary *in vitro* studies to fill the gap between proof-of-concept laboratory findings and clinically useful findings. It will also be crucial to find and enable high-cited scientists with high H-indices and extensive networks, as they would be the trendsetters to guide the future of nanomaterials in cancer therapy.

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