Exploring fatty acid methyl esters: A bibliometric review of gas chromatography applications

Marta Ostojčić*, Sanda Hasenay, Sandra Budžaki, Daniela Čačić Kenjerić

Josip Juraj Strossmayer University of Osijek, Faculty of Food Technology Osijek, Franje Kuhača 18, 31000 Osijek, Croatia

KEY CONTRIBUTION

Biodiesel is the first alternative fuel whose physicochemical characteristics are governed by suitable standards. Minimum percentage of fatty acid methyl esters in biodiesel needs to be 96.5% according to EN 14214 standard. The method prescribed by the standard for the fatty acid methyl analysis is gas chromatography. This study provides the first bibliometric overview of the use of gas chromatography analysis in the field of fatty acid methyl esters from biodiesel based on literature data from the WoS CC database published from 2019 to 2023.

ABSTRACT

The search for alternative fuels led to the development of biodiesel research. However, in order for biodiesel to meet the prescribed standards, it must first fulfil the proportion of fatty acid methyl esters (FAME) in its composition. Among several possible methods for the determination of FAME, the standard prescribes the use of gas chromatography (GC). The aim of this study was to provide an overview of the international literature dealing with this topic over the last five years. To achieve this goal, a search of the Web of Science database (WoS) was carried out, followed by a bibliometric analysis in the VOSviewer software. The analysis included 99 studies published over the last five years. The main authors, countries, institutions, journals and keywords were identified to highlight important contributions in the field. The scientific mapping revealed collaborative networks and research focus areas such as analysis, catalysts, conversion, yield, biomass, but also biodiesel production itself. The review showed that this research is carried out by scientists from different scientific categories linked by this highly topical issue in total link strength of 273.

Introduction

Fossil fuels have been the primary source of energy since their discovery, and energy is regarded as one of the most crucial resources for maintaining a nation's economic prosperity. Researchers are searching for alternative, affordable, sustainable, renewable, and efficient energy sources as a result of environmental issues brought on by fuel burning, price increases, and the depletion of natural energy sources like fuel reserves (Mathew et al., 2021; Ragonese et al., 2009). Biodiesel is one of the most significant substitutes for fossil fuels. It is the first alternative fuel whose physicochemical characteristics are governed by suitable standards, specifically American ASTM D 6751 and European EN 14214 (EN 14214, 2019; Ostojčić et al., 2020). Biodiesel is a mixture of fatty acid methyl (FAME) or ethyl esters (FAEE) and is produced from biological materials such as vegetable oils (soybean, rapeseed, sunflower, palm and coconut oil), waste cooking oils, non-edible oils, animal fats, microalgae as well as plant and waste products (Adewale et al., 2015; Gopinath et al., 2015; Gupta et al., 2016; Kim et al., 2022; Ramos et al., 2019; Suzihaque et al., 2022; Toldrá-Reig et al., 2020). Minimum percentage of FAME in biodiesel needs to be 96.5% according to EN 14214 standard (EN 14214, 2019). Additionally, figuring out FAME in biodiesel is crucial for the production and blending process as well as for quality assurance in distribution operations (Sitko et al., 2011). Although FAME can be determined by different methods such as X-ray (Sitko et al., 2011), nuclear magnetic resonance (Knothe and Kenar, 2004; Mello et al., 2008) or FTIR spectroscopy (Oyerinde and Bello, 2016; Rabelo et al., 2015; Torres et al., 2020), as well as by radiocarbon analyses (Norton et al., 2012) and from dynamic viscosity measurements (Borges et al., 2011), the most commonly used, but also the method prescribed by the standard, is gas chromatography (GC). Modern GC, first developed by Martin and James in 1952, has since evolved into one of the most essential and widely used analytical methods in contemporary chemistry (Bartle and Myers, 2002). GC is an analytical technique for the separation and analysis of volatile compounds that is commonly applied in chemical analysis, quality control, and research, playing a crucial role in various industries such as pharmaceuticals, petrochemicals, and forensics (Fauzi et al., 2017; Kaur and Sharma, 2018; Maji et al., 2023). The aim of this study was to carry out bibliometric analysis for exploring the application of GC in biodiesel analysis. Bibliometric analysis is implemented due to the several key considerations. First, it facilitates a systematic exploration of scientific literature, providing quantitative insights into research trends, key topics, and leading authors in the field. This is particularly significant for biodiesel analysis, where GC plays a central role, yet a comprehensive overview of existing research remains lacking. Second, this method enables the identification of research gaps and emerging directions, which is especially important given the dynamic advancements in technologies for biodiesel analysis and the growing demand for sustainable fuels. Finally, bibliometric analysis offers an objective foundation for evaluating the impact of GC within this interdisciplinary field. As such, this approach not only delivers a holistic overview of existing knowledge, but also serves as a guide for future research.
To achieve this goal, a search of the Web of Science Core Collection (WoS CC) and study selection was first carried out, followed by a bibliometric analysis in VOSviewer. The analysis focused on last five years, highly cited papers, prominent journals and authors, as well as relevant research areas.

Data sources and research methodology

Data sources
The data were sourced from the WoS CC. In the WoS CC database, a search was conducted using subject terms with the time frame set from 2019 to 2023. The search formula employed was through Topic filed

using the BOOLEAN expression (keywords "*Gas chromatography*" OR "*Gas-chromatography*" OR GC for studies that also include keywords "*Fatty Acid Methyl Esters*" OR FAME). This search yielded a total of 124 studies. The search was further refined by limiting the source type to Article, Review Article, Proceeding Paper, Data Paper or Book Chapter. After a subsequent screening process, 99 studies were identified as eligible for bibliometric analysis. In this screening process, the abstracts of the papers were reviewed, and only those relevant to this research were selected.

Research methodology

The articles obtained from WoS CC were imported into VOSviewer (1.6.19) to apply the bibliometric analysis. Since VOSviewer focuses on the analysis of keywords and citations, it is suitable for determining the intellectual structure of a subject area and important research topics (Pratama et al., 2024). Bibliometric is the study and analysis of published scientific literature or related data, as well as the statistics and description of the relationships between published studies. The bibliometric software VosViewer, which was used in this study, is ideally suited for the creation and visualization of bibliometric maps. These maps can be created to visualize author or journal networks based on co-citation data or keyword networks based on coincidence data. This program enables the creation of comprehensive bibliometric maps down to the smallest detail. First, the number of studies in the encompassed period was analyzed, then the type of the studies and the category they cover. Then an analysis of the author's review of scientific collaboration was carried out by country, institution, journal and, finally, by keywords. It was examined how the application of GC in the research of biodiesel (FAME) has connected scientists from different fields and different institutions in different countries over the last five years and what has been the focus of this research.

Results and discussion

Analysis of publication outcome: study trends and publication types

Data on published scientific studies by year are crucial for tracking the development of biodiesel research, identifying emerging topics in biofuel production, and evaluating the impact and quality of publications in this field. These data enable the analysis of progress trends in biodiesel technologies, facilitate comparisons across different subfields of bioenergy, and provide insights into the evolution of research methodologies. Furthermore, they support strategic decision-making related to funding allocations and guide the direction of future biodiesel-related research. According to Sales et al. (2022) there has been a discernible increase in the number of publications on the production of biodiesel, with a notable increase in the number of publications pertaining to feedstocks for biodiesel production in 2021 compared to prior years. In this study, there were 99 relevant studies related to the analysis of FAME with GC in the last five years. These studies were included in the bibliometric analysis. Figure 1 shows the number of published studies per year, revealing that in years 2019 and 2020 the most studies were published, 24 and 23, respectively. The figure shows a slight decline after two years, and the same was reported by Pratama et al. (2024), explaining this as presumably due to the indirect impact of the Covid-19 pandemic. After 2020, a slight decline is seen in the publications on this topic, with the fewest of 12 studies published in the last year examined, 2023.

After reviewing the publication of studies by year, the aim was to analyse the types of studies. Data on the types of published studies over a specific period are important because they allow for the analysis of research trends and focuses within particular disciplines. Different types of papers, such as original

research, reviews, methodological articles, or reports, can indicate specific directions in the scientific community.
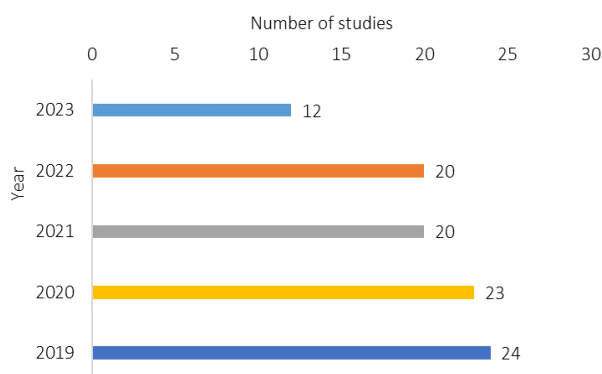

Figure 1. Number of published studies per year.

These data also help assess the quality of research, as different paper types have varying levels of impact and expertise. According to Figure 2, out of the 99 published studies that were analysed, 95% are articles, 3% are proceeding papers and 1% are book chapters and data papers. According to the literature, some other bibliometric analyses related to biodiesel also had the most original scientific papers in their structure (Kusuma et al., 2024; Rajeswari et al., 2023). An increase in the number of original research papers on FAME over a specific period may indicate a growing emphasis on practical innovations, new experimental approaches, or the exploration of under-researched areas within the field. This trend often reflects an active and dynamic research environment where scientists are extending the boundaries of existing knowledge by introducing novel contributions. Such a rise in original research can also signal important advancements in biodiesel production technologies, feedstock utilization, and sustainability, and it highlights a shift toward addressing real-world challenges in biofuel development.
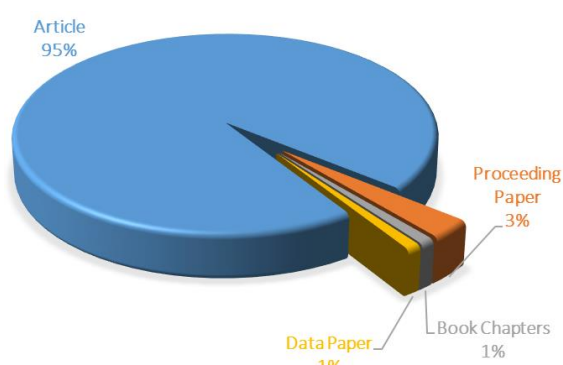

Figure 2. Study types.

The number of scientific fields, that a particular topic covers, provides valuable insight into its interdisciplinary nature and potential for broader impact. When a topic spans multiple area, it often reflects complex, multifaceted research that draws on diverse methodologies and expertise. This can drive innovation by integrating knowledge from various disciplines, leading to novel solutions and insights that may not emerge within a single field. Here, the 99 published studies covered as many as 24 WoS categories/areas, showing that research on the application of GC in FAME analysis is conducted by scientists from different fields that are interconnected. Figure 3 shows the WoS categories and the

representation of the analysed studies in each of them. Some publications are due to their interdisciplinary approach listed in more than one category. It can be seen that most articles were published in the area of energy fuels, followed by engineering chemicals and environmental sciences. These scientific fields have proven to be the most significant in other bibliometric analyses of biodiesel (Biberci, 2023; Pratama et al., 2024; Sales et al., 2022). Interdisciplinary research in the analysis of FAME is often associated with higher citation rates, because it draws attention from a wider academic audience. Topics that span multiple scientific areas, such as chemistry, environmental science, and engineering, foster collaborations and increase visibility across various research communities. These collaborations often lead to breakthroughs that would be difficult to achieve within the confines of a single discipline. In the context of FAME analysis, such interdisciplinary efforts are essential for advancing both theoretical knowledge and practical applications, such as the improvement of biodiesel production, analysis of, processes and the enhancement of sustainability practices. The range of scientific fields involved is an indicator of the complexity, innovation potential, and cross-disciplinary relevance of the research, which plays a crucial role in driving progress in biofuel technology and its broader applications in energy and environmental sectors.
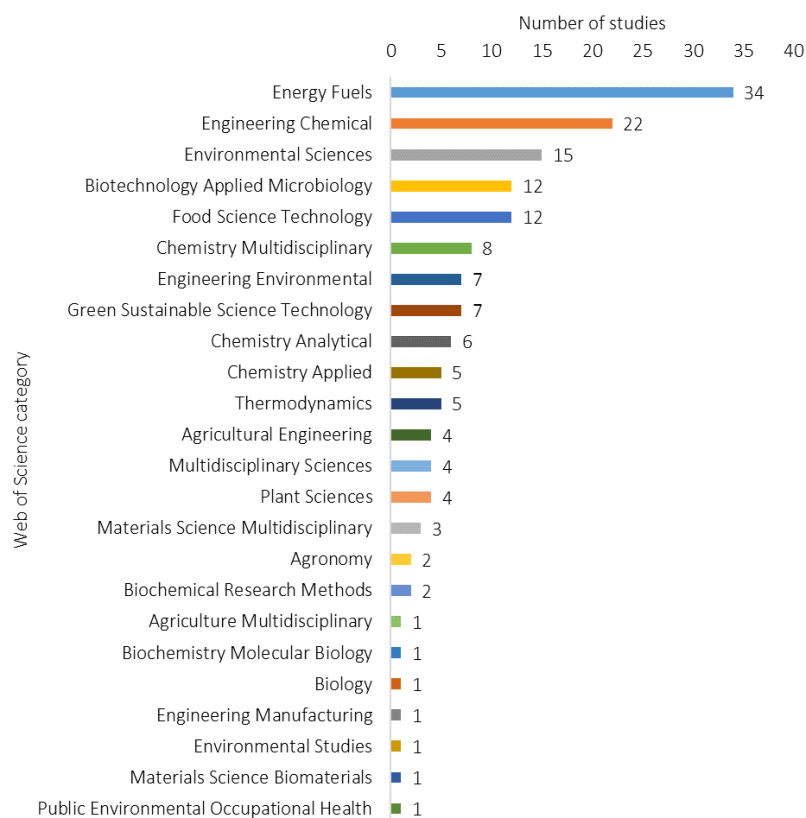

Figure 3. Distribution of studies by Web of Science categories.

Science mapping: social cooperation

Collaboration between researchers from different organizations and countries is essential for biodiesel research due to the interdisciplinary nature of the field. It brings together diverse expertise in areas like chemistry, environmental science, and policy, leading to solutions that are more comprehensive. Additionally, access to varied resources such as raw materials, technologies, and research facilities enhances the quality and scope of the research. Global collaboration also ensures that research considers regional differences in feedstocks, production processes, and regulatory frameworks,

accelerating innovation and ensuring sustainability across different contexts. A relevant research paper that supports the importance of international collaboration in biodiesel research is published by Sales et al. (2022). This study highlights the global engagement in biodiesel research, emphasizing the contributions of key countries such as China, Malaysia, and India. It also notes how collaboration across borders enhances the development of biodiesel technologies by pooling resources, expertise, and knowledge from diverse regions to address challenges such as feedstock sustainability and production efficiency. In bibliometric analysis, the collaboration between authors can be represented through co-authorship networks, where authors are connected based on joint publications. The frequency of citations between authors also indicates intellectual collaboration, as it shows how often they refer to each other's work. Additionally, the analysis of institutional and international collaboration, through mapping authors' affiliations, highlights cross-institutional and global research partnerships. Keyword and subject overlap also illustrate collaboration in specific research domains. These relationships can be visualized in network maps, revealing the strength and breadth of author collaboration.

Authors

By visualizing author collaboration, the ten most significant authors were filtered out, with the number of published studies and total link strength shown in Table 1. It was found that Ahmad Mushtaq and Zafar Muhammad play the leading role in this research with 6 and 5 published studies respectively. The other authors had four or less published studies.

Table 1. List of ten most significant authors in the examined research area.

Author	Number of publications	Total link strength
Ahmad, Mushtaq	6	47
Zafar, Muhammad	5	36
Show, Pau Loke	4	33
Rozina	4	28
Sultana, Shazia	3	29
Munir, Mamoona	3	31
Asif, Saira	2	23
Bokhari, Awais	2	23
Saeed, Muhammad	2	19
Waseem, Amir	2	19

Out of 99 studies analysed, there were 466 authors with at least one published study. These 466 authors were divided into six clusters with 229 links and a total link strength of 273. The visualization shows over 40 authors that have achieved the greatest collaboration (Figure 4).

Countries

International collaboration among countries and institutions with varying agricultural and technological capabilities brings unique perspectives. This helps them to overcome challenges such as feedstock scarcity, technological limitations, and regulatory barriers (Sales et al., 2022). Sharing knowledge and best practices across borders fosters global innovation, speeds up the research process, and enhances the transition to more sustainable biodiesel production. Out of the 99 studies analysed, 37 countries

were visualized with at least one study per country. These countries are divided into seven clusters (Figure 5) with 64 links and a total link strength of 95.
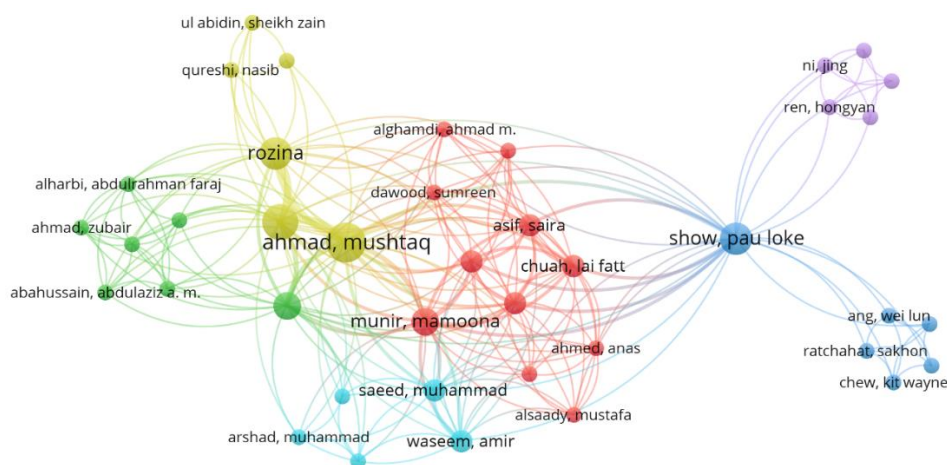

Figure 4. Co-authorship analysis with authors as the units of analysis.
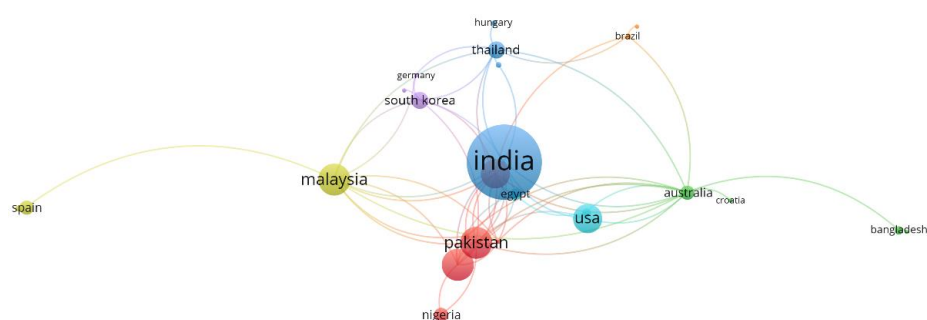

Figure 5. Cooperation analysis with country as the unit of analysis.

Figure 6 shows the number of studies published for each country, where some studies are connected to several countries, because the authors of the same study are from different countries. According to Figures 6 and 7, the leading country was India with 26 publications in the analysed period, followed by Malaysia, Pakistan and China with 11 publications, and Saudi Arabia and USA with 10. Other countries had six or less publications. The largest number of countries, 15 of them, had only one publication each. As already mentioned, the global engagement in biodiesel research emphasized the contributions of key countries such as China, Malaysia, and India (Sales et al., 2022). These countries are also mentioned in other bibliometric analyses of biodiesel, but in a different order. So Sales et al. (2022) highlighted the four most prolific countries in the area of feedstocks for biodiesel production as follows: China, Malaysia, India, USA. On the other hand, Pratama et al. (2024) in green diesel production for energy sustainability showed a somewhat different sequence: USA, China, Malaysia, India. All this shows that these countries are real leaders in biodiesel topic, it just depends on which aspect of biodiesel the publications look at (Biberci, 2023; Kombe, 2023; Rajeswari et al., 2023). According to Figures 5 and 6, it is evident that India had the greatest significance in the examined research according to the number of publications. India has a prominent presence in biodiesel research due to several factors, including its large agricultural sector, significant feedstock availability, and a national focus on energy sustainability (Kumar et al., 2021;

Kumar. J and Majid, 2020; Rahul and Anil P., 2016). The country's vast agricultural industry generates substantial crop residues that are a key resource for biodiesel production, particularly through non-edible oils like jatropha and animal fats (Borugadda and Goud, 2012; Jain and Sharma, 2010; Kumar and Sharma, 2011).
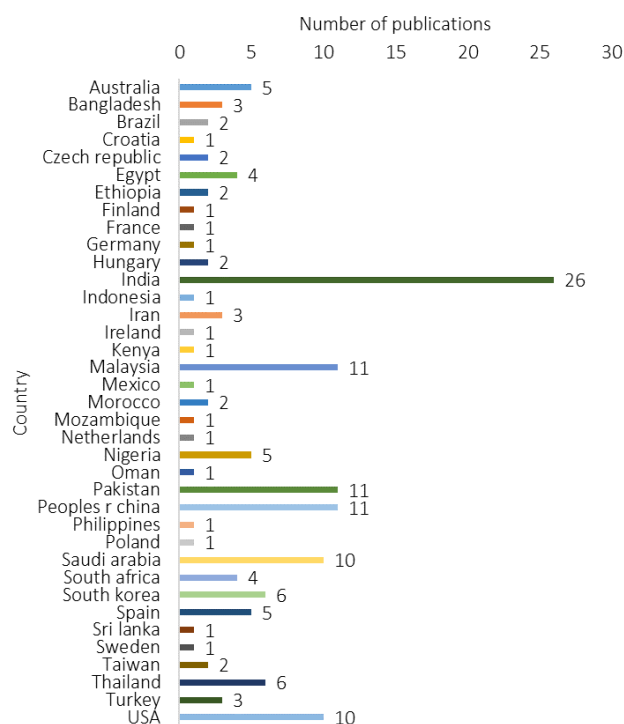

Figure 6. Distribution of studies per country.
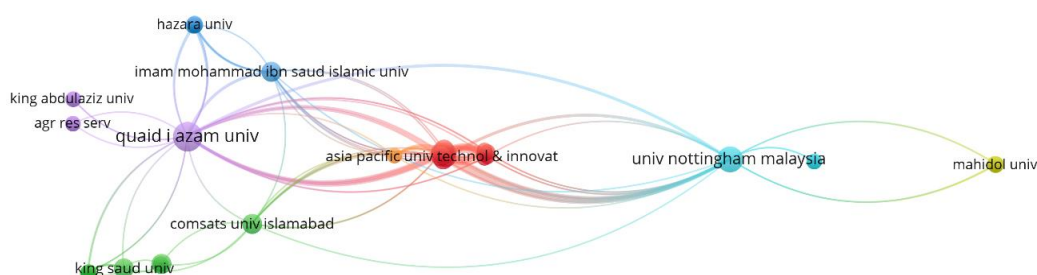

Figure 7. Cooperation analysis with organizations as the units of analysis.

Moreover, India has taken active policy measures, such as the Biofuel Policy and targets for biodiesel blending, to reduce its dependency on imported fossil fuels (Das, 2020; Saravanan et al., 2018). Additionally, India's growing interest in alternative energy sources, including biodiesel, is driven by environmental goals to reduce greenhouse gas emissions and enhance domestic energy security. The country's large-scale initiatives and research efforts aim to address challenges like feedstock availability and emission reductions, further boosting the number of research papers published on biodiesel. However, Pakistan and Saudi Arabia (red cluster) showed a higher connection strength (25), i.e., they

achieve greater collaboration despite a lower number of publications, namely, 11 and 10 respectively. This is exactly what can be seen from the red lines intersecting with the largest number of different countries. Biodiesel research in Pakistan and Saudi Arabia is driven by their need for sustainable energy solutions and the reduction of reliance on fossil fuels. Both countries have focus on utilizing local feedstocks like waste oils for biodiesel production, reflecting both countries' goals of diversifying energy sources and reducing environmental pollution (Chakrabarti et al., 2012; Khan et al., 2021; Rehan et al., 2018). As for Croatia, this topic has not been widely covered in the last five years. The only paper that covered the topic was that of our research group (Ostojčić et al., 2021).

Organizations

The involvement of different organizations and universities in biodiesel research is essential for several reasons. First, it enables interdisciplinary collaboration, where various areas of expertise—ranging from engineering to environmental science—can be integrated to address complex challenges such as feedstock optimization, production efficiency, and sustainability (Sales et al., 2022). Universities play a crucial role in advancing fundamental research and developing new technologies, while organizations, particularly industry players, offer practical insights and scalable solutions. These collaborations accelerate innovations and bridge the gap between research and real-world application. A total of 99 studies analysed resulted in 205 organizations from 37 countries. These 205 organizations are visualized through seven clusters with 120 connecting lines and a total link strength of 199. Figure 7 shows the organizations with the greatest collaboration, where it is evident that cluster 1 (purple) achieves the greatest cooperation. Quaid-i-Azam University from Islamabad, Pakistan, is the leading organization with six publications and a total link strength of 37. It is not surprising that the aforementioned most significant author from this topic, Ahmad Mustaq, comes from this university. The other organizations each had three or less, but mostly one, publication. Here Asia Pacific University and Portal Rasmi Universiti Malaysia Terengganu from Malaysia, Brno University of Technology from the Czech Republic, Pir Mehr Ali Shah Arid Agriculture University and Rawalpindi Women University from Pakistan, and Wenzhou University from China should be singled out. These organizations/ universities, with only two publications each, created total link strengths of 22. It is evident from the above mentioned that scientists in this field do not collaborate only within one specific environment, but rather with scientists from different organizations in different countries.

Journals

Regarding the scientific journals in which this topic was published, it is clear that these are the journals that support the found 24 WoS scientific categories shown in Figure 3. The 99 analysed studies were published in 63 different journals, 55 of which are interconnected. These 55 journals were divided into seven clusters with 359 links and a total link strength of 853, and are shown in Figure 8. The most important journal was Fuel with 11 publications and a total link strength of 212, followed by Chemosphere with 4 publications and a total link strength of 85. In all other journals, three or less publications were published. This is not surprising since journals Fuel and Chemosphere are both excellent choices for publishing biodiesel research, each offering distinct advantages. Fuel has a 2023 Impact Factor of 6.7 and is well-regarded for its focus on energy-related topics, including sustainable fuels and advanced analytical methods like GC, making it highly suitable for biodiesel studies. Chemosphere, with an even higher 2023 Impact Factor of 8.1, emphasizes environmental chemistry and technology, aligning with biodiesel's role in renewable energy and pollution reduction. Both journals provide rigorous peer-review processes, international readerships, and high citation potential, ensuring

broad visibility and significant impact for published work. In the other bibliometric analysis of biodiesel, Fuel journal also ranks first (Chen et al., 2021; Pratama et al., 2024), second (Biberci, 2023; Kombe, 2023), or fifth (Kusuma et al., 2024; Sales et al., 2022).
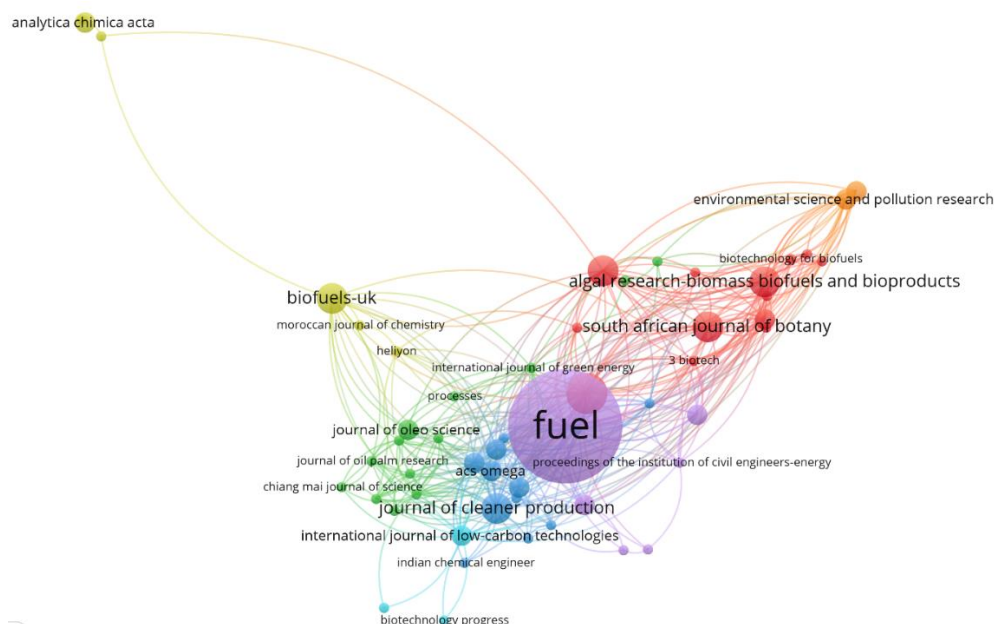

Figure 8. Bibliographic coupling with journals as the units of analysis.

Research focus: keywords

Keyword analysis in bibliometric studies is crucial as it helps to identify the main themes, trends, and research priorities in a particular field. By analysing the frequency and co-occurrence of keywords in academic papers, researchers can uncover emerging areas of interest, pinpoint gaps in existing research, and track how certain topics evolve over time. Keyword analysis provides insights into the interdisciplinary nature of a research area. It reveals how topics from different fields are connected, highlighting collaborations between various disciplines. This can foster new directions for research by identifying unexplored or underexplored connections between concepts. Keywords are vital for mapping the research landscape, allowing researchers and policymakers to allocate resources effectively, design targeted interventions, and set future research agendas.

Following the research focus, 3176 terms were found from the analysed 99 studies, while 199 terms that appear at least five times were included in the further analysis. Out of these 199 terms, general words such as units of measurement, parameters, and abbreviations that seemed unknown, were excluded. After this, 116 terms were obtained that were included in the visualization. The visualization showed the connection of these terms through six thematically related clusters. The first, largest cluster (red), contained 30 related keywords, where the common topic of research is the analysis of FAME on GC. The second cluster (green) consisted of 24 interrelated keywords linked in the thematic research of biodiesel synthesis. The third cluster (blue) connected 22 keywords with a focus on biodiesel research as a fuel and therefore its blends, but also diesel engines and the impact of biodiesel on the environment. The fourth cluster (yellow) connected 21 keywords with the research topic of biodiesel itself, the raw materials used for its production, primarily lipids, waste oils, but also microalgae. The fifth cluster (purple) contained 11 keywords where the emphasis is on biodiesel as a final product, that is, on FAME

and yield. Finally, the last, sixth cluster (light blue) connected only eight keywords, where the focus is on the synthesis of biodiesel. This cluster actually connects everything important into one whole, from the production and catalysis to the properties of biodiesel, where it also touches on the prescribed standard. With the last cluster, the whole story about biodiesel is actually completed. In this research, biodiesel was, as expected, the most frequently used word, which was found 171 times in these 99 studies, and, as it can be seen in Figure 9, it extends through all, and also connects all clusters. The keywords found in this analysis, as expected, also appear in all other bibliometric analyses related to biodiesel (Biberci, 2023; Chen et al., 2021; Kombe, 2023; Pratama et al., 2024; Rajeswari et al., 2023; Sales et al., 2022).
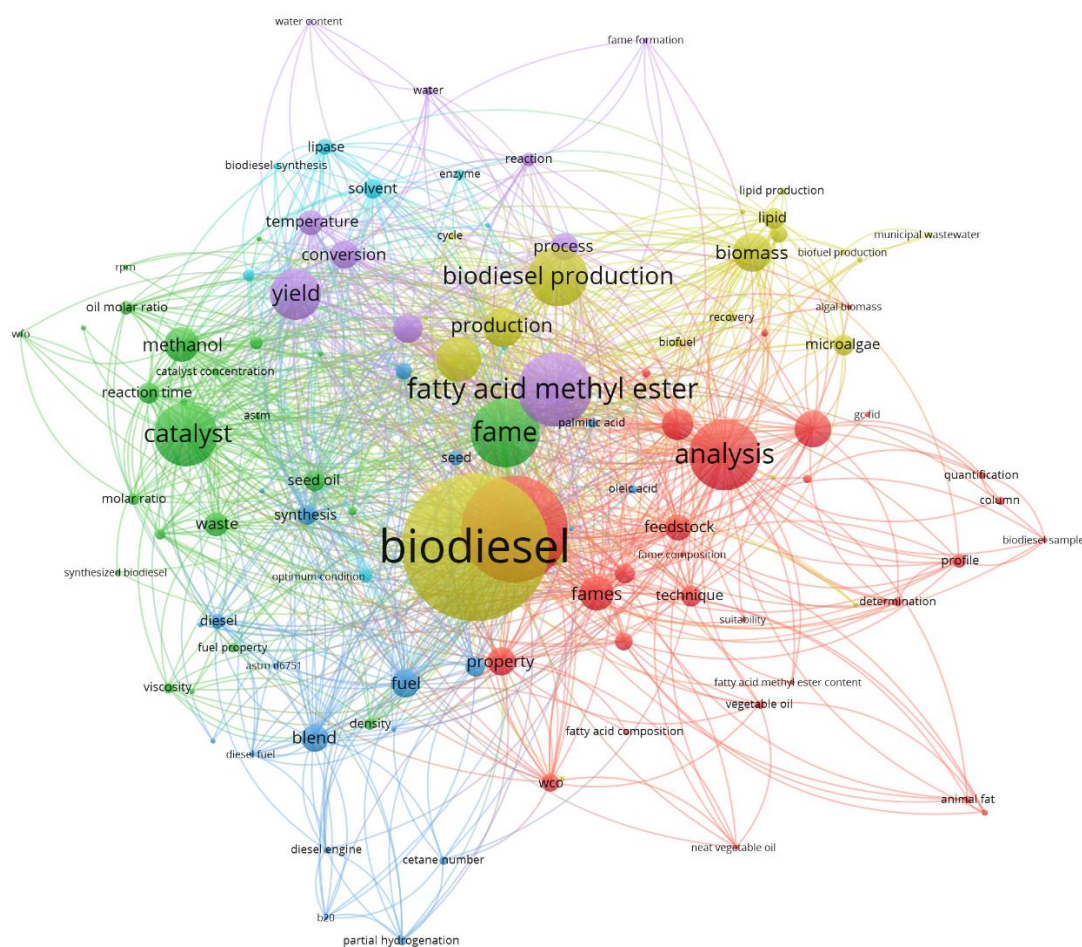

Figure 9. Co-occurrence analysis with author keywords as the units of analysis.

Conclusions

This study provides the first bibliometric overview of the use of GC analysis in the field of FAME from biodiesel. The overview is based on literature data from the WoS CC database published from 2019 to 2023 using the bibliometric method and the VOSviewer software tool. The 99 publications analysed gave an overview of the research trend, the success of authors from different organizations and different countries on the topic of research related to the analysis of biodiesel. The results showed that the number of articles changed during the research period, i.e., it was the highest in 2019 and 2021, and included 466 authors from 205 organizations from 37 countries with publications in 63 scientific

journals. India, Malaysia, Pakistan and China were the leading countries that contributed the most published papers to this study. In addition, the main keywords of the study were summarized. Studies related to biodiesel production, the raw materials used as well as catalysts, diesel engines and biodiesel yield analysis were current research topics. The analysis has shown that this topic is very interesting as it brings together scientists from different scientific categories, which leads to interdisciplinarity and enables higher quality publications.

References

Adewale, P., Dumont, M.-J., Ngadi, M. (2015): Recent trends of biodiesel production from animal fat wastes and associated production techniques. *Renewable and Sustainable Energy Reviews* 45, 574–588. https://doi.org/10.1016/j.rser.2015.02.039

Bartle, K. D., Myers, P. (2002): History of gas chromatography. *TrAC Trends in Analytical Chemistry* 21(9), 547–557. https://doi.org/10.1016/S0165-9936(02)00806-3

Biberci, M. A. (2023): Bibliometric Analysis of the Use of Biodiesel Production from Essential Oils as Biofuels. *Processes*, 11(4), 974. https://doi.org/10.3390/pr11040974

Borges, M. E., Díaz, L., Gavín, J., Brito, A. (2011): Estimation of the content of fatty acid methyl esters (FAME) in biodiesel samples from dynamic viscosity measurements. *Fuel Processing Technology*, 92(3), 597–599. https://doi.org/10.1016/j.fuproc.2010.11.016

Borugadda, V. B., Goud, V. V. (2012): Biodiesel production from renewable feedstocks: Status and opportunities. *Renewable and Sustainable Energy Reviews* 16(7), 4763–4784. https://doi.org/10.1016/j.rser.2012.04.010

Chakrabarti, M. H., Ali, M., Usmani, J. N., Khan, N. A., Hasan, D. B., Islam, Md. S., Abdul Raman, A. A., Yusoff, R., Irfan, M. F. (2012): Status of biodiesel research and development in Pakistan. *Renewable and Sustainable Energy Reviews* 16(7), 4396–4405. https://doi.org/10.1016/j.rser.2012.03.064

Chen, C., Chitose, A., Kusadokoro, M., Nie, H., Xu, W., Yang, F., Yang, S. (2021): Sustainability and challenges in biodiesel production from waste cooking oil: An advanced bibliometric analysis. *Energy Reports* 7, 4022–4034. https://doi.org/10.1016/j.egyr.2021.06.084

Das, S. (2020): The National Policy of biofuels of India – A perspective. *Energy Policy* 143, 111595. https://doi.org/10.1016/j.enpol.2020.111595

EN 14214. (2019): EN 14214:2012+A2:2019—Liquid petroleum products—Fatty acid methyl esters (FAME) for use in diesel engines and heating applications—Requirements and test methods. European Committee for Standardization. https://standards.iteh.ai/catalog/standards/cen/0a2c5899-c226-479c-b277-5322cc71395d/en-14214-2012a2-2019. Accessed December 10, 2024.

Fauzi, A., Hameed, I., Kadhim, M. (2017): A Review: Uses of Gas Chromatography-Mass Spectrometry (GC-MS) Technique for Analysis of Bioactive Natural Compounds of Some Plants. *International Journal of Toxicological and Pharmacological Research* 9(1), 81-85. https://doi.org/10.25258/ijtpr.v9i01.9042

Gopinath, A., Sairam, K., Velraj, R., Kumaresan, G. (2015): Effects of the properties and the structural configurations of fatty acid methyl esters on the properties of biodiesel fuel: A review. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 229(3), 357–390. https://doi.org/10.1177/0954407014541103

Gupta, J., Agarwal, M., Dalai, A. K. (2016): Optimization of biodiesel production from mixture of edible and nonedible vegetable oils. *Biocatalysis and Agricultural Biotechnology* 8, 112–120. https://doi.org/10.1016/j.bcab.2016.08.014

Jain, S., Sharma, M. P. (2010): Prospects of biodiesel from Jatropha in India: A review. *Renewable and Sustainable Energy Reviews* 14(2), 763–771. https://doi.org/10.1016/j.rser.2009.10.005

Kaur, G., Sharma, S. (2018): Gas Chromatography -A Brief Review. *International Journal of Information Science and Computing Science* 5(7), 125–131.

Khan, H. M., Iqbal, T., Yasin, S., Irfan, M., Kazmi, M., Fayaz, H., Mujtaba, M. A., Ali, C. H., Kalam, M. A., Soudagar, M. E. M., Ullah, N. (2021): Production and utilization aspects of waste cooking oil based biodiesel in Pakistan. *Alexandria Engineering Journal* 60(6), 5831–5849. https://doi.org/10.1016/j.aej.2021.04.043

Kim, J. Y., Jung, J.-M., Jung, S., Park, Y.-K., Tsang, Y. F., Lin, K.-Y. A., Choi, Y.-E., Kwon, E. E. (2022): Biodiesel from microalgae: Recent progress and key challenges. *Progress in Energy and Combustion Science* 93, 101020. https://doi.org/10.1016/j.pecs.2022.101020

Knothe, G., Kenar, J. A. (2004): Determination of the fatty acid profile by 1H-NMR spectroscopy. *European Journal of Lipid Science and Technology* 106(2), 88–96. https://doi.org/10.1002/ejlt.200300880

Kombe, G. G. (2023): An Overview of Algae for Biodiesel Production Using Bibliometric Indicators. *International Journal of Energy Research* 9596398. https://doi.org/10.1155/2023/9596398

Kumar, A., Sharma, S. (2011): Potential non-edible oil resources as biodiesel feedstock: An Indian perspective. *Renewable and Sustainable Energy Reviews* 15(4), 1791–1800. https://doi.org/10.1016/j.rser.2010.11.020

Kumar, A., Vachan Tirkey, J., Kumar Shukla, S. (2021): Comparative energy and economic analysis of different vegetable oil plants for biodiesel production in India. *Renewable Energy* 169, 266–282. https://doi.org/10.1016/j.renene.2020.12.128

Kumar. J, C. R., Majid, M. A. (2020): Renewable energy for sustainable development in India: Current status, future prospects, challenges, employment, and investment opportunities. *Energy, Sustainability and Society* 10(1), 2. https://doi.org/10.1186/s13705-019-0232-1

Kusuma, H. S., Az-Zahra, K. D., Saputri, R. W., Utomo, M. D. P., Jaya, D. E. C., Amenaghawon, A. N., Darmokoesoemo, H. (2024): Unlocking the potential of agricultural waste as biochar for sustainable biodiesel production: A comprehensive review. *Bioresource Technology Reports* 26, 101848. https://doi.org/10.1016/j.biteb.2024.101848

Maji, S. R., Roy, C., Sinha, S. K. (2023): Gas chromatography–mass spectrometry (GC-MS): A comprehensive review of synergistic combinations and their applications in the past two decades. *Journal of Analytical Sciences and Applied Biotechnology* 5(2), 72-85. https://doi.org/10.48402/IMIST.PRSM/jasab-v5i2.40209

Mathew, G. M., Raina, D., Narisetty, V., Kumar, V., Saran, S., Pugazhendi, A., Sindhu, R., Pandey, A., Binod, P. (2021): Recent advances in biodiesel production: Challenges and solutions. *Science of The Total Environment* 794, 148751. https://doi.org/10.1016/j.scitotenv.2021.148751

Mello, V. M., Oliveira, F. C. C., Fraga, W. G., do Nascimento, C. J., Suarez, P. A. Z. (2008): Determination of the content of fatty acid methyl esters (FAME) in biodiesel samples obtained by esterification using 1H-NMR spectroscopy. *Magnetic Resonance in Chemistry* 46(11), 1051–1054. https://doi.org/10.1002/mrc.2282

Norton, G. A., Cline, A. M., Thompson, G. C. (2012): Use of radiocarbon analyses for determining levels of biodiesel in fuel blends—Comparison with ASTM Method D7371 for FAME. *Fuel* 96, 284–290. https://doi.org/10.1016/j.fuel.2012.01.026

Ostojčić, M., Brkić, S., Tišma, M., Zelić, B., Budžaki, S. (2020): Membrane Filtration as an Environmentally Friendly Method for Crude Biodiesel Purification. *Kemija u Industriji* 69(3–4), 175–181. https://doi.org/10.15255/KUI.2019.049

Ostojčić, M., Budžaki, S., Flanjak, I., Bilić Rajs, B., Barišić, I., Tran, N. N., Hessel, V., Strelec, I. (2021): Production of biodiesel by *Burkholderia cepacia* lipase as a function of process parameters. *Biotechnology Progress* 37(2), e3109. https://doi.org/10.1002/btpr.3109

Oyerinde, A. Y., Bello, E. I. (2016): Use of Fourier Transformation Infrared (FTIR) Spectroscopy for Analysis of Functional Groups in Peanut Oil Biodiesel and Its Blends. *British Journal of Applied Science & Technology* 13(3), 1-14. https://doi.org/10.9734/BJAST/2016/22178

Pratama, J. H., Rahmawati, Z., Widyanto, A. R., Gunawan, T., Abdullah, W. N. W., Jamari, N. L. A., Hamzah, A., Fansuri, H. (2024): Advancements in green diesel production for energy sustainability: A comprehensive bibliometric analysis. *RSC Advances* 14(48), 36040–36062. https://doi.org/10.1039/D4RA06262K

Rabelo, S., Ferraz, V., Oliveira, L., Franca, A. (2015): FTIR Analysis for Quantification of Fatty Acid Methyl Esters in Biodiesel Produced by Microwave-Assisted Transesterification. International *Journal of Environmental Science and Development* 6, 964–969. https://doi.org/10.7763/IJESD.2015.V6.730

Ragonese, C., Tranchida, P. Q., Sciarrone, D., Mondello, L. (2009): Conventional and fast gas chromatography analysis of biodiesel blends using an ionic liquid stationary phase. *Journal of Chromatography A* 1216(51), 8992–8997. https://doi.org/10.1016/j.chroma.2009.10.066

Rahul, W., Anil P., D. (2016): Agricultural Sector: Status, Challenges and it's Role in Indian Economy. *Journal of Commerce and Management Thought* 7(2), 209–218. https://doi.org/10.5958/0976-478X.2016.00014.8

Rajeswari, S., Saravanan, P., Kumaraguru, K., Jaya, N., Rajeshkannan, R., Rajasimman, M. (2023): The scientometric evaluation on the research of biodiesel based on HistCite and VOSviewer (1993-2019). *Biomass Conversion and Biorefinery* 13(5), 4093–4103. https://doi.org/10.1007/s13399-021-01461-6

Ramos, M., Dias, A. P. S., Puna, J. F., Gomes, J., Bordado, J. C. (2019): Biodiesel Production Processes and Sustainable Raw Materials. *Energies* 12(23), 4408. https://doi.org/10.3390/en12234408

Rehan, M., Gardy, J., Demirbas, A., Rashid, U., Budzianowski, W. M., Pant, D., Nizami, A. S. (2018): Waste to biodiesel: A preliminary assessment for Saudi Arabia. *Bioresource Technology* 250, 17–25. https://doi.org/10.1016/j.biortech.2017.11.024

Sales, M. B., Borges, P. T., Ribeiro Filho, M. N., Miranda da Silva, L. R., Castro, A. P., Sanders Lopes, A. A., Chaves de Lima, R. K., de Sousa Rios, M. A., Santos, J. C. S. dos. (2022): Sustainable

Feedstocks and Challenges in Biodiesel Production: An Advanced Bibliometric Analysis. *Bioengineering* 9(10), 539. https://doi.org/10.3390/bioengineering9100539

Saravanan, A. P., Mathimani, T., Deviram, G., Rajendran, K., Pugazhendhi, A. (2018): Biofuel policy in India: A review of policy barriers in sustainable marketing of biofuel. *Journal of Cleaner Production* 193, 734–747. https://doi.org/10.1016/j.jclepro.2018.05.033

Sitko, R., Zawisza, B., Kowalewska, Z., Kocot, K., Polowniak, M. (2011): Fast and simple method for determination of fatty acid methyl esters (FAME) in biodiesel blends using X-ray spectrometry. *Talanta* 85(4), 2000–2006. https://doi.org/10.1016/j.talanta.2011.07.046

Suzihaque, M. U. H., Alwi, H., Kalthum Ibrahim, U., Abdullah, S., Haron, N. (2022): Biodiesel production from waste cooking oil: A brief review. *Materials Today: Proceedings* 63, 490–495. https://doi.org/10.1016/j.matpr.2022.04.527

Toldrá-Reig, F., Mora, L., Toldrá, F. (2020): Trends in Biodiesel Production from Animal Fat Waste. *Applied Sciences* 10(10), 3644. https://doi.org/10.3390/app10103644

Torres, A., Fuentes, B., Rodriguez, K. E., Brito, A., Diaz, L. (2020): Analysis of the Content of Fatty Acid Methyl Esters in Biodiesel by Fourier-Transform Infrared Spectroscopy: Method and Comparison with Gas Chromatography. *Journal of the American Oil Chemists' Society* 97(6), 651–661. https://doi.org/10.1002/aocs.12350