Carbon Dioxide Sequestration by Algae: Worldwide Research Trend

TAMANNA DESWAL, SHIVANI NARWAL, AZAD YADAV AND RAJESH DHANKHAR*

Department of Environmental Sciences, Maharshi Dayanand University, Rohtak-124 001 (Haryana), India
*(e-mail: rajeshdhankar.EVS@mdurohtak.ac.in; Mobile: 81687 93039)

ABSTRACT

The increasing concentration of carbon dioxide (CO_2) in the earth's atmosphere has had a profound impact on the planet's balance. Algal biomass has notable superiority higher than terrestrial plants in respect of carbon dioxide sequestration, wastewater treatment, biomass production accompanying with production of many bioactive compounds/products. A bibliometric study was used to examine global microalgae research trends in this paper. To ascertain the development and most recent trends in this field, the number and distribution of publications were looked at, as well as the journals and keywords which were most relevant. The findings confirmed that the number of publications in this field was expanding rapidly. Bioresource technology and science of total environment are the journals that are most pertinent to this topic. The primary keywords that were used in over 315 publications were typically associated with algae's ability to store carbon dioxide, such as "Microalgae, carbon sequestration, and biofuel." The keyword "microalgae" stands out among the others since it may be found in practically all publications. According to a bibliographic study, research on the sequestration of carbon dioxide by algae has been quite active in recent years, growing rapidly along with industrial output. Expectations are therefore high in this sector for the foreseeable future.

Key words: Biblometric, carbon dioxide, journals, publications, sequestration

INTRODUCTION

In the mid-eighteenth century, when the industrial revolution was growing, greenhouse gases released through human activities increased the carbon dioxide concentration in the atmosphere from 280 ppm in 1750 to 414 ppm in 2022 which led to global warming. Since 1958, the Mauna Loa Observatory in Hawaii has provided a graphical picture (Keeling Curve) of how carbon dioxide concentrations in the atmosphere changes with seasons and annually. According to the curve, average atmospheric CO_2 concentrations increased from about 316 ppm in 1959 to roughly 370 ppm in 2000, 390 ppm in 2010 and 414 ppm in 2022. A major cause for concern is the curve's upward trend after 1970, which indicates an increase of about 2 ppm per year. The Keeling curve clearly depicts a rise in CO_2 concentration that accelerates over time. A lot of extreme weather events and natural disasters are attributed to climate change, making it one of the most popular topics in the 21st century. Due to an increase in the frequency of powerful wind storms and huge floods, as well as the extravagant melting of glacier that has caused increasing in sea levels, people all over the world have experienced both indirect and direct detrimental consequences on their life qualities and living conditions (Ghanbari *et al.*, 2021; Wasko *et al.*, 2021).

Concerns about carbon emissions and global warming have spurred curiosity in types of storage of carbon discharge by the fossil fuels consumption. Anthropogenic action has a direct and indirect impact on nearly half of the biological carbon cycle on land. Vegetation and soil carbon will expand as atmospheric CO_2 levels rise owing to faster growth rates. However, as photosynthesis achieves its maximum and soil respiration rate rises with warmth, higher atmospheric CO_2 levels restrict growth because they induce photosynthesis to reach its maximum efficiency. The ocean sucks up more than a quarter of the yearly anthropogenic CO_2 emissions. The method of extracting CO_2 from flue gases and storing it for a long time to prevent emissions is known as direct carbon capture and sequestration. It has been defined as the purposeful, human-controlled isolation of CO_2 from other combustion by-products and transfer to a non-atmospheric reservoir for long-term or almost long-term storage (Vanek

et al., 2016). Indirect carbon sequestration, on the other hand, has been described as CO_2 accumulation that doesn't require human management; rather, processes in nature, such as the CO_2 uptake by creatures, are encouraged to collect CO_2 at more quickly than would normally happen (Vanek *et al.,* 2016). The term "biological carbon mitigation" (BCM) refers to the process through which autotrophic plants and organisms use photosynthesis to turn CO_2 into organic carbon, producing a significant quantity of biomass. Carbon is incorporated into the cells of these creatures via photosynthesis and other metabolic pathways. If the carbon cycles were carefully managed, biomass could be used for different commercial uses while assuring that sufficient carbon was stored in biological media to maintain carbon dioxide in the atmosphere at an acceptable level. It is essential to choose the best carbon sequestration media in order to achieve a high degree of CO_2 removal and maximize economic benefit from the procedure. The Framework Convention of the United Nations on Climate Change and the Kyoto Protocol, along with a number of other political accords connected to climate change, were created by the worldwide community, and numerous actions have been taken to combat climate change (Wang *et al.*, 2018).

Using the research output from Scopus Database, the purpose of this manuscript is to examine the global trends in carbon dioxide sequestration by algae research and highlight any new perspectives on the subject. A bibliometric study can be used for this purpose. Bibliometry is the process of using tools and methods to analyze and evaluate the findings of all the research-related literature. Using these tools, a number of different conclusions can be reached, including: recognizing the principal establishments what's more, the main specialists in an examination field, assessing the main achievements over the historical backdrop of a logical field, or anticipating patterns or logical crazes through the investigation of the advancement of the delivered writing. Numerous bibliometric analyses in a variety of scientific fields over the past few years have demonstrated great utility of this method.

The knowledge status, characteristics, and patterns within a particular field can be successfully described via bibliometric analysis. The examination of publications by databases using statistics and computational technologies is known as bibliometrics, and it encompasses qualitative as well as quantitative analysis (Aleixandre-Benavent *et al.*, 2017). This method has been extensively utilized to assess how well various disciplines are performing (Ekundayo and Okoh, 2018; Wang *et al.*, 2018). Furthermore, it is knowledge graphs use for the mining of data, processing of information, scientific measurement and graphic design to present the scientific understanding of an area or discipline. They also combine traditional scientometrics citation analysis with information visualization technology. Therefore, one can investigate the evolution of and connections between various bodies of scientific knowledge using knowledge graphs.

MATERIALS AND METHODS

In the current research, a total pursuit of the Scopus data set was completed utilizing [TITLE-ABS-KEY ("Carbon" and "dioxide" and "sequestration" and "by" and "Algae")] limited to Environmental Science as the search inquiry. After limiting the search period to 1994 to 2023, 315 documents were retrieved in CSV format and Bibtex file. It was noticed that assuming different pursuit boundaries, the outcomes would change. This method had some holes because the authors used keywords that don't relate to the subject of the articles. Keywords with the same meanings were grouped together, and those that did not contribute to this study were discarded. Additionally, the most significant data were selected and presented in a manner that made them simpler to comprehend. These aspects were examined: the annual number of publications, their distribution by institution and nation, their sources, and their keywords. A community is a collection of nodes that are more tightly connected to each other than to the rest of the network in the study of complex networks. Using the VOS viewer software tool, communities were detected. With the help of this programme, one can create sophisticated graphs where each nation or term is represented by a node and the connections between nodes signify the interaction of the two words that the nodes stand for.

For conducting scientometric investigations,

Italy created the open source R package Bibliometrix (Aria and Cuccurullo, 2017). The programme can receive data feeds from a variety of sources, including WoS and Scopus, etc. The original Bibliometrix tool needs coding expertise to use because it was created in the R programming language (to enable connections). Biblioshiny, software made for Bibliometrix by non-coders, has been developed. It offers a straight forward, understandable and well-structured web interface (Moral-Munoz *et al.*, 2020). Multiple types of graphs can be created using Biblioshiny, which is one of its primary advantages. The bulk of the analyses in this manuscript were carried out using this tool due to its unique feature.

RESULTS AND DISCUSSION

Table 1 depicts the bibliometric data summary published in the scopus database with basic information regarding data along with document contents, authors, authors' collaborations, and document type with their outputs. A total of 315 documents were looked into. Fig 1 (a) and (b) summarise the bibliometric metadata statistics; the number of published records consisting of 1277 authors and 315 documents, from 1994 to 2023. The annual growth of publications per year was 11.07%; and the average number of citations per document was 40.23. Interestingly, the number of documents on this research area increased in 2013 and 2021. In the past few years, the carbon dioxide sequestration by algae has given rise to major worries, especially in light of the pressure being put on climate change. As a result, the increase in peer-reviewed publications point to an international field of study with implications for scientists and stakeholders. It is important to note that 2021 had the most productivity, accounting for 13% of the total with 44 articles. A large number of publications on carbon dioxide sequestration by algae were research articles (76.2%) followed by reviews (16.8%) and conference papers (2.9%). Less often seen papers include book chapters, notes, and brief surveys. The majority of the research was papers that were published in English-language international publications, therefore, it makes sense that 99% of the documents were written in nglish language (Fig. 2).

Table 1. Dataset used in research of carbon dioxide sequestration by algae

| Details	Results
Basic information	
Period	1994:2023
Documents	315
Sources	103
Average age of document	5.47
Yearly growth rate (%)	11.07%
Per document avg. citations	40.23
References	20192
Content of documents	
Author's keywords	945
Keywords plus	3710
AUTHORS	
Authors	1277
Single-authored docs	13
Collaboration of authors	
Documents of single-authored	13
Documents in co-authorship	4.87
International co-authorship	30.48%
Types of documents	
Review	53
Article	240
Conference paper	9
Book	3
Book chapter	7
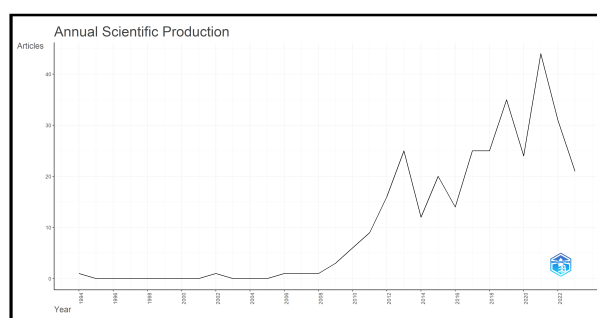
Fig. 1(a). Annual scientific production of publications on carbon dioxide sequestration by algae.
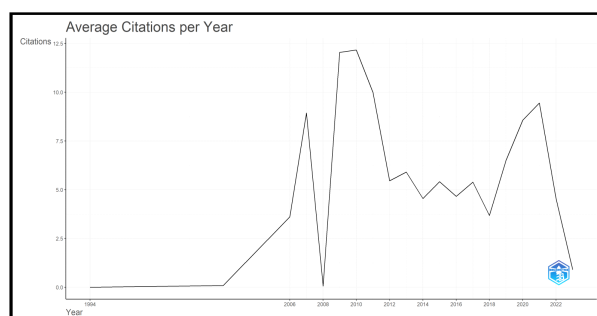

Fig. 1(b). Average citations of publications per year on carbon dioxide sequestration by algae.

The Bradford law measures the correlation between publications in journals and papers themselves (Figueroa-Rodríguez *et al.*, 2019). It indicated that only a few core journals will supply the bulk of documents on a given
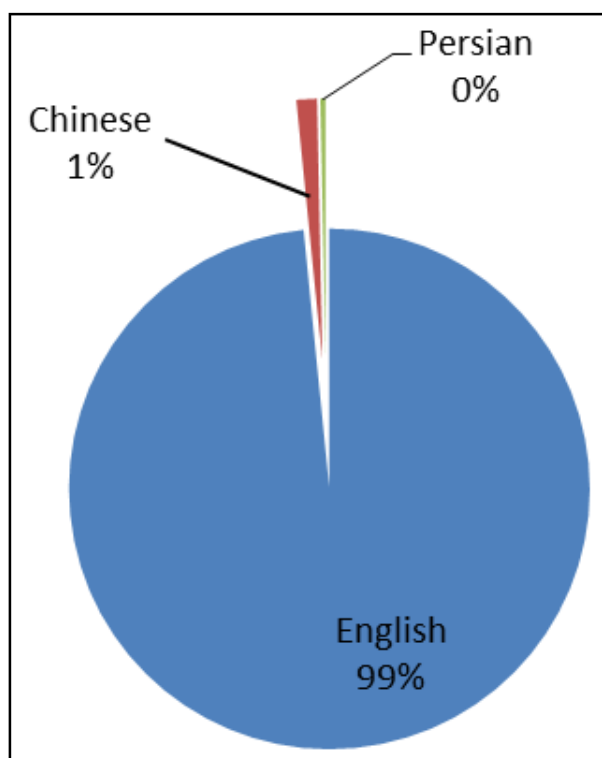
Fig. 2. Publication numbers with language used.

research area. The first clump (Table 2) included 163 documents (10 extremely effective journals), most effective documents, and a greater cumulative frequency of citations/publications than other clumps. Bioresource Technology and Science of the Total Environment were identified with the highest productivity out of these 10 journals. The highest numbers of documents published in the top 10 nations are shown in Fig. 3. It is astonishing that China dominated scientific production by a large margin. The most pertinent institutional affiliation was chosen using the affiliation disambiguation approach. Based on the co-authorship index for each

publication, this revealed the top institutions that had contributed to the field. The results shown in Fig. 3 indicate that the top three most notable affiliated institutions were National Cheng Kung University (16), Indian Institute of Technology, Kharagpur (15) and Xiamen University (9) out of 565 institutions.

Three hundred and fifteen articles on carbon dioxide sequestration by algae were written by a total of 1277 authors from 1994 to 2023 (Table 3 and Fig. 4). The top ten authors in terms of output over time are listed here, along with their H-index. H-index of the author is a measure at the individual author level that aims at evaluating the output of a scientist or academic along with the effect of the citations on their documents. H-index offers the list of authors' commonly referenced work together with the number of times those works have been cited in other documents. R. Sen was at the top of the list who was the most productive author in terms of total number of publications, producing eight documents, followed by J. S. Chang and C. Song. J. S. Chang, D. Das and K. Kumar were the most cited authors in terms of total citations (730 TC), followed by D. Das (590 TC) and K. Kumar (542 TC). The most prolific author was still R. Sen, whose works laid the foundation for the current important study project. Furthermore, his Lotka's law was employed in this study. He had 60% of publications in this subject. Furthermore, as per Amsaveni and Batcha (2019) authors who have published more frequently (10 or more papers) should be considered for validation.

CONCLUSION

This study combined bibliometric maps and graphs distribution by applying VOS viewer and

Table 2. First clump of most dominant journals in carbon dioxide sequestration by algae research

Journal	M index	Hirsch index	G index	N P	P Y	T C
Bioresource technology	1.941	33	58	58	2007	3716
Science of total environment	2.375	19	38	38	2016	1510
Chemosphere	0.818	9	12	12	2013	426
Journal of environmental management	0.889	8	9	9	2015	413
Applied energy	0.538	7	8	8	2011	554
Biomass and bioenergy	0.538	7	10	10	2011	371
Journal of cleaner production	1.167	7	8	8	2018	216
Biotechnology for biofuels	0.545	6	6	6	2013	332
Ecological engineering	0.545	6	6	6	2013	163
Environmental science and pollution research	0.500	6	7	7	2012	124

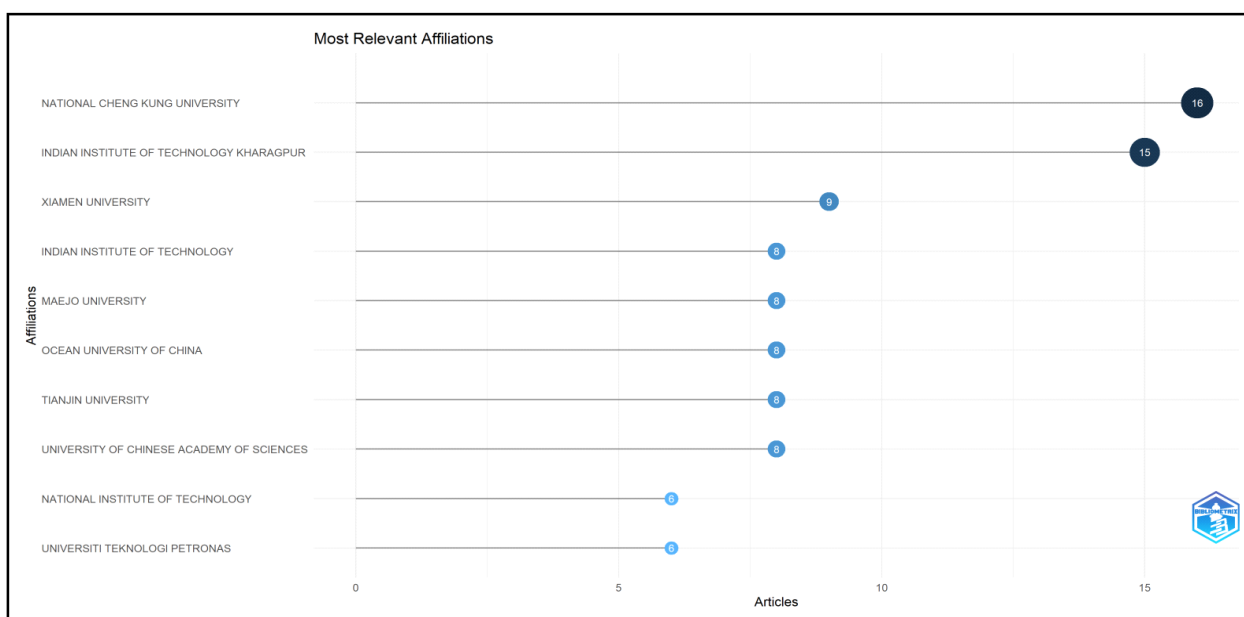* TC – Total citations, PY – Publication year and NP – Number of publications.
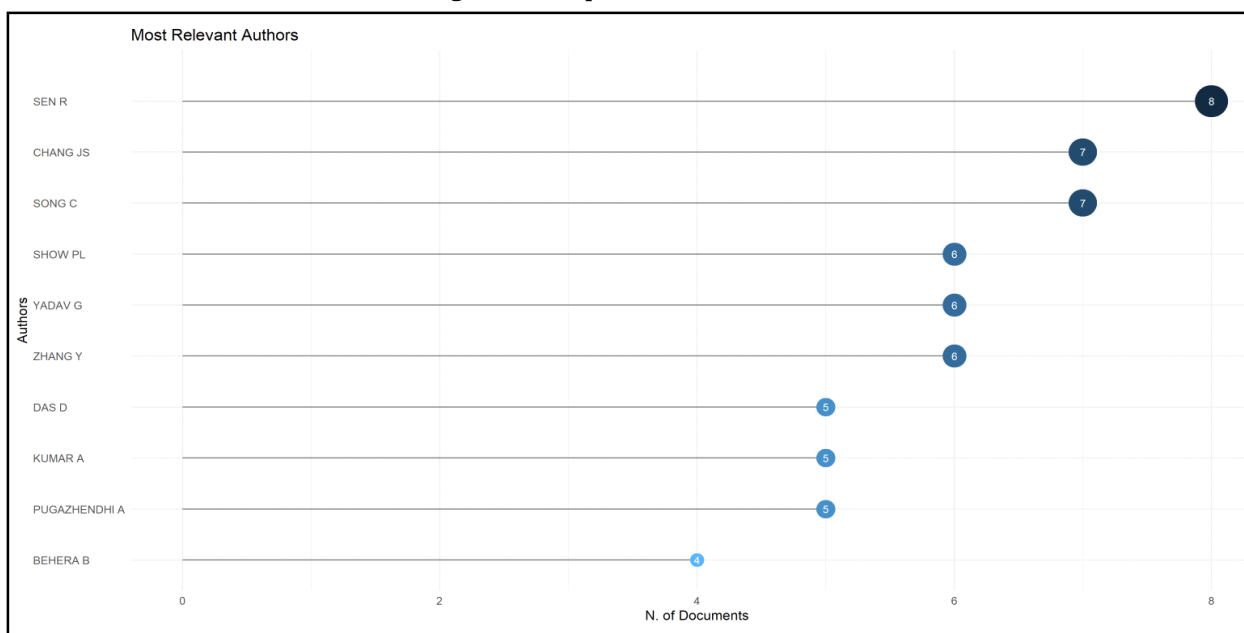
Fig. 3. Most pertinent affiliations.

Fig. 4. The top 10 writers with the highest relevance.

Table 3. Most active authors in carbon dioxide sequestration by algae research

Authors	Articles	Articles fractionalized
Sen, R.	8	2.12
Chang, J. S.	7	1.57
Song, C.	7	1.24
Show, P. L.	6	0.90
Yadav, G.	6	1.48
Zhang, Y.	6	0.71
Das, D.	5	1.53
Kumar, A.	5	1.31
Pugazhendhi, A.	5	0.82
Behera, B.	4	1.37

Biblioshiny application to analysis of bibliographic data of biological carbon dioxide sequestration research documents indexed by Scopus data base. Analysing the number of microalgae-related publications from 1994 to 2023, a significant rise in evolution was shown, which was particularly notable from the year 2013 onwards. Other factors connected to scientific production, such as the types and languages of publications, the key authors, and the institutions, were analyzed in this study in addition to the trend of the number of

publications. As a result, articles made up the majority of publications (76.2%), followed by reviews (16.8%) and conference papers (2.9%). Nearly all of them (99%) were written in English. Using the keywords "carbon," and "dioxide," and "sequestration" and "by" and "algae", data were filtered to produce the desired results. The topic categories, titles, keywords and abstracts of the references used in this study were all covered by the bibliographic data. The array of 315 documents for Bibliometrixn by Biblioshiny and VOS viewer were analyzed to determine the expansion of academic research, whose viewpoints were most influential, and which research goals were most significantly moving the field forward. When selecting what should be published and where, researchers should consider the creativity of the field, majority of pertinent journals, countries, authors, thematic evolution, institutions, etc. Bibliometric analysis helps by examining the trend of publications and design to express the core concepts and overall efficiency of the field. Over the past few years, the percentage of publications and citations had continuously improved. The results indicated variations in research during the last five years. Specifically, there were 35 documents in 2019, 24 in 2020, 44 in 2021, 31 in 2022, and 21 in 2023. In order to conduct future research, research data in a broader sense need to be examined, for example using Web of Science, Google Scholar and not just with reference to the Scopus database.

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