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*Review Article*

# The Potency of Microalgae as a Marine Source: A Bibliometric Analysis

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**Abstract:** Microalgae were a marine source that was highly sustainable and offered numerous benefits in industrial applications. Many species were safe and effective as active ingredients in the food, cosmetics, and pharmacy industries and became raw materials for renewable energy, such as biofuel. The exploration of bioactive compounds was enticing for the research. The study of microalgae potency is a fascinating subject that deserves further exploration. The bibliometrics analysis can provide a good overview of microalgae research and its applications in industry. This overview was derived from the Scopus database, which contained all articles published between 1993 and 2023 with the keywords "microalgae" and "their application. Based on this discovery, many papers reported the potential of microalgae for antioxidants, nutrition, vaccine adjuvants, bioethanol, biofuel, and other applications for 2021-2022. This review criticizes the cultivation in a controlled environment up to the toxicity of microalgae. According to this review, many researchers focused and collaborated on exploring microalgae in the top three international journals, such as Algal Research, Marine Drugs, and Journal of Applied Phycology. Several countries, including Italy, Spain, and China, were the most focused on declaring the application of microalgae. The keywords described the core discussion and could be read generally and comprehensively. This bibliometric analysis was expected to contribute to developing microalgae for many applications.

**Keywords:** Bibliometric analysis; microalgae; raw material, its applications

## 1. INTRODUCTION

Algae are oxygen-containing photosynthetic organisms in aquatic and wetland environments [1]. There was an increasing trend of using photosynthetic microorganisms, including macro- and microalgae [2]. Microalgae, as marine organisms, offer a promising alternative natural source to meet the increasing demand in industrial applications [3]. They were capable of surviving in extreme environmental conditions and could grow at a rapid pace [4]. Microalgae, rich in bioactive compounds such as phycobilin, carotenoids, polysaccharides, polyunsaturated fatty acids, vitamins, sterols, proteins, and enzymes, have garnered considerable attention [5–15]. Many algae offer skin benefits, including protection against UV rays and prevention of skin roughness, wrinkles, and

sagging [16]. Their antioxidant content further prevents skin aging [17–22]. The utilization of bio-compounds and seaweed extracts in cosmetic formulations is increasing, driven by the availability of safe ingredients from environmental resources [23–26].

In recent years, bioactive compounds derived from microalgae have emerged as potential raw material substitutes in the pharmaceutical industry [27–29], cosmetics [16,21,30,31], a future food source and supplements [31–33], biofertilizers [34], biofuel [35–37], animal feed [38–40], and wastewater cleaning [41–43]. Microalgae materials are renewable and can be cultured [44,45]. Microalgae are raw materials for various industries [46–48]. Microalgae are a source of human and animal nutrition [40], a source of renewable energy [4,20,36,44], have properties as antioxidants [19,49,50], antibacterials [51], anti-inflammatory [49], immunomodulators [52,53], and can even be adjuvants for vaccines [54,55]. This is very interesting because there is a guarantee of sustainability in microalgae.

This study comprehensively reviews microalgae as a raw material, employing bibliometric techniques to measure scientific publications' productivity quantitatively. This approach assessed the research quality, analyzed primary research areas, and predicted future research directions.

## 2. MATERIALS AND METHODS

### *2.1. Data Collection and Search Strategy*

In this study, data for bibliometric analysis were obtained from the Scopus database. The keyword search string employed in the search engine was (TITLE-ABS-KEY (microalgae) and its applications), which aimed at excluding publications that did not meet the specified criteria. Subsequently, titles, abstracts, and keywords were downloaded in comma-separated values (.csv) file format and subjected to VOS Viewer co-occurrence mapping. This mapping included network, overlay, and density visualization, utilizing the association strength method, and incorporated the publication time from 1993 to 2023 as crucial complementary factors. The co-occurrence map, a network comprising verified selected keywords from numerous papers, was employed semantically. The selection of the acceptable paper is given in Figure 1.

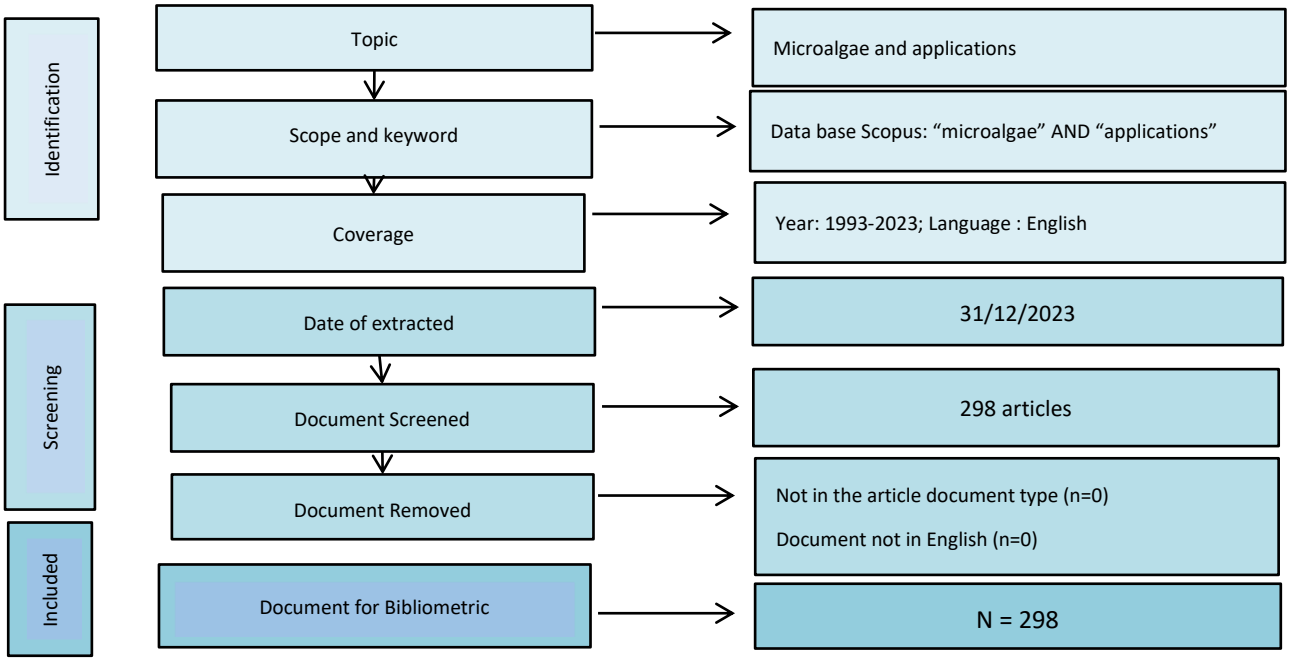


**Figure 1**. Articles search procedures

*2.2. Data Analysis*

In the bibliometric analysis, all terms in the previously mentioned search string sections were treated as significant units of analysis. However, minor adjustments were made as deemed necessary. Subsequently, the data underwent further analysis and interpretation using the RStudio-based Biblioshiny tool (https://www.bibliometrix.org/Biblioshiny.html).

## 3. RESULTS AND DISCUSSION.

*3.1. Metadata Analysis*

A bibliometric analysis has become a prominent and growing field of research in recent years [56]. The bibliometric analysis identified research into microalgae as a raw natural material applied in many products developed over the last thirty years. From the Scopus database, 298 publications were obtained using the specified keywords. The flowchart in Figure 1 outlines the successive steps in conducting a literature review that a bibliometric examination utilized microalgae as a raw material for many products. The investigation included questioning Scopus to recognize and categorize information concepts related to progressing investigations into microalgae as a raw material for industry. Metadata evaluation in Figure 2 was conducted to ensure article completeness. No articles lacked essential elements such as abstract, author information, cited references, document type, journal details, language, publication year, title, or total citation. Incomplete articles were identified: 0.34% lacked affiliation information, 2.01% did not have a corresponding author, 2.35% lacked a DOI, and 11.41% did not include keywords. Despite these variations, all articles met the criteria for completeness in bibliographic metadata.

| Metadata | Description | Missing Counts | Missing % | Status |
|---|---|---|---|---|
| AB | Abstract | 0 | 0.00 | Excellent |
| AU | Author | 0 | 0.00 | Excellent |
| CR | Cited References | 0 | 0.00 | Excellent |
| DT | Document Type | 0 | 0.00 | Excellent |
| SO | Journal | 0 | 0.00 | Excellent |
| LA | Language | 0 | 0.00 | Excellent |
| PY | Publication Year | 0 | 0.00 | Excellent |
| TI | Title | 0 | 0.00 | Excellent |
| TC | Total Citation | 0 | 0.00 | Excellent |
| C1 | Affiliation | 1 | 0.34 | Good |
| RP | Corresponding Author | 6 | 2.01 | Good |
| DI | DOI | 7 | 2.35 | Good |
| DE | Keywords | 34 | 11.41 | Acceptable |

**Figure 2.** Completeness of bibliographic metadata about microalgae and cosmetics all over the world.

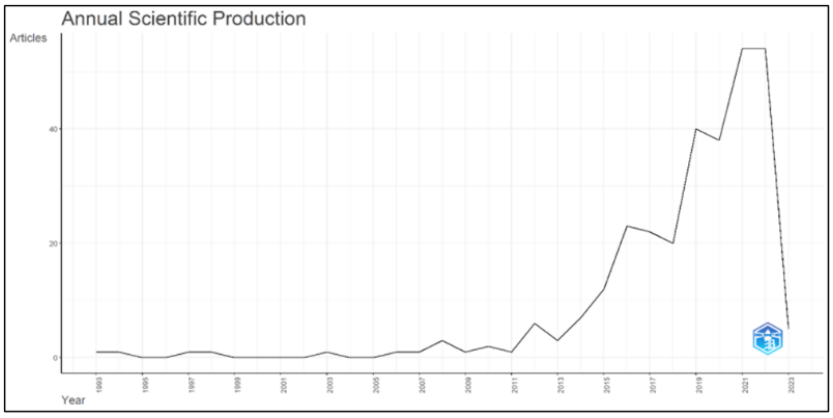


**Figure 3.** Evolution of the number of scientific papers published about microalgae worldwide

Figure 3 illustrates the global development of scientific articles on microalgae and their application from 1993 to 2023, as recorded in the Scopus database. In particular, there has been a significant increase in publications since 2011. In 2021, the highest number of publications to date was recorded, with 60 papers. The annual average number of documents published remains below 40. Figure 3 shows the increase in publications on using microalgae as raw materials in the industrial sector since 2011. The use of microalgae has grown over the last decade in various industrial raw materials, including food, cosmetics, nutraceuticals, and others [47,57,58]. In addition to articles on using microalgae as raw materials for industrial products, publications in the bibliometric scope cover the processing of cultivating microalgae in a controlled environment [1]. This article includes publications on microalgae bioprocesses and interventions for higher active compounds such as polyphenols, terpenoids, beta-carotene, vitamins, fatty acids, and others [59–61]. Studies on increasing the production of primary and secondary metabolite compounds have been conducted, such as increasing the production of phycocyanin, polyunsaturated fatty acids (PUFA), Docosahexaenoic Acid (DHA), Eicosapentaenoic Acid (EPA), squalene, astaxanthin, and other metabolites [62–64]. This is closely related to the use of microalgae as industrial raw materials.

*3.2. The area of Scientific Journals, Productive Authors, and Geographical Analysis*

The international publications of microalgae between 1993 and 2023 have been accepted in the top three international journals, such as Algal Research, which emerged as the leading source with 19 articles, followed by Marine Drug and Journal of Applied Phycology, which had 18 and 17 articles, respectively (Figure 4). This study has identified journal productivity, the most influential authors and countries, and developing thematic trends in the research on microalgae as raw materials for cosmetic products. The top 3 journals publish articles on microalgae, specifically algae biology, biomass production, cultivation, harvesting, extraction, bioproducts, biorefinery, engineering, and econometrics.

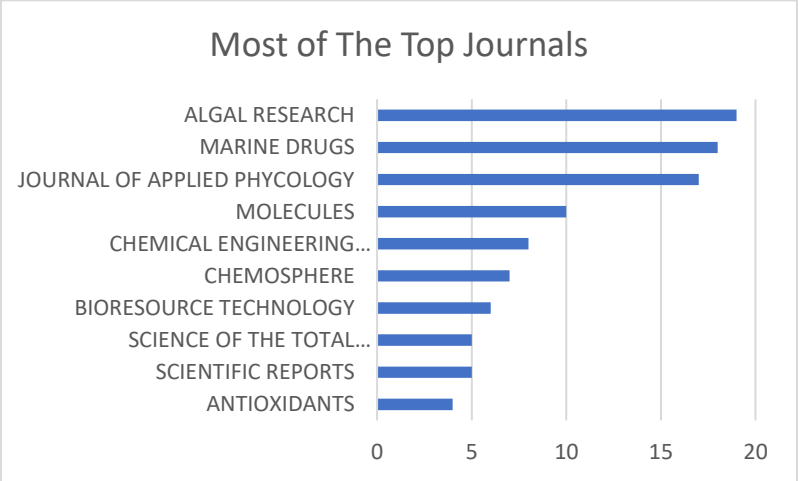


**Figure 4**. Most of the top journals between 1993 and 2023.

Furthermore, publications in specific databases demonstrate that researchers play a crucial part in assessing research development. This study examines individual authors and their collaborative efforts and identifies those strong publishing skills and significant contributions. According to the

bibliometric analysis, Molino A. and Musmara D. have the most publications. Various Molino's articles on microalgae covered production, cultivation, potential activity, and applications [9,17,65–71]. Exploration of secondary metabolites in microalgae is also a topic in his research [9,65,68,72]. Molino also does not limit himself to certain microalgae by collaborating with other researchers in various countries. Molino has had the most collaborations with other authors, closely followed by Musmara D. Figure 5 depicts the article's authors' collaboration network.

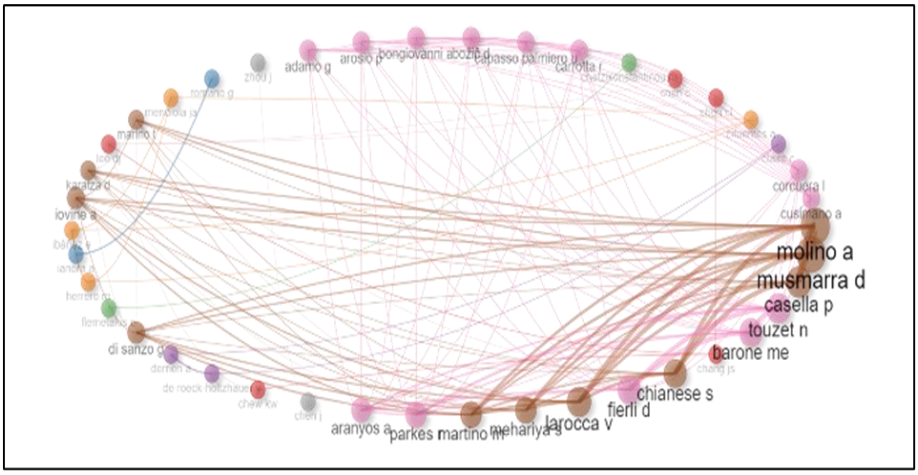


**Figure 5**. Visualization of article authors' collaboration network

Microalgae researchers can be found all over Europe, America, and Asia. The majority of authors came from Italy (34 papers), Spain (31 papers), and China (23 papers), with only a few from other countries (Figure 6). Based on this discovery, European countries focused on evaluating microalgae, which use numerous renewable natural resources. China and India were the top Asia countries involved in microalgae research (Figure 6).

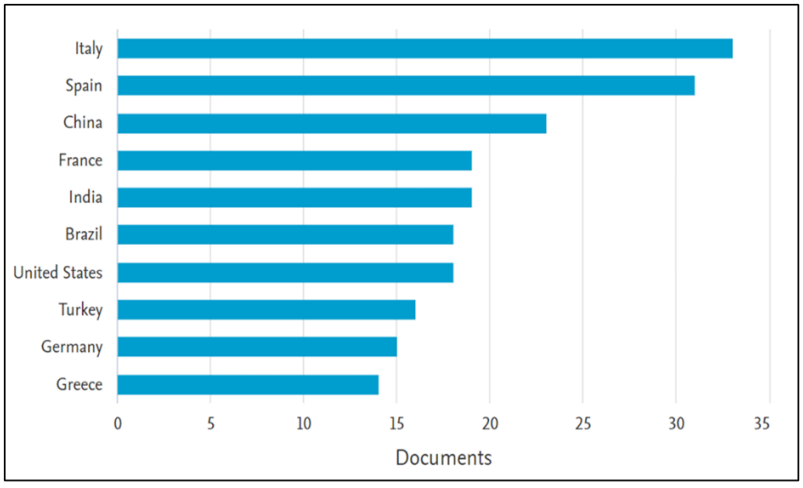


**Figure 6.** Authors by their respective countries

According to Rumin et al. (2020a), research on microalgae and phytoplankton has seen significant development in Europe and the Euro-Atlantic region. A bibliometric study conducted from 1960 to 2017 revealed a total of 79,020 worldwide articles, with 26,137 originating from researchers in Europe (constituting 33% of global publications) and 6,989 articles from the

EuroAtlantic region (27% of European publications and 9% of global publications). China and the USA are leading countries in Asia and America with extensive microalgae research activities [73]. Europe and the Euro-Atlantic region have excellent research, innovation, and industrial development potential, and they are actively participating in international research networks. These regions host many specialized research sites that sustainably produce high-quality microalgae biomass, bringing together biotech companies and technology platforms. This study offers a comprehensive overview of global microalgae research, focusing on Europe and the Euro-Atlantic region. New research concepts are highlighted, emphasizing regional bioeconomic development perspectives that differ from global activities in Europe and worldwide [43,73,74]. Articles that met the inclusion criteria for microalgae and their applications in this study were 298, from 1993 to 2023. This proves that the relationship between microalgae and their applications was not a widely published study. This bibliometric study was more specific to the relationship between microalgae and their applications, and only 298 articles were included in the inclusion criteria. According to this bibliometric analysis, since 2015, there has been an increase in the number of publications, and it will continue until 2023. This indicates that many researchers have realized that microalgae change materials have great potential and can be studied for their benefits [75]. Moreover, microalgae were a source of sustainable resource material [20,76–78].

### *3.3. Trend Topics Analysis of Microalgae Studies*

The most popular topics in articles on microalgae and their applications from 1993 to 2023 were analyzed using VOSviewer. Figure 7 provides a visual representation of the arrangement. Key phrases were depicted as circles of different colors, with a size proportional to their frequency in the title and abstract. Letters and circles were then sized based on their frequency of occurrence. The letter and circle measurements were then determined based on the frequency of occurrence. When the letter and circle measurements were expanded, the observed miracles revealed a more remarkable recurrence of occurrence for specific keywords. A corpus of 289 related articles was used to identify 10,451 keywords. The focus was on experimental data from articles on microalgae as natural materials used in various industrial sectors.

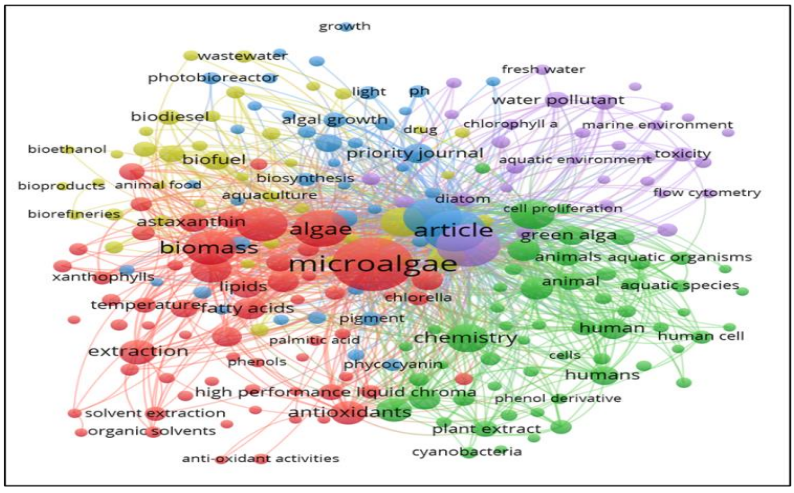


**Figure 7**. Visualization topic area by VOSviewer using network visualization

The topics discussed were divided into 5 clusters marked with different colors. The size of the circle indicated a higher frequency. The most widely used keywords were microalgae, algae, article, biomass, and chemistry. In addition to the five keywords, many other keywords were used in articles about microalgae and their applications. These keywords are related to various applications of microalgae in the pharmaceutical, food, and cosmetic industries, biofuel, wastewater, aquatic ecosystems, marine ecosystems, and other fields.

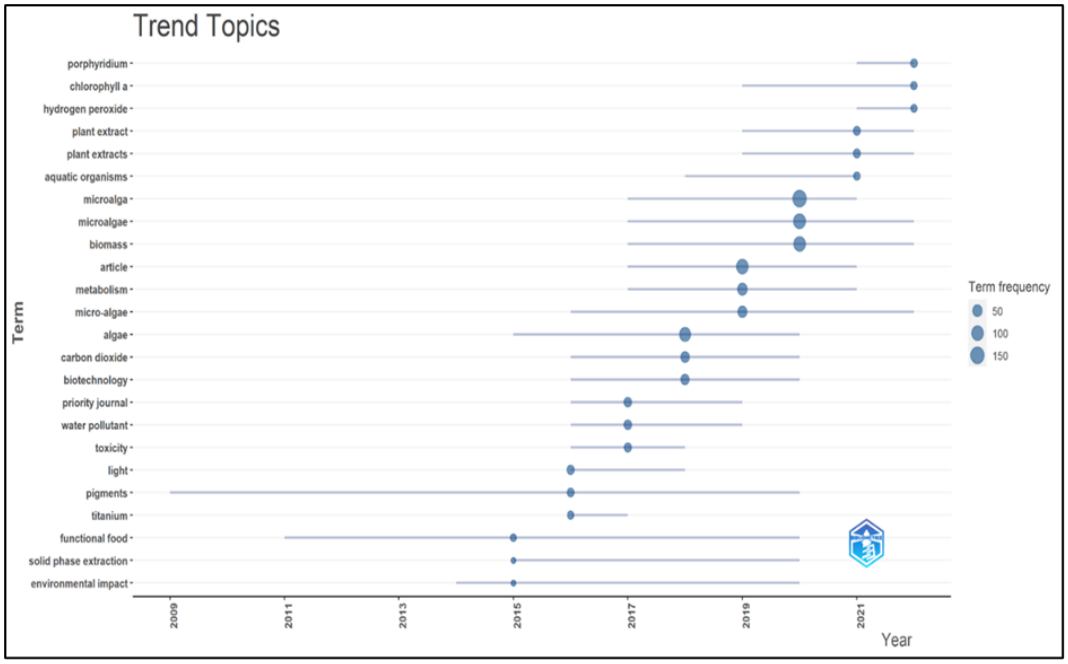


**Figure 8**. Trend Topics in 1993–2023

In a manuscript, Figure 8 uses the keywords microalgae, macroalgae, and biomass. Notably, microalga has the highest frequency from 2017 to 2021, as reported in Figure 8; however, it is essential to note that terms such as algae, microalgae, and microalgae can have similar meanings. Algae produce many unique and critical bioactive metabolites through photosynthesis and other pathways and have attracted attention in the cosmetic and cosmeceutical industries [79]. A wide range of bioactive compounds includes proteins, vitamins, minerals, carbohydrates, pigments, polysaccharides, exopolysaccharides, and essential oils [80]. This article provides an overview of several types of microalgae, their cultivation methods, and the use of microalgae biomass [81].

The keywords in this study were significantly related to the article. The keywords described the core discussion of the article. Therefore, publications that fall into the inclusion criteria in this bibliometric study can be read generally and comprehensively. By looking at Figures 7 and 8 directly, we could read the general topics of the articles in this study [73,82,83].

Researchers interested in microalgae could use this bibliometric analysis to find the direction of current research developments. The utilization of microalgae could be divided into 5 clusters, and its extent is depicted in Figure 7. Utilizing microalgae in the pharmaceutical field, such as research toward extraction systems [57,84], determination of compound content [39,51,85,86], and antioxidant potential testing [8,10,18,49,87–89], was a fascinating study.

Microalgae are raw materials from the sea and have varying active substance content. Extraction technology is needed to separate each active substance according to the needs of the pharmaceutical and vaccine industries, the cosmetic industry, and the food and animal feed industry [1,9,22,28,45]. Multilevel extraction is in great demand for a better purity level of active substances [65-68]. The vaccine industry will prioritize squalene results in its extraction [13,55,61]. Then, the food and animal feed industry will utilize the remaining active ingredients to obtain beneficial fatty acids such as DHA [10].

Furthermore, the theme of microalgae biochemistry [90], an aquatic and marine organism [44,49,91], continues to be studied regarding the specifications and classification of microalgae widely distributed in waters and oceans worldwide [44,91,92]. In addition, renewable energy source research is widely studied [93]. Microalgae can be used as a source of biofuel [35,37,70], bioethanol, biodiesel, photobioreactors, and the like through bioprocesses carried out on a large scale [35–37,46,94–96]. The application of microalgae as a guardian of the balance of aquatic and marine ecosystems is widely studied along with water and ocean quality parameters. The more diverse the microalgae in the waters and oceans, the better the balance of the ecosystem is maintained [13,97–101]. Research that is also in great demand is microalgae cultivation technology outside its natural ecosystem. This will make it easier to control the process of microalgae cultivation and harvesting [1,102,103].

Bibliometric studies provide a general overview of the studies that significantly contribute to publishing knowledge. This bibliometric analysis is expected to contribute to the development of microalgae from aquatic and marine sources and their applications in many fields.

## 4. CONCLUSION

According to a bibliometric analysis, microalgae as a raw material have evolved over the last three decades. The potential functions of these organisms were to replace synthetic materials in various industrial applications, including cosmetics, pharmaceuticals, and food ingredients. Microalgae were applied for biofuel, wastewater, aquatic ecosystems, marine ecosystems, and other fields. The increased number of microalgae studies from 2019 to 2021 demonstrated their high potency as natural sources.

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**Conflicts of interest:** no conflict of interest.

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