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Bibliometric Analysis on Green Synthesis of Nanoparticles Using Leaf Extract Based on the Scopus Database

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ABSTRACT

This study aims to analyze the development of scientific publications related to green synthesis using leaf extract through a bibliometric approach with data sources from the Scopus database. The data analyzed included 64 articles published between 2015 and 2024. The analysis was carried out with the help of VOSviewer software to map network visualization, overlay, and density of the most frequently used keywords. The results show that the number of publications has increased although it is fluctuating, with the peak of publications occurring in 2024. India is the country with the highest contribution, both in terms of number of articles, institutions, and authors. The keyword green synthesis has a higher frequency and link strength than leaf extract, indicating that this topic is broader in scope and taking center stage in sustainability research. Overall, this analysis provides a comprehensive overview of trends, scientific collaborations, and research development directions in the field of leaf extract-based green synthesis.

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INTRODUCTION

Green synthesis and biosynthesis are described as the synthesis of compounds using materials such as plant extracts, fungi, algae, and microorganisms (Radulescu et al., 2023) . The aim of these methods is to minimize the effects of toxic chemicals typically used in the metal oxide synthesis process (Singh et al., 2018) . The use of extracts plants allows the synthesis of metal oxides as a reducing and masking agent during the process (Meiliyadi et al., 2026), replacing the need for reducing agents from hazardous substances (Aigbe & Osibote, 2024) . Green synthesis methods have many advantages (Meiliyadi et al., 2025), such as being environmentally friendly, cheap, and not requiring much energy (Abady et al., 2025). One method that is gaining popularity is the use of leaf extracts as preducing and stabilizing agents in the synthesis process (Khattak et al., 2019). The leaves of various plants are known to contain phytochemical compounds such as (Das et al., 2024), phenols (Sugitha et al., 2024), and tannins (Hashemia et al., 2020) that play an active role in the formation of nanoparticles, making it a safer, cheaper and more sustainable alternative to conventional methods (H.Nahari et al., 2022).

Bibliometric analysis is one of the effective quantitative methods to evaluate and map the development of a field of science based on scientific publications (Aliero et al., 2015). By utilizing the scopus database, this analysis allows researchers to identify the number of publications,

annual trends, authors, citations, countries, institutions, collaboration patterns, and dominant keywords that appear in green synthesis research using leaf extracts (Shuaixuan Ying et al., 2022).

Similar previous research is from (Ahmed et al., 2016) who used neem leaf extract to synthesize silver nanoparticles which showed anti-microbial activity against gram-positive bacteria and E coli. Furthermore, research from (Islam et al., 2019) who used moringa leaf extract to synthesize silver nanoparticles with sunlight irradiation as the main energy source. The resulting nanoparticles showed antimicrobial activity against various strains of bacteria and fungi. Then research from (Yan et al., 2020) which uses guava leaf extract to evaluate its anti-bacterial activity against common pathogens. And the last is research from Lomelí-Rosales et al., 2022 which uses cayenne leaf extract to compare the effectiveness of plant parts (leaves, stems, roots) in the nanoparticle synthesis process.

Although numerous experimental studies on green synthesis using leaf extracts have been reported, most previous studies have primarily focused on synthesis procedures, characterization, and antimicrobial applications. To date, there is still limited research that comprehensively maps the global scientific development, collaboration patterns, research trends, and thematic evolution in the field of green synthesis using leaf extracts through a bibliometric approach. Existing traditional literature reviews generally discuss findings descriptively and are limited in their ability to visualize research networks, identify influential contributors, and detect emerging research topics. Therefore, a bibliometric analysis is urgently needed to provide a broader and more systematic overview of the research landscape, identify research gaps, and reveal future research opportunities in this field.

Therefore, the purpose of this research is to conduct bibliometric analysis of scientific publications on green synthesis using leaf extract. This study offers novelty by systematically visualizing publication trends, collaboration networks, keyword co-occurrence, and thematic developments using VOSviewer, which has not been comprehensively discussed in previous traditional review studies. Through this research for mapping research data can use the VOSviewers application which includes network mapping, overlay, and density. Bibliometric analysis in this study also includes the classification of publications, authors, years, number of citations, affiliations and countries on the Scopus database in 2015-2024.

RESEARCH METHOD

Bibliometric analysis is a quantitative method for evaluating and analyzing the scientific literature (Sorooshian, 2024). This technique is used to measure the productivity of authors (Mirawati et al., 2024), institutions (Chissaque et al., 2024), or countries (Jiang et al., 2024) in a field of research (Khojasteha et al., 2023). One of its main goals is to identify research trends and map the development of science (Huang et al., 2024). The data analyzed usually comes from databases such as Scopus (Xiao et al., 2022), Web of Science (Pandey et al., 2024), or Google Scholar (Du et al., 2024). Some common indicators used include the number of publications (Filippi et al., 2023), the number of citations (Bautista-Puig et al., 2022), and the h-index (Duque-Acevedo et al., 2020). Bibliometric analysis also includes the visualization of collaborative networks between authors or institutions (Ajibade et al., 2024). In addition, it can be used to identify the most influential journals or topics in a discipline (Donthu et al., 2021). This method is particularly useful in academic decision-making and research policy (Wiwatkunupakarn et al., 2024). Tools such as VOSviewer or Bibliometrix are often used to make analysis easier (Cui et al., 2025). With bibliometric analysis, researchers can understand the direction of future research and avoid topics that are already too saturated.

In this study, data were collected from the Scopus database using the Boolean search query TITLE-ABS-KEY (“green synthesis” AND “leaf extract”). The use of this query aimed to ensure that the retrieved publications specifically discussed green synthesis research involving leaf extracts.

The publication period was limited to 2015–2024 because research on green synthesis using leaf extracts has shown significant development during the last decade, particularly in nanoparticle synthesis and environmentally friendly materials research. This time limitation was

applied to obtain recent, relevant, and up-to-date publication trends while avoiding older studies with limited relevance to current scientific developments.

The inclusion criteria in this study covered journal articles indexed in the Scopus database published between 2015 and 2024. In addition, only English-language articles were included to ensure consistency in data analysis and to facilitate the interpretation of scientific information at the international level. Publications outside the specified period, non-English articles, conference papers, book chapters, and documents unrelated to green synthesis using leaf extracts were excluded from the analysis. Statistical analysis in this study was carried out descriptively by calculating publication frequencies, citation counts, author productivity, institutional contributions, and keyword occurrences. Network analysis and visualization were performed using VOSviewer to identify relationships among keywords, collaboration patterns, and research clusters.

Using bibliometric analysis, this research presents and maps the development of green synthesis topics. Article data in this research is obtained from the Scopus database. The steps of data collection are shown in Figure 1. (Note Figure 1), First what must be done is to determine the keywords first "green synthesis" and "leaf extract" with the categories of title, article, abstract, year, keywords, author, number of citations, and data sources from 2015-2024 by using scopus to search for articles. Then the second step is to collect data from Scopus. Furthermore, the data obtained from scopus is filtered using Microsoft Excel 2019 to analyze data on the number of publications per year, number of citations. and the number of sources that published the article.

The last step is data visualization, using VOSviewers to perform data visualization to analyze keyword development trends and analysis of authors of articles that appear a lot. In this study, the results of VOSviewer visualization include three mappings, namely network, overlay, and density. In previous research that has been done by (Shidiq, 2023);(Soegoto et al., 2022);(Nurvianie & Sundari, 2024) which shows information related to VOSviewe.

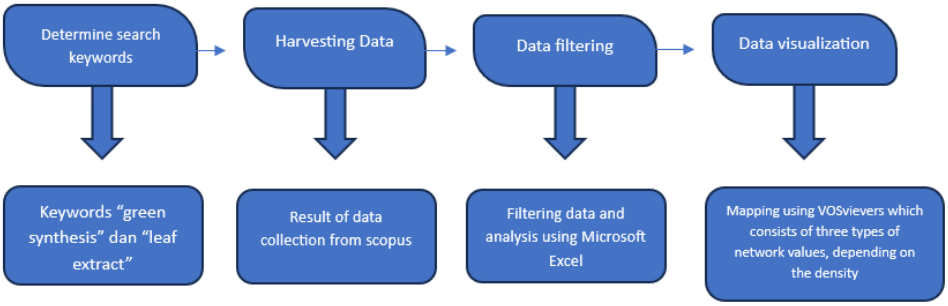

Figure 1: Data collection steps of bibliometric analysis

RESULTS AND DISCUSSION

Increased Research Using Green Syntesis Keywords and Leaf Extracts

Figure 2 shows data on the increase in research using the keywords green synthesis and leaf extract based on the Scopus database for 10 periods (2015-2024). As shown in Figure 2 (Note Figure 2), based on the graph of the development of the number of documents from 2018 to 2024 with the keywords green syntesis and leaf extracts, it can be divided into three stages of publication development. In the early stages, namely 2018 to 2019, the number of publications is still relatively low. In 2018 there were only four documents, then increased slightly to five documents in 2019. This shows that this topic is just starting to get attention from researchers. Entering 2020 to 2023, the publication trend began to show stability. The number of documents recorded in 2020 and 2021 was ten, and then slightly decreased to nine in 2022 and 2023. This reflects that despite not experiencing a sinificant spike, related research is consistently taking place, signaling the interest that continues to be maintained in the academic sphere.

Furthermore, the year 2024 shows There was a significant increase in the number of publications, with seventeen documents. This surge indicates that there is an increasing interest

in green synthesis research using leaf extracts, possibly influenced by the urgency of implementing environmentally friendly technologies as well as the increasing relevance of this topic in the context of sustainability and biotechnology.

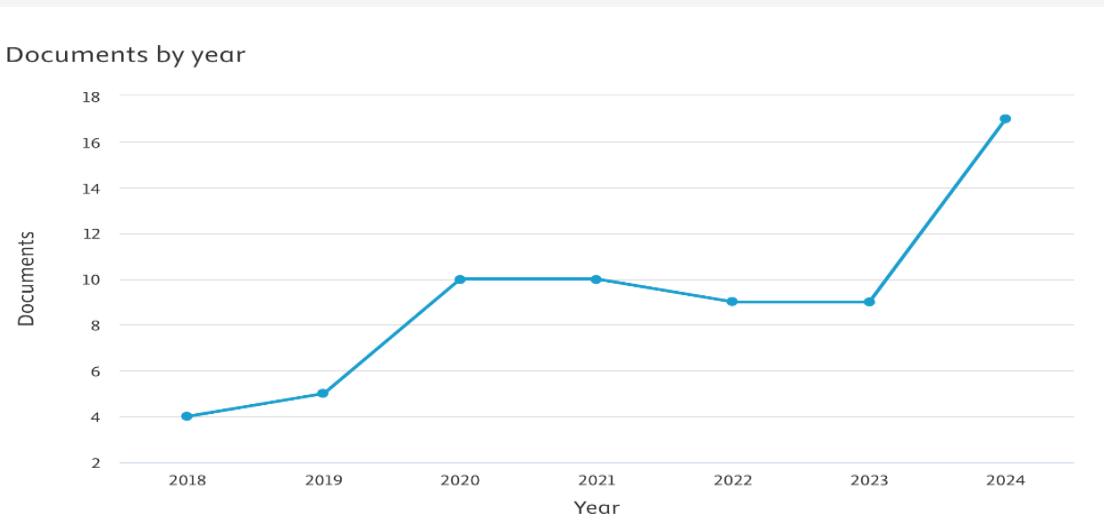

Figure 2. Research enhancement using green synthesis keywords and leaf extracts

Top 10 most cited articles with keywords green synthesis and leaf extracts

Table 1 presents the 10 most frequently cited articles. Based on the data in **Table 1** the number of articles with the most citations published in 2019 is with a total of 254 citations.

Table 1. Top 10 most frequent articles Retrieved

No	Author	Title	Year	Number of Citations	Journal Identity
1	Devi et al	Green synthesis of iron oxide nanoparticles using Platanus orientalis leaf extract for antifungal activity	2019	254	Green Processing and Synthesis, 8(1), pp. 38-45
2	Jamzad & Kamari Bidkorpeh	Green synthesis of iron oxide nanoparticles by the aqueous extract of Laurus nobilis L. leaves and evaluation of the antimicrobial activity	2020	141	Journal of Nanostructure in Chemistry, 10(3), pp. 193-201
3	Bouafia & Laouini	Green synthesis of iron oxide nanoparticles by aqueous leaves extract of Mentha Pulegium L.: Effect of ferric chloride concentration on the type of product	2020	104	Materials Letters, 265, 127364
4	Alex Mbachu et al.	Green synthesis of iron oxide nanoparticles by Taguchi design of experiment method for effective adsorption of methylene blue and methyl orange from textile wastewater	2023	87	Results in Engineering, 19, 101198
5	Serrapede et al.	Fiber-shaped asymmetric supercapacitor exploiting rGO/Fe2O3 aerogel and electrodeposited MnOx nanosheets on carbon fibers	2019	67	Carbon, 144, pp. 91-100

No	Author	Title	Year	Number of Citations	Journal Identity
6	Jegadeesan et al.	Green synthesis of iron oxide nanoparticles using Terminalia bellirica and Moringa oleifera fruit and leaf extracts: Antioxidant, antibacterial and thermoacoustic	2019	65	Biocatalysis and Agricultural Biotechnology, 21, 101354
7	Asoufi et al.	Green route for synthesis hematite (α-Fe2O3) nanoparticles: Toxicity effect on the green peach aphid, Myzus persicae (Sulzer)	2018	64	Environmental Nanotechnology, Monitoring and Management, 9, pp. 107-111
8	Sridevi et al.	Structural characterization of cuboidal α-Fe2O3 nanoparticles synthesized by a facile approach	2023	60	Applied Nanoscience (Switzerland), 13(8), pp. 5605-5613
9	Selvaraj et al.	Green synthesis of magnetic α–Fe2O3 nanospheres using Bridelia retusa leaf extract for Fenton-like degradation of crystal violet dye	2021	59	Applied Nanoscience (Switzerland), 11(8), pp. 2227-2234
10	Yang et al.	Synthesis of montmorillonite-supported nano-zero-valent iron via green tea extract: Enhanced transport and application for hexavalent chromium removal from water and soil	2021	57	Journal of Hazardous Materials, 419, 126461

Top Articles by Affiliation, Author, and Country by Keyword Green Syntesis and Leaf Extracts

Based on the results of data from the Scopus database shown in Figure 3, 10 affiliations were obtained with the keywords green synthesis and leaf extracts. In Figure 3 (Note Figure 3) it can be seen that Career Point University Hamirpur is the most productive institution in publishing articles related to the keywords green synthesis and leaf extracts, with a total of 6 documents. This shows that the institution is very active in ongoing research involving green technologies and natural materials.

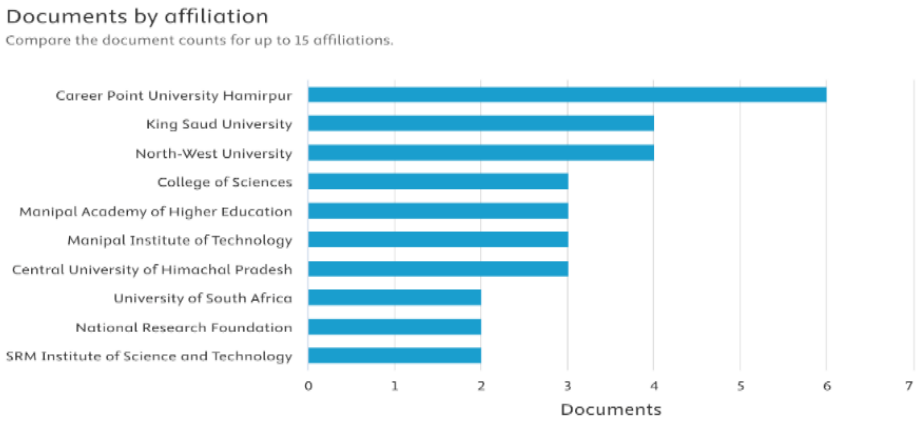

Figure 3. Top affiliations that are most active using the keywords green syntesis and leaf exstract

King Saud University and North-West University published four articles each, showing that interest in the topic of green synthesis and leaf extracts is spread across different countries, including Asia and Africa. In addition, several universities such as the College of Sciences, Manipal Academy of Higher Education, and Manipal Institute of Technology are also actively researching with three publications each. Although the number of documents from institutions such as Central University of Himachal Pradesh, University of South Africa, National Research Foundation, and SRM Institute of Science and Technology is only 2 documents, it still shows that this topic is of interest to institutions from various regions and backgrounds.

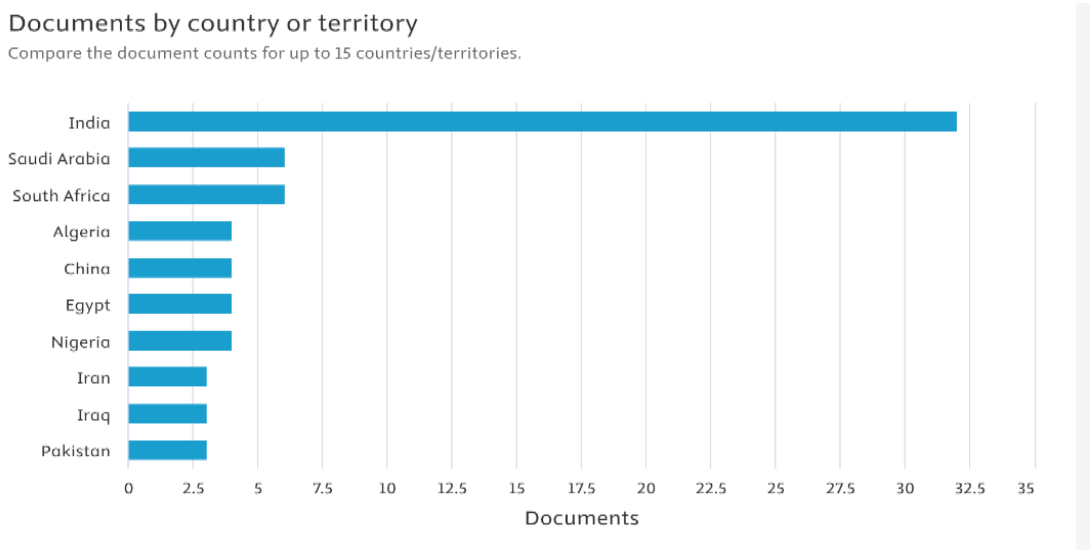

Figure 4. Top countries most actively using green synthesis and leaf extract keyword.

Figure 4 shows the countries that published the most articles with the keywords green synthesis and extracts. Leaf. From Figure 4 (Note Figure 4), it can be seen that there are 10 most active countries, and India takes the top spot with a total of 32 articles. This indicates that India isbecoming a major center in the development and scientific contributions on this topic. Countries such as Saudi Arabia and South Africa followed with a relatively small number of publications, around 4 documents, followed by Algeria, China, Egypt, Nigeria, Iran, Iraq and Pakistan which each contributed around 2 to 3 documents.

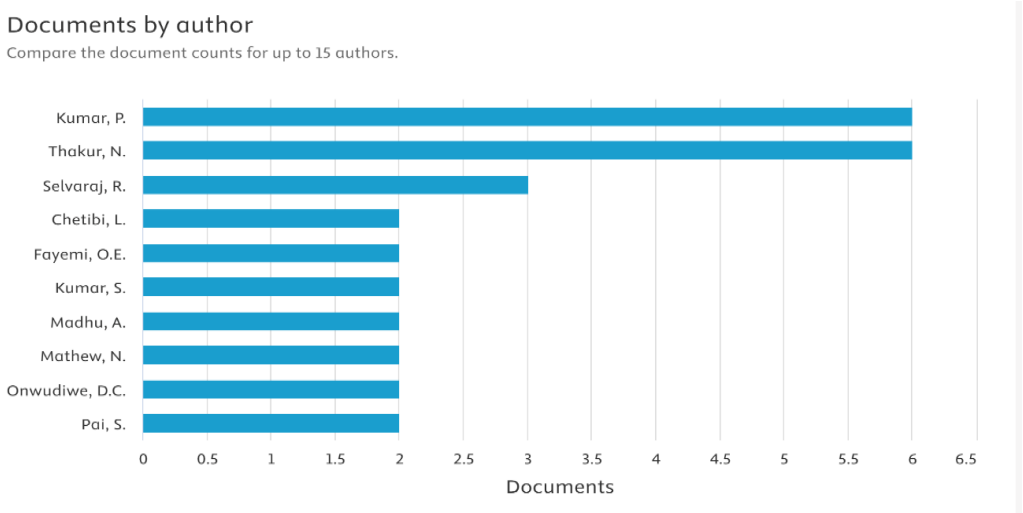

Figure 5. Top authors who are most active using the keywords green synthesis and leaf exstract

Figure 4 is in line with Figure 5 (Note Figure 5) which shows that 2 authors from India namely Kumar, P. and Thakur, N. are the most active authors in articles with 6 articles each. This shows their significant contribution in the development of this topic. In the next position, Selvaraj,

R. follows with 3 documents, followed by several other authors such as Chetibi, L., Fayemi, O.E., Kumar, S., and others who have 2 documents each.

Top Articles by Type, Field of Study and Source Based on Keywords Green Syntesis and Leaf Extracts

Based on the results of data from the Scopus database shown in Figure 6, 2 types were obtained with the keywords green synthesis and leaf extract. In Figure 6 (Note Figure 6) it can be seen that the type with the highest number of publications related to green syntesis keywords and leaf extracts is an article which is 92.2% of documents while the least number of publications is a conference paper of 7.8%.

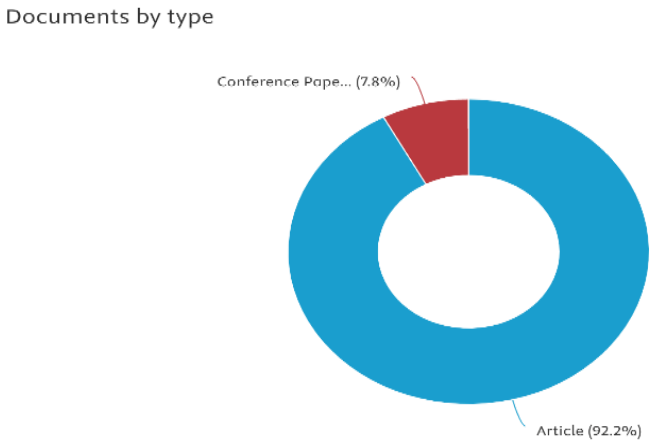

Figure 6. Top most active types using green syntesis and leaf extract keyword

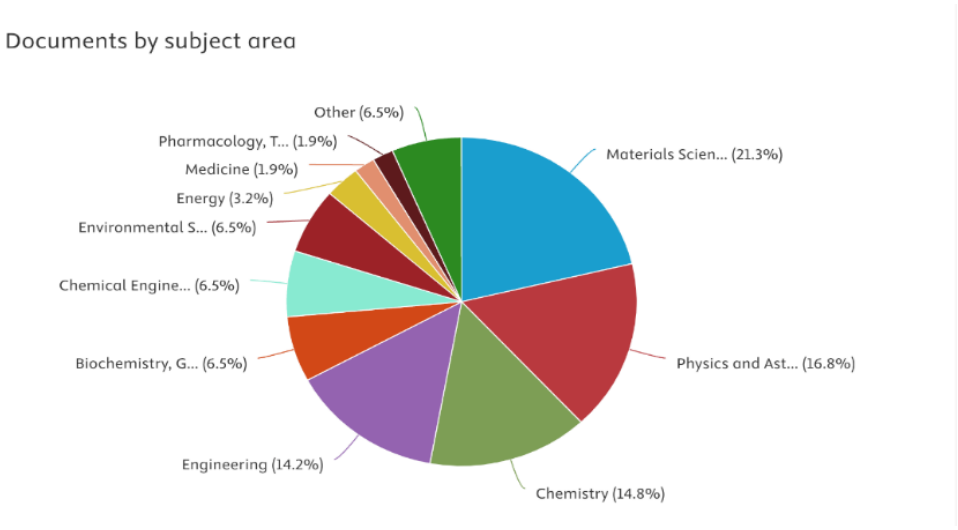

Figure 7. Top most active fields of study using green synthesis and leaf extract keywords.

Figure 7 shows the fields of study that published the most articles with the keywords green synthesis and leaf extracts, it can be seen that the *Materials Science* field dominates with a contribution of 21.3%, followed by *Physics and Astronomy* (16.8%), *Chemistry* (14.8%), and *Engineering* (14,2%).

In addition, the fields of *Biochemistry, Genetics and Molecular Biology* and *Chemical Engineering* each contributed about 6.5%, indicating a biotechnology and chemical engineering approach in the development of environmentally friendly synthesis methods. The contribution of *Environmental Science* (5.6%) also underscores the importance of sustainability and environmental impact in this research.

Other fields such as *Energy*, *Medicine*, and *Pharmacology* also contributed albeit in smaller proportions, indicating that the application of green synthesis is also starting to expand into the fields of renewable energy and healthcare. (See **Figure 7**)

Table 2 shows that the sources that publish the most articles, it can be seen that there are 5 sources that are most active and materials today proceedings occupy the top position with the number of articles as much as 4 documents. Meanwhile, Applied Nanoscience Switzerland and Journal of Materials Science Materials In Electronics had 3 documents each. In addition, other journals such as Biomass Conversion and Biorefinery and Journal of Molecular Structure also contributed with 2 documents each. (See Table 2).

Table 2. Top sources that most actively use the keywords green synthesis and leaf extract

No	Source	Number of Document
1	Materials Today Proceedings	4
2	Applied Nanoscience Switzerland	3
3	Journal Of Materials Science Materials In Electronics	3
4	Biomass Conversion And Biorefinery	2
5	Jaournal Of Molecular Structure	2

Visualization of Green Syntesis Keywords and Leaf Extracts Using Vosviewer Analisis Parameter Kimia

The use of VOSviewer requires at least 10 relationships between terms. After analysis using VOSviewer, 4 groups of topics were found which are marked with red, green, blue and yellow colors shown in Table 3 (Note Table 3). VOSviewer provides three types of views in bibliometric mapping, namely network (Figure 8), overlay (Figure 9) and density (Figure 10). In this analysis, the keywords used are shown as colored circles. The more frequently the keywords appear in the title and abstract, the larger the circle size and font. This means that keywords that are used more often will appear more prominent (Note Figure 8). The red cluster is the most dominant because it focuses on nanoparticle applications and functional properties such as magnetic and photocatalytic activities. The green cluster represents nanoparticle synthesis and characterization processes, which are important stages in green synthesis research. The blue cluster focuses on fundamental studies of synthesis methods and iron oxide materials, making it more specific and limited. Meanwhile, the yellow cluster contains the fewest keywords because research on graphene and advanced morphology is still relatively new and has not been widely explored.

Table 3. VOSviewer cluster results

No	Number of Items	Color	Items
1	13	Red	Saturation magnetization, citrus fruit, synthesized, dye azo, activity, photocatalytic, nanoparticle, aromatic compounds, photo- catalytic, energy gap, Crystallite size, degradation, hematite nanoparticles.
2	11	Green	Metal nanoparticles, plant extracts plants, nanoparticles iron oxide, nanoparticles, iron oxide, chemistry, scanning microscopy electron, chemistry green, microscopy transmission electron crystallinity, article.
3	5	Blue	Green synthesis, synthesis (chemistry), magnetite, xrd, iron ore.
4	2	Yellow	Graphene, morphology.

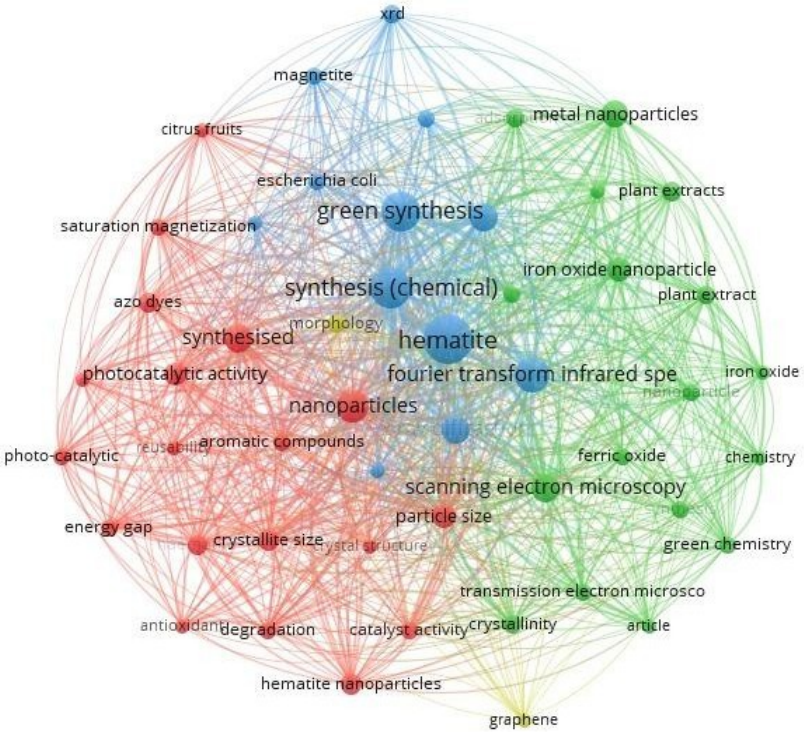

Figure 8. Network visualization based on keywords

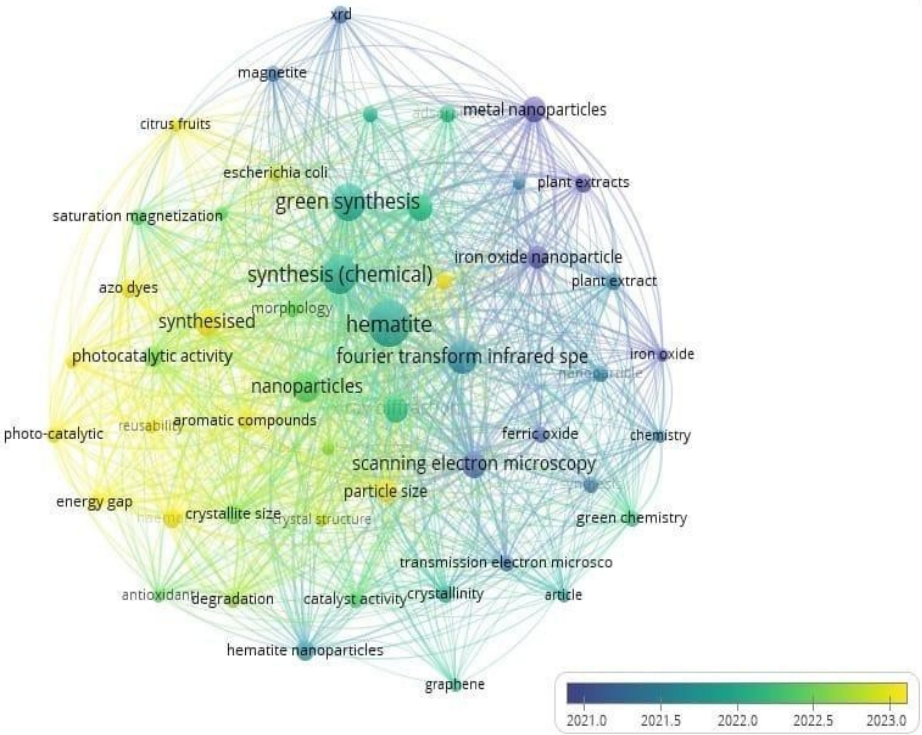

Figure 9. Visualization of overlays based on keywords

From the results of data extraction of keyword titles and abstracts derived from 64 Scopus indexed articles for the period (2015- 2024), information was obtained that the keywords "green synthesis" and "leaf extract" were in different cluster groups. Figure 9 shows that keywords such as "green synthesis" were most researched in 2022. The darker color in the overlay visualization indicates that the topic is being heavily researched (Note Figure 9).

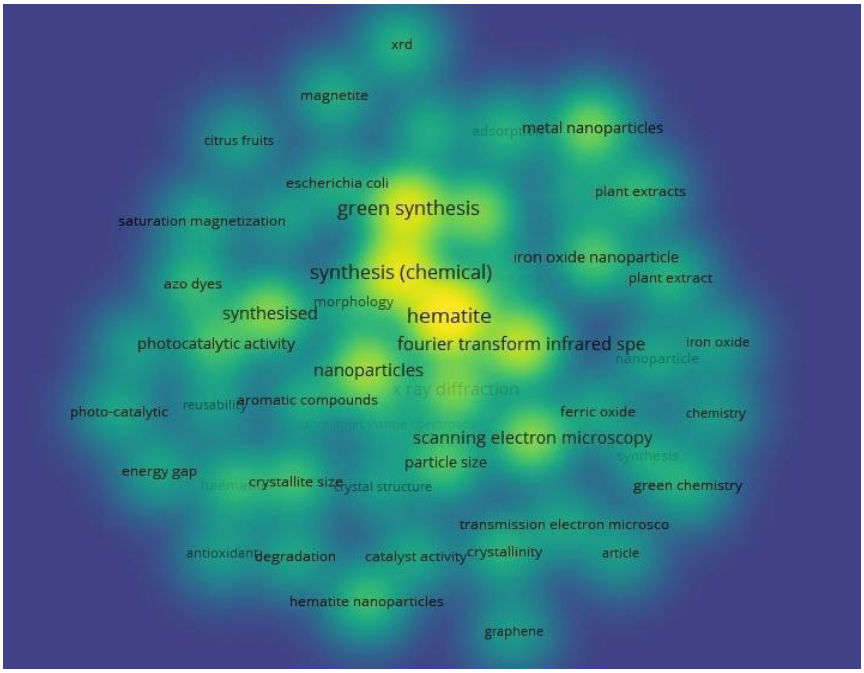

Figure 10. Visualization of density based on keywords

In general, as shown in **Figure 8** and **Figure 9** as well as **Figure 10** (Note **Figure 10**) the keyword green synthesis is still very often used in research. While the keyword leaf extract although also often researched but not as much as green synthesis. This is because green synthesis includes a variety of environmentally friendly approaches in material synthesis, including the use of microorganisms, enzymes, plant extracts (including leaves) and sustainable methods. others. As this concept touches on many disciplines such as materials chemistry, biotechnology, nanotechnology, and the environment, the number of studies is much larger and diverse.

CONCLUSION

This research succeeded in providing a mapping the development and trends of scientific publications related to green synthesis using leaf extracts in the period 2015-2024. Through a bibliometric approach conducted using data from the Scopus database, as well as visualization with VOSviewer, this research succeeded in identifying the authors, affiliations, countries, fields of study, and keywords that contributed most to the topic. This success is demonstrated by the mapping of 64 relevant articles, as well as the discovery of significant patterns of scientific collaboration and research distribution across regions.

The majority of articles originated from India, both in terms of the number of publications, institutions, and the most prolific authors. The most published articles come from the field of materials science, with journal articles being the dominant publication type. Data visualization shows that the keyword green synthesis has a higher connection and intensity than leaf extract because the concept of green synthesis has a broader scope and includes various environmentally friendly approaches. Therefore, it can be concluded that research on green synthesis is more dominant and has become the primary focus compared to more specific studies on leaf extracts. However, this study is limited because it only used the Scopus database and English-language publications, which may not fully represent all relevant studies in this field. Future research is recommended to explore topics with lower density levels, such as graphene-based materials, advanced morphology studies, and multifunctional magnetic and photocatalytic nanoparticles, as these areas still provide broad opportunities for further development.

AUTHOR CONTRIBUTIONS

The contributions of the authors in this study are described as follows: Dela Yunita Rizki contributed to the development of the research concept, data collection, data analysis, and manuscript preparation. Nurul Titian Lestari was responsible for reference collection and

research data validation. NF and LIM participated in data processing, methodology development, and manuscript revision. Meanwhile, Lalu Ahmad Didik Meiliyadi, Kurniawan Arizona, and Muh Wahyudi acted as supervisors by providing guidance in concept refinement, result analysis, and the final review of the manuscript. All authors have reviewed and approved the final version of the article.

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