

Recent trends in conversion of rice straw into bioethanol: a bibliometric analysis

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Abstract. Second-generation bioethanol produced from lignocellulosic biomass, such as rice straw, is the optimal choice for development due to its abundant availability, sustainability, and lack of competition with food sources. A comprehensive bibliometric analysis of the literature on bioethanol production from rice straw was conducted to identify research trends, knowledge gaps, and provide suggestions for further investigation. A total of 483 relevant publications from 2004 to June 2024 were gathered from the Scopus database. The bibliometric analysis was performed using VOSviewer. India emerged as the most productive country, while the United States emerged as the most influential country with the highest Total Citation to Total Publication ratio. According to the keyword occurrence analysis, the terms "rice straw," "production," "fermentation," and "bioethanol" are the most commonly cited terms in all publications. Keyword analysis also indicates the recent research focus, which has predominantly centered on the pretreatment of rice straw. The results of the bibliometric study offer a comprehensive overview and suggest future directions for bioethanol production from rice straw.

1 Introduction

Increased global population and economic activity geared towards industrialization have led to heightened human activity in the transportation sector and increased energy demands. Most of the world's energy needs are met through fossil fuels, which have been shown to negatively impact the environment. The combustion of fossil fuels produces greenhouse gas emissions that contribute to global warming [1]. Given this situation, it is essential to develop alternative energy sources that are renewable and environmentally friendly. Recently, researchers have focused on several renewable energy sources, including biogas, biodiesel, and bioethanol [2]. Bioethanol is a promising alternative energy source with the potential to replace fossil fuels. It boasts a higher octane number, a faster heat of vaporization, and can be directly applied to motor vehicles by mixing it with petrol [3]. Bioethanol is recognized

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for its lower carbon emissions compared to fossil fuels, offering a reduction in greenhouse gases by up to 70% [4, 5]. Bioethanol derived from lignocellulosic biomass, known as second-generation bioethanol, has gained popularity in recent decades [6]. Compared to first-generation bioethanol, which uses sugar and starch as raw materials, and third-generation bioethanol, which utilizes algae as raw materials, second-generation bioethanol employs agricultural and forestry waste as raw materials, which are more readily available and less expensive [7]. Second-generation bioethanol is considered the optimal choice considering factors such as food security, economic feasibility, and environmental sustainability [8].

The utilization of rice straw as a primary material for the production of second-generation bioethanol is being explored. Projections indicate that Indonesia is poised to generate 53.63 million tons of rice by 2023 [9]. According to Gadde et al. [10] and Gheewala et al. [11], rice straw production in Indonesia may range from 54 to 80 million tons in 2023, based on a grain-to-straw ratio of 1–1.5. Although burning is the simplest and least expensive option, it can have negative effects on the environment and society [12, 13]. Meanwhile, rice straw contains 32–38% cellulose, 19–35% hemicellulose, and 13–22% lignin [14]. Simple sugars are the building blocks of cellulose and hemicellulose. The starting point for fermenting sugar into ethanol is sugar. Consequently, rice straw has the potential to be converted into bioethanol, an environmentally friendly and sustainable energy source that can replace fossil fuels. The conventional lignocellulose biorefinery process consists of three independent stages: pretreatment, enzymatic saccharification, and fermentation [15]. Pretreatment of the feedstock is necessary for the efficient enzymatic saccharification of lignocellulose. The pretreatment of lignocellulose facilitates the release of the tightly bound lignocellulosic biomass structure by dissolving the hydrogen bonds and van der Waals contacts of cellulose microfibrils. It also aims to isolate other biomass constituents, especially lignin, from cellulose and hemicellulose [16]. Pretreatment technology has emerged as the most significant stage since it regulates the amount of bioethanol produced. Rice straw that has been pretreated is used as a raw material for the subsequent stages of hydrolysis and fermentation. At this point, several methods have been developed, such as separate hydrolysis and fermentation (SHF), simultaneous saccharification and fermentation (SSF), simultaneous saccharification and co-fermentation (SSCF), and consolidated bioprocessing (CBP) [17, 20].

In recent years, numerous publications have emerged concerning bioethanol, particularly review articles. However, most of these reviews address bioethanol production from lignocellulosic biomass in general, making it challenging to find articles that specifically focus on bioethanol production from rice straw. Conversely, there is a substantial amount of research dedicated to this topic. This situation complicates the ability of researchers to effectively organize, summarize, and analyze the advancements in bioethanol production from rice straw over a specific period. Therefore, a bibliometric analysis of the latest trends in bioethanol production from rice straw is essential. Several studies related to the bibliometric analysis of bioethanol have been conducted. For instance, Devos et al. [21] evaluated solid-state fermentation (SSF) technology for bioethanol production, emphasizing the reduction of overall production costs through the selection of suitable raw materials and the optimization of production parameters such as pH, yeast, and enzymes. Santoyo-Castelazo et al. [22] investigated the environmental impact of bioethanol production from sugarcane bagasse using the gasification conversion process. Additionally, Guimares et al. [23] discussed the production of sustainable first and second-generation bioethanol utilizing sugar-based feedstock. However, no research has specifically addressed the bibliometric analysis of bioethanol production from rice straw.

Bibliometric reviews are a popular method for analyzing scientific publications using statistical techniques to offer a comprehensive overview of research strengths and the overall structure of research coverage [24, 25]. Bibliometric methods are used to examine various

publication characteristics such as country, institution, journal, research field, and citations to provide a comprehensive illustration of research trends and developments in a field [26, 27]. Bibliometric analysis can also assist researchers in more effectively identifying future research directions [28]. This research aims to conduct a comprehensive bibliometric analysis to explore research on bioethanol production from rice straw. The specific objectives of this study are to identify the most productive and influential countries and authors; understand the research topics and future research limitations through keyword analysis. This research contributes to the existing body of knowledge by exploring technologies and opportunities for developing advanced methods to enhance the market value of bioethanol derived from rice straw, enabling it to compete effectively with fossil fuels.

2 Materials and methods

2.1 Dataset used

The Scopus database was used to search for publications about bioethanol production from rice straw during the period 2004–2024 (the latest data was downloaded on June 30). Launched by Elsevier in 2004, the Scopus database is the most comprehensive and continuously updated source of searchable citations and abstracts for literature searches [29, 30]. Scopus provides a database of high-quality scientific journals, conference proceedings, and books that have been rigorously selected and re-evaluated by an unbiased advisory board. The following phrase was used to search for titles, abstracts, and keywords in the Scopus database: TITLE-ABS-KEY (“rice straw” AND bioethanol). The (“...”) sign is used to search for exact phrases. A total of 483 documents published between 2004 and June 2024 were identified. This search was limited to the specified years. The analysis results from the Scopus database provided the total number of documents per year, documents per author, affiliations, types of documents, and documents by country. The collected data was then exported and downloaded in CSV file format for analysis using Microsoft Excel 2010. Bibliometric indicators were gathered and analyzed both quantitatively and qualitatively to determine the characteristics of the publications, including year, country, and author [31]. Microsoft Excel effectively displays essential information related to the articles, such as citation details, bibliographic data, abstracts, and keywords. The data is presented in tabular form, facilitating the screening process to eliminate articles that are not relevant. Additionally, Microsoft Excel features data processing tools to remove duplicates, ensuring that the articles selected are valid for further analysis.

2.2 Bibliometric analysis

Data that has been downloaded into Microsoft Excel 2010 is imported into VOSViewer software (version 1.6.20, Leiden University, Leiden, Netherlands) for further analysis [32]. VOSviewer is the most widely used software for bibliometric studies due to its reliable capabilities in creating and visualizing network maps [33]. VOSviewer is utilized to visualize research trends in various keywords represented in a network map [34]. VOSviewer can also identify research trends through burst analysis of keywords that emerge over a specific period. This analysis provides an overview of research topics that require further investigation and highlights future research trends [28]. Additionally, the co-occurrence network visualization in VOSviewer is configured to detect keywords that appear more than 40 times. The database utilized exclusively includes data from Scopus, which may not comprehensively represent all literature on bioethanol production from rice straw.

Consequently, there may be relevant articles omitted from the analysis, potentially impacting the overall results.

3 Results and discussions

3.1 Analysis based on publication type, language, and year

Table 1. Document types and languages of the publications on Scopus regarding bioethanol production from rice straw.

Rank	Document type	Records	% of 483	Language	Records	% of 483
1	article	405	83.85%	English	475	98.35%
2	conference paper	30	6.21%	Chinese	3	0.62%
3	book chapter	19	3.93%	Japanese	2	0.41%
4	review article	18	3.73%	Korean	2	0.41%
5	conference review	7	1.45%	Persian	1	0.21%
6	notes	3	0.62%			
7	short survey	1	0.21%			

The bibliometric analysis of research on bioethanol production from rice straw, based on publications indexed in Scopus from 2004 to June 2024, yielded a total of 483 documents. Table 1 presents the types of documents obtained. The most common were research articles, accounting for 405 documents (83.85%), followed by 30 conference papers (6.21%), 19 book chapters (3.93%), and 18 review articles (3.73%). Research articles constitute the largest proportion, indicating that the trend in the development of bioethanol production research from rice straw continues to rise. This finding suggests that bioethanol research remains a significant area of interest for many researchers. Most researchers publish their manuscripts in English because it is the official language at most international conferences. In addition, the use of English also facilitates communication and enhances the impact of research [31, 35].



Fig 1. Annual publications per year on bioethanol production from rice straw (2004–June 2024)

The publication trend has been increasing since 2009, as shown in Figure 1. In 2020, there was a notable increase, with 56 documents produced, significantly more than in 2019, when there were only 34 documents. These findings indicate that researchers' motivation to replace fossil fuels with bioethanol has significantly increased. Despite the COVID-19 pandemic occurring in 2020, the number of published articles actually rose, reflecting ongoing efforts to develop environmentally friendly and sustainable fuels. These results align with the findings of Guimares et al. [23], which showed that publications on sustainable bioethanol

production from first- and second-generation sugar-based feedstocks were the most prevalent in 2020. In the upcoming years, it is predicted that the trend of publications will continue to rise.

3.2 The most influential country

A total of 47 countries have contributed to 483 papers on bioethanol production from rice straw published from 2004 to June 2024. The top 10 countries with the highest publications are listed in Table 2. The top 5 most productive countries are India (148), followed by China (88), Japan (63), South Korea (37), and Egypt (32). 76.19% of the total 483 documents are concentrated in these five countries. This is due to the fact that China and India are the largest rice-producing countries in the world, with total rice production in 2022 of 208 and 196 million metric tons, respectively. Japan, South Korea, and Egypt are also among the top rice-producing countries, with total rice production in 2022 of 10, 4, and 5 million metric tons, respectively [36]. As the largest rice producers in the world, these countries utilize available resources, such as rice straw, as raw materials for developing second-generation bioethanol. The availability of cheap and abundant raw materials has enabled these countries to produce the largest publications on bioethanol production from rice straw. Table 2 also shows that among the 10 countries with the highest publication output, 8 are Asian countries, with only Egypt and the United States being non-Asian. This is due to the fact that rice is a staple in the diet of the majority of Asians [37]. India, China, and Japan possess significant economic power and invest heavily in research and development of technological innovations in the field of renewable energy. With ample resources at their disposal, these three nations are the leading contributors to the publication of articles on bioethanol production from rice straw. Guimares et al. [23] also found that India and China are the most prolific countries in sustainable bioethanol research.

Table 2. Top 10 countries with the highest publications on bioethanol production from rice straw

Rank	Country	Total Publication (TP)	Total Citation (TC)	TC/TP ratio
1	India	148	3839	25.94
2	China	88	2041	23.19
3	Japan	63	1955	31.03
4	South Korea	37	1231	33.27
5	Egypt	32	563	17.59
6	Taiwan	26	890	34.23
7	Thailand	22	560	25.45
8	Indonesia	20	76	3.80
9	United States	17	1803	106.06
10	Iran	14	280	20.00

The noteworthy point from Table 2 is that the United States, a non-Asian country, stands out as the most influential country in research on bioethanol production from rice straw. The United States has a TC/TP ratio greater than 100 (106.06), followed by Netherlands (62.00), Singapore (58.00), Spain (51.50), and Sweden (47.33). Total citations are a parameter used to determine the significance of a publication's impact. Therefore, the higher the total number of citations received by a paper, the greater the scientific quality of the paper [38]. Publications in reputable journals with the highest quartile scores and prestigious publishers have a significant impact on the total number of citations received [39]. India, China, Japan, South Korea, and Egypt must enhance the quality of their publications to increase their global academic influence in the field of bioethanol research derived from rice straw.

3.3 The most productive authors

In general, more than 1000 authors participated in research on bioethanol production from rice straw between 2004 and June 2024. Table 3 presents a list of the top 10 authors with more than 6 publications. Japan, India, and China dominate the list of the 10 most influential authors. This condition aligns with Table 2, which lists Japan, India, and China as the top three countries with the highest total publications. Akihiko Kondo from Kobe University was the most productive author with 14 publications, followed by Ken Tokuyasu and Ashok Pandey with 13 and 11 publications, respectively. Regarding the number of citations, Ashok Pandey is the author with the highest number of citations (1358), followed by Rajeev Kumar Sukumaran and Akihiko Kondo with 902 and 576 citations, respectively. In comparison to authors from other countries, it can be claimed that Indian authors have the most academic influence. As a result, future studies on bioethanol production from rice straw will likely be more influenced by their work.

Table 3. Top 10 most productive authors who have published articles on bioethanol production from rice straw

Rank	Author	Document	Citation	Country
1	Akihiko Kondo	14	576	Japan
2	Ken Tokuyasu	13	359	Japan
3	Ashok Pandey	11	1358	India
4	Rajeev Kumar Sukumaran	9	902	India
5	Tomohisa Hasunama	8	495	Japan
6	Liangcai Peng	8	177	China
7	Yanting Wang	8	177	China
8	Ravi P Gupta	7	96	India
9	Riki Shiroma	7	248	Japan
10	Qiuzhuo Zhang	7	124	China

3.4 Co-occurrence for all keywords

Figure 2 displays the VOSviewer co-occurrence network visualization mapping of the top 30 keywords that appear more than 40 times. The four most frequently appearing keywords are "rice straw," "production," "fermentation," and "bioethanol." Keywords reflect the essence of the content of an article concisely; in other words, they are the soul of an article. Through keyword occurrence analysis, research focus and trends can be accurately revealed [40, 41]. Each of these keywords is interconnected, forming three clusters that demonstrate the close relationship between the keywords. Clusters with strong related keywords represent similar research fields [28]. The first green cluster focuses on bioethanol production from a variety of raw materials and includes economic analysis. The second cluster in red focuses on the sugar saccharification process and the fermentation of sugar into ethanol. The third cluster in blue focuses on the pretreatment of rice straw and the saccharification of holocellulose into sugar.

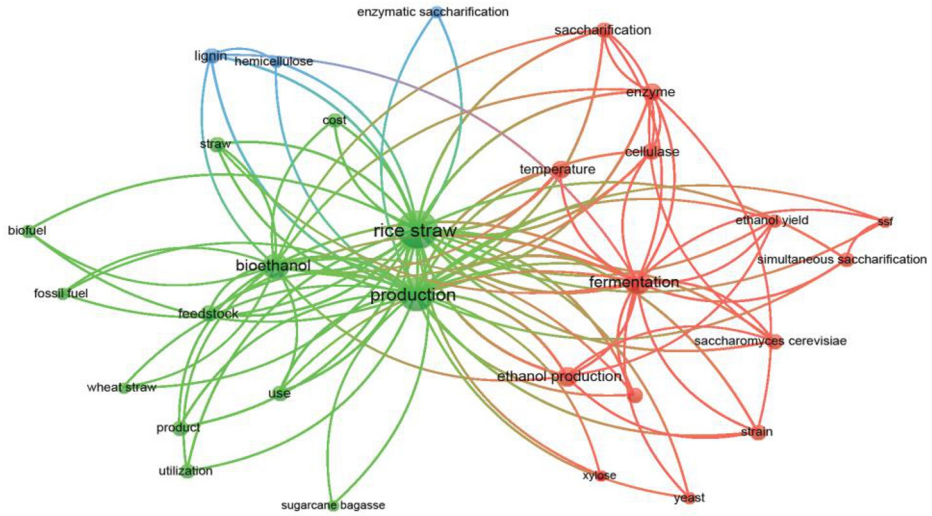


Fig 2. VOSviewer co-occurrence network visualization mapping of the top 30 keywords.

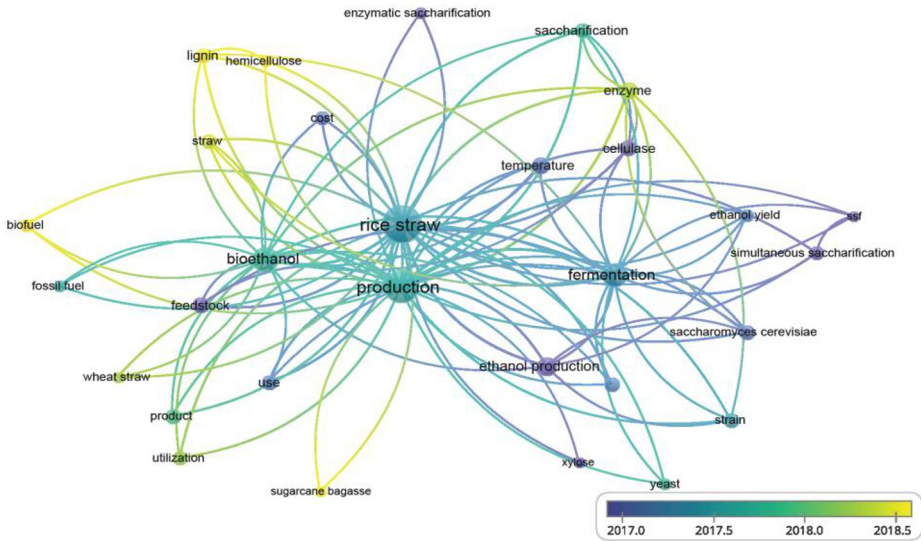


Fig 3. VOSviewer co-occurrence overlay visualization mapping of the top 30 keywords.

Figure 3 displays the VOSviewer co-occurrence overlay visualization mapping of the most frequent keywords. Each keyword is represented by a different color indicating the year the keyword appeared. In recent years, it has been observed that certain keywords (highlighted in yellow) have been used frequently. These words are: lignin, hemicellulose, sugarcane bagasse, and biofuel. The current trend in bioethanol research is to focus on the pretreatment process of lignocellulosic biomass, specifically rice straw, as the raw material for bioethanol. Lignocellulosic biomass is inexpensive, abundantly available, and does not compete with food. However, the lignin content in lignocellulose poses a significant challenge to bioethanol conversion, necessitating a pretreatment process to address this issue. The objectives of pretreatment include reducing lignin content, breaking down the robust

structure of lignocellulosic materials, enhancing surface area, decreasing cellulose crystallinity, and improving enzyme accessibility during hydrolysis [42, 43]. Various pretreatment methods have been developed, including chemical, physical, physicochemical, and biological approaches.

Chemical, physical, and physicochemical pretreatment of rice straw is expensive, energy-intensive, and not environmentally friendly, but it is also very effective and quick [44, 45]. In contrast, biological pretreatment, which does not require the use of acids or bases and is a mild procedure, can efficiently break down lignin in an environmentally acceptable way. Another advantage of biological pretreatment is that the carbohydrate components are not converted into hazardous chemicals, which could inhibit the hydrolysis process [46]. Several species of white rot fungi have been utilized in the rice straw pretreatment process, such as *Phanerochaete chrysosporium*, *Pyrenophora phaeocomes*, *Trametes versicolor*, *Ceriporiopsis subvermispora*, *Pleurotus ostreatus*, and *Ganoderma lucidum*. This fungus can produce ligninolytic enzymes such as laccase and manganese peroxidase at lower and can depolymerize and mineralize lignin into CO₂ and H₂O by utilizing lignin degradation products as a carbon source in its metabolism [47]. However, biological pretreatment is time-consuming, which poses challenges when applied on an industrial scale [48]. Currently, researchers are focusing on creating an effective and efficient pretreatment method that can reduce the cost of producing bioethanol from rice straw, enabling it to compete with fossil fuels in terms of price.

4 Conclusions

A bibliometric analysis of bioethanol production from rice straw has been conducted based on 483 documents retrieved from the Scopus database between 2004 and June 2024. The majority of papers are research articles (83.85%), followed by conference papers and book chapters. A total of 98.35% of papers were written in English. The publication trend related to bioethanol production from rice straw has been increasing since 2009, with the most significant surge observed in 2020, with 56 papers. India is the most productive country, followed by China and Japan. However, the United States is the most influential country, with the highest TP/TC ratio of 106.06. Akihiko Kondo has the highest number of publications (14 articles), while Ashok Pandey has the highest number of citations, totaling 1358. Keywords in research on bioethanol production from rice straw are divided into three clusters, which describe different research focuses. Rice straw pretreatment research is currently the focus of researchers.

From a practical perspective, these results are valuable for researchers analyzing existing publications. This analysis can guide the focus of future research on the development of bioethanol as a renewable energy alternative to fossil fuels. This finding makes a significant contribution, as the bibliometric method is applied for the first time to analyze the trends in rice straw-based bioethanol production. Future research should aim at developing effective and efficient pretreatment methods to reduce overall production costs while maintaining an environmentally friendly process. From a global perspective, this study represents a positive trend in the development of renewable and environmentally friendly alternative energy sources. Therefore, sustainable rice straw-based bioethanol production can help mitigate the impacts of global warming and climate change.

It must be acknowledged that this research has limitations. Firstly, the database utilized only includes data from Scopus, which may not comprehensively represent all the literature on bioethanol production from rice straw. Secondly, some relevant articles may have been overlooked, while some irrelevant articles may have been included. In the future, these research deficiencies should be addressed to ensure more accurate results.

Acknowledgements: The authors thank the Universitas Diponegoro for access to the database

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