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NANOCAGE MOLECULES: A COMPREHENSIVE BIBLIOMETRIC ANALYSIS OF THE APPLICATIONS OF NANOCAGE TECHNOLOGIES IN CONTEMPORARY RESEARCH

Riska Cindi Yustiarini[1*]

[1] Department of Chemistry, UIN Sunan Gunung Djati Bandung, Indonesia
Email: riskacindi25@gmail.com

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Abstract:

The burgeoning field of nanotechnology has experienced a surge of interest in nanocages, fullerene-like molecular structures with hollow interiors and internal cavities that offer unique containment properties. To elucidate the current landscape of this field, we conducted a comprehensive bibliometric review of nanocage applications. Quantitative variables were analyzed using Vosviewer, and a thorough literature search on Scopus yielded 1,418 articles, which were refined to 223 relevant publications. Our findings indicate that China leads in the volume of nanocage-related research publications, while the United States stands out as the most collaborative country. 'Adsorption' emerged as the most frequently used keyword in nanocage applications. Ayub, K. was identified as the most prolific author, and the Chemical Engineering Journal ranked as the top journal in terms of the number of articles published. The peak year for publications on nanocage technology applications was 2022, with 48 publications, and the Ministry of Education of the People's Republic of China was the leading contributing institution. These results highlight knowledge gaps and emerging trends, emphasizing the potential of nanocages to address significant global challenges.

Keywords:

Application, Adsorption, Bibliometric, Fullerene-Like, Nanocages.

Introduction

The idea of nanocages has become an interesting field for research and development in the field of nanotechnology (Malik, Muhammad, & Waheed, 2023). In the field of nanotechnology, the word "nanocages," which comes from the fullerene family of carbon-based nanomaterials,

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has become well-known for its versatility and enormous potential in a wide range of scientific and technological applications. Nanocage has become important since it describes a wide range of nanostructures that are distinguished by their tiny hollow, cage-like designs (Saleh & Hassan, 2023). These structures, which bear a resemblance to molecular cages, display exceptional properties and functionalities that have great potential for a wide range of scientific and engineering applications. With their limited areas, nanocages provide a special substrate for enclosing visitor molecules, giving exquisite control over chemical reactivity and interactions. Since the 1980s, when fullerene molecules were discovered, the idea of nanocages has expanded to include a wide range of materials other than carbon-based structures (Zaytseva & Neumann, 2016). Applications ranging from energy storage and sensing to medicine delivery and catalysis show promise for these nanoscopic frameworks. Their customizable characteristics, including size, shape, and surface chemistry, also make them extremely adaptable for a wide range of uses, including sensing, imaging, drug administration, and catalysis.

Although there has been a lot of progress and growing interest in nanocage materials, there is still a considerable research gap in the sector due to the comparatively limited study and use of these nanostructures. Although there is widespread recognition of the promise of nanocages for a range of applications, including drug administration, catalysis, and sensing, there are a number of obstacles that prevent theoretical ideas from being put into practice. The present status of research indicates a deficiency of thorough knowledge concerning the synthesis, characterisation, and modification of nanocages to customize their characteristics for particular uses. Furthermore, major obstacles stand in the way of the general adoption and industrial feasibility of nanocage production techniques due to their scalability and reproducibility. The current state of research highlights the vital need for methodical studies meant to close the gap between basic science and practical applications of nanocage materials, thus realizing their full potential and promoting innovation across a range of technological fields.

In recent years, bibliometric analysis has become incredibly popular in business research (Kumar, Lim, Pandey, & Christopher Westland, 2021). We begin a scholarly investigation driven by empirical data and quantitative reasoning with this introduction to bibliometric analysis as a mathematical and statistical undertaking. The aim of this paper to analyze about the trend in all related to bibliometrical analysis about the application of nanocage. The specific research questions of this study are the follows:

1. How is the global trend and citation on board diversity?
2. What is the country's contribution and collaboration in nanocage technology?
3. What is the popular institution’s contribution in nanocage technology?
4. Which the authors and journal with greatest contribution in nanocage technology?
5. What is the most common application that adapted in nanocage?

Key issues in nanocage research include gaps in synthesis, characterization, and modification, which hinder the ability to tailor their properties for specific applications. Scalability and reproducibility challenges further limit their industrial feasibility. Although nanocages show promise in energy storage, sensing, drug delivery, and catalysis, more extensive application studies are needed to bridge the gap between theoretical potential and practical use. Interdisciplinary collaboration across materials science, chemistry, and engineering can accelerate advancements. The research questions in bibliometric analysis need clearer alignment with the focus on nanocages, and incorporating the latest developments will provide

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a more current perspective. Emphasizing innovation and practical applications, along with rigorous application of empirical data and quantitative reasoning, will enhance the study's impact and credibility. Addressing these issues will refine research focus, ensure clarity, and advance the field of nanocage technology.

Literature Review

There are two points will be discussed in literature review

Nanocage

Nanocages is nanostructure that resemble tiny cages on a nanoscale, distinguished by their porous frameworks and hollow interiors (Li, Li, Yu, Wang, & Li, 2023). A wide range of materials, such as metals, metal oxides, polymers, and carbon-based materials, can be used to create them. Because of their distinctive construction, which provides unique benefits like high surface area, variable porosity, and multifunctionality, nanocages are appealing for a variety of applications (Pan et al., 2020). The structural characteristics of the nanocages include surface morphology, wall thickness, morphology and morphology. These characteristics can be optimized by careful consideration of component design and material selection (Baskar et al., 2021). For example, the size of the nanocage can be controlled by varying the shape of the template during synthesis or reaction conditions. Like this, the nanocages can be shaped by using different templates or by modifying the growth of the nanomaterials.

Fullerenes are a family of carbon allotropes that were initially identified in 1985 by Kroto, Heath, O'Brien, Curl, and Smalley (Kroto, Heath, O’Brien, Curl, & Smalley, 1985). They are distinguished by their closed-cage structure, which is made up of pentagonal and hexagonal rings of carbon atoms. C60, also referred to as buckminsterfullerene or buckyball, is the archetype fullerene; it has a symmetrical structure resembling a soccer ball with 60 carbon atoms (Kroto et al., 1985). Fullerenes provide an excellent starting point for the synthesis of nanocages by utilizing a variety of techniques, including chemical functionalization, surface modification, and template-directed assembly. These techniques provide exact control over the dimensions, morphology, and surface characteristics of nanocages, allowing customized designs for particular uses. Moreover, fullerene-derived nanocages have remarkable physicochemical qualities, such as excellent stability, a large surface area, tunable pore size, and distinctive electrical and optical properties (Isaacson, Kleber, & Field, 2009), making them very appealing for a variety of technological developments.

The fabrication of nanocages requires precise control over nanoscale assembly processes and careful selection of materials and methods to achieve desired structural characteristics (Xia et al., 2011). The investigation of nanocage applications has expanded rapidly in the last several years, covering a wide range of industries including drug delivery, catalysis, sensing, energy storage, and biomedical imaging. The work of (Kazemzadeh & Mozafari, 2019), is noteworthy because it emphasizes the utilization of fullerene-based nanocages as adaptable platforms for targeted drug administration. Similar to another research, the remarkable catalytic performance of fullerene-derived nanocages in a range of chemical processes, highlighting their potential as effective catalysts for environmentally friendly chemical synthesis (Dai, Wang, Zhu, Huang, & Zhao, 2023). Here is a summary table of several past findings on nanocages:

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Table 1: Previous Research of Nanocage

Author(s)	Year	Findings
Kroto, Heath, O'Brien, Curl, & Smalley	1985	Fullerenes, a family of carbon allotropes, have closed-cage structures made of pentagonal and hexagonal rings of carbon atoms, with C60 as the archetype.
Isaacson, Kleber, & Field	2009	Fullerene-derived nanocages have excellent stability, large surface area, tunable pore size, and distinctive electrical and optical properties.
Kazemzadeh & Mozafari	2019	Fullerene-based nanocages are adaptable platforms for targeted drug administration.
Baskar et al.	2021	Structural characteristics of nanocages (surface morphology, wall thickness) can be optimized through component design and material selection.
Li, Li, Yu, Wang, & Li	2023	Nanocages are nanostructures with porous frameworks and hollow interiors, made from various materials like metals, metal oxides, polymers, and carbon-based materials
Dai, Wang, Zhu, Huang, & Zhao	2023	Fullerene-derived nanocages show remarkable catalytic performance in various chemical processes, highlighting their potential as catalysts for environmentally friendly synthesis.

Bibliometric

Bibliometric analysis is a method of measuring, tracking, and searching bibliographies using a number of quantitative techniques (Roemer & Borchardt, 2010). It lists the papers of the authors, the most popular journals, the methods used and the results (Rojas-Sánchez, Palos-Sánchez, & Folgado-Fernández, 2023). The first bibliometric examination looked at their most important publications and intellectual flow, primarily based on author or citation information (Calero-Medina & Noyons, 2008) (Dai et al., 2023). Network analysis and sociometric analysis based on abstract data, titles, and keywords have recently been incorporated into bibliometric analysis (Rezende, Blackwell, & Gonçalves, 2018). A bibliometric analysis depends on pointers where the unwavering quality basically depends on strategy, and a few information standardization shapes are required (Abdullah & Sofyan, 2023). It was performed by recognizing, sorting out and examining the foremost basic viewpoints of a particularstudy theme (Abdullah, Roslan, & Illias, 2023). Below is a summary table highlighting several key findings from past bibliometric studies, illustrating the method's application and value in understanding research trends and intellectual structures of bibliometric within various fields:

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Table 2: Previous Research of Nanocage

Author(s)	Year	Findings
Calero-Medina & Noyons	2008	The first bibliometric examination focused on important publications and intellectual flow, primarily based on author or citation information.
Roemer & Borchardt	2010	Bibliometric analysis measures, tracks, and searches bibliographies using quantitative techniques, listing authors' papers, popular journals, methods, and results.
Abdullah, Roslan, & Illias	2023	Performed bibliometric analysis by identifying, organizing, and analyzing critical aspects of a particular study theme.
Abdullah & Sofyan	2023	Bibliometric analysis depends on reliable methods and data normalization shapes.
Dai, Wang, Zhu, Huang, & Zhao	2023	Fullerene-derived nanocages show remarkable catalytic performance in various chemical processes, highlighting their potential as catalysts for environmentally friendly synthesis.
Rojas-Sánchez, Palos-Sánchez, & Folgado-Fernández	2023	Recent bibliometric analysis incorporates network analysis and sociometric analysis based on abstract data, titles, and keywords.

Material And Methods

There are three points will be discussed in methods

Data Source and Data Collection

Scopus served as the main source of information for the exported file. To mitigate the bias caused by daily database updates, the literature search was conducted on a single day. The Figure 1 displays a flowchart of the search strategy for every database. The term of the time range was unrestricted, but the document type was restricted to original articles only. Each article's details, including the author, title, abstract, affiliation, year of publication, source, and keywords, were exported from Scopus in CSV forms. 1418 articles in all were found and retrieved from the Scopus database, leading to additional record filtering.

Data Extraction

A Microsoft Excel file was created by exporting the CSV file. The first step in the article selection process involved checking titles for inclusion and exclusion criteria. The relevance of the chosen publications to the examination of nanocage applications was then determined by reading their abstracts, and in some cases, the full paper for comprehensive analysis. Authors' names, article titles, publication sources, affiliations, publication years, keywords, and citation counts were among the information extracted from the chosen publications.

Data Analysis and Visualization

Microsoft Excel 365 was used to manually examine the data by the exported files from scopus. Numerous factors were subjected to statistical analysis, such as the distribution of publications by year, the authors that publish most frequently, institutions and the country that provide the most publications, journal sources, and keywords. VOSviewer version 1.6.20

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(http://vosviewer.com), a program for visualizing networks in scientific literature, was used to visualize the extracted data. This software offers insights into co-authorship, citations, co-citations, and co-occurrence analysis and to explore the visualizing map in relationship between journal, authors, countries, co-occurrence analysis, and the co-authorship (Wu, Tong, Wang, Yan, & Sun, 2021)

Results

Global Trend

1418 papers in total were obtained from Scopus. As it observed in Figure 1, just 223 items of paper were eligible for inclusion criteria. Figure 2 illustrates the upward trend in worldwide publishing about application of nanocage from 1991 (n =1) to 2024 (n = 8). The highest total of publication was reached in 2022 is 48 paper.

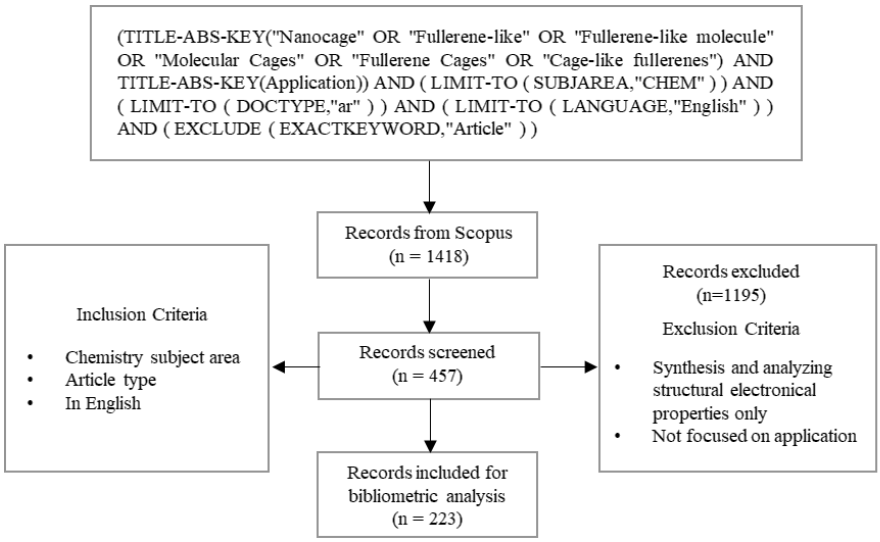

Figure 1: Flowchart of Screening Strategy

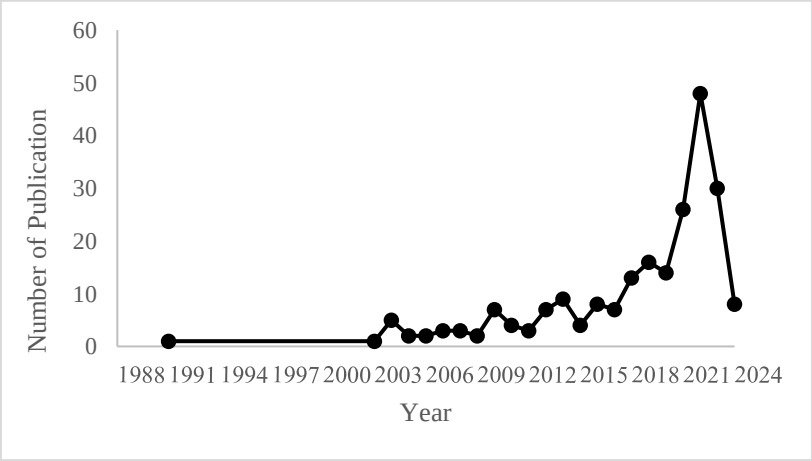

Figure 2: Number of Publications Per Year

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Contribution of Countries

In total, 41 nations contributed the implementation of nanocage. Figure 3 leading the field with 116 publications was the China, followed by United States (n = 27), Iran (n = 25), India (n = 13), and Pakistan (n = 10). Based on co-authorship analysis of the countries, 11 clusters totaling sixty links were identified in Figure 4. Occupying the center of the largest cluster, the United States boasted a total of eight links with a link strength (TLS) of 16, showcasing its strong ties to several other nations including India, Iran, Iraq, Turkey, Pakistan, Saudi Arabia, South Korea, Japan, Spain, China, and United Kingdom. Furthermore, with seven links and a TLS value of 13, Saudi arabia hosted the second-largest cluster.

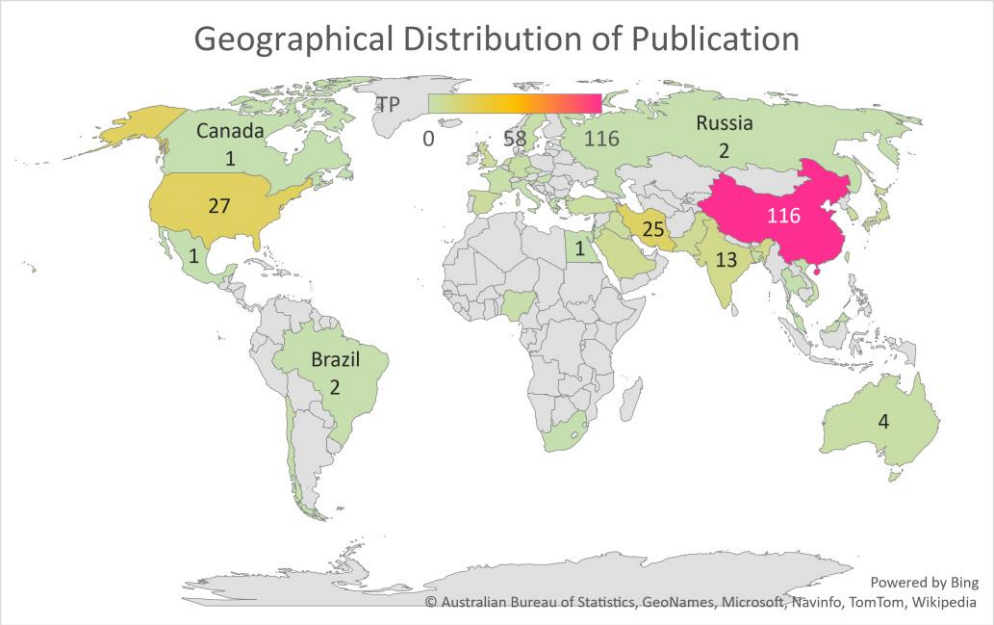

Figure 3: Countries's Contribution

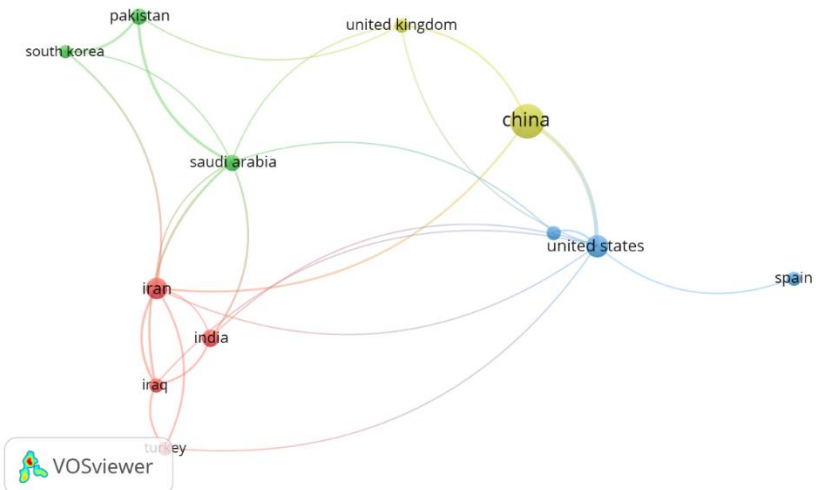

Figure 4: Visualization Map of Countries's Contribution

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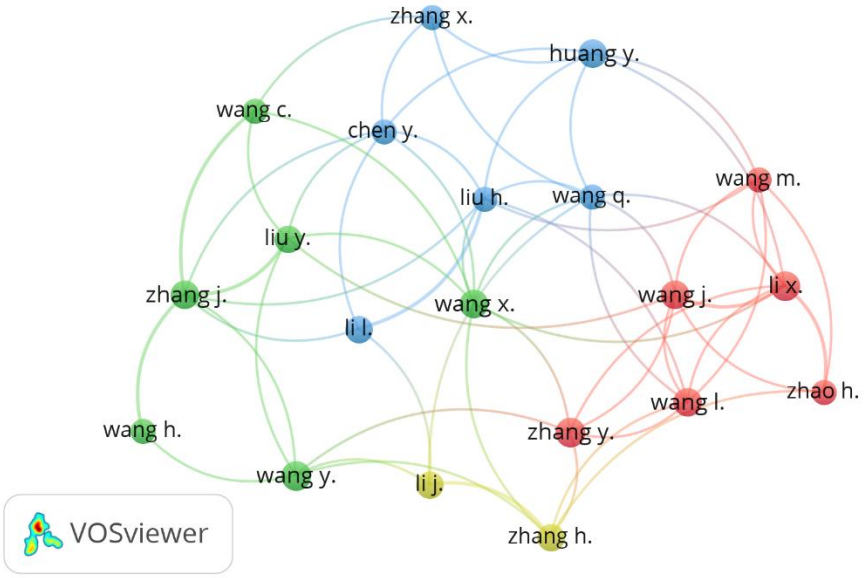

Figure 5: Visualization Map of Authors's Co-Authorship

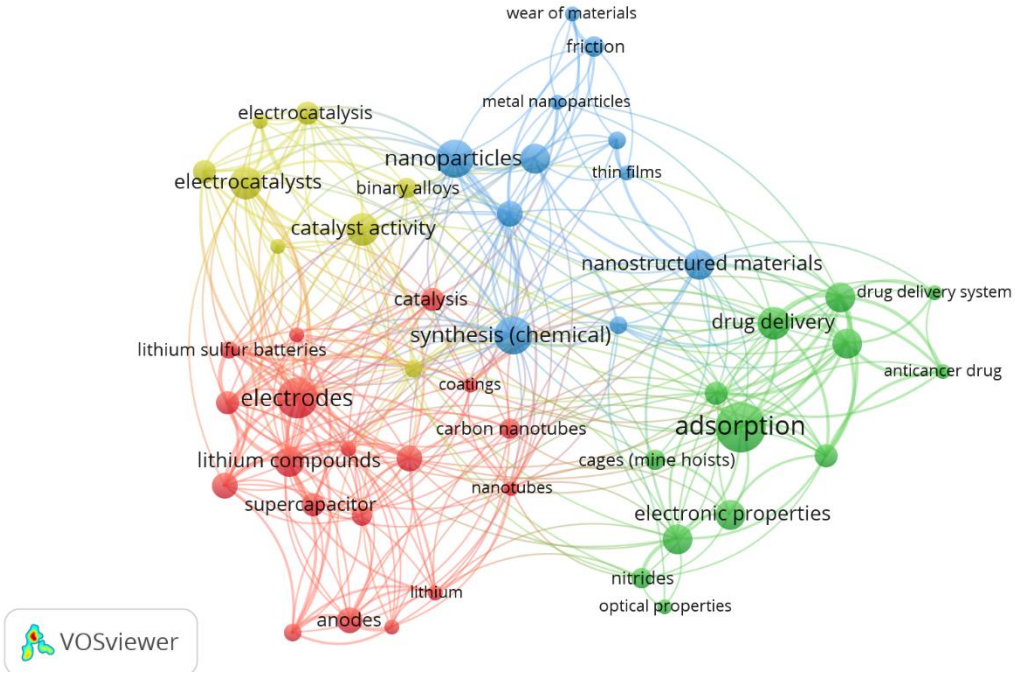

Figure 6: Visualization Map of Keyword Co-Occurance Analysis

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Figure 7: Visialization Map of Institution's Co-Authorship

Contribution of Institution

In total, 31 different institutions contributed to research on the topic. Ministry of Education of the People's Republic of China made the most contributions with 23 total publication, followed by Chinese Acedemy of Sciences (n=15), COMSATS University Islamabad, Abbottabad Campus (n=9), Qingdao University of Science and Technology (n=7), and other universities. Furthermore, the visualization in Figure 7 displays 4 clusters with a total of 6 items, 2 links, and 5 TLS Value as per the co-authorship analysis. Islamic university of Najaf, Iraq has a largest TLS Value at 3 with 20 citation in 3 documents related this topic.

Contribution of Author

Publications on application of nanocage based on nanomaterial involved 31 authors from various countries. Ayub,K. was the highest ranked of them all with 8 publications and 209 total citations. With five publications, Tenne, R. came in second, followed by Hussain, R. (n = 8), Mahmood, T. (n = 7), Naffakh, M. (n = 7), and Adnan, M. (n = 3). The visualization network in Figure 5 displays four clusters with varying quantities of items and 59 linkages based on co-authorship analysis.

Journal Analysis

A total of 31 journals published selected publications on the subject. Among them, 68 papers were published in the top 10 journals in Table 1**.** The top-ranked journal was the Chemical Engineering Journal, with 13 publications and 138 total citation with 7 papers.

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Table 3: Most Active Source Title

Source Title	TP	TC	Publisher	Cite Score
Chemical Engineering Journal	13	138	Elsevier	N/A
Chemical Science	7	99	Royal Society of Chemistry	14,4
Journal Of Materials Chemistry A	7	104	Royal Society of Chemistry	19,6
Inorganic Chemistry	6	154	American Chemical Society	7,6
Journal Of Molecular Liquids	6	100	Elsevier	10,2
Journal Of Molecular Structure	6	23	Elsevier	7
Journal Of Physical Chemistry C	6	257	American Chemical Society	6,4
Rsc Advances	13	9	Royal Society of Chemistry	6,8
Small	7	59	Wiley-Blackwell	19,0
Carbon	7	139	Elsevier	20,1

Notes: TP=total number of publications; TC=total citations

Keywords Analysis

In 223 articles, 2319 keywords were used a total of 1441 times. The most frequently occurring keywords were "Adsorption" and "Electrodes," appearing 17 and 13 times, respectively. The next most popular keywords were nanoparticles, synthesis (chemical), nanoparticle, electrocatalysts, and drug delivery, with 13, 13, 13, 11, and 11 occurrences, respectively. The co-occurrence analysis separated all discovered terms into 4 clusters in total 5 items, as illustrated in Figure 5. "Adsorption" and "Electrodes" were the most notable clusters. This indicates that the most prominent topics in nanocage application research are adsorption with TLS values of 27 and 49 respectively.

Discussion

Nanocages, intricate nanostructures with hollow interiors, have emerged as versatile tools with immense potential across various fields (Li et al., 2023). Their unique properties, such as high surface area-to-volume ratio (Biener et al., 2009), tunable pore size, and controllable surface chemistry, make them ideal candidates for applications in drug delivery, catalysis, imaging, sensing, etc (Khan, Saeed, & Khan, 2019). To maximize the potential of nanocage applications, strategic approaches are essential. By fostering innovation and collaboration, researcher can unlock the full potential of nanocages and harness their transformative capabilities for the benefit of society.

Despite significant advancements, challenges persist in areas such as scalability, biocompatibility, and targeted delivery efficacy (Hamid & Manzoor, 2020). Moreover, the potential of nanocages in emerging areas such as environmental mitigation, energy storage,

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and nanoelectronics is still largely untapped, requiring interdisciplinary efforts to unlock opportunity new and address existing constraints are needed to stimulate

The findings of this research show that research in the field of nanocage-based nanomaterials has experienced an increase in research exploration, publications experienced an increasing trend from 1991 to 2023 with the potential to increase rapidly in 2024. A total of 222 articles were published during that period. Based on these discoveries, the first research in 1991 discovered the application of $[^{11}BH]_6^{2-}$ ion-based nanocages to detect its electronic structure. The authors in the early years explained the synthesis and electronic structure of nanocage systems that will be applied to various sectors. Recently, nanocages function as gas sensors. proven by the latest research in 2024 dominated by the sensing capabilities of nanocages. Then followed by as an adsorption agent and as a drug nanocarrier

As a gas sensor, nanocages utilized their high surface area and tailored pore structures to detect and quantify specific gases (Pereira Silva & Varela Júnior, 2023). When exposed to gas molecules, the surface of the nanocage undergoes changes in conductivity, fluorescence, or other properties, enabling sensitive detection. As an adsorption agent, nanocage retain molecules or ions within their hollow interiors or on their surfaces, making them ideal candidates for purification, separation, and storage processes (Kaewruksa, Du, & Ruangpornvisuti, 2022). By adjusting the chemical composition and surface functional groups of the nanocages, researchers can tailor their adsorption properties to target specific contaminants or pollutants, offering sustainable solutions for water treatment, gas purification, and environmental remediation. In drug delivery, nanocage's hollow interiors provide ample space for drug encapsulation, while surface modifications enable controlled release and enhanced biocompatibility (Karimi et al., 2017). Nanocages can be functionalized with targeting ligands to improve specificity and reduce off-target effects, offering personalized treatment options for various diseases, including cancer, infectious diseases, and neurological disorders.

The application of nanocages as adsorption agents, especially for water and gas contaminants, is becoming a fairly rapid trend and the most applications of nanocages are from 2021-1991. this is demonstrated in the analysis of co-occurring keywords in publications related to cage-based nanomaterial applications. Keywords are terms or phrases that represent the main concepts or themes of a research article. Followed by "electrodes" for application of nanocage properties making them promising candidates for energy storage and conversion devices such as batteries, supercapacitors, and fuel cells. By incorporating nanocage materials into electrode designs, researchers aim to enhance performance metrics such as energy density, power density, and cycling stability, ultimately contributing to the development of more efficient and sustainable electrochemical technologies.

As many as 41 countries contributed to this topic, of which China had the most publications, followed by the United States as shown in Figure 3. This shows that the articles published are increasing in the international arena. It shows the significance of the distribution in various countries which is quite even across the globe. China shows the highest ranking of total paper contributions in the international arena. These two countries are the 2 largest paper producing countries in the field of nanocage applications.

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Collaboration between institutions, authors and countries is analyzed using bibliometrics based on co-authorship and Total Link Strength (TLS) shows the frequency and closeness of collaboration between authors, institutions and countries. A high TLS value indicates a high frequency of collaboration between the two (Wu et al., 2021). In this research, Ayub.K and Tenne, R were found to have had the most collaborations with other authors in the field of cage-based nanotechnology to synthesize nanocages and the applications of these nanocages.

Meanwhile, from an institutional perspective, the Islamic University of Najaf, from Iraq, is the most collaborative and has the largest TLS Value at 3, collaborating with Pakistan and Nigeria. Collaborative author impact in bibliometrics refers to the influence and productivity of researchers who collaborate with others on scholarly publications. Collaborative authorship patterns to assess the impact of research collaborations on scientific productivity, citation rates, and overall scholarly impact (Patel et al., 2019). Author collaboration in terms of the co-occurrence authorship graph has not yet collaborated competitively so that many authors still write individually. This is a concern for future collaboration to find applications with a deep, multidisciplinary scope.

Chemical Engineering journal with 13 publications is the journal with the highest total publications compared to other journals with the most significant numbers. Followed by Chemical Science, Journal of Materials Chemistry A, Inorganic Chemistry, Journal of Molecular Liquids. Productive journal impact refers to the influence and productivity of academic journals in publishing research articles. Chemical Engineering Journal, as a journals with high productivity attract a large number of submissions and publish a substantial volume of articles each year. It play a crucial role in disseminating new research findings, shaping scholarly discourse, and advancing knowledge on application of nanocage.

Conclusion

Based on the findings from 1991 to 2023, nanocages have demonstrated substantial growth and potential for further expansion into 2024. China leads in contributions, with significant collaboration from the United States in nanocage research. The Ministry of Education of the People's Republic of China has been particularly influential with 23 publications, underscoring its pivotal role. Ayub, K., stands out as the most prolific author, while the Chemical Engineering Journal has emerged as the leading publisher in nanocage applications. Nanocages are primarily utilized as effective adsorbing agents and show promise in electrode applications. This study successfully highlights these contributions, identifies key players, and suggests future research directions, including exploring emerging trends and expanding the scope of applications beyond adsorption and electrodes.

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