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Bibliometric Analysis on Biobutanol Production Research Trends from 2010-2022 using Scopus Database

(Analisis Bibliometrik mengenai Tren Penyelidikan Pengeluaran Biobutanol dari 2010-2022 menggunakan Pangkalan Data Scopus)

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ABSTRACT

The global demand for biofuels as an alternative energy source is on the rise due to the anticipated decline in fossil fuel (gasoline). Biobutanol, among various biofuels, has garnered significant attention for its advanced features and suitability as an alternative to fossil fuels. Recognizing the importance of understanding research issues and fostering collaborative networks, this bibliometric analysis focuses on synthesizing research trends in biobutanol production over the past 12 years. Examining 357 Scopus-indexed documents, the study shows that over 80% of relevant articles were published after 2010, indicating the recent emergence of literature in this field. Citation analysis identifies publishing trends dating back to 2010, highlighting leading scholars. In 2016, 47 publications in Chemical Engineering were attributed to the field, with Professor Sahaid authoring 12 publications, primarily affiliated with UKM. Chemical Engineering comprised the predominant subject area, with articles constituting 75.07% of total publications. Bioresource Technology was the primary source title, and the keyword Biobutanol was frequently associated with the research (92.16%). UKM led in institutional contributions with 12 publications, while India had the highest total publications at 17.65%, and Malaysia contributed 6.44%. The majority of publications (88.24%) originated from journal publications, and English was the predominant language, accounting for 96.64% of the publications. This paper underscores the recent surge in biobutanol research and the importance of collaborative efforts for further advancements.

Keywords: Bibliometrics; biobutanol; biofuel; *Clostridium*; mapping knowledge domains

ABSTRAK

Permintaan global untuk biofuel sebagai punca tenaga alternatif semakin meningkat berikutan jangkaan penurunan bahan api fosil (petrol). Biobutanol, antara pelbagai biobahan api, telah mendapat perhatian yang ketara untuk ciri canggih dan kesesuaiannya sebagai alternatif kepada bahan api fosil. Menyedari kepentingan memahami isu penyelidikan dan memupuk rangkaian kerjasama, analisis bibliometrik ini memberi tumpuan kepada mensintesis trend penyelidikan dalam pengeluaran biobutanol sepanjang 12 tahun yang lalu. Meneliti 357 dokumen yang diindeks Scopus, kajian itu mendedahkan bahawa lebih 80% artikel berkaitan diterbitkan selepas 2010, menunjukkan kemunculan kepustakaan baru-baru ini dalam bidang tersebut. Analisis petikan mengenal pasti aliran penerbitan sejak 2010, menonjolkan

sarjana terkemuka. Pada 2016, 47 penerbitan dalam Kejuruteraan Kimia dikaitkan dengan bidang tersebut, dengan Profesor Sahaid mengarang 12 penerbitan, terutamanya bergabung dengan UKM. Kejuruteraan Kimia merangkumi bidang subjek utama, dengan artikel membentuk 75.07% daripada jumlah penerbitan. Teknologi Sumber Bio ialah tajuk sumber utama dan kata kunci Biobutanol sering dikaitkan dengan penyelidikan (92.16%). UKM mendahului dalam sumbangan institusi dengan 12 penerbitan, manakala India mempunyai jumlah penerbitan tertinggi pada 17.65% dan Malaysia menyumbang 6.44%. Majoriti penerbitan (88.24%) berasal daripada penerbitan jurnal dengan bahasa Inggeris adalah bahasa utama, menyumbang 96.64% daripada penerbitan. Oleh itu, kajian ini menggariskan lonjakan baru-baru ini dalam penyelidikan biobutanol dan kepentingan usaha kolaboratif untuk kemajuan selanjutnya.

Kata kunci: Bibliometrik; biobahan api; biobutanol; *Clostridium*; pemetaan domain pengetahuan

Introduction

Over the last several decades, biobutanol has attracted interest as a promising biofuel contender due to the expected fossil fuel depletion. The promising usage of biobutanol as a sustainable fuel was recognised by large corporations such as DuPont and BP in 2009 (Al-shorgani et al. 2018; Bao et al. 2020; Capilla et al. 2022). The investments made by these two companies had a positive impact on research and development and were demonstrated to be economically viable. Throughout the years, ongoing research has been conducted in order to fully exploit biobutanol on a bigger industrial scale and to combat the main problem of utilizing biobutanol, which is product inhibition (Amiri 2020; Del Campo et al. 2018; Dong et al. 2016; Ibrahim, Kim & Abd-Aziz 2018; Kushwaha et al. 2019).

Biobutanol has good characteristics such as less corrosive, low volatility, high heat value, high viscosity and high hydrophobicity which are comparable to gasoline, demonstrating the benefit of selecting biobutanol as the next generation of biofuels (Jiang et al. 2018; Jiménez-Bonilla & Wang 2018; Khalifa et al. 2018; Peabody & Kao 2016; Salleh et al. 2019). This clearly depicts the fundamental reasons behind the choice of utilizing biobutanol as an alternative source of renewable energy. Aside from that, biobutanol is regarded as an environmentally friendly product due to its low vapour pressure, which makes it easier to store and handle than standard fuels. Biobased product like biobutanol not only caters environmental concerns but also will be beneficial in many commercial applications namely transportation fuel, industrial solvent, pharmaceuticals, chemical intermediates, plasticizers and even herbicides (Gomez-Flores et al. 2018; Kolesinska et al. 2019). All these remarkable properties demonstrate the significance of using biobutanol as a biofuel and an alternative for traditional fuels.

Despite the significant impact and benefits associated with biobutanol production, limited effort is made to compile extensive and precise data on the global trajectory of biobutanol production. Recent research, such as the one conducted by Ashani, Shafiei and Karimi (2020) and Birgen et al. (2019) has emphasized on the utilization of very specific raw materials for the synthesis of biobutanol, such as lignocellulosic biomass and municipal solid waste. This showed that the focus study is not projected on detailed analysis of biobutanol production trend. In terms of bibiometric analysis, earlier works by Shi et al. (2012) and Xu and Boeing (2013) demonstrate a different perspective on the scope of biobutanol than our study. Shi et al. (2012) confine their investigation to a single method, anaerobic digestion for biobutanol production, and the study also lacks visual mapping diagrams, which are necessary for observing the interactions between various keywords produced from the Web of Science database. As for Xu and Boeing (2013), their paper considered only a subset of biobutanol-related topics because it included a broad range of biofuels, which is insufficient to conduct a thorough analysis of the biobutanol research trend.

However, our study is more comprehensive in that it not only showed a decade of biobutanol research trends, but also demonstrated the relationship between each published paper over the years and a variety of critical components, including publishing countries, study areas, journals and author keywords, citation analysis, and also other important components that will be discussed in detail in this paper. Also, this study will discuss field of research that needs additional study, which is essential for directing future researchers towards identifying research gaps and promising research areas in biobutanol production. Apart from that, to the best of our knowledge, this is the first research to highlight

the biobutanol production trend by detailed bibliometric analysis performed using a variety of sophisticated software tools such as latest version of Microsoft Excel, VOSviewer and Harzing's Publish or Perish. This study addresses the following research questions (RQs): RQ1: What state of development are biobutanol publications at the moment? RQ2: Which articles have the largest impact on biobutanol production? RQ3: Which countries have contributed the most on biobutanol production? RQ4: Who are the most influential authors on biobutanol production? RQ5: What are the current citation patterns of publications on the biobutanol production? RQ6: Which publishers have the most impact on biobutanol production? RQ7: What areas involving biobutanol production need additional study? In short, the aim of the paper was to provide insights on the overall biobutanol production trend from 2010-2022 through bibliometric analysis using Scopus database. Table 1 shows the comparison of previous studies of biobutanol production and our study.

Materials and Methods

Bibliometric analysis is a well-rounded analysis that incorporates important inputs such as assessing the worldwide trend or pattern of research based on the outputs of an academic literature database (Ahmi & Mohamad 2019; Wahid, Ahmi & Alam 2020). This method differs from a review paper in that it focuses on the most recent advances, difficulties, and future directions of a particular issue. Therefore, the method in this study focuses on the process of gathering data and analysing it thoroughly before being filtered and used as final data collection (Kushairi & Ahmi 2021). Our study employed the Scopus database, which is distinct from prior studies that used the Web of Science (WOS) database in their bibliometric papers. Scopus was chosen not only because it contains a diverse range of research articles, but also because it is the 'largest single abstract and indexing database ever built', with an abstract literature search list and the largest searchable citation database. This demonstrates the Scopus database's credibility in offering relevant databases as well as a comprehensive overview of research outputs, which is critical for undertaking bibliometric analysis (Ahmi & Mohd Nasir 2019; Veza, Muhamad Said & Latiff 2021; Yao et al. 2022).

TABLE 1. Comparison of previous studies of biobutanol production and our study

Elements of comparison	Shi et al. (2012)	Xu & Boeing (2013)	Our study
Time period	2001-2011	2003-2012	2010-2022
Database	Web of Science	Web of Science	Scopus
Keywords	'Anaero*', 'butanol*', 'butyl alcohol*'	'biofuel*'	'butanol', 'biobutanol'
Focus of study	To identify and highlight specifically on the method of anaerobic digestion for biobutanol production	To conduct a global analysis of biofuel research trends that include all types of biofuels	To investigate the overall biobutanol production trend that is essential in identifying potential field of research in biobutanol production
Methodology	Bibliometric	Bibliometric	Bibliometric
Protocol	Microsoft Excel	SPSS 13.00 and PC-ORD 4.0 software	VOSviewer, Microsoft Excel, Harzing's Publish or Perish

The research flowchart shown in Figure 1 depicts the overview flow on the data retrieved from Scopus database. The data was generated from Elsevier's Scopus database as of September 2022. However, instead of employing very specific keyword that caters certain methods, our search strategy is broader by conducting a topic that is combined in title, abstract and keywords (TITLE-ABS-KEY) string query. Prior to analysis, the search query was initially executed separately on 'butanol' and 'biobutanol'. The result showed that the number of records identified for both keywords were different. Therefore, to ensure both keywords were included in the overall data collection process, the search query was then changed to TITLE-ABS-KEY('butanol') AND KEY('biobutanol'). The logical operator 'AND' was employed in our search method to ensure that the selected keywords were discussed thoroughly in every section of every publication that was contained in our data collection. This specific search query strategy leads to a total number of records identified in our data is 357. The query search keyword in the Scopus database covers all document type, languages and source type but the time frame was limit to 11 years of data compromise from 2010 to 2022.

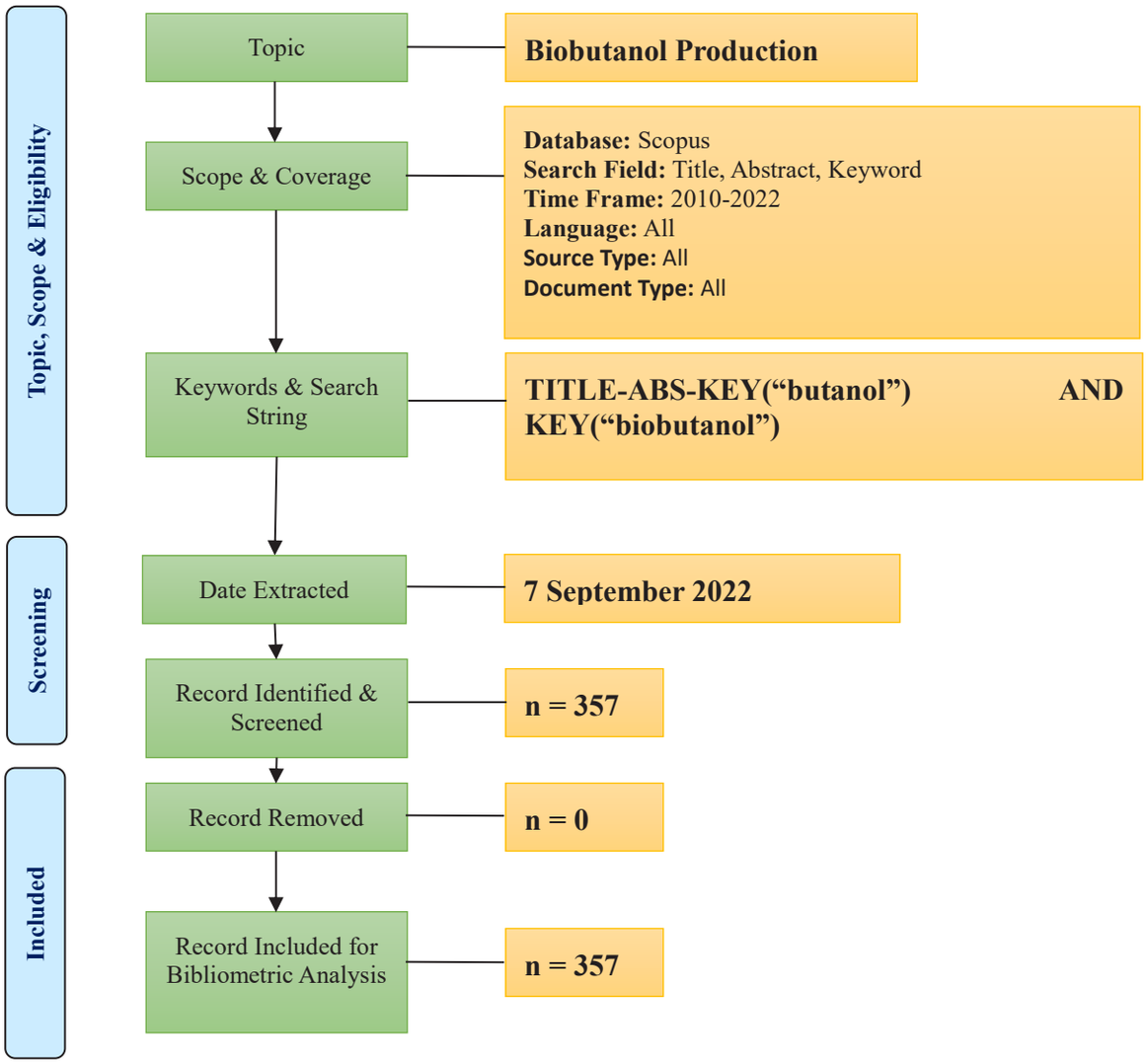


FIGURE 1. Flow diagram of the search strategy (Zakaria et al. 2021)

All the publications found were analysed using three main software whereby each of the software serves its own function. For instance, Microsoft Excel was used to retrieve the frequencies and percentage of publications in order to develop charts and graphs. VOSviewer 1.6.16, on the other hand, assists in the formation and visualisation of bibliometric networks as well as mapping analyses such as keywords and citation co-occurrence networks. Harzing's Publish or Perish software adds to the citation and authorship analysis that are critical for assessing the overall research publishing trend. Furthermore, the core of this software is that it retrieves and analyzes academic citations using a variety of data sources to obtain the raw citations, then analyzes them and presents a variety of citation metrics, such as the number of papers and total citations. As for data extraction, the data was extracted directly from the Scopus database in two formats: RIS and CSV. The data was analysed using each software's export data, with RIS data corresponding to VOSviewer and CSV data corresponding to Microsoft Excel.

Results and Discussion

Documents profiles distribution

Document and source type are one of the important scopes in document profiles which were further shown in Figure 2(i) and Table 2. Based from the data retrieved, it is evident that for biobutanol production related studies are mostly published in the form of articles with total publication (TP) of 268 that accounts up to 75.07% from the total document type. This was further supported as journals also dominates the overall source type with 315 publications with the weightage of 88.24%. Apart from that, the data also demonstrates that conference-based resources are one of the components that were least produced with less than 20 publications in both document and source type with accumulation of less than 15%. Moreover, in document type, editorial and short survey were rarely published with each type has 1 publication only while review paper was recorded as second choice among researchers but not as prominent as article with only 44 publications that is also equivalent to 12.32%. In addition, in terms of book-based resources such as book, book chapter and book series were also one of the preferred choice of resources for researchers but was not as significant as other choices as it only accumulates less than 10% for overall weightage in both document and source type.

Based on Figure 2(ii), it is evident that majority of the documents found in Scopus database is prevalent towards English language with total publications (TP) of 345 that is approximately 96.64%. This is also due to the fact that English medium provide a premise for researchers to communicate their results to the global scientific community as it promotes more engagement among researchers around the world. Besides, the results also showed that other languages such as Chinese, Czech, Korean and Spanish are below 3.5% with 12 total accumulation of all publications. Therefore, this further proves that having a lingua franca such as English allows researchers from all over the world to communicate in one common language.

TABLE 2. Source type

Source type	Total publications (TP)	Percentage (%)
Journals	315	88.24
Book	18	5.04
Book Series	14	3.92
Conference Proceeding	10	2.80
Total	357	100.00

PREFERRED SUBJECT AREA

In addition, to further asses in terms of subject area, Table 3 and Figure 2(iii) showed on the top 10 subject area involved in biobutanol production field. In a publication premise, a subject area refers to a specific area of instruction in which the main keyword is mostly found within the context. For instance, since biobutanol is highly linked with engineering-based process, therefore most of the TP comes from the subject area such as chemical engineering, chemistry and engineering that accumulates more than 50% of overall total publication. Not only that, biobutanol is also known as advanced biofuel that act as future replacement of fossil fuels which is also the reason this study was found in the subject area of Energy with 153 TP that is also equivalent to 42.86%.

PUBLICATION OUTPUT INTERPRETATION

Apart from that, in terms of research trends, the timeframe chosen for this study was 12 years that starts from 2010 and up until 2022 as shown in Table 4 that also includes important components such as total publication (TP) and total citations (TC). Based from the data retrieved, RQ 1 which was stressed on the state of development of biobutanol publications at the moment was further enlighten in which it is evident that the research trends on biobutanol production increases over time from 2010 to 2017. However, there was a slight decrease in the publication trend from 2019-2020 that might be due to the COVID-19 pandemic that affect worldwide and leads to the restriction of research progress such as experimental work. In 2021, there was prominent

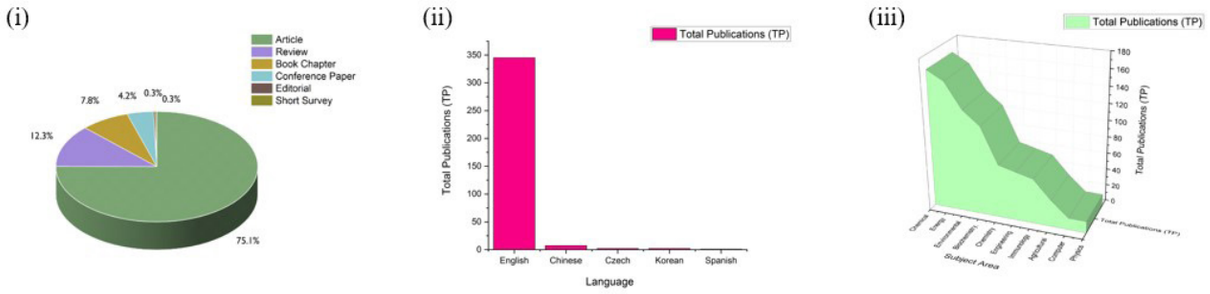


FIGURE 2. (i) 3D Pie chart representation of the document type (ii) Bar column representation of the most frequent language used for publications (iii) 3D Stacked walls of top 10 subject area

TABLE 3. Top 10 subject area

Subject area	Total publications (TP)	Percentage (%)
Chemical Engineering	164	45.94
Energy	153	42.86
Environmental Science	123	34.45
Biochemistry, Genetics and Molecular Biology	107	29.97
Chemistry	64	17.93
Engineering	59	16.53
Immunology and Microbiology	54	15.13
Agricultural and Biological Sciences	32	8.96
Computer science	14	3.92
Physics and Astronomy	14	3.92

increase with up to 40 TP while as for 2022 only 22 TP was recorded which was not the overall count since the data obtained was only until September 2022. In addition, Table 4 also demonstrates that the interwoven relationship between TP and TC are not directly proportional as high number of TP does not necessarily guarantee high number of TC. For instance, in 2011, there was only 16 TP but in terms of TC it recorded the highest value compared to other years. Not only that, this section also provides the premise in showing RQ 5 on the current citation patterns of publications on the biobutanol production. In the same context, citation patterns reached its peak in the year of 2011 onwards with more than 1000 TC recorded. Besides, as for the number of cited publications (NCP), most of the published paper on the respective years has been cited with only few papers were excluded. In addition, in the year of 2022, the recorded NCP was less than 50% which is probably due to lack of exposure of the paper and the published paper is still recent and new. Furthermore, our findings also showed that average citations per publications (C/P) is highly influence by TC as high number of TC in most cases leads to increase chances of producing high C/P.

In addition, there are several countries that are actively pursuing on biobutanol based research activities. Figure 3(i) illustrates top 10 countries with high total publications. Based from the figure, it is evident that the most influential countries dominating in this research sector currently is from India and China which is approximately the same amount of TP with 63 and 60, respectively, that also accumulate a total of 35% of global publications from the total of 58 countries involved in biobutanol field. This is further supported by market trend of both countries that relies on the abundance of biomass for bioenergy development. Based on power plant survey published on January 2023, 2955 MW of installed biopower capacity was generated in China which is mainly due to agricultural and forestry residues (Wang et al. 2023). Generally, china produces over 900 million metric tons of agricultural and forestry biomass every year, which can generate power equal to nearly 400 million tons of coal (Qaseem & Wu 2021). The type of forestry biomass used in China includes fuel wood, wood processing residue, wood felling and bucking residue, firewood and bamboo residues (Zhang, Zhang & Xie 2015). Municipal waste is also another biomass resource that have been exploited extensively in China for electricity and biofuel generation (Kang et al. 2020). A total of 60% of current municipal waste produced in China has potential to produce about 1-2 billion cubic meter of methane if used in landfill methane applications (Guo, Cui & Li 2022).

TABLE 4. Year of publication

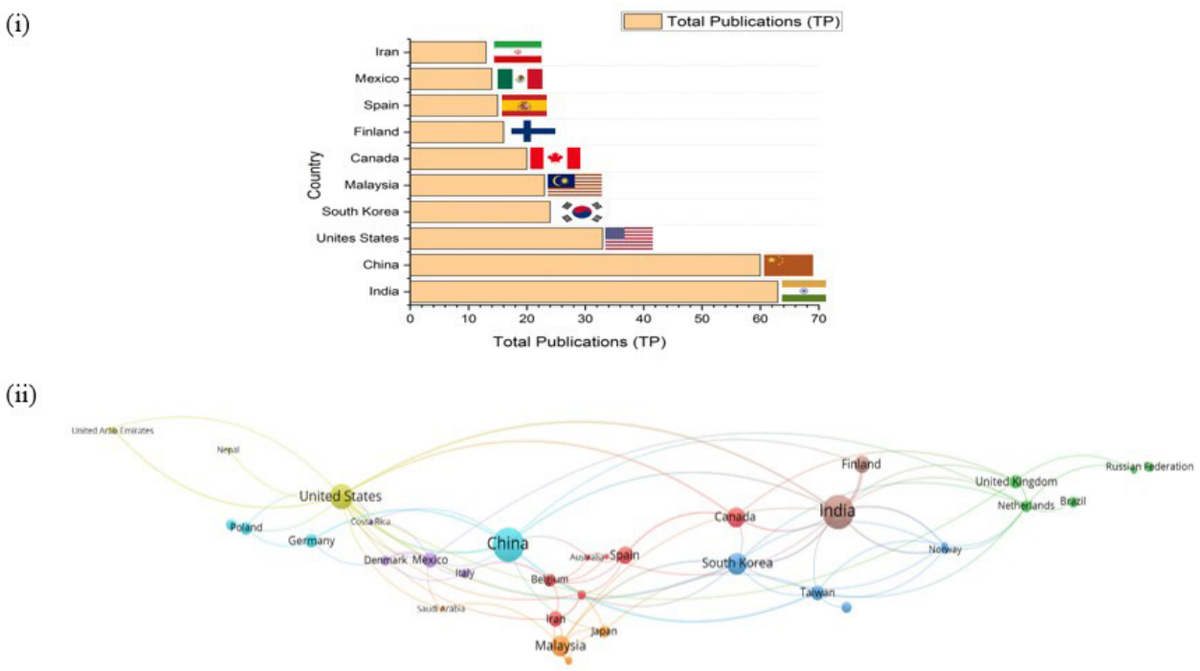
Year	TP	NCP	TC	C/P
2022	14	6	10	0.71
2021	40	34	179	4.48
2020	30	29	230	7.42
2019	25	25	343	13.72
2018	35	35	685	19.03
2017	41	36	760	18.54
2016	47	44	1406	29.91
2015	26	24	655	25.19
2014	26	21	694	27.76
2013	26	24	1333	53.32
2012	20	19	1278	63.90
2011	16	16	1614	100.88
2010	11	11	668	60.73
Total	357			

TP= total number of publications; NCP= number of cited publications; TC= total citations; C/P= average citations per publication

In the same context, as for India, the major biomass utilized for bioenergy development is derived more towards agriculture waste such as rice straw, wheat straw, sugarcane bagasse, and corn stover (Negi et al. 2023). India is also known as agricultural powerhouse that is highly attributed to the abundant land availability for agricultural sectors which covers net sown area of about 139.3 million hectares (Mha) (42.4%) from a total geographical area of 328.7 Mha (Graham et al. 2022). Presently, India produces about 990 MMT of agricultural biomass annually, which is the second highest after China. In addition, at present, the biomass utilization accounts up to 32% of all the primary energy use for bioenergy development in India. Furthermore, Negi et al. (2023) also showed that biomass power potential at India is expected to increase to 32,937.83 MWe and 35,994.52 MWe by the years 2025-2026 and 2030-2031, respectively, that further highlights the tremendous potential of India for bioconversion of biomass to environmentally sustainable bioenergy.

Furthermore, United States is ranked 3rd overall with 33 TP, then followed by South Korea, Malaysia, Canada, Finland, Spain, Mexico and Iran about 24, 23, 20, 16, 15, 14, and 13, respectively. Not only that, other Asian countries like Malaysia and South Korea also depict high number of TP that is equivalent to more than 20 publications. This may be due to the fact that there are many abundant potential biomass feedstocks that is suited for biobutanol production in which further push the interest of researchers to pursue in this field. For instance, Malaysia is the world's leading supplier of palm oil which leads to abundance type oil palm waste generated in the field and at oil palm mills. The wastes from the mill comprised of empty fruit bunches (EFB), oil palm shell (OPS), palm kernel shell (PKS), and palm oil mill effluent (POME) which has a great prospect to be commercialized for bioenergy production (Amin et al. 2022).

Apart from that, as for South Korea, biomass utilization is also derived mostly on agricultural waste such as rice straw to produce liquid fuel. Hochman and Tabakis (2020) also added that rice straw is an abundant and therefore attractive lignocellulosic material for biofuel production. It has high cellulose and



Minimum number of documents of a country = 1; Minimum number of citations of a country = 15

FIGURE 3. (i) Top 10 countries with the most total publications, (ii) Network visualization map of the co-authorship by countries

hemicellulose content that can be readily hydrolyzed into fermentable sugars. Not only that, this section also further shed the light on RQ 3 in which the countries that contributed the most publication on biobutanol related field is Southeast countries namely India and China. The interwoven relationship among major countries with minimum number of documents of a country is 1 and minimum number of citations of a country is 15 were further illustrated through network visualization map as shown in Figure 3(ii).

Apart from that, based on Figure 3(ii), it is proven that the size of the node represents the total link strength of the major countries in forming alliance to publish papers with other countries. For instance, China has prevalent size of node due to high amount of collaborations with countries like Germany, Poland, India, Taiwan, Japan and Finland which result in high number of TP. In the same context, China also has a strong co-authorship connection with India which is another country that strongly dominates biobutanol production field on a global scale. On the other hand, Malaysia has two-way network interaction with Iran which shows that these two countries have formed collaboration towards one and another. Malaysia research trend also focus primarily in forming collaboration with Asian countries like Japan and South Korea. Besides, the size of node also reflects to the number of citations in which the bigger the node, the higher the number of citations of that particular countries. This is due to the fact that the minimum citations for our findings was set to 15 to really screen the top tier countries that highly venture in biobutanol based research field.

Next, in terms of institutions that contributed the most paper in biobutanol field can be reviewed through Table 5 that demonstrates the top 10 of most influential institutions with minimum of seven publications. The results show that the top institutions with 12 publications comes from Universiti Kebangsaan Malaysia (UKM), Malaysia. This further proves that there is no co-relation between the top countries and most influential institutions, since in the previous section it was proven that the top 1 country in biobutanol field was India while Malaysia was recorded at 5th place. Furthermore, China still dominate as top institutions that contributes total accumulated publications up to 26 publications that were retrieved from Nanjing Tech University, Beijing University of Chemical Technology, and Ministry of Education China. One of the key factors that drives researchers to investigate and publish their discoveries in this field is the enormous amount of biomass that can be discovered in China, as was indicated in the section previously. Furthermore, China invests substantially in research and development that has great potential to be used for the economy of the nation, such as the production of biofuel, which is essential as a replacement for fossil fuels that will become less prevalent in the coming years (Qaseem & Wu 2021).

TABLE 5. Top 10 of Most influential institutions with minimum of seven publications

Affiliation	Country	TP
Universiti Kebangsaan Malaysia	Malaysia	12
Nanjing Tech University	China	11
Aalto University	Finland	11
University of Isfahan	Iran	10
Indian Institute of Technology Guwahati	India	9
Universidad de Guanajuato	Mexico	9
Beijing University of Chemical Technology	China	8
Ministry of Education China	China	7
National Cheng Kung University	Taiwan	7
Lodz University of Technology	Poland	7

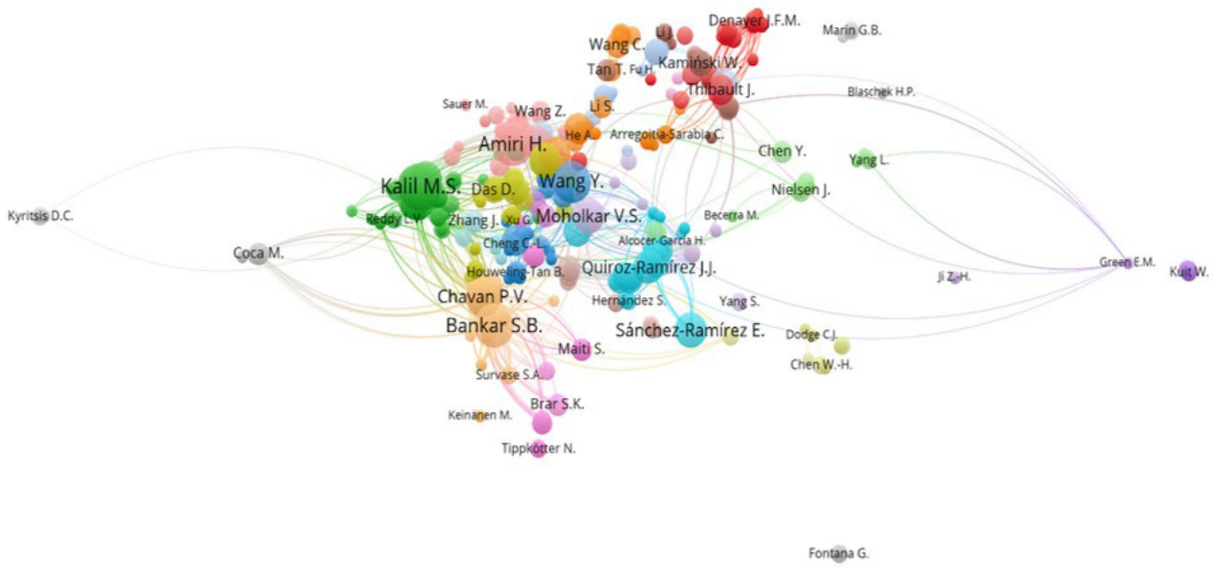
TP=total number of publications

LEADING AUTHORS IN PAST DECADE

In addition, the fundamental information showed in the preceding section on the top countries and affiliation has provide the premise that further enlightens the top authors found in this biobutanol research field. On the other hand, Table 6 shows the top 10 of most productive authors. The top ten authors, according to their affiliations, are from four different nations: India (4 authors), Malaysia (3 authors), Iran (2 authors), and China (1 author). The analysis of the top leading authors of the field shows that India is the country with the highest number of authors in the list of top 10 leading authors. In fact, 7 out of the 10 authors in Table 8 belongs to India and Malaysia, which contrary with the facts stated in the country analysis that states that India and China are the top countries that dominates biobutanol production field. In the same context, this is due to the fact that only the accumulated publications from the data retrieved shows that China is one of the countries with highest TP but lacking in terms of leading authors with at least minimum seven publications. This means that most of the published work from other authors in China are mostly less than seven publications. Apart from that, in order to fully understand the connection of each authorship which results in their respective TP is further demonstrated in Figure 4 which showed the network visualisation map of the citation by authors with specific set of conditions such as minimum number of documents of an author is 1 and minimum number of citations of an author is 10. Based from Figure 4, the size of the node represents a country's contribution, while the connecting lines represent author collaboration.

LEADING SOURCE TITLE

Apart from that, Table 7 has further demonstrated the top 10 most active source title. There are several important terms that was emphasised in this section that plays an important role in order to evaluate the most impactful source title such as cite score, and Source Normalized Impact per Paper (SNIP). For instance, cite score refers to the average citations received per document published in the serial. On the other hand, SNIP refers to the actual citations received relative to citations expected for the serial's subject field. In terms of publishers that have the most impact on biobutanol production which reflect towards RQ 6 is primarily dominated by Elsevier that covers 6 source title out of top 10 most active source



Minimum number of documents of an author = 1; Minimum number of citations of an author =20

FIGURE 4. Network visualization map of the citation by authors

title with accumulated of 77 total publications. Not only that, Bioresource Technology is the only source title that account more than 1000 citations that recorded up to 1934 TC which is also from the same publishing group. Generally, SNIP values greater than 1.0 are associated with an impactful journal; so, based on our findings, the SNIP value for the source title from top publisher Elsevier was greater than 1.0, demonstrating the publisher's significance in the biobutanol-based research sector.

TABLE 6. Top 10 of most productive authors

Author's name	Affiliation	Country	TP
Kalil, M.S.	Universiti Kebangsaan Malaysia (UKM)	Malaysia	12
Amiri, H.	University of Isfahan	Iran	10
Bankar, S.B.	Bharati Vidyapeeth University	India	10
Al-Shorgani, N.K.N.	Universiti Kebangsaan Malaysia UKM)	Malaysia	9
Chavan, P.V.	Bharati Vidyapeeth University	India	8
Khedkar, M.A.	Bharati Vidyapeeth University	India	8
Nimbalkar, P.R.	Bharati Vidyapeeth University	India	8
Yusoff, W.M.W.	Universiti Kebangsaan Malaysia (UKM)	Malaysia	8
Hamid, A.A.	Islamic Azad University	Iran	7
Jiang, M.	Nanjing Tech University	China	7

TP=total number of publications

TABLE 7. Top 10 of most active source title

Source title	TP	TC	Publisher	Cite score	SNIP 2021
Bioresource Technology	28	1934	Elsevier	17.14	2.060
Fuel	11	375	Elsevier	6.3	1.087
BioResources	9	94	North Carolina State University	3.4	0.598
Biochemical Engineering Journal	8	128	Elsevier	6.7	0.998
Industrial Crops and Products	8	158	Elsevier	9.6	1.713
Renewable Energy	8	194	Elsevier	13.6	2.108
Biotechnology for Biofuels	7	249	BioMed Central Ltd	11.5	1.575
Computer Aided Chemical Engineering	7	60	Elsevier	1.4	0.473
Journal of Chemical Technology and Biotechnology	7	171	John Wiley & Sons	6.1	0.804
Renewable and Sustainable Energy Reviews	7	647	Elsevier	28.5	4.535

TP=total number of publications; TC=total citations

HIGHLY CITED INSIGHTFUL ARTICLES

Apart from that, in order to show RQ 4 that emphasised on the current citation patterns of publications on the biobutanol production, citation analysis was carried out for this study which was generated using Publish or Perish software. The data showed in Table 8 reflect towards several components known as citation metrics. This overall data was obtained by using the same Scopus database as in the previous section but through different file known as RIS format. Besides, this was further proven since the total number of papers retrieved was 357 that was similar as the record identified and screened using Scopus database. Since the range for this study was for a specific timeframe from 2010-2022, therefore the total number citations of 9842 was collected from 12 years of total publications.

In order to prepare a scientific paper, it is essential to utilized a credential and impactful papers as source of references. Table 9 highlights the top 10 of highly cited articles found by using biobutanol as keyword. Based from the data, it is evident that the most cited articles were mostly from 2011 as the top 3 articles were found within that year. One of the reasons is may be due to the fact that these articles emphasized on generic biobutanol production fermentation that covers all the fundamentals overview such as challenges, properties, applications and many other aspects. Therefore, most researchers will cite these articles to further elaborate on the overview of biobutanol production before discussing their respective niche topics. This is further supported by Sjögårde and Didegah (2022) that showed the association between topic growth and citation impact of research publications in which a research paper that concentrates on the broad overview of a field serves as the basis and fundamental for producing well-informed, pertinent, and significant contributions to the field. Furthermore, this would enable academics to delve further into the topic's specialty outside the primary focus, which is essential for the advancement of research and development. In addition, research works with a higher number of references particularly high impact and recent references are observed to be mentioned more frequently. This makes article references another crucial factor that influences an article's future impact (Ebrahim et al. 2014). Apart from that, this section also further enlightens on RQ 2 that covers on which paper have the largest impact on biobutanol production. Based on Table 9, it is evident that the title 'Fermentative production of butanol-the industrial perspective' from Green (2011) is the paper that has the largest impact which secured the highest citations with 547 cites and also has the record of 49.73 cites per year. On the other hand, since biobutanol production is known for its significant properties and advantages, however, it also possessed many challenges before it is economically viable for large scale production which therefore makes García et al. (2011), the Top 2 highly cited articles with the title that emphasised on challenges in biobutanol production and how to improve the production efficiency.

Besides, lack of comprehensive review on developments in biobutanol production which propels Kumar and Gayen (2011) paper Top 3 with 353 cites and 32.09 cites per year. Apart from that, due to the growing fascination among researchers with strain improvement strategies as a means to address the biobutanol toxicity challenge, Hong and Nielsen (2012) paper on 'Metabolic engineering of Saccharomyces cerevisiae: A key cell factory platform for future biorefineries' has emerged as

TABLE 8. Citations metrics

Metrics	Data
Papers	357
Number of Citations	9842
Years	12
Citations per Year	820.17
Citations per Paper	27.72
Authors Paper	4.64
h-index	50
g-index	86

a dominant force, securing a prominent position among the top four highly cited articles. This paper's key discovery is that it offers a foundation for understanding the metabolic pathway of a common Saccharomyces cerevisiae, which is widely used in industry. This opens the door to the possibility of performing extremely detailed phenotypic characterization of microorganisms that can function as effective cell factories for the synthesis of chemicals and fuels. In addition, this study has also clarified the progress made in S. cerevisiae metabolic engineering, which results in the production of biofuels such biobutanol, bioethanol, and biodiesel. Furthermore, the articles in the Top 5 to Top 10 are largely focused on biobutanol recovery approaches, which is one of the key fundamental scopes in biobutanol production research.

TABLE 9. Top 10 highly cited articles

No.	Authors	Title	Year	Cites	Cites per year
1	Green, E.M.	Fermentative production of butanol-the industrial perspective	2011	547	49.73
2	García, V., Päkkilä, J., Ojamo, H., Muurinen, E. & Keiski, R.L.	Challenges in biobutanol production: How to improve the efficiency?	2011	358	32.55
3	Kumar, M. & Gayen, K.	Developments in biobutanol production: new insights	2011	353	32.09
4	Hong, K-K. & Nielsen, J.	Metabolic engineering of *Saccharomyces cerevisiae*: A key cell factory platform for future biorefineries	2012	299	29.90
5	Black, G., Curran, H.J., Pichon, S., Simmie, J.M. & Zhukov, V.	Bio-butanol: Combustion properties and detailed chemical kinetic model	2010	276	23.00
6	Xu, G.C., Ding, J.C., Han, R.Z., Dong, J.J. & Ni, Y.	Enhancing cellulose accessibility of corn stover by deep eutectic solvent pre-treatment for butanol fermentation	2016	253	42.17
7	Abdehagh, N., Tezel, F.H. & Thibault, J.	Separation techniques in butanol production: Challenges and developments	2014	214	26.75
8	Liu, S., Liu, G., Zhao, X. & Jin, W.	Hydrophobic-ZIF-71 filled PEBA mixed matrix membranes for recovery of biobutanol via pervaporation	2013	208	23.11
9	van der Wal, H., Sperber, B.L.H.M., Houweling-Tan, B., Bakker, R.R.C., Brandenburg, W. & López-Contreras, A.M.	Production of acetone, butanol, and ethanol from biomass of the green seaweed *Ulva lactuca*	2013	190	21.11
10	Jouzani, G.S. & Taherzadeh M.J.	Advances in consolidated bioprocessing systems for bioethanol and butanol production from biomass: A comprehensive review	2015	140	20.00

KEYWORDS CO-OCCURRENCE ANALYSIS

Keywords are an essential indicator for a research in determining the concept and overview of the content of the research paper. The proper use of keywords will benefit the readers to understand the main point that will be discussed in the paper. Not only that, keywords in research paper also act as a tool to help indexers and search engines find relevant papers. Therefore, to further assess the top keywords in biobutanol research field, Table 10 demonstrates the top 10 keywords used whereby the author keywords reflect towards the keywords given by authors to their respective paper. Therefore, the total cumulative of the keywords used from all the papers is shown in the total publication (TP) column. In terms of top keywords, the results obtained is mostly influenced by the search query incorporated in this study. As mentioned in the methodology section, the search query of biobutanol was emphasized twice which leads to the top used keywords with total publication of 329 (92.16%) is 'Biobutanol'. Apart from that, biobutanol production is widely produced through the process of Acetone-Butanol-Ethanol (ABE) fermentation, which is also the reason behind the inclusion of the terms 'Acetone', 'Butanol', 'Ethanol' and 'Fermentation' in the top 10 keywords. This was further corroborated by a recent study by Muñoz Muñoz and López-Galán (2024), which focused on the biorefinery approach of producing butanol from lignocellulosic residues and found that acetone, butanol, and ethanol have the highest keyword links to a network of topics related to butanol, with a broader size of node that is comparable to our study. Besides, out of 3414 keywords, 126 met the threshold requirement of a minimum number of repetitions of the terms of 10. After screening the keywords, a final map was constructed with 160 significant keywords. The frequency of co-occurrence, on the other hand, increases with connection line thickness as well as node size. The greater the node size, the greater the total link strength of the specific terms. For instance, the terms 'Biobutanol' and 'Fermentation' had larger nodes than other keywords because these two terms are frequently used and mentioned in most publications due to their interwoven relationship in which biobutanol production necessitates the need for fermentation.

Not only that, industrial microorganism that is utilized for biobutanol production is mostly derived from Clostridium species such as Clostridium acetobutylicum and Clostridium saccharoperbutylacetonicum which made the term 'Clostridium' in the top 6 keywords with 102 TP (28.57%). In the same context, to further emphasised on the interwoven relationship of these keywords, Figure 5 illustrates a screenshot of bibliometric map based on keywords co-occurance network with network visualization with overlay visualization mode produced via VOSviewer. Apart from that, Cluster 1 from Figure 5 further shed the light on RQ 7 which is what areas involving biobutanol production need additional study. It is evident that the components found in Cluster 1 are most of the keywords involved in downstream processing of biobutanol production. As a result, our findings suggest that there is lack of research conducted in this area due to minimum internetworking connection found from keywords like 'Recovery', 'Distillation', 'Adsorption', 'Separation', 'Pervaporation' and 'Evaporation'. Therefore, this further proves that downstream processing is one of hot topic that can be pursued by researchers in these upcoming years in order to fill this research gap in biobutanol production.

TABLE 10. Top 10 keywords

Author keywords	Total publications (TP)	Percentage (%)
Biobutanol	329	92.16%
Fermentation	212	59.38%
Acetone	147	41.18%
Butanol	121	33.89%
Biofuel	107	29.97%
Clostridium	102	28.57%
Ethanol	98	27.45%
Article	92	25.77%
Biofuels	85	22.13%
Alcohol	79	23.10%

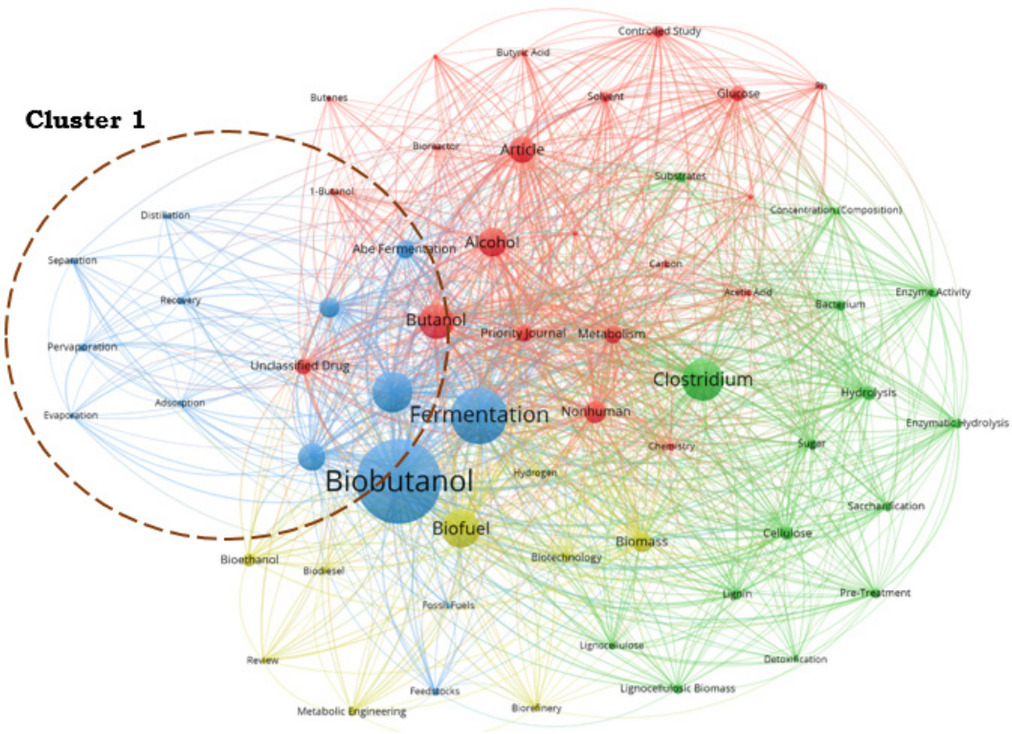


FIGURE 5. Keywords co-occurrence network

Conclusion

In conclusion, all of the proposed research questions in this study were successfully answered which gives proper insights to the recent biobutanol production research trend. The publications were extracted within 10 years from 2010 to September 2022 using Scopus database that accumulate up to 357 publications. Publication growth has been rapid since the last 10 years, and it is anticipated to continue to rise throughout the years. Not only that, but the top countries and institutions actively involved in biobutanol production are clearly dominated by Southeast Asian countries such as India, China, South Korea, and Malaysia. As a result, this lays the groundwork for future researchers interested in this particular biobutanol field to network and collaborate with researchers mostly from these nations. Additionally, the majority of biobutanol-based research falls under the purview of Chemical Engineering and Energy. Similarly, Elsevier is the publisher with the biggest influence on biobutanol production, with the top two source titles being Bioresource Technology and Fuel. This will also assist future researchers choose the best platform for both the source title and the publisher when dealing with biofuel-related topics such as biobutanol production. In addition, our keywords co-occurrence analysis has also shed the light on the upcoming hot topics for biobutanol research field that is driven towards downstream processing. This is because there is a lack of co-occurrence discovered among the terms that emphasise downstream processing, necessitating the need for future research to bridge this research gap in biobutanol production.

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