

Research Trends and Scientific Mapping of Natural-Based Activated Carbon Synthesis from Banana Leaf and Water Hyacinth: A Bibliometric Analysis

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ABSTRACT

Activated carbon is a porous material widely used in wastewater treatment, water purification, and energy storage. The use of natural biomass such as banana leaf and water hyacinth as raw materials for activated carbon continues to grow due to their environmentally friendly and sustainable nature. This study aims to analyze the development and trends in research on banana leaf- and water hyacinth-based activated carbon using a bibliometric approach. The study employed a quantitative descriptive method based on the Scopus database, covering publications from 2015 to 2024. A total of 297 articles were analyzed using Microsoft Excel and VOSviewer to generate network visualizations, overlay visualizations, and density visualizations. The results indicate that publication trends have shown a significant increase, albeit with fluctuations, with the highest number of publications occurring in 2023. Bibliometric analysis indicates that research topics are dominated by adsorption, chemical activation, biomass, and the application of activated carbon in wastewater treatment and energy storage. Additionally, network visualizations reveal the development of collaboration among researchers, institutions, and countries. This study provides a comprehensive overview of the direction of research on natural biomass-based activated carbon as a reference for sustainable research development.



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INTRODUCTION

One of the organic materials used in both large and small industries is activated carbon (Altmann et al., 2016; Gao et al., 2020; Muttill et al., 2023; Tan et al., 2017). Activated carbon is one of the potential absorbents in the adsorption process. The content of carbon material

Activated carbon consists of porous solids with a carbon content of 85-95% ((Bläker et al., 2019; Neolaka et al., 2023; Suhas et al., 2016). So that activated carbon is widely utilized in various applications, ranging from water purification, waste treatment, to energy fields such as supercapacitors and batteries ((Dos Reis et al., 2020; Tan et al., 2017). In recent decades, attention to the synthesis of Activated carbon from natural

materials is increasing along with the demand for sustainability and cost efficiency (Reza et al., 2020; Sharma et al., 2022). Among various biomass sources, banana leaf and water hyacinth are promising raw materials due to their abundant availability, renewable nature, and high carbon content (Donthu et al., 2021; Kalantari et al., 2017).

The development of research on activated carbon synthesis from natural materials shows a significant increase, both in terms of quantity and variety of approaches used (Sosa et al., 2023; Ukanwa et al., 2019). To get a comprehensive picture of these research trends, a bibliometric approach is one of the effective methods (Donthu et al., 2021; Kalantari et al., 2017). Through bibliometric analysis, information such as the number of publications, dominant keywords, collaboration between researchers, and the most influential journals and institutions can be systematically identified (Agostini et al., 2020; Liew et al., 2018; Skute et al., 2019).

Previous research has shown the great potential of these two materials in producing quality activated carbon, both through chemical and physical activation. Research conducted by (Misran et al., 2022; Taer et al., 2020) used banana stems as raw material for supercapacitor electrodes. The resulting activated carbon showed promising performance as an electrode with significant surface area. Study by (Alam et al., 2020). developed activated carbon from banana stems as a low cost adsorbent for the removal of methylene blue from wastewater, showing effective adsorption capacity. The study by (Ab Ghani et al., 2016) successfully produced activated carbon with high surface area from banana leaf through a one-step chemical activation process. This study evaluated the effect of activator type ($ZnCl_2$ and H_3PO_4), impregnation ratio, activation time, and activation temperature on the yield and quality of activated carbon produced (Kundu et al., 2015). Research by (Mohammaad & Kijevčanin, 2022) used water hyacinth biomass for activated carbon synthesis through chemical activation with $ZnCl_2$, followed by controlled pyrolysis. The resulting activated carbon has a high specific surface area and significant total pore volume, making it effective in the adsorption of glyphosate from aqueous solutions. However, although these studies have been carried out in a comprehensive manner. sporadically, there has not been much comprehensive mapping of the trends, collaborations, and direction of research developments in this field.

Although research on the synthesis of activated carbon from natural biomass continues to advance, studies that comprehensively map research trends remain relatively limited, particularly regarding activated carbon derived from banana leaf and water hyacinth. Most studies focus more on the synthesis process, characterization, and material applications, while analyses of publication trends, keyword trends, researcher collaboration networks, and institutional and national contributions have not been systematically examined. However, the increasing number of scientific publications in the field of activated carbon requires an analysis capable of providing a structured overview of the direction of research development, thereby serving as a foundation for identifying future research and technology development opportunities.

Therefore, this study was conducted to analyze the development of scientific publications related to the synthesis of activated carbon based on banana leaf and water hyacinth using a bibliometric approach based on the Scopus database with the assistance of the VOSviewer application. This analysis presents network, overlay, and density visualizations to illustrate the relationships between studies, publication trends, author distribution, dominant keywords, citation counts, affiliations, and the countries contributing to the development of research on natural biomass-based activated carbon. This study is expected to provide a more comprehensive overview of the dynamics of activated carbon research and to serve as a scientific reference for the development of more focused and sustainable biomass-based research.

RESEARCH METHOD

This study employs a quantitative descriptive research design with a bibliometric approach to analyze the development and trends in research on natural biomass-based activated carbon, specifically banana peels and water hyacinth. The bibliometric approach was chosen because it provides a systematic overview of the development of scientific publications, author collaboration patterns, keyword trends, citation counts, and the contributions of countries and institutions within a research field. The research data source comes from the Scopus database, which was selected for its extensive coverage of high-reputation international journals (Meiliyadi et al., 2026; Meiliyadi, Arizona, et al., 2025).

The population in this study consists of all scientific articles related to activated carbon, banana leaf, and water hyacinth indexed in the Scopus database (Meiliyadi, Rahman, et al., 2025). The research sample was obtained using purposive sampling by specifying the search keywords "activated carbon," "banana leaf," and "water hyacinth." The search was conducted in the title, abstract, and keywords fields of the articles, covering the publication years 2015–2024. Based on the search results, a total of 297 articles meeting the inclusion criteria were identified and used as the research sample. Data collection was conducted through documentation by downloading article metadata from the Scopus database in CSV format. The data collected included article titles, author names, publication years, citation counts, affiliations, countries, keywords, and document sources. The primary tools in this study were the Scopus database as the source of publication data, Microsoft Excel as a tool for data management and classification, and the VOSviewer software to visualize and analyze bibliometric relationships among the research data. Bibliometric analysis using VOSviewer was conducted to generate network visualizations, overlay visualizations, and density visualizations (Tamala et al., 2022). Network visualizations were used to examine relationships and collaborations among authors as well as connections between keywords (Husaeni & Husaeni, 2022). Overlay visualizations were used to illustrate research trend developments based on publication year, while density visualizations were used to identify the most dominant and frequently studied research topics. (Husaeni et al., 2022; Nova et al., 2024; Soegoto et al., 2022).

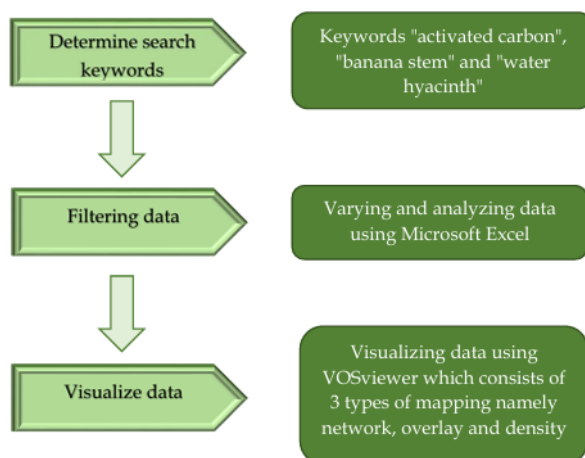


Figure 1: Data Collection Steps of Bibliometric Analysis

RESULTS AND DISCUSSION

See **Figure 2** for research trends using the keywords "activated carbon", "banana leaf" and "water hyacinth" based on Scopus database sources over the past 10 years (starting

from 2015 to 2024).

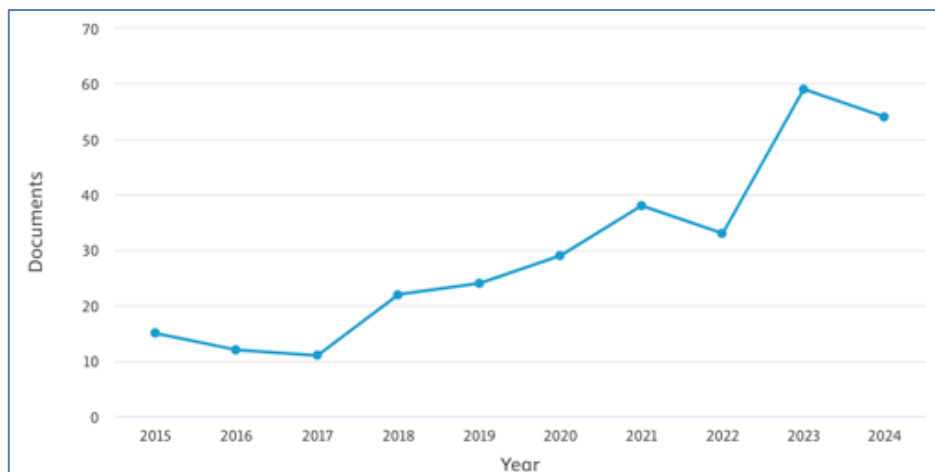


Figure 2. Research progress with keywords activated carbon, banana leaf and water hyacinth

As presented in Figure 2 in this study, the research trend with the keywords "activated carbon", "banana leaf" and "water hyacinth" has experienced instability over the past 10 years. The number of articles from 2015 to 2017 has decreased, where in 2015 as many as 15 articles were published, then in 2016 as many as 12 articles were published, and in 2017 as many as 11 articles were published. Then from 2018 to 2021 there was an increase in publications, where the articles published in 2018 were 22 articles, in year 2019 articles were published. 24 articles, in 2020 the articles published were 29 articles and in 2021 the articles published were 38 articles. However, in 2022 the publication of articles decreased, where the articles published this year were 33 articles. Then experienced an increase in article publishing in 2023 totaling 59 articles. However, the publication of articles decreased again from 59 to 54 articles in 2024.

Based on Figure 2, the publication trend graph from 2015 to 2024 can be divided into three stages of development. The first stage, from 2015 to 2017, shows the initial exploration phase with a low number of documents and tends to fluctuate. In this phase, research related to activated carbon from banana leaf and water hyacinth is still preliminary and has not received much attention.

Entering the second stage, from 2018 to 2020, there was a steady increase in the number of publications. This indicates a growing interest in the utilization of biomass waste as a raw material for activated carbon, as well as the development of technical approaches in the activation process and adsorption applications.

The third phase runs from 2021 to 2024 and is the expansion phase. The number of publications increases sharply, especially in 2023 when it reaches its peak. Although there was a slight decrease in 2024, the number is still relatively high. This trend shows that the topic of activated carbon from local biomass sources is gaining prominence in current research, in line with the increasing focus on environmental and sustainability issues.

The results of this study are consistent with previous research indicating that research on natural biomass-based activated carbon continues to advance year after year, particularly regarding the use of agricultural waste and aquatic plants as environmentally friendly materials for adsorbents and energy storage. Research by Sosa et al. (2023) and Ukanwa et al. (2019) indicates that the growing demand for sustainable materials is driving the increase in publications related to biomass-based activated carbon. Furthermore, Donthu et al. (2021) explain that an increase in the number of scientific publications in a field indicates high academic interest and the expansion of

research directions. Thus, the rising publication trend in this study suggests that activated carbon derived from banana leaf and water hyacinth holds significant potential for further development as an economical and sustainable alternative material in the future.

Referring to Table 1, there are 10 articles with the highest number of citations published in 2015, 2017, 2018, 2020, 2021, and 2026. At Among these years, articles published in 2018 occupied the top position with a total of 249 citations. This indicates that articles from that year are often referenced by other researchers in the same field.

Table 1. The top 10 articles with the highest number of citations were obtained based on the use of the keywords activated carbon, banana leaf, and water hyacinth.

No	Author	Title	Year	Number of Citations	Journal Identity
1	Liew, R.K. et al (Liew et al., 2018)	Microwave pyrolysis with KOH/NaOH mixture activation: A new approach to produce micro-mesoporous activated carbon for textile dye adsorption	2018	249	Bioresource Technology
2	Akpmie, K.G & Conradie, J (Akpmie & Conradie, 2020)	Banana peel as a biosorbent for the decontamination of water pollutants. A review	2020	181	Environmental Chemistry Letters
3	Van Thuan, T., et al (Thuan et al., 2017)	Response surface methodology approach for optimization of Cu ²⁺ , Ni ²⁺ and Pb ²⁺ adsorption using KOH-activated carbon from banana peel	2017	180	Surfaces and Interfaces
4	Lam, S.S., et al (Lam et al., 2016)	Fruit waste as feedstock for recovery by pyrolysis technique	2016	176	International Biodeterioration and Biodegradation
5	Zhang, Y. et al (Zhang et al., 2016)	High-performance supercapacitors and batteries derived from activated banana-peel with porous structures	2016	169	Electrochimica Acta
6	Li Y, et al (Zhang, Y. Gon Z. Song. N., Li, 2016)	A green adsorbent derived from banana peel for highly effective removal of heavy metal ions from water	2016	112	RSC Advances
7	Getachew, T., et al (Getachew et al., 2015)	Defluoridation of water by activated carbon prepared from banana (Musa paradisiaca) peel and coffee (Coffea arabica) husk	2015	106	International Journal of Environmental Science and Technology
8	Fasakin, O., et al (Fasakin et al., 2018)	Synthesis and characterization of porous carbon derived from activated banana peels with hierarchical porosity for improved electrochemical performance	2018	100	Electrochimica Acta
9	Gupta, H., & Gupta, B. (Suhas et al., 2016)	Adsorption of polycyclic aromatic hydrocarbons on banana peel activated carbon	2016	99	Desalination and Water Treatment
10	Acevedo, S.A., et al (Alzate Acevedo et al., 2021)	Recovery of banana waste-loss from production and processing: A contribution to a circular economy	2021	94	Molecules

Based on the search results that have been conducted on the Scopus database,

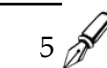


Figure 3 shows that there are 10 top affiliations that use the keywords activated carbon, banana leaf and water hyacinth.

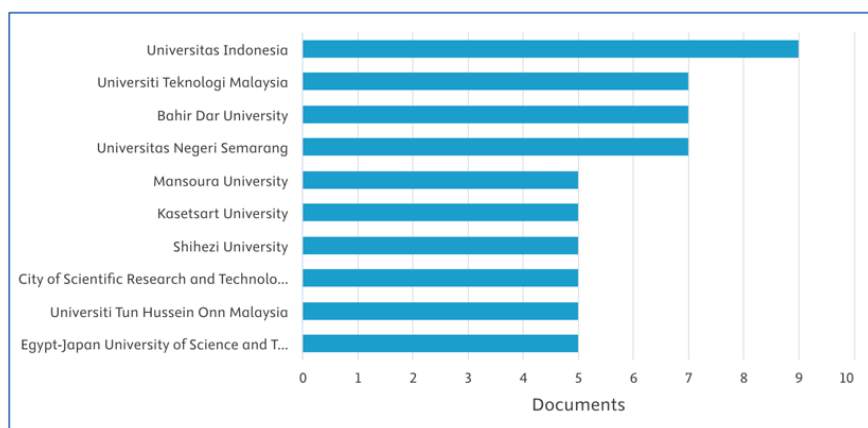


Figure 3. Top affiliations that are most active using the keywords activated carbon, banana leaf and water hyacinth.

From Figure 3, it can be seen that the University of Indonesia is the affiliate that wrote the most articles related to the keywords activated carbon, banana leaf and water hyacinth with a total of 9 articles. Take a look at Figure 4 for 10 most active countries in using the keywords "activated carbon", "banana leaf" and "water hyacinth". Based on Figure 4, it can be seen that there are 10 countries that dominate in the number of article publications.

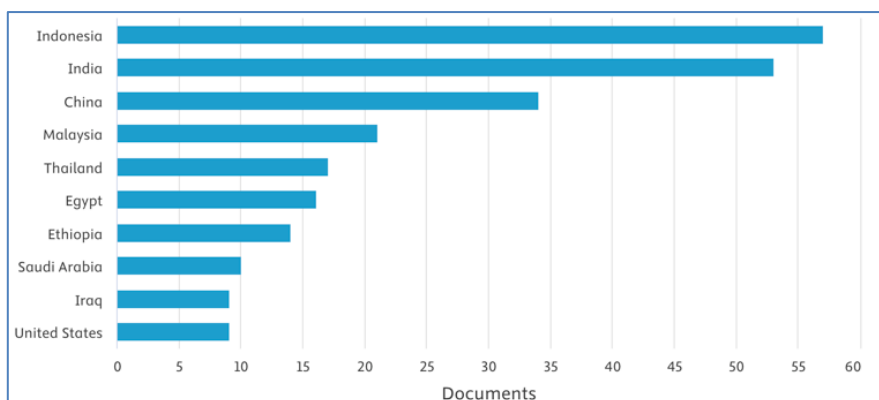


Figure 4. Top 10 countries that are most active in using the keywords activated carbon, banana leaf and water hyacinth.

Based on Figure 3 and Figure 4, the graphs show that Indonesia is the most active country using the keywords activated carbon, banana leaf, and water hyacinth, but only two universities from Indonesia are included in the top affiliation list. This is because although interest in these topics is high nationally, research in Indonesia tends to be spread across many small institutions and has not been concentrated in large universities. In addition, much of the research may not have been published in internationally reputable journals and therefore not detected in the global affiliation mapping. Meanwhile, other countries that are not as active as Indonesia nationally have institutions that are more consistent and strong in publications, making them more visible in the affiliation graph.

Take a look at Figure 5 for the top 10 most active authors using the keywords "activated carbon", "banana leaf" and "water hyacinth". Figure 5 shows the ten most

productive authors in activated carbon research, particularly those using biomass materials such as banana leaf and water hyacinth. The author with the highest number of publications is Kyzas, G. Z. with 5 documents, showing his important role in the development of activated carbon materials. Followed by Yang, F., Yu, F., and Yuan, A. who each have 4 documents, showing their consistency in this field. Several researchers from Indonesia are also listed, such as Ariyanti, D., Elvitria, and Frida, E., each of whom have 3 publications. This shows that research on activated carbon from local wastes such as water hyacinth and banana leaf has received serious attention at the national level. The dominance of authors from various countries shows this topic is global, with great potential for international collaboration. In addition, the presence of local researchers is also very important to encourage the utilization of biomass waste in a sustainable manner and based on regional potential.

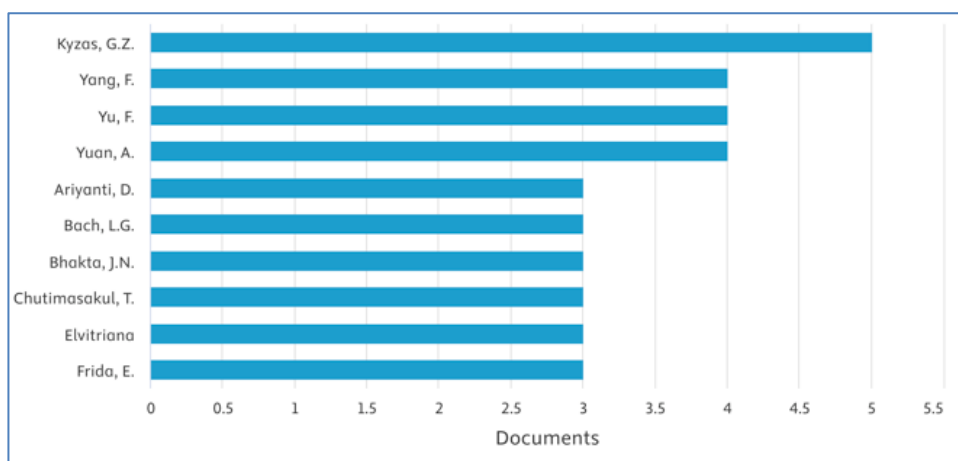


Figure 5. The top 10 most active authors using the keywords activated carbon, banana leaf and water hyacinth.

From Figure 6, it can be seen that articles are the most common type related to the keywords activated carbon, banana leaf and water hyacinth with a total of 128 documents. This graph shows the proportion of document types from the bibliometric analysis with the keywords activated carbon, banana leaf, and water hyacinth. The majority of publications (66.7%) are journal articles, indicating that this topic is widely researched seriously in academic domain.

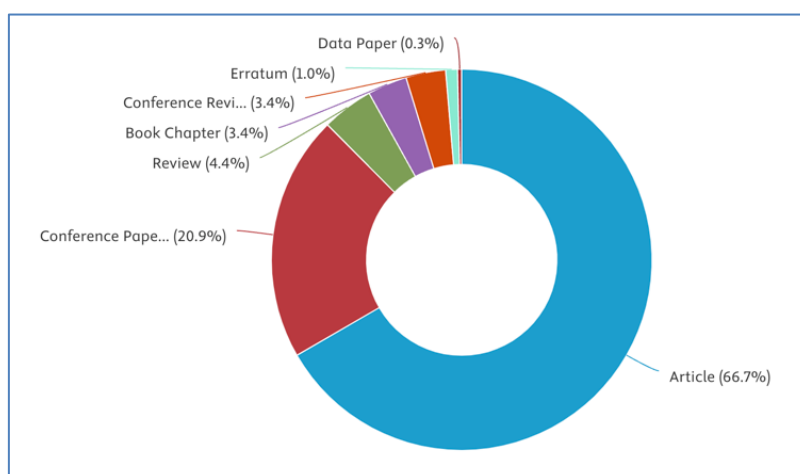


Figure 6. Top most used keywords for activated carbon, banana leaf and water hyacinth

A total of 20.9% were conference papers, indicating a high interest in early

research presentations. The rest consisted of publications such as reviews (4.4%), book chapters and conference reviews (3.4% each), erratum (1%), and data papers (0.3%). This shows that despite being quite developed, the field still has opportunities for further exploration especially in data publications and thorough reviews. Figure 7 shows that there are 11 top fields of study using the keywords activated carbon, banana leaf and water hyacinth.

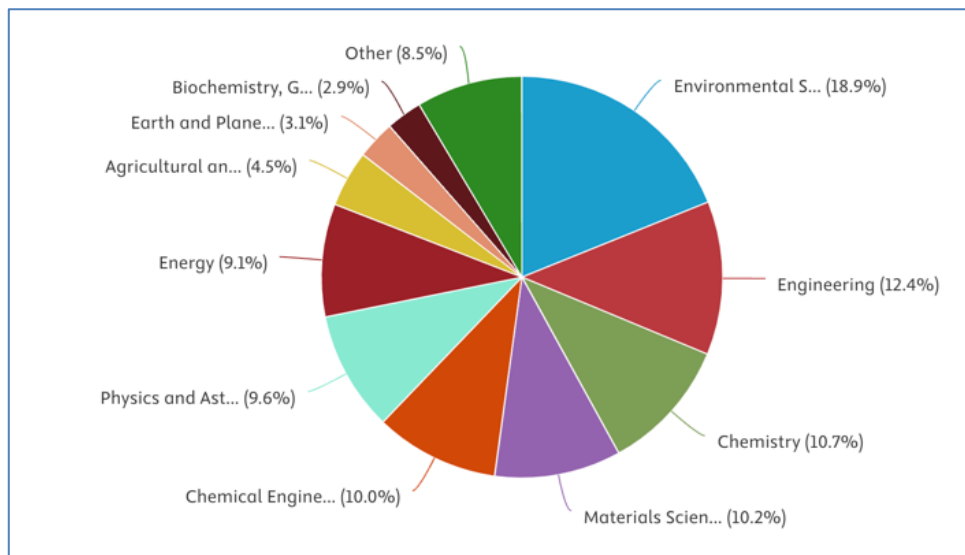


Figure 7. Fields of study that use the keywords activated carbon, banana leaf and water hyacinth.

From Figure 7, it can be seen that there are 11 fields of study that have the most published articles, and environmental science occupies the top position with 104 articles. The graph shows the field distribution of publications that discuss banana leaf and water hyacinth-based activated carbon. The majority of the research was in the field of Environmental Science (18.9%), showing a major focus on environmental applications such as waste treatment and adsorption of pollutants. Engineering (12.4%), Chemistry (10.7%), and Materials Science (10.2%) also dominated, indicating great attention to the manufacturing process, characterization, and efficiency of activated carbon materials. Other disciplines such as Chemical Engineering, Energy, and Physics show a multidisciplinary approach, covering aspects of reactors, renewable energy, and physical properties of materials. This makes it clear that research on activated carbon from biomass waste is not only environmentally focused, but also involves engineering and materials science at large.

Based on Table 2, the most common sources used the keywords activated carbon, banana leaf and water hyacinth. This table shows the five main sources of scientific publications that most discuss the topic of activated carbon from banana leaf and water hyacinth based on bibliometric analysis. The top sources are from the Journal Conference Series Physics with 17 documents, showing a strong focus on the physics and characterization aspects of materials. This is followed by AIP Conference Proceedings and IOP Conference Series Earth and Environmental Sciences, indicating the topic is also of interest in multidisciplinary and environmental fields. Publications in Biomass Conversion and Biorefinery and ACS Omega indicate that this research is relevant in the context of converting biomass waste into high-value materials and has reached reputable international journals. Overall, research on activated carbon from tropical biomass waste has gained widespread attention in various scientific fields.

Table 2 shows the sources that used the keywords activated carbon, banana leaf and water hyacinth most

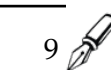
No	Source	Number of Document
1	Physics Journal Conference Series	17
2	AIP Conference Proceedings	13
3	IOP Conference Series Earth Sciences and Environment	11
4	Biomass Conversion and Biorefinery	8
5	ACS Omega	6

The results of this study indicate that research on natural biomass-based activated carbon, particularly from banana leaf and water hyacinth, has seen significant progress and involves various countries, institutions, and scientific disciplines. These findings align with previous research stating that increasing attention to environmentally friendly and sustainable materials is driving the growth of scientific publications related to biomass-based activated carbon (Sosa et al., 2023; Sharma et al., 2022). Indonesia's dominance as the most active country in terms of publications highlights the high potential for utilizing local biomass waste, although institutional contributions remain spread across various universities. Furthermore, the dominance of the fields of Environmental Science, Engineering, and Materials Science indicates that activated carbon research is not only focused on environmental aspects but is also expanding into the fields of materials and technology. These results also support the research by Donthu et al. (2021) and Agostini et al. (2020), which explains that the growth in the number of publications, author collaborations, and the dominance of journal articles indicate that a research field has developed globally and holds great potential for further development through multidisciplinary approaches and international collaboration.

Table 3. Clustering output obtained through VOSviewer

No	Number of Items	Color	Items
1	22	Red	Activated carbon, banana leaf, water hyacinth, moisture, fruits, aromatic compounds, banana peel waste, agricultural waste, crystallinity, zinc chloride, carbonization, specific surface area, capacitance, supercapacitor, sewage analysis, carbon dioxide, electrolyte, electrocatalyst, porous carbon, nitrogen, activation and particle size, nitrogen, activation and particle size.
2	17	Green	Reusable, fruit, pyrolysis, waste, electrode, food waste, organic carbon, surface area, potassium, biomass, sentience, carbon, catalysts particles, catalysts, non-human, classifiable drugs and physical chemistry.
3	16	Blue	Metals heavy, treatment wastewater, penetrating, leading, industrial textile, feces, activated charcoal, wastewater, ph, oxygen demand chemistry, charcoal, remediation, bioremediation, water pollution chemicals and Eichhornia.
4	14	Yellow	Initial concentration, adsorption isotherms, adsorbent isotherms, adsorbents, dyes, kinetics, low-cost, heavy metal heavy, groundwater activated carbon treatment, concentration (composition), adsorption, dye, isotherm and reusable.

To be able to use VOSviewer, at least 10 relationships between terms are required. After the analysis is carried out using VOSviewer, there are four groups marked with red, green, blue, and yellow colors that describe the relationship between interrelated topics, as shown in Table 3. VOSviewer provides three views of bibliometric mapping, namely network, overlay and density. The keyword with the largest circle indicates that the keyword is the most frequently used. Search



results from the Scopus database which includes titles, keywords and abstracts found 297 articles from 2015 to 2024 (the last 10 years).

Table 3 shows the results of the bibliometric analysis based on the keywords "activated carbon", "banana leaf" and "water hyacinth" grouped into four color clusters. The red cluster focuses on the stages of making activated carbon from biomass waste, such as banana leaf and water hyacinth, including carbonization, activation, and analysis of pore characteristics. The green cluster deals with the application of activated carbon in waste treatment, heavy metal adsorption, and recyclability. The blue cluster emphasizes the use of water hyacinth as a biosorbent in bioremediation of industrial wastewater, especially from the textile sector. Meanwhile, the yellow cluster addresses modeling of adsorption processes such as kinetics, isotherms, efficiency, and thermodynamics to evaluate the performance of activated carbon.

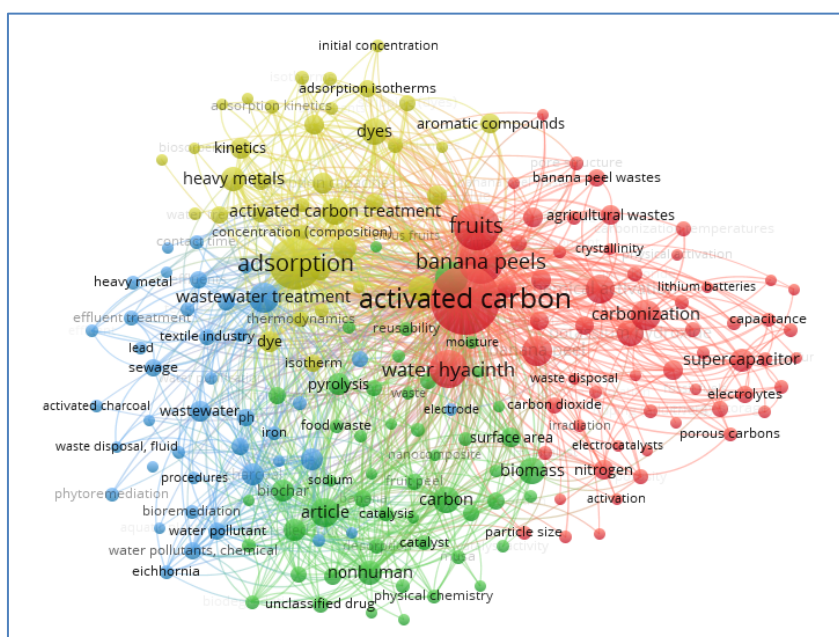
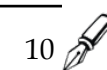


Figure 8. Network mapping displayed based on keyword usage

Figure 8 shows the division of groups based on the topic under study. This image from VOSviewer shows a map of the relationships between keywords in the topic of activated carbon, specifically related to banana leaf and water hyacinth. The keyword "activated carbon" is at the center because it appears most frequently and is connected to many other terms. "Banana leaf" is seen predominantly in the red cluster, which focuses on agricultural waste feedstock, carbonization processes, and applications such as supercapacitors. Meanwhile, "water hyacinth" or water hyacinth appears between the red and green clusters, signifying its role as biomass for activated carbon production. The blue and yellow clusters represent activated carbon applications in water treatment and heavy metal or dye adsorption studies. This visualization shows that research on activated carbon from biomass waste, including water hyacinth and banana leaf, is widely conducted especially for adsorption applications and enhancement of surface characteristics such as pore area and absorptive capacity. This map can help you see where your research stands in the scientific trends.



water hyacinth. The largest words such as "activated carbon", "adsorption", "banana leaf", and "water hyacinth" indicate the most frequently used keywords that are at the center of research in this field. This visualization also shows the strong link between natural raw materials, such as biomass and agricultural waste, and the use of activated carbon in sewage treatment, particularly for adsorption of dyes and heavy metals in wastewater. In addition, the level of research intensity is also depicted through the colors-the darker the color, the higher the amount of research that has been conducted on the topic. Frequently appearing methods such as chemical activation (e.g. KOH), carbonization, and pyrolysis indicate the main focus on the manufacturing process of activated carbon. On the other hand, terms such as surface area, pore size, and thermodynamics indicate researchers' attention to the physical characterization and performance of activated carbon. Overall, this figure shows that research in this field is highly developed with a strong focus on utilizing biomass waste for environmental treatment.

CONCLUSION

Based on the results of a bibliometric analysis of 297 articles indexed in the Scopus database from 2015 to 2024, research on natural biomass-based activated carbon, particularly from banana leaf and water hyacinth, has shown significant growth, albeit with some fluctuations. Publication trends have increased year by year, peaking in 2023, indicating a growing academic interest in the utilization of natural biomass as a raw material for environmentally friendly and sustainable activated carbon. Analysis using VOSviewer successfully mapped relationships among authors, keywords, institutions, and countries, and revealed that research topics are dominated by adsorption, chemical activation, biomass, and applications of activated carbon in waste treatment and energy storage. Thus, this study successfully provides a comprehensive overview of the trends and direction of research on natural biomass-based activated carbon and can serve as a scientific reference for the development of more effective, economical, and sustainable activated carbon research and technological innovation in the future.

AUTHOR CONTRIBUTIONS

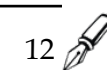
The authors' contributions to this study are as follows: Nadia Febriana was involved in developing the research concept, collecting data, analyzing data, and writing the manuscript. Lia Ismi Mawanti and Dela Yunita Rizki contributed to data processing, developing the methodology, and revising the manuscript. Nurul Titian Lestari assisted in the process of gathering references and validating the research data. Ahmad Didik Meiliyadi, Kurniawan Arizona, and Muh. Wahyudi served as advisors in refining the concept, analyzing the results, and conducting the final review of the manuscript. All authors have read and approved the final version of the article.

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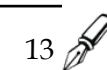
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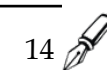
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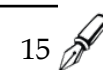
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