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Research Article

A Bibliometric Analysis of Jaggery Related Literature Published During 2000-2023

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ABSTRACT

The study proposed to provide a bibliometric analysis of the jaggery-related literature published from 2000 to 2023. The data for this study was retrieved from the Scopus database and analyzed using VOSviewer, Bibliometrix, and word cloud for the following: trend of publications, type of document, *h*-index, performance of countries and authors, most cited publications and most prolific journals. Further, a co-authorship network of countries and authors, a co-citation network of authors and references, a co-occurrence network, word clouds of keywords, and a thematic map were also analyzed to find research hot spots and current and future directions of research. Results showed that India, Colombia, and Pakistan are the leading producers of scientific literature while Sugar Tech and Journal of Food Science and Technology are the most influential journals in this field. A Co-authorship network indicates a low level of cooperation among the countries and the researchers, which is not conducive to the progress of research in the field. Word cloud and thematic map show that research related to jaggery is moving in a diversified direction. It is anticipated that this bibliometric study will be crucial to the researchers' understanding of research trends, hotspots, advancements, and current and future directions.

Keywords: Bibliometric analysis, VOSviewer, Bibliomterix, Non-centrifugal sugar, Sugarcane, Jaggery.

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INTRODUCTION

Jaggery, or Non-Centrifugal Sugar (NCS), is a traditional and widely consumed sweetener with substantial cultural and nutritional value across various societies. Jaggery is a nutraceutical, functional, and fortified food that has the potential to not only supply essential nutrition to our body but also offer multiple health benefits (Rao and Singh 2022). It is consumed in its raw form or in the form of value-added food products such as jams, bakery products, Bomboyson, confectionary products, energy drinks, juices, spirit beverages, and so on (Dingre 2023). Further, jaggery has also been found to have some unique applications, such as the isolation of bio-fungicide, to increase the rate of facemask (COVID-19) degradation and exfoliation of graphite graphite (Mousumi Das *et al.* 2021; Patil *et al.* 2021; Suvarna and Binitha 2019). Additionally, byproducts of jaggery and waste from jaggery production are valuable commodities used to produce ethanol, bio-fertilizer, bio-methane, nanomaterials, and nanocomposites (El-Shafey 2021; Mendieta *et al.* 2019; Motaung and Mochane 2018).

Jaggery is produced from cane juice through heating and evaporation using traditional open-hearth furnaces in rural settings. Because of their low thermal efficiency and high resource consumption, which are linked to higher thermal irreversibilities in the combustion and heat transfer processes, jaggery producing units have poor thermal and environmental performance (Alok Kumar *et al.* 2023). Jaggery is produced in nearly 25 countries, India and Colombia are the two largest jaggery producers worldwide, with contributions of 70% and 12%, respectively (Solís-Fuentes *et al.* 2019). Also, India is the largest consumer of jaggery; however, in consumption per capita, Columbia is leading the way with a consumption of 24 kg/capita/year. Jaggery is available in solid, liquid, and powder (granular) form, and freshly produced solid and powder jaggery contains 10-13% and 8-10% moisture, respectively. The high moisture content of jaggery adversely impacts its shelf-life, and moisture in jaggery needs to be reduced to 1-2% before storage to avoid microbial deterioration. A significant fraction, about 10% of the total jaggery produced, worth US$0.6 million, is lost yearly due to deterioration caused by moisture content (Sreedevi *et al.* 2021). The shelf-life of the jaggery can be improved by drying, covering the solid jaggery pieces with special coatings, and storing them in air-tight containers, Low-Density Polyethylene (LDPE), storage bins, and so on. Demand for jaggery has been increasing steadily, stimulated by lifestyle change, awareness about the

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health benefit of jaggery consumption, the adverse impact of white sugar on human health, and improved socio-economic conditions (Tyagi *et al.* 2022). In order to meet the growing demand, jaggery production should be increased sustainably, and efforts are underway in this direction, as is evident from the noticeable upsurge in research and discourse concerning jaggery production.

In recent years, multiple traditional reviews on jaggery production have been published. However, to the best of understanding and knowledge, only one bibliometric analysis review concerning jaggery-related documents is available in the literature, which focuses on only one country, Columbia (Flórez-Martínez *et al.* 2023). The present study analyses jaggery-related scholarly literature from bibliometric, network, and thematic mapping perspectives in a global context. Further, this review is intended to uncover the hot research topic, highlight the current research direction, offer new insight in terms of leading researchers, institution and provide scholars with essential inspiration in directing their future research efforts, and determine the best journal for their future publications. In essence, the following are the main objectives of this review:

What is the trend in jaggery-related literature publications, types, and research fields of publications?

Which publications, countries, institutions, authors, and journals are prolific in jaggery-relevant publications?

What is the level of collaboration among the researchers and institutions in the jaggery-related research field?

What is the current status and the emerging research theme in jaggery-related research?

METHODOLOGY

The quantitative review technique known as "bibliometric analysis" encompasses the utilization of data mining, statistics, and mathematics to uncover research course and the quality of peer-reviewed scientific articles published in a particular research field (Guo 2022; Tamala *et al.* 2022). This technique has grasped the attention of researchers in different research fields in recent years. The popularization of this technique among the scientific community is attributed to the development, accessibility, and availability of bibliometric software such as VOSviewer, Bibliometrix, Citespace, BibExcel, Gephi, and so on, and the development of scientific databases like Scopus, Web of Science (WoS) and PubMed (Donthu *et al.* 2021). Furthermore, the proliferation of scientific literature in the last few decades has manifested the weaknesses of the traditional review such as subjectivity, incompleteness, and time constraints. However, bibliometric analysis is capable of handling a large number of scientific literature accumulated over time, while the reliability of results can be verified easily through the transparent reproducible review process (Qin *et al.* 2022). Given these advantages and versatility, bibliometric techniques have found their applicability beyond of information and library science domain, from where they originated (Mejia *et al.* 2021).

Scope of the study

Bibliometric analysis has been conceptualized to handle a large amount of bibliometric data; therefore, it is imperative to assess the scope of the study to ensure that the field of study is adequately broad. According to Donthu *et al.* (Donthu *et al.* 2021), a field of study should have more than 300 articles to qualify for the bibliometric analysis. On the other hand, Rogers *et al.* (Rogers *et al.* 2020) argued that the small volume of articles used for bibliometric analyses leads to a higher variance under the average normalized citation impacts category and showed a significant decrease in the variance as the volume of articles increases. Furthermore, they concluded that bibliometric analysis of a research field could be warranted if the number of articles is more than 200. This study encapsulates 384 articles after applying screening criteria; therefore, this study qualifies for bibliometric analysis.

Data source and screening strategy

To accumulate literature data for this study, the Scopus database, which is the most comprehensive database of citations and abstracts for peer-reviewed literature and encapsulates peer-reviewed articles from a wide range of reputed journals, was mined on a single day, July 20, 2023, to avoid any miss in data as the Scopus database is updated on a daily basis. The mined data from the Scopus database can be extracted in various file formats such as CSV, RIS, BibTeX, and Plain text. For the intended study, the mined data was exported in an Excel file with a CSV file format.

For the database search, three keywords, “jaggery” OR “jaggery production” OR “non-centrifugal sugar” were used, and some restrictions such as subject area, time range, document type, publication stage, and language were imposed. Initially, these keywords produced 586 documents, which, after applying the constraints mentioned above, were condensed to 384 documents. These 385 documents were downloaded in CSV format (Microsoft Excel, which, after removing duplicate records, condensed to 384 documents that are included in the bibliometric analysis. Figure 1 shows the framework of the methodology employed in this study. The final query string used to extract bibliometric data from Scopus is also given below.

(TITLE-ABS-KEY (JAGGERY OR"JAGGERY PRODUCTION"OR "NON-CENTRIFUGAL SUGAR")) AND PUBYEAR > 1999 AND PUBYEAR < 2024 AND (LIMIT-TO(SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "AGRI") OR LIMIT-TO (SUBJAREA,"ENVI") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA,"MULT") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA,

"CENG")) AND (EXCLUDE (SRCTYPE, "d")) AND (LIMIT-TO (LANGUAGE, "English")) AND (EXCLUDE (PUBSTAGE, "aip"))

Software employed and bibliometric analysis

This study employed multiple tools that include VOSviewer (version 1.6.19), Biblioshiny (web app of bibliometrix), and word cloud. The VOSviewer is a freely available software tool developed in Java programming language by Nees Jan van Eck and Ludo Waltman in 2010 for constructing, visualizing, and exploring bibliometric maps from network data. It offers a user-friendly, flexible, and excellent graphic quality experience (Arruda *et al*. 2022). VOSviewer investigates co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation relation through one of the three available visualization modes: network visualization, overlay visualization, and density visualization (Arruda *et al*. 2022; Entezari *et al*. 2023). Biblioshiny is a web-based app interface of biblimoterix designed for those who do not have coding skills (Dervis 2019). Bibliomterix is an open-source tool developed in R programming that encapsulates all main bibliometric methods of analysis.

Bibliometric analysis techniques are exhibited across two categories: the first one is performance analysis, while the other is science mapping (Yildirim *et al*. 2022). At its core, performance analysis explores the contribution of research constituents to a research field (author, journal, institutions, and countries), while science mapping examines the relationship among research constituents.

RESULTS AND DISCUSSION

This section is organized into two sub-sections: performance analysis and science mapping. The performance analysis and science mapping were further evaluated and explained under multiple sub-categories.

Performance analysis

Performance analysis is employed to determine the performance and influence of the publications, authors, institutions, countries, and journals on bibliometric data obtained from the Scopus. For this study, the number of articles published each year, types and research areas of publications, most productive journal, most

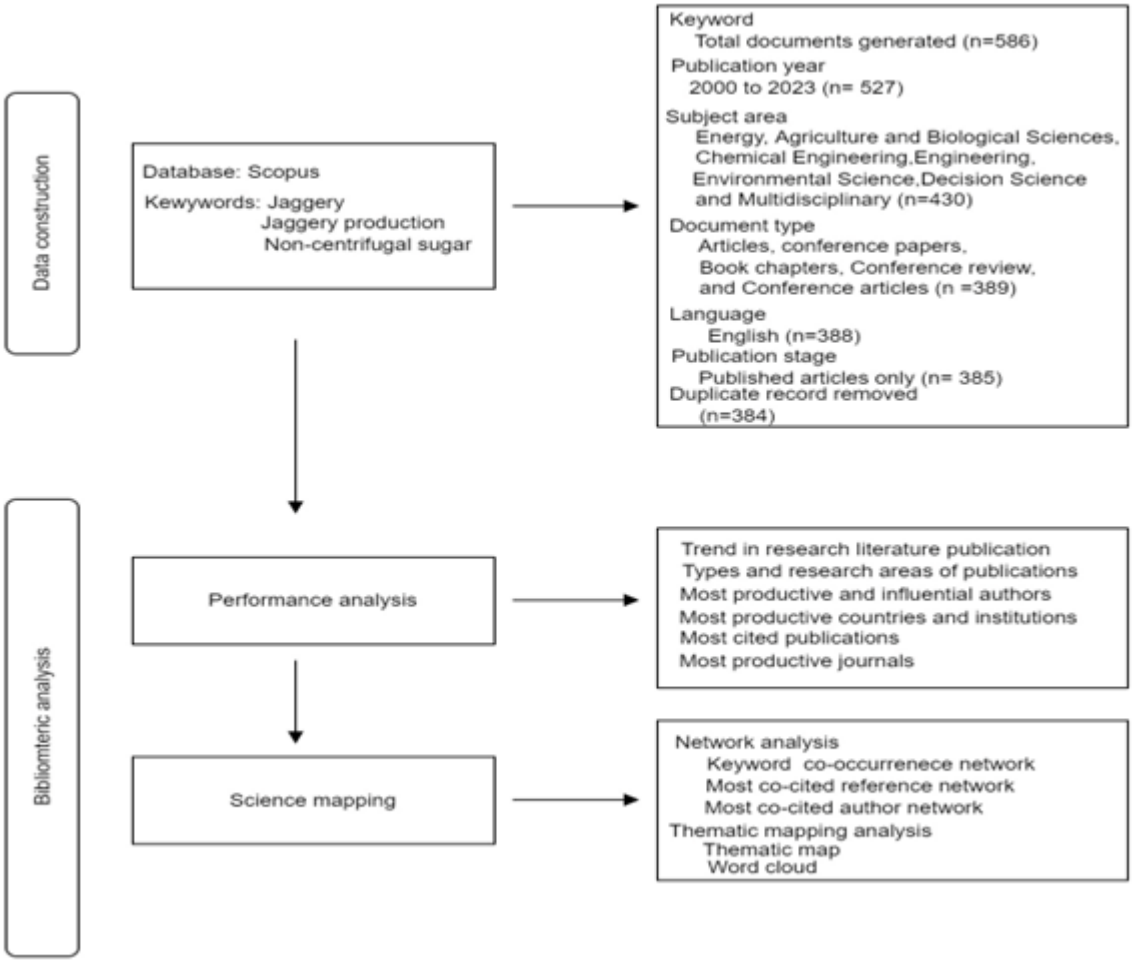

Figure 1: Framework of the methodology for this study (Yildirim *et al*. 2022).

productive country, total citation per year, and most productive and influential authors, and h-index are presented.

Publication performance analysis

The frequency of articles published in a year in a particular research field is an important parameter to assess the productivity of that research field. Figure 2 depicts the total number of publications in each active year between 2000 and 2023, from 384 articles. It is observed from the Figure 2 that 2022 was the most productive year in the jaggery research field, with a total of 49 publications, whereas 2000 was the least productive year, with just two publications. In addition, the number of publications year-wise has been increasing with an Average Annual Growth Rate (AAGR) of 24%, with some intermittent fluctuations. Actual growth in publications in this field started after 2008 with some fluctuations.

The number of articles published by a research constituent, publication frequency in this case, represents research productivity. However, it does not provide any information concerning the impact and influence of a research constituent. The number of citations per year or research constituent is a measure of the impact and influence of a research constituent. Figure 3 shows the growth of citations per year, and it is observed that citations of publications in this field of study are increasing exponentially, with an average annual growth rate of 32%. However, citations proliferated after 2011, which is evidence that this field of research has gained the attention of researchers. Further, the rate of increase of citations received by the articles is significantly higher than that of the number of publications each year, which signifies the influence of published articles. Publication or citations alone do not provide a clear picture of the research's significance and influence. H-index is the parameter that overcomes this shortcoming and is discussed in the next paragraph.

Additionally, the h-graph (Figure 3) was extracted from Scopus. The vertical axis represents their corresponding total citations in integers, whereas the horizontal axis shows the total documents in descending order of their citations. The straight line in the graph represents a linear proportional relation between the published documents and total citations. The point where the straight line cuts the citation-documents curve, marked with a yellow star, represents the h(Hirsch)-index, which indicates the influence of published documents. The h-index is a parameter expressed in numbers, and it is used to depict the productivity and influence of an author in a research field; however, in this case, it represents the influence of documents included in this study. According to the bibliographic data, the h-index for the data set is 34, which indicates that 34 articles from this set of 384 articles have at least 34 citations.

Publication types and research areas

Within Scopus, documents can be classified into many categories, allowing for the simultaneous appearance of multiple types for a given document. Additionally, the amount of all the documents

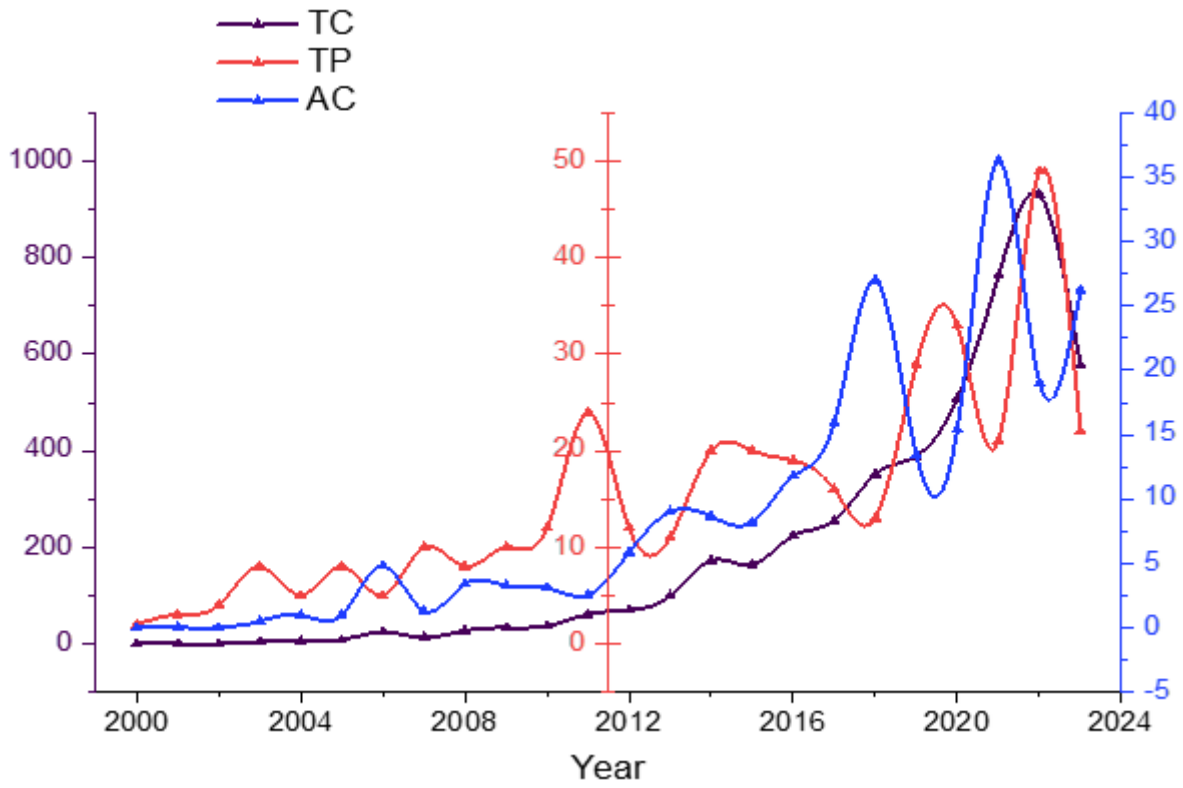

Figure 2: Annual growth trend of TC, AC, and TP of jaggery-related literature (2000-2023).

for each type added up exceeds the total number of documents extracted from Scopus. The distribution of documents based on their type is shown in Figure 4. Five types of documents were retrieved, and the highest contribution came from articles (320, 83%), followed by Conference papers (26, 6.7%), Reviews (21, 5.45%) and Book chapters (17, 4.41%) and the least contribution comes from Conference review (1, 0.3%).

Similarly, each publication can appear in more than one research field. The distribution of retrieved documents by research area is shown in Figure 5. From Figure 5, Agricultural and Biological Sciences and Engineering are the two most popular research areas, contributing to (243, 48.8%) and (76, 15.2%), respectively. These are followed by Environmental Science (60, 12%), Chemical Engineering (52, 10.4%), Energy (47, 9.4%), and Multidisciplinary (17, 3.4%), and Decision Sciences has a marginal representation of 1% only.

Performance of Countries/territory and authors

From Figure 6, it is observed that India, in terms of the number of publications, is way ahead of other countries with a contribution of more than 83%, followed by Pakistan and Colombia, each having a contribution of 2.3%. Further, Table 1 shows that citations received by various countries do not follow the same order as of number of publications by them. For instance, Colombia and Pakistan published the same number of documents (9), but Pakistan received about 36% more citations. Also, Malaysia is ranked 4th in the number of publications but received the least citations (30). However, regarding the number of Average Citations Per publication (ACP), Spain is the most influential country, while India is ranked 7th despite being the most productive country with a score of 12 (Table 1).

The most productive author, regarding the number of published articles (14), is Kumar S from Bhabha Atomic Research Centre, Mumbai, India (S. Kumar *et al.* 2022). His work has focused on the production of value-added products. On the other hand, G. N. Tiwari from the Indian Institute of Technology Delhi, India, is the least productive author with the second highest number of citations (230), Figure 8. His work extensively focused on the jaggery drying process, which other researchers have ignored (Anil Kumar and Tiwari 2006a, 2006b).

Figure 7 shows the production of the top 15 most productive authors over time. The dark color and size of the bubbles

Table 1: **Top ten countries by number of publications.**

Sl. No.	Country	Publications	Citations	ACP
1	India	323	3871	12
2	Pakistan	9	134	14.9
3	Colombia	9	98	10.9
4	United States	7	132	18.8
5	Malaysia	6	30	5
6	Spain	5	123	24.6
7	South Korea	5	90	18
8	China	5	69	13.8
9	Peru	5	45	9
10	Australia	4	87	21.7

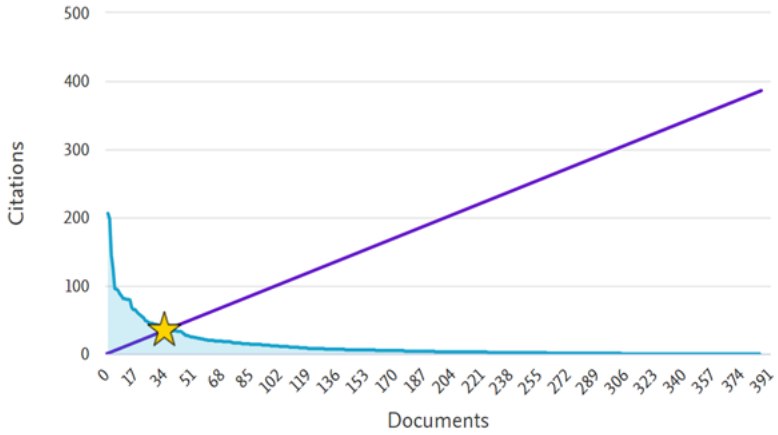

Figure 3: h-graph of the collected documents.

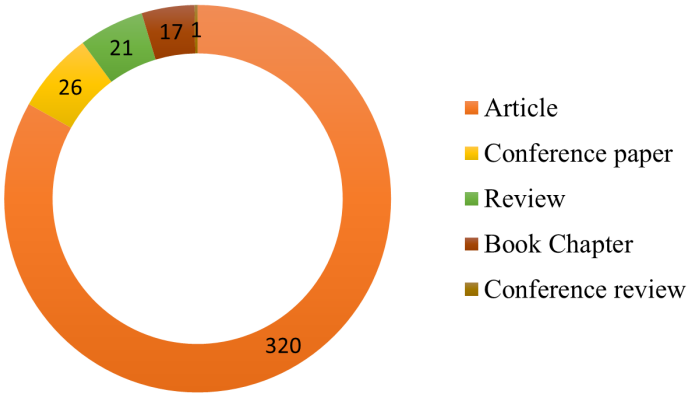

Figure 4: The distribution of documents based on type.

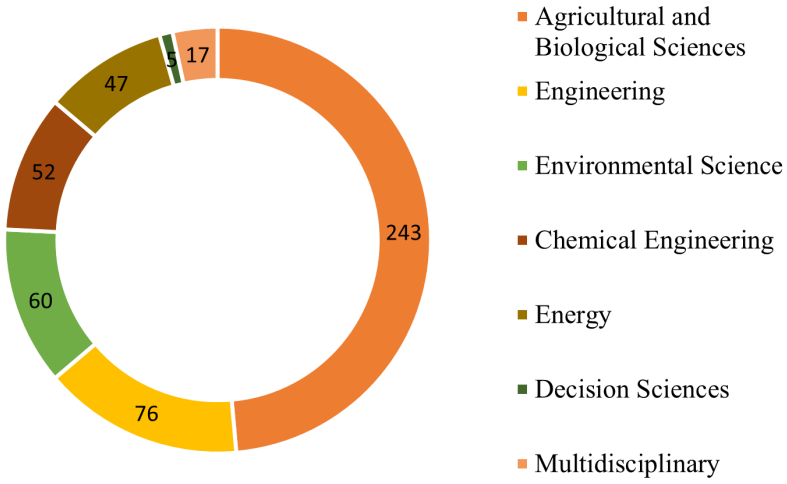

Figure 5: Distribution of documents by subject area.

correspond to the article and number of articles published, respectively. In contrast, light color bubbles and their size correspond to the citations and citations received by the author per year, respectively. The two most exciting facts observed from Figure 7 are: first is that G N Tiwari published the least number of articles (6), and his last articles were published back in 2006 but received the second highest number of citations (230); see Figure 8. Second, Kumar S has been publishing for the most extended period and published the highest number of articles (14), but he ranked 3rd in the number of citations (118) received. Only authors with a minimum of six publications published and 69 citations were considered when creating Figure 8. This diagram gives a glimpse of the authors that are influential as well as productive. Furthermore, the size of the bubbles corresponds to the citations received by the authors.

Performance of institutions

According to Scopus data, 162 institutes worldwide have published relevant documents in this field. Among them, the majority of the institutes are from India, and the Indian Council of Agricultural Research Lucknow and the ICAR-Indian Institute of Sugarcane Research Lucknow are the two most productive institutes globally, with 14 documents each, see Figure 9. The following four Institutes in the list are Indian Institute of Technology Delhi, Govind Ballabh Pant University of Agriculture and Technology, Indian Institute of Technology Bombay and Vellore Institute of Technology, each with 12 documents. Furthermore, outside the Indian geographic region, the Universidad Nacional de Colombia and the Universidad de Piura are the two most productive institutes with 6 and 5 documents, respectively.

Highly cited publications

A scientific document gains recognition among the scientific community when other researchers cite it. Additionally, the citation received by a publication over time is a parameter used to measure its quality and influence on the research field (Hong *et al.* 2020). Since old publications tend to receive more citations, the total citations of a publication may not display its influence with respect to time on research in a particular field

Table 2: The top ten papers with the most citations.

Rank	Title	Type	Journal	year	TC	AC	NA	References
1	Additives aided composting of green waste: Effects on organic matter degradation, compost maturity, and quality of the finished compost.	Article	Bioresource Technology.	2012	206	17.2	7	(Gabhane *et al.* 2012)
2	Presence of amorphous carbon nanoparticles in food caramels.	Article	Scientific reports	2012	198	16.5	5	(Sk *et al.* 2012)
3	Synthesis of silver nanoparticles by polysaccharide bioflocculant produced from marine Bacillus subtilis MSBN17.	Article	Colloids and Surfaces B: Biointerfaces.	2013	145	13.2	3	(Sathiyanarayanan *et al.* 2013)
4	Sugar intake, obesity, and diabetes in India.	review	Nutrients	2014	95	9.5	2	(Gulati and Misra 2014)
5	Health Effects of Non-Centrifugal Sugar (NCS): A Review.	review	Sugar Tech	2012	85	7	1	(Jaffe 2012)
6	Nutritional and functional components of non-centrifugal cane sugar: A compilation of the data from the analytical literature.	review	Journal of Food Composition and Analysis.	2015	81	9	1	(Jaffe 2015)
7	Thermal modelling of a natural convection greenhouse drying system for jaggery: An experimental validation	Article	Solar Energy	2006	81	4.5	2	(Anil Kumar and Tiwari 2006a)
8	Cytoprotective and antioxidant activity studies of jaggery sugar.	Article	Food Chemistry.	2009	79	5.3	5	(Harish Nayaka *et al.* 2009)
9	Jaggery: A novel substrate for pullulan production by Aureobasidium pullulans CFR-77.	Article	Process Biochemistry.	2001	68	3	4	(Vijayendra *et al.* 2001)
10	Evaluation of convective mass transfer coefficient during drying of jaggery.	Article	Journal of Food Engineering.	2004	62	3.1	3	(Tiwari *et al.* 2004)

[a]TC: Total citations, AC: Average citation per year, NA: Number of authors.

(Hong *et al.* 2020). In order to comprehend a publication's impact on a research field, the average annual citations received by a publication are determined and presented in Table 2, along with the total citations received by the publication. These two parameters are not alternatives to each other but complement one another. On analysis, it was found that Gabhane*et al.* (Gabhane *et al.* 2012) is credited with the most significant publication, which has received 206 citations so far. From Table 2, it may also be inferred that except for three documents, all are journal articles. Tables 2 and 3 include the most cited publications in the descending order of Total Citations (TC) and Average Citations received per year (AC), respectively, along with document type, journal/source, publication year, and number of authors. Table 2 summarizes the documents published between 2001 and 2015. On the other hand, Table 3 encapsulates the documents published between 2012 and 2021, which indicates that recently published documents are being cited, in general, at a faster rate, while the rate at which old documents receive citations vanishes with time. In Table 3, four items are different concerning AC from Table 2, and all these four items have recently been published.

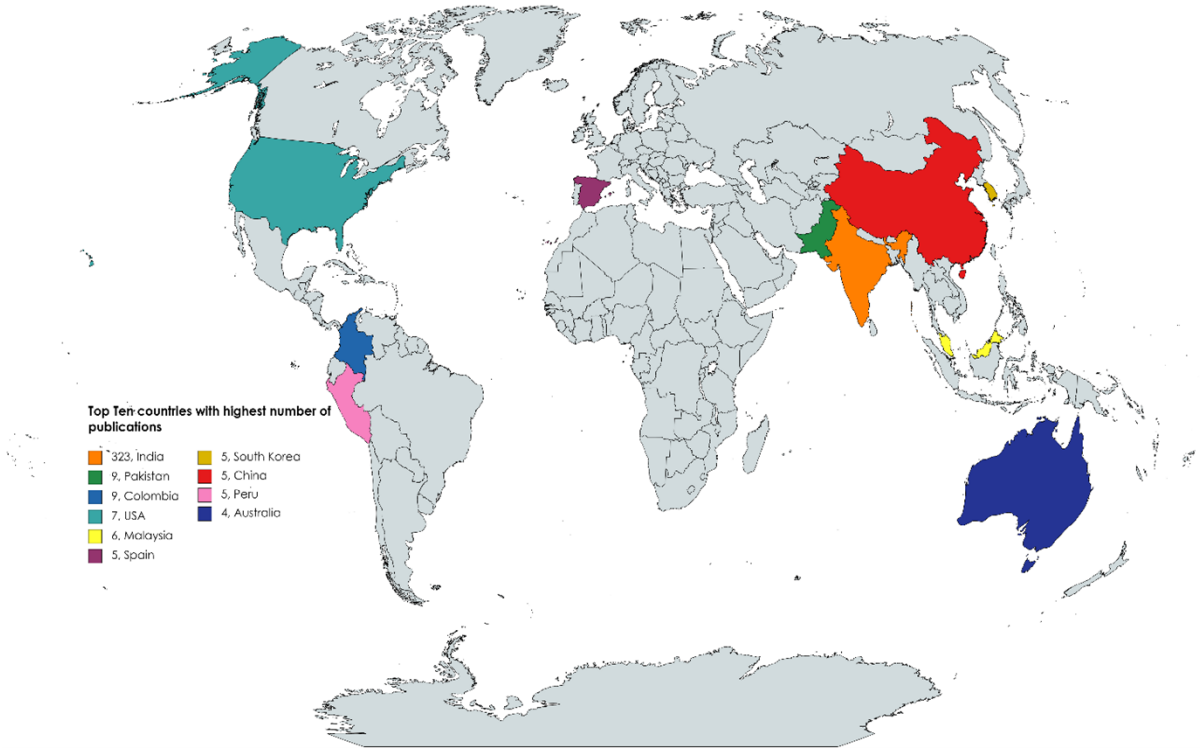

Figure 6: Country-wise publication of top 10 countries.

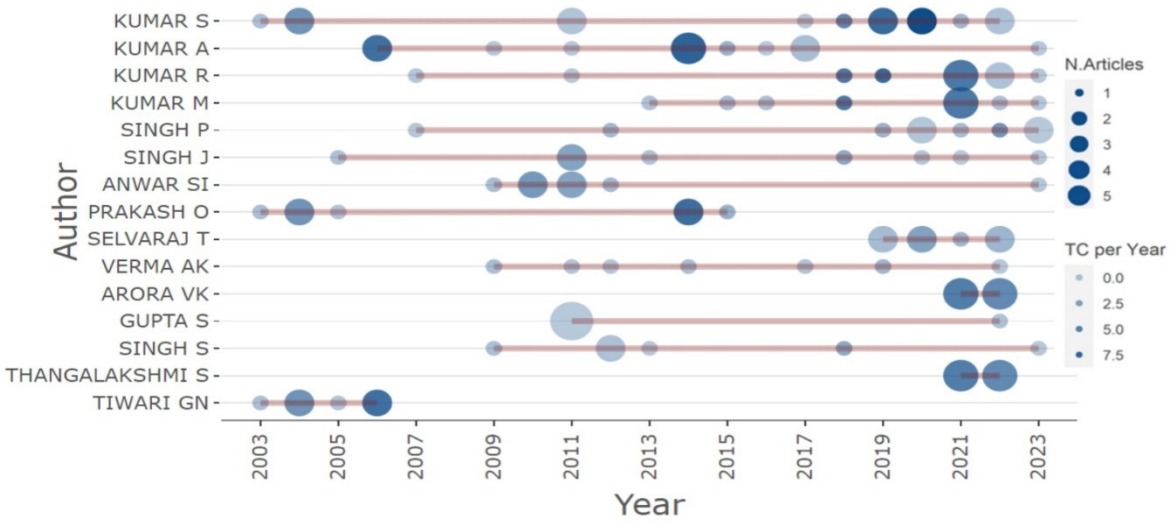

Figure 7: Top 15 Authors' production over time.

Moreover, these publications primarily focused on discussions concerning the health effects of jaggery consumption, drying of jaggery, quality of jaggery, and application of jaggery in producing other substances. It may also be concluded that documents that have explored the application of jaggery in the production of other substances are the most influential ones. It is further evident from Table 3 that except for two articles, all of the other publications are written in collaboration, and this suggests that collaborative work is a more effective way to make an impact in a particular research field. Additionally, none of these ten most influential publications discussed technical interventions aimed at enhancing the thermal performance and emission characteristics of jaggery production.

Most productive journals

One of the most popular venues for publishing scientific literature is journals. Table 4 gives a glimpse of the most productive journals along with other details such as the Number of Publications (NP), Total Citations (TC), and Average Citations Per publication (ACP) received by the journal. Sugar Tech is the most productive and influential journal, with 48 relevant publications and 571 citations; however, it has no impressive ACP. Furthermore,

Table 3: The top ten publications with most average citations.

Rank	Title	Type	Journal	year	TC	AC	NA	References
1	A Needleless electrospun phytochemicals encapsulated nanofibre based 3-ply biodegradable mask for combating COVID-19 pandemic.	Article	Current Science	2021	65	21.67	10	(Patil *et al.* 2021)
2	Additives aided composting of green waste: Effects on organic matter degradation, compost maturity, and quality of the finished compost.	Article	Bioresource Technology	2012	206	17.2	3	(Gabhane *et al.* 2012)
3	Presence of amorphous carbon nanoparticles in food caramels.	Article	Scientific reports.	2012	198	16.5	5	(Sk *et al.* 2012)
5	Synthesis of silver nanoparticles by polysaccharide bioflocculant produced from marine Bacillus subtilis MSBN17.	Article	Colloids and Surfaces B: Biointerfaces.	2013	145	13.2	3	(Sathiyanarayanan *et al.* 2013)
5	Sugar intake, obesity, and diabetes in India.	Review	Nutrients	2014	95	9.5	2	(Gulati and Misra 2014)
6	Nutritional and functional components of non-centrifugal cane sugar: A compilation of the data from the analytical literature.	Review	Journal of Food Composition and Analysis.	2015	81	9	1	(Jaffe 2015)
7	Treatment of urban municipal landfill leachate utilizing garbage enzyme.	Article	Bioresource Technology.	2020	35	8.75	4	(Rani *et al.* 2020)
8	Health Effects of Non-Centrifugal Sugar (NCS): A Review.	Review	Sugar Tech	2012	85	7	1	(Jaffe 2012)
9	Modelling and Forecasting of Sugarcane Production in India.	Article	Sugar Tech	2021	20	6.67	9	(Mishra *et al.* 2021)
10	Upgradation of jaggery production and preservation technologies.	Review	Renewable and Sustainable Energy Reviews.	2018	38	6.33	2	(R. Kumar and Kumar 2018)

although Bioresources Technology published only four articles, it has received the second-highest TC (309) and impressive ACP (77.2). This indicates that every relevant document published in this journal has received an average of 77-78 citations. Another interesting journal is the Journal of Food Engineering; although it has published only three documents, it received the second-highest ACP (54). Furthermore, Table 4 solidifies the fact that the highest TC and ACP are not always associated with the highest number of publications.

Science Mapping

Science mapping is assessed under two categories: co-occurrence mapping and co-authorship mapping. Co-occurrence mapping, also known as the semantic network, explores the relationship among the keywords. On the other hand, a co-authorship explores the interactions among the authors, institutions, and countries from the perspective of research field development.

Keyword occurrence

Keyword analysis shows the research hotspots and interests of scientists and researchers in a particular research field, helps researchers systematically understand the evolution track of the field, and provides future research directions for the researchers (Zhang *et al*. 2023). The full counting method was used to assist the appraisal of author keywords alone as the unit of analysis in the co-occurrence mapping. Certain limitations were placed on the software for analysis purposes during the investigation. For example, the minimum number of keyword occurrences was limited to three (3). Consequently, only 72 out of the 1282 keywords from the 385 articles qualify.

All keywords were obtained and analyzed using the VOSviewer software, and the occurrence, links, and total link strength of a keyword with other keywords were also computed. The keywords with the highest occurrence along with their cluster number, links, total link strength, and occurrence, are shown in Table 5. Jaggery, sugarcane, sugar, bagasse, fermentation, and sugarcane juice are the most frequently co-occurring keywords with occurrence frequencies of 127,32,10,9 and 8, respectively. Every node represents a keyword, while the size of the node corresponds to its frequency of co-occurrence. In the context of keyword co-occurrence, the occurrence of an item (keyword) represents the number of articles in which both terms appeared together in the title, abstract, or keyword of the articles (Yousef *et al*. 2023). A link represents the relation/connection between the two items(keywords), i.e., represents the co-occurrence of two keywords simultaneously in an article, while the link strength between the two keywords represents the number of articles in

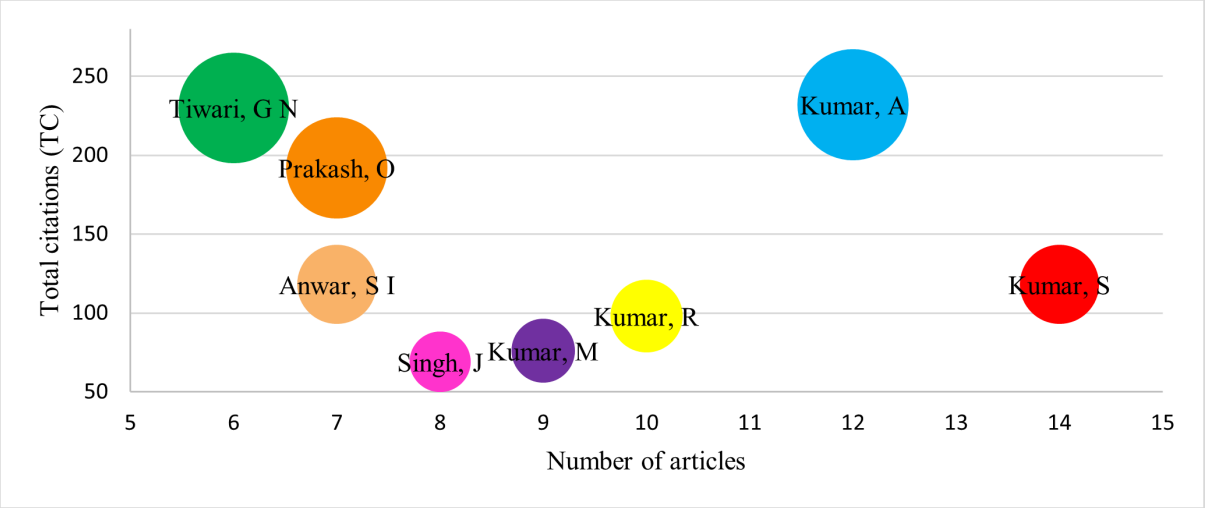

Figure 8: Most productive and influential authors.

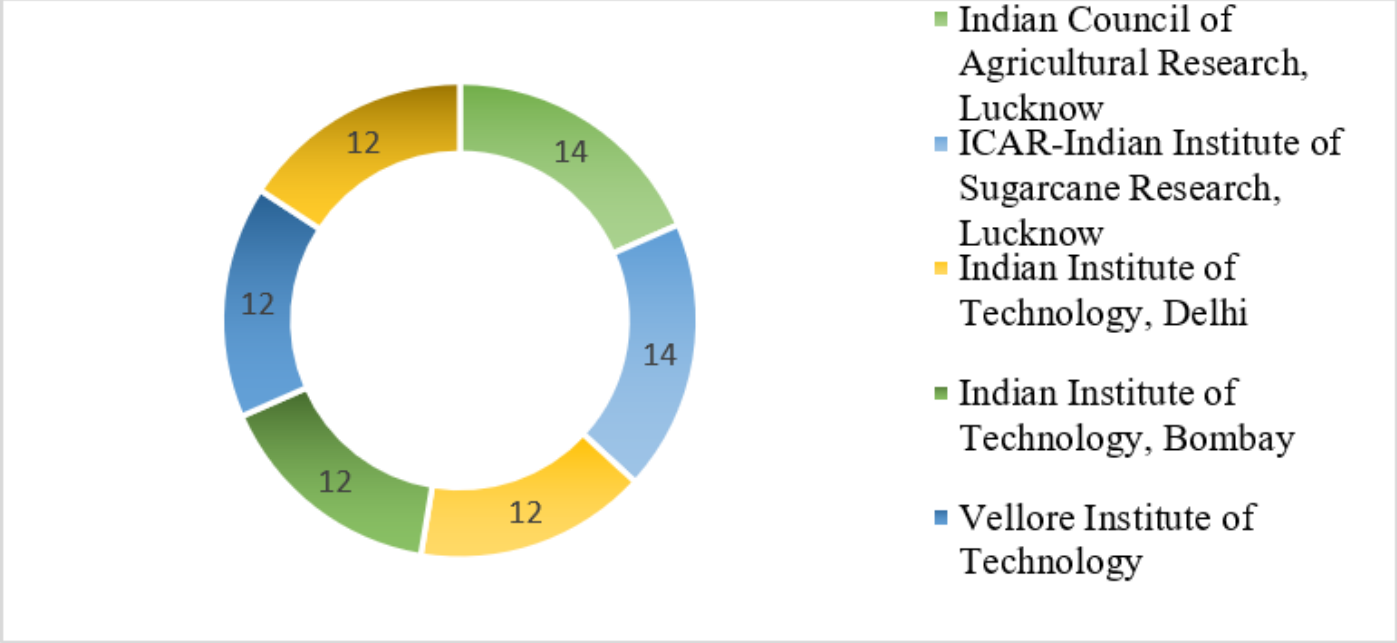

Figure 9: Most productive institutes globally.

Table 4: **Top 10 highest productive journals in jaggery related-research field.**

Rank	Journal	NP	TC	ACP
1	Sugar Tech	48	571	11.9
2	Journal of Food Science and Technology.	16	91	5.7
3	Indian Journal of Animal Sciences.	8	25	3.12
4	Journal of Food Process Engineering.	7	28	4
5	Food Chemistry.	7	174	24.8
6	International Journal of Biological Macromolecules.	5	251	50.2
7	Scientific Reports.	4	214	53.5
8	Current Science.	4	84	21
9	Bioresource Technology.	4	309	77.2
10	Biological Rhythm Research.	4	8	2
11	Journal of Food Engineering.	3	162	54

[b]NP: Number of Publications; TC: Total citations; ACP: Average citation per publication.

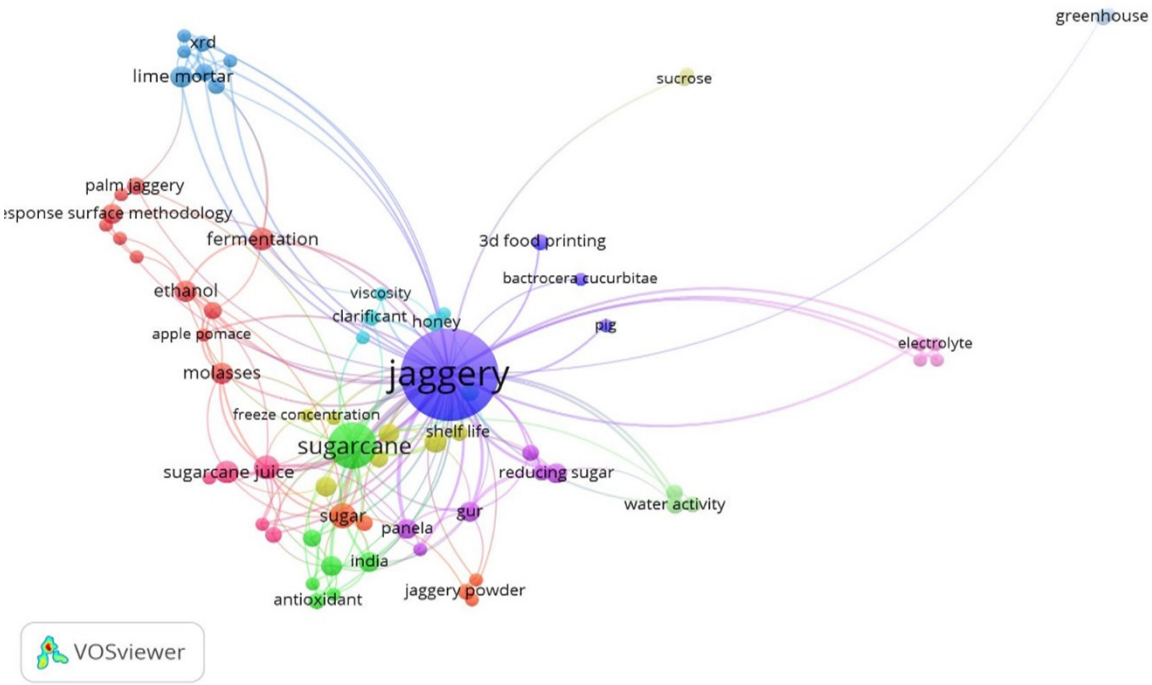

Figure 10: Network visualization of the co-occurrence keywords.

which these two keywords appeared simultaneously. The total link strength indicates the total number of articles in which a keyword appeared with keywords connected to it.

A visualization network of co-occurrence keywords, constructed using VOSviewer software, is shown in Figure 10. It is evident from Figure 10 that 72 words were able to form 13 clusters, of which cluster 10 (blue), cluster 2 (green), and cluster 8 (pink) are the prominence clusters. A cluster is a collection of items (keywords) in a visualization network, and the size of the circle and the text in a cluster indicates the strength of their co-occurrence with other keywords (Martins *et al.* 2022). The distance between the nodes (keywords) represents the closeness of the two nodes (close the two nodes, strongly they are related). The lines (links) represent the correlation of the keywords; more the thickness of the line between two keywords, the more co-occurrence they have. Further, it is concluded that more general terms such as jaggery and bagasse have been used extensively as keywords by the authors, while technical parameters that are used to evaluate the performance of jaggery plants, such as thermal efficiency,

freeze pre-concentration, exergy analysis, and heat transfer are not frequently used as keyword. This, however, further confirms the fact that research in jaggery field has been more focused on jaggery storage and its value-added products. On the other hand, technical interventions that have the potential to significantly improve the thermal, environmental, and economic performance of the jaggery production process have received less attention.

Additionally, the keywords were examined by the word cloud to identify the most frequently used words across the jaggery research field. In the downloaded file, Scopus provides two types of keywords: author keywords and index keywords. Author keywords are selected by the authors and reflect the issues related and preferences in the document from the perspective of the author. On the other hand, index keywords are chosen by Scopus and standardized based on vocabularies. Also, when selecting index keywords, Scopus considers synonyms, different spellings, and plural forms of the words (Scopus 2022). Figure 11 shows the word cloud of the top 50 authors and index keywords. The keyword size in the word cloud corresponds to the frequency of its occurrence. From Figures 11a, 11b, it is evident that "Jaggery" is the most commonly used keyword by the authors, followed by "sugarcane" and "sugar". Additionally, some used other keywords are "bagasse," "fermentation," "juice," and so on. Contrary to this, Figure 11(b) shows that "sugar" is the most used index keyword, followed by "food" and "jaggery", respectively. Furthermore, it is obvious from the two figures that several keywords are common to both figures. This is because index keywords include many terms and a wide range of meanings. In this sense, index keywords of jaggery-related research are better in the bibliometric analysis of the structure in this field of study.

Co-authorship analysis

The collaborative (co-authorship) network between the countries shows the graphical visual representation of collaboration and

Table 5: **Most co-occurring keywords.**

Sl. No.	Keywords	Cluster Number	Occurrence	Links	Total Link Strength
1	Jaggery	10	127	60	149
2	Sugarcane	2	32	24	50
3	Sugar	7	10	11	19
4	Bagasse	8	9	13	23
5	Fermentation	1	8	6	9
6	Sugarcane juice	8	8	6	10
7	Lime mortar	3	7	8	12
8	Molasses	1	7	8	13
9	Ethanol	1	7	10	12
10	Non-centrifugal sugar	2	6	10	14

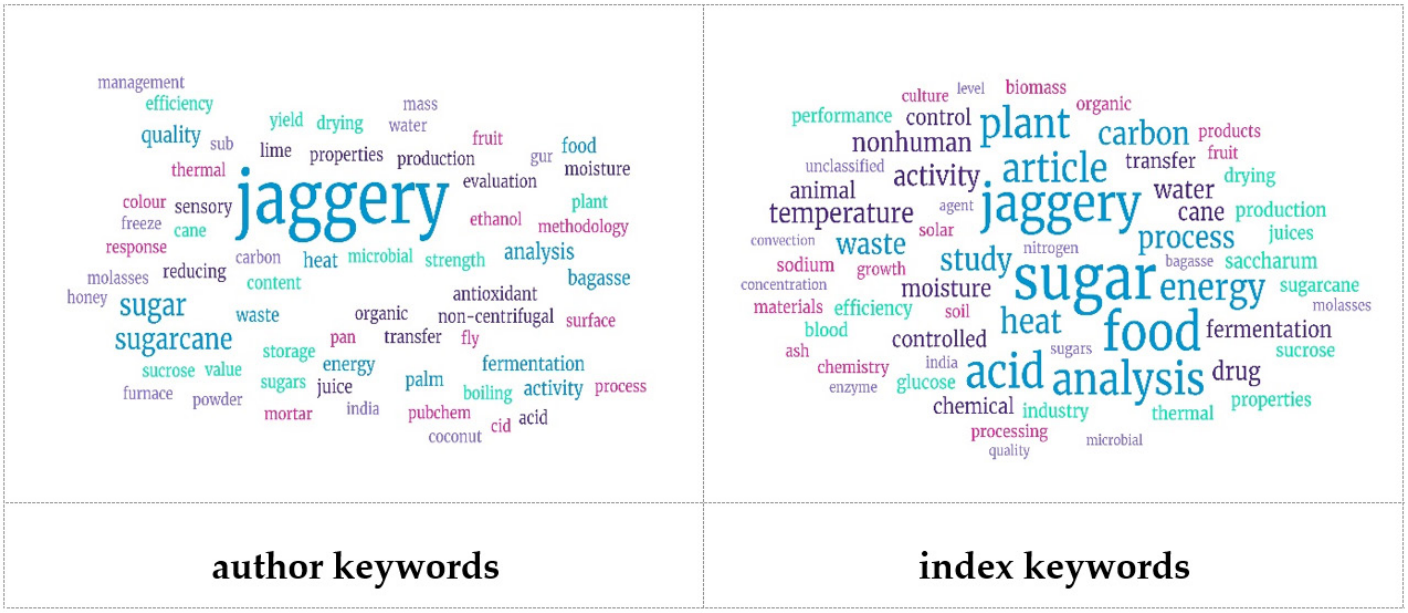

Figure 11: Word cloud of the keywords.

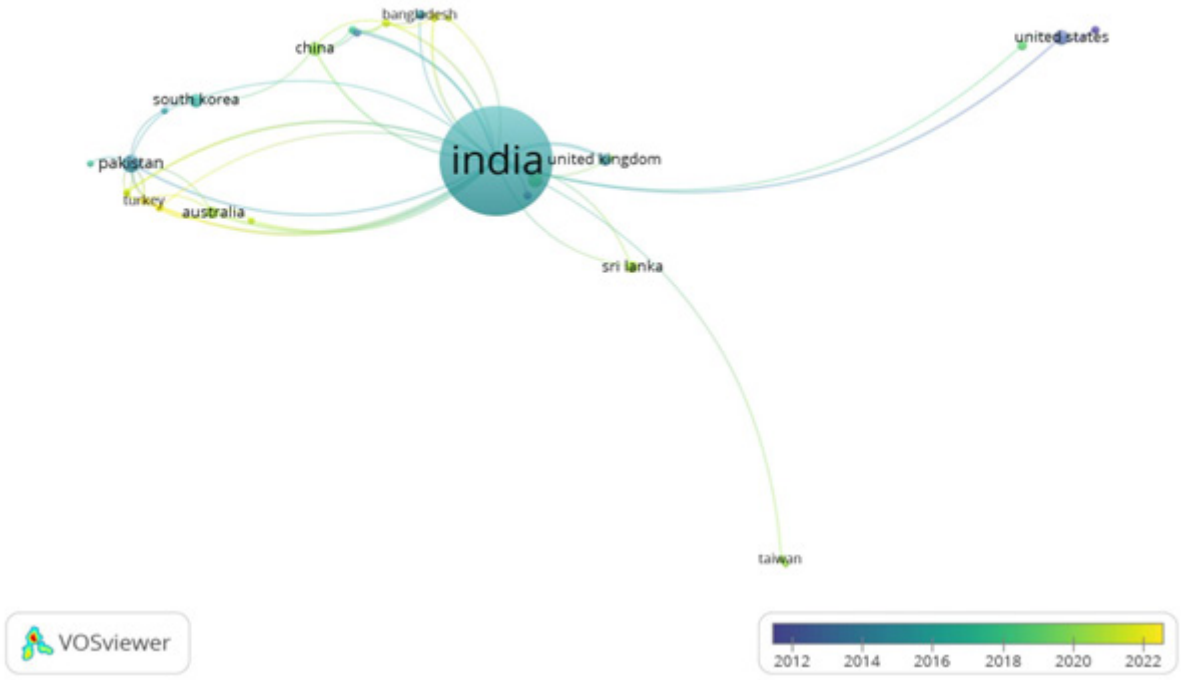

Figure 12: The co-authorship network of countries with timeline (2000-2023).

the degree of communication among various countries in jaggery research field. The size of the node represents the influence of the country, whereas the link represents the cooperation between the countries, and the thickness and length of the link represent the frequency and degree of cooperation between the two countries. To obtain this network, we imposed a limit of at least one document from each country; 43 countries reached the threshold. Among all the countries, India has collaborated with most countries (26) with a total link strength of 39, while the second most productive country, Colombia, has not collaborated with any other country. Further, not all countries have collaborated with other countries; the largest co-authorship network of 32 countries is represented in Figure 12.

The authors' collaborative network offers a visual, graphical depiction of the cooperation among scholars in a given research field (Tuncer and Gezici 2024). As per the VOSviewer analysis, 359 authors contributed to the research field, of which 283 met the threshold when a constraint of 1(one) for each minimum citation and minimum document was imposed. Figure 13 show that 283 authors created 283 clusters, which indicates that a low level of collaboration exists among the authors which is evident from Figure 12. The size of the node corresponds to the number of articles published by the author(s), while color of the node represents the average year of publication. The darker the shade of color, the previous is the average year of publication of the corresponding authors' work.

Co-citation analysis

A co-citation relationship exists between the two items (e. g. authors, articles); when both items are cited in the same documents. This relationship can be put into use to obtain the structure and relationship between the research topics (Martins *et al*. 2022). With this in view, a co-citation analysis was performed to examine the potential relationship between the research items, authors, and articles, in this case. The co-citation analysis has been further categorized as co-citation analysis of authors and co-citation of references, and results are discussed in the subsequent paragraphs.

To put co-citation analysis in the context of authors and identify the intellectual structure of a research domain, an author co-citation network was constructed. Author co-citation analysis is used to visualize the structure and relation among authors that are frequently cited together in several publications (Jeong *et al*. 2014). Figure 14 depicts the authors' co-citation network, obtained by applying a minimum limit of 20 citations per author. The size of the colored sphere corresponds to the number of citations of the corresponding author, under a threshold of 20 citations. Based on author co-citation analysis, Singh J is the most dominant author pertaining to total citations (116) and co-citations, co-cited 66 times with different authors. Kumar S. and Anwar S. I. are the next two most co-cited authors, co-cited 108 and 96 times, respectively, with other authors.

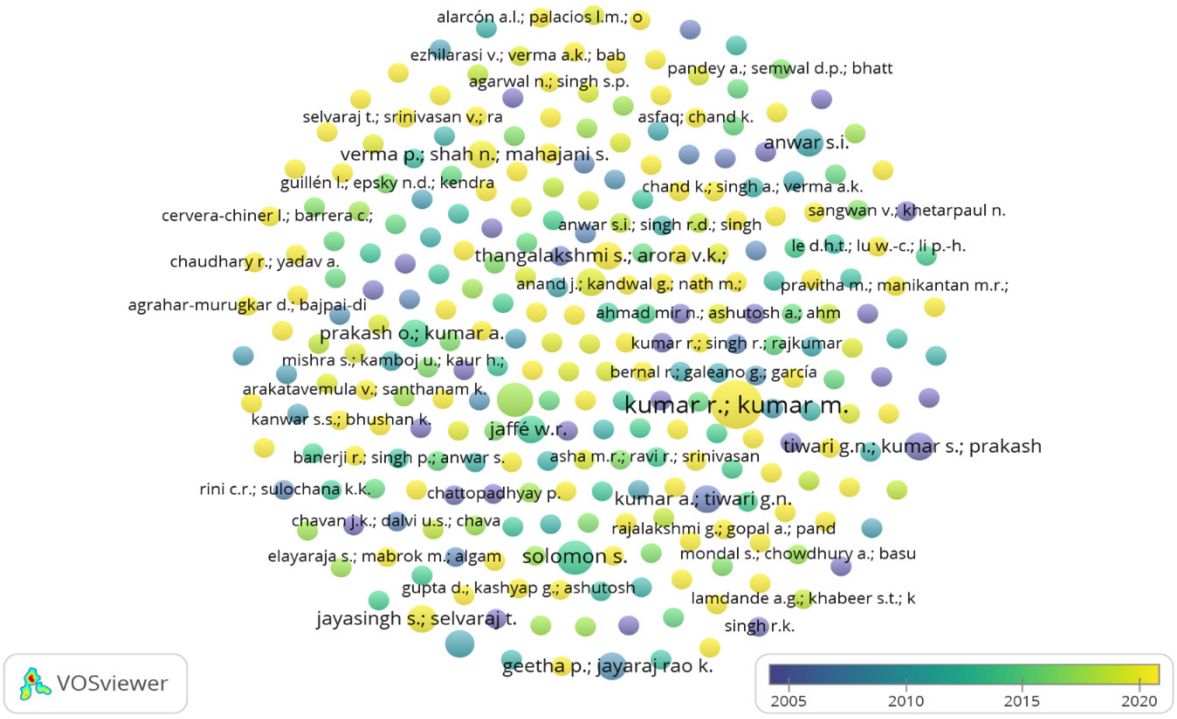

Figure 13: Collaborative network of authors with the timeline.

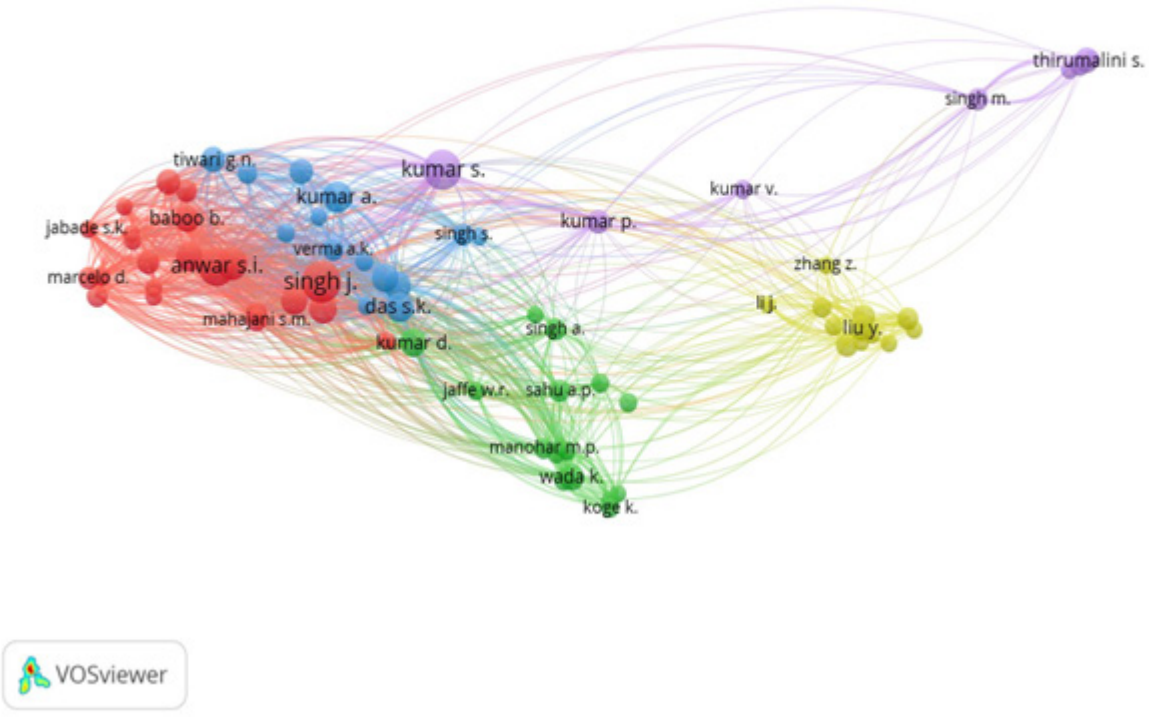

Figure 14: Co-citation network of authors.

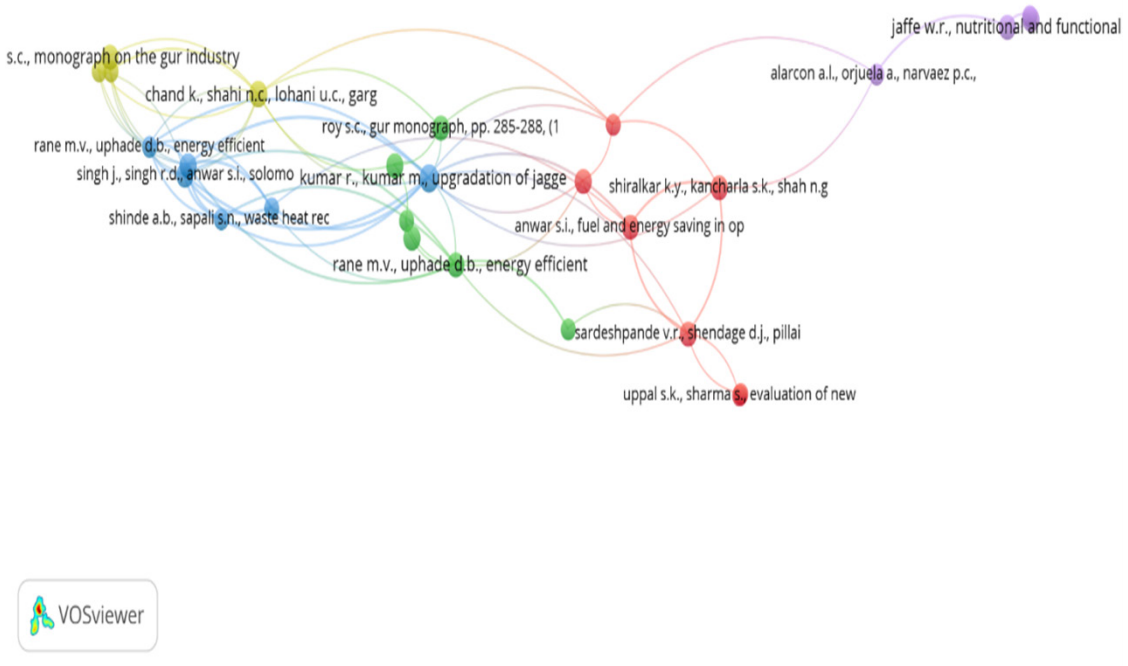

Figure 15: The co-citation network of references.

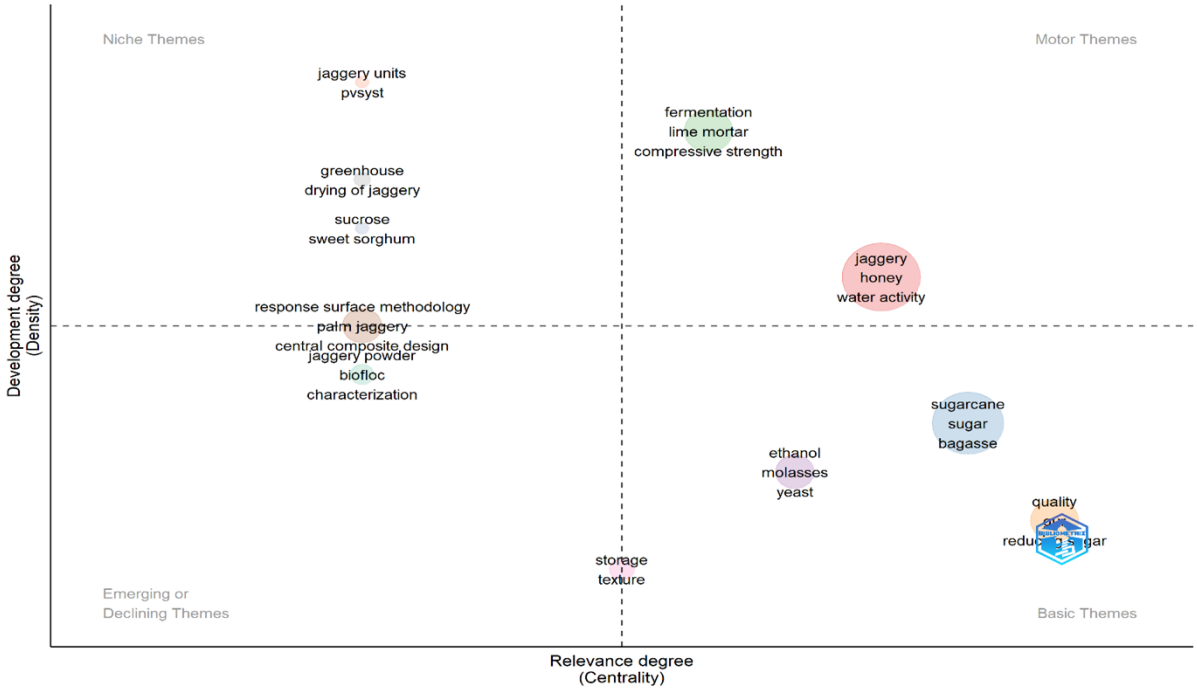

Figure 16: Thematic map of the authors' keyword.

To construct a reference co-citation network, the minimum number of citations of a cited reference were limited to 4 in the software, out of 11029 cited references, 49 met the threshold. From the Figure 15, it is perceived that R. Kumar and Kumar (R. Kumar and Kumar 2018) is the biggest node with 13 links followed by Chand *et al.*, (Chand *et al.* 2011) and Rane and Uphade(Rane and Uphade 2017), and Sardeshpande *et al.* (Sardeshpande *et al.* 2010), each having 9 links. A close look at these highlighted documents shows that they are most related to the thermal performance improvement of the jaggery production process and jaggery storage.

Thematic mapping

The Bibliometrix software was also used to create a thematic map (see Figure 16) of the author's keywords to get further insight into the current state and future direction of the field's research. The thematic map divided the topic in the given field

into four quadrants based on the relevance degree(centrality) and development degree (density). The density represents the development maturity level of the topics, while centrality represents the importance of the issues. The four quadrants are: the top right quadrant (Q1) represents the motor theme, the top left quadrant (Q2) represents the niche theme, the lower left quadrant (Q3) represents the emerging or declining theme, and the lower right quadrant (Q4) represents the basic theme.

Notably from the figure, quadrant Q1 includes topics such as water activity (effect of moisture on jaggery quality), honey (adulteration of honey with jaggery), lime mortar (clarification and turbidity) jaggery, fermentation (ethanol production from jaggery or its byproducts), and so on. The Q2 quadrant includes topics such as drying of jaggery (shelf-life enhancement of jaggery), pvsyst (use of solar energy), greenhouse (jaggery drying), sucrose (quality of jaggery), and so on. The Q3 quadrant consists of topics that include biofloc (use of jaggery as a carbon source) and characterization (quality evaluation of jaggery). Some terms such as jaggery powder, palm jaggery, response surface methodology (optimization of cane juice clarification and optimizing coating thickness for enhanced jaggery life during storage), and central composite design (use of byproduct) lie at the boundary of Q2 and Q3 quadrants. The Q4 quadrant represents the elementary topics essential for the field's development. These topics are sugarcane (feedstock for jaggery production), bagasse and molasses (byproduct of jaggery plant), ethanol and yeast (use of byproduct), quality, and reducing sugar (related to jaggery quality).

Limitations of the study

This study uses VOSviewer, Bibliomterix, and Word cloud to perform a bibliometric analysis of the jaggery-related scholarly literature mined from Scopus. However, this study is subjected to some limitations as bibliometric data from a single source, Scopus, is used; therefore, the authors are in no position to claim that the list is exhaustive. Further, the Scopus database encapsulates several reputed journals, thereby considered sufficient; the study included no other database. However, incorporating data from different databases like PubMed and Web of Science (WoS) undoubtedly can help enhance the validity of the bibliometric study, and the possibility of missing important articles may be reduced considerably (Arora and Mehta 2023). However, the non-existence of standardized data format and data that may not necessarily agree with one another across various bibliographic sources make concatenating data from multiple bibliometric sources impossible (Huang *et al*. 2020). Additionally, the study excluded non-English documents during the search from Scopus, which may have undermined the importance of non-English papers in this field of research.

CONCLUSION

The study reviews the jaggery-related documents published between 2000 and 2023 using a bibliometric analysis, and some fundamental characteristics and trends of the jaggery-related scholarly literature were found. First, the jaggery-related research can be divided into two phases: prior to and after 2009. Before 2009, progress in publications was sluggish. However, after 2009, jaggery-related publications received some momentum but with many fluctuations. Much of the progress in the publications is attributed to the interest of researchers in exploring various applications of jaggery, such as the source of carbon, treatment of municipal landfill leachate, and so on. Additionally, the researchers' interest in improving the thermal and environmental performance of the jaggery production process has advanced the development of publications pertaining to jaggery from a sustainability perspective. Second, jaggery-related literature is published in various fields ranging from agricultural and biological sciences to environmental engineering to decision sciences; however, more than 48% of the documents published in agricultural and biological sciences in the given time frame. Third, the authors' analysis shows that Kumar S is the most productive author regarding the number of publications and research continuity; however, he showed a low level of collaboration and received fewer citations. Fourth, the journal analysis showed that Sugar Tech is the most productive journal during the given period, followed by the Journal of Food Science and Technology, and the Indian Journal of Animal Sciences. Five, analysis from the perspective of country/territory reveals that India, Colombia, and Pakistan are the most significant contributors to the jaggery-related research field. However, they lack close cooperation in terms of research, which is a hurdle in the process of improving research capacity. Finally, a keyword analysis was conducted through the network, word cloud, and thematic map to determine the development trajectory and intellectual dynamics of the jaggery-related research. Analysis of the most frequently used keywords through word cloud and thematic map showed that research concerning the jaggery field is moving in a diversified direction.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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