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ORIGINAL RESEARCH

Revealing the utilization of microalgae in cosmetics: insights from a comprehensive scientometric analysis over the last two decades

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Abstract Utilizing microalgae in cosmetics has become a rapidly expanding sector, valued for its sustainability and potential for innovation. The current article provides a detailed scientometric analysis of microalgal research within the cosmetics industry over the last two decades. Our findings reveal a notable annual growth rate of 13% in research activity, underscoring the increasing global interest and advancements in this field. International collaboration plays a significant role, with nearly 30% of research efforts involving partnerships across countries, showcasing a strong global network. The interdisciplinary nature of the research is evidenced by its presence in leading journals such as Marine Drugs, Science of the Total Environment, and Algal Research. China leads the way with (538) publications, followed by India (234), Spain (174), and Portugal (173). Other major contributors include Brazil, the USA, South Korea, and Italy, further highlighting the widespread international focus on microalgae in cosmetics. This global involvement reflects the importance of collaboration and interdisciplinary approaches in advancing the field. Our study offers key insights into the current trends, major contributors, and emerging topics in the use of microalgae for cosmetics, providing a solid foundation for future research and innovation in the development of sustainable cosmetic products.

Keywords Microalgae . Cosmetics . Product development and innovation . Scientometric networks . Intellectual structure . Keyword co-occurrence . Collaboration networks

Introduction

Microalgae, which are photosynthetic microorganisms present in marine and freshwater habitats, have attracted considerable attention in the cosmetic business because of their abundant content of bioactive compounds (Priyadarshani and Rath 2012), these compounds possess several advantageous characteristics, including antioxidant, anti-aging, anti-inflammatory, and antibacterial actions, which make them highly attractive components for cosmetic and cosmeceutical formulations (Martínez-Ruiz et al. 2022). Metabolites generated from microalgae, such as chlorophyll, β-carotene, astaxanthin, and phycobiliproteins, possess potent antioxidant qualities that aid in diminishing indications of aging and safeguarding the skin against oxidative stress (Martínez-Ruiz et al. 2022; Morocho-Jácome et al. 2020). In addition, chemicals derived

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from microalgae as "phycocyanin, carotenoids, and omega-3 fatty acids" demonstrate notable anti-inflammatory and antibacterial properties, making them valuable for the treatment of skin problems and the prevention of infections (Yarkent et al. 2020; Dussably et al. 2022). Furthermore, the metabolites produced by microalgae can protect the skin from damage caused by UV radiation, promote skin repair and healing, and prevent inflammation. This makes them well-suited for use in sunscreen and skin-whitening treatments (Wang et al. 2015). Additionally, microalgal lipids and other bioactive compounds have proven to be highly effective as moisturizing, emollient, and softening agents. They significantly improve the texture and hydration of cosmetic products (De Luca et al. 2021). Through the increasing consumer preference for natural and sustainable ingredients, microalgae offer an eco-friendly alternative to synthetic compounds. Their incorporation aligns with the global shift towards green beauty products (Sasounian et al. 2024). The beauty and personal care market, predicted to reach $736.80 billion by 2028 with a steady annual growth rate (Statista 2024), underscores the economic potential of sustainable, microalgae-based ingredients.

Even though microalgae exhibit considerable metabolic variability, numerous species are distinguished by their high protein content (Leu and Boussiba 2014). The cosmetic industry greatly values the lipid content of these microorganisms, which can range from 70% to 80% in some species (De Luca et al. 2021). In addition, microalgae are abundant sources of vitamins such as A, B1, B2, B6, B12, and C (Carballo-Cárdenas et al. 2003; Grossman 2016), pigments including various carotenoids (β-carotene, lycopene, lutein, canthaxanthin, astaxanthin) (Ambati et al. 2019), and phycobiliproteins such as phycocyanins and phycoerythrins (Manirafasha et al. 2016). Consequently, microalgae from the genus *Thalassiosira*, which has a high content of amino acids, especially serine, are highly valued for their potential use in moisturizing products (Cardozo et al. 2007; Couteau and Coiffard. 2018). Furthermore, species such as *Monodus subterraneus*, which contains a large amount of polyunsaturated fatty acids, are highly esteemed for their use in cosmetic products (Couteau and Coiffard 2018; Derrien et al. 1998). Additionally, it is worth mentioning that microalgae of the genus *Nannochloropsis* are recognized for their significant concentration of linolenic acid, which makes them especially remarkable in this specific context (Guedes et al. 2011). Also, carotenoids are essential in preventing the creation of reactive oxygen species. Among these pigments, β-carotene is the most abundant in the halotolerant microalgae *Dunaliella salina*, making up to 10% of its dry weight (de Jesus Raposo et al. 2013). β-carotene is well-known for its ability to operate as a provitamin A, which is highly beneficial in the production of antiaging products (Couteau and Coiffard 2018). Astaxanthin, which is abundant in *Haematococcus pluvialis*, has a higher antioxidant efficacy than tocopherol, making it very desirable for antiaging products (Wan et al. 2014). *H. pluvialis* is widely acknowledged as the most abundant natural reservoir of astaxanthin, with the ability to amass more than 3 g/kg of dry biomass in large-scale industrial settings (Couteau and Coiffard 2018). Studies have demonstrated that extracts derived from *Chlorella vulgaris* have potential in the field of antiaging. These extracts can stimulate the creation of collagen, which is essential for maintaining the structure of the skin and minimizing the formation of wrinkles. As individuals age, the natural production of collagen decreases, making this property of *C. vulgaris* extracts particularly valuable (Wang et al. 2015).

Scientometric and bibliometric analyses are essential techniques for studying scientific literature, providing quantitative insights into its growth, structure, and influence. These approaches are crucial for assessing research output, patterns of collaboration, and the impact of funding on scientific progress. Scientometrics, bibliometrics, and informetrics are closely related fields that study the processes and patterns of generating scientific knowledge. Bibliometrics primarily examines scientific papers, whereas scientometrics contains a wider range of quantitative measures related to scientific activity (Hood and Wilson 2001; Salinas-Ríos. 2022). These domains have seen gradual changes, improving the terminology and procedures used to increase the analysis of scientific communication and research evaluation. Scientometric and bibliometric analyses are essential for advancing science by enhancing the quality of scientific research and communication, they help to tackle social disparities by promoting fair possibilities for development through scientific advancements (Boichenko and Zinchenko 2022). The key indications obtained from these analyses are crucial for understanding the quantitative aspects of scientific literature and its influence in different scientific fields (Vinkler 2010).

The objective of the current work is to provide a thorough scientometric analysis of the research conducted on the use of microalgae in cosmetics during the last twenty years. This is to clarify the dynamic progression of this area by analyzing the development of scholarly publications, identifying significant thematic trends, and mapping notable authors and pivotal papers. Moreover, the study examines the spatial dispersion of research contributions and examines the collaboration networks of researchers, institutions, and countries engaged in this field.

Methodology

Our scientometric investigation followed these approaches. First, we selected a database and established search criteria. This was followed by a preliminary statistical analysis. Third, we conducted a comprehensive analysis of the bibliometric network. Fourth, we explored conceptual themes and historical context. Lastly, we analyzed the reference publication years. To facilitate these analytical tasks, we utilized R version 4.4.1 software, renowned for its flexibility and extensive capabilities. We incorporated libraries such as bibliometrix for analysis (R-Development-Core-Team 2021), and employed VOSviewer for network visualization (van Eck and Waltman 2019).

Data source and processing

We obtained published documents related to microalgae and cosmetics from the Clarivate Analytics Web of Science (WoS) database. While other studies have used the Scopus database for bibliometric analyses, recent research indicates that approximately 70% of researchers rely on the WoS for scientometric studies (Cuccurullo et al. 2016; Zupic and Čater 2015). To ensure the accuracy of our findings and to avoid false-positive results, we conducted searches using a topic filter by role, which includes the title, abstract, keyword plus, and author keywords. We used the search term "(microalgae OR algae OR cyanobacteria) AND (cosmetics OR "personal care products" OR skincare OR "beauty products")". We specifically focused on documents written in English, spanning the period from 2005 to 2024. As indicated in (Table 1), we successfully identified 1,000 research and review papers, which exhibited an annual growth rate of 13%. These papers averaged 48.25 citations per document and were authored by a total of 4,269 researchers. Among the selected works, 19 were authored by a single individual, and the rate of international co-authorship was 29.9%.

Table 1 Key data characteristics of microalgae and cosmetics publications

Description	Results
Main information about data	
Timespan	2005:2024
Sources (Journals, Books, etc)	381
Documents	1000
Annual Growth Rate %	13
Document Average Age	4.79
Average citations per doc	48.25
References	60940
Document contents	
Keywords Plus (ID)	2888
Author's Keywords (DE)	2674
Authors	
Authors	4269
Authors of single-authored docs	19
Authors collaboration	
Single-authored docs	19
Co-Authors per Doc	5.32
International co-authorships %	29.9
Document types	
article	605
Article; book chapter	31
Article; early access	3
Article; proceedings paper	14
Review	335
Review; book chapter	5
Review; early access	7

Scientometric network analysis

A network can be conceptualized as a structure comprising a group of individuals or entities, referred to as actors, interconnected through various relationships, as described by Knoke and Yang (2019). In Social Network Analysis (SNA), these relationships are depicted as "edges," representing the links between two interacting nodes or actors. As data accumulates, the network graph evolves from a simple connection between two nodes (a dyad) into an intricate social network. This evolution supports the notion that employing SNA techniques to analyze existing literature from a network perspective can uncover hidden patterns, thereby facilitating theory development and the exploration of future research areas, as suggested by Khan and Wood (2016). Various statistical tools can be employed to describe these networks from a social network perspective (Gruzd et al. 2011). In our study, we concentrate on descriptors such as node size (indicating the number of nodes or actors/users in the network), density (reflecting the proportion of actual connections relative to all possible connections in the network), and diameter (denoting the longest distance between any two nodes in the network).

In a co-citation network, co-citation occurs when two papers or authors, such as A and B, are both cited by a third paper, C. A high frequency of co-citation indicates a shared thematic relevance between these papers, forming cohesive research clusters, as noted by Benckendorff (2009) and Hjørland (2013). Co-citation acts as a measure of similarity between authors or documents based on their content. More co-citations suggest a stronger semantic association, as discussed by Shiau et al. (2017). According to Yang et al. (2015), co-citation analysis can effectively map the knowledge structure of specialized research areas, identifying key authors and influential journals within a field. By tracking co-citation patterns over time, we can gain insights into the evolving landscape of a research domain and detect shifts in prevailing schools of thought, as demonstrated by Fang et al. (2018) and Yang et al. (2016). When creating a co-citation network, connections (edges) are established between nodes, representing authors or articles, when a third party consistently cites both. This process helps form conceptual clusters, signifying recurring co-citations among specific groups of authors or articles. In journal co-citation analysis, the strength of the connection between two journals is positively correlated with the frequency of their co-citation, uncovering the structural foundations of research fields (Wakefield 2008). This approach highlights the critical role of academic journals in disseminating knowledge and reveals commonalities between journals, such as research focus or methodology.

Furthermore, scientific collaboration networks can be analyzed at various levels, including individual authors, research institutions, and countries. Collaboration among individual authors is essential for sharing knowledge and disseminating information, which leads to higher-quality research, as highlighted by Zou et al. (2018). Empirical evidence suggests that co-authored works are more likely to be published in high-impact journals and receive more citations, as noted by Moed et al. (2004). Ding (2011) emphasizes the importance of collaboration not only among individual authors but also among research institutions, which can significantly influence scientific domains and contribute to policy development. Additionally, keyword co-occurrence networks offer a complex web of the main themes within a research area. By examining these networks, we can identify "signal words" that encapsulate the core content and essential concepts in the literature, reflecting the main ideas and topics being explored, as discussed by Benckendorff (2009) and Spence and Owens (1990).

Thematic and conceptual structure

The concept of thematic mapping, initially proposed by Law et al. (1988), is also known as a strategic diagram. It is a valuable tool for examining how clusters of keywords or co-occurring words in academic literature evolve and change over time. Thematic maps utilize the density and centrality metrics introduced by Callon et al. (1991), and combine ideas from co-word networks and portfolio analysis, as explained by Avila-Robinson and Wakabayashi (2018). This straightforward yet powerful diagram has become widely adopted in academic discussions, as demonstrated by researchers like Zong et al. (2013). Similarly, the conceptual structure of a research area can be mapped using conceptual structure maps, which involve breaking down a subject into distinct knowledge clusters to gain new insights from the data associated with each cluster, as discussed by Wetzstein et al. (2019). Temporal analysis is crucial in bibliometric research, allowing us to explore the evolution of a particular field of research. Emerging trends within a scientific field can be identified through articles that experience a "citation burst," where they suddenly receive a significant number of citations. This approach, illuminated by Kim and Chen (2015), helps recognize impactful developments in academia.

Results

Analyzing the global research landscape and growth trends

We conducted an in-depth investigation by extracting a corpus of 1,000 documents focused on the intriguing intersection of microalgae and cosmetics. This substantial collection involved the collaborative efforts of 4,269 authors from 79 different countries, highlighting the global interest in this field, as depicted in (Figure 1). Our study spans two decades, from 2005 to 2024. The research into the use of microalgae in cosmetics has been fascinating, a story vividly illustrated (Figure 2). The graph reveals an impressive annual growth rate of 13%, indicating a strong and growing interest in this area. However, it is important to note that this interest has not developed uniformly over time. The graph indicates that from 2005 to 2011, the research on the utilization of microalgae in cosmetics was relatively limited, with very few articles published, reflecting its lack of widespread recognition at the time. Between 2012 and 2020, there was a noticeable and gradual increase in published articles, likely due to the growing interest in and reliance on natural products in personal care items. This sparked discussions and research into the convergence of microalgae and cosmetics. The most significant trend emerged from 2021 to 2023, where the number of articles published about cosmetics derived from microalgae experienced exponential growth, with 149 articles in 2021, 155 in 2022, and 125 in 2023. This highlights the rapid development and growing importance of this field. However, in the recent year up to July 2024, there has been a slight plateau or slowdown in growth, with 51 articles possibly indicating the field's maturation and a shift towards more in-depth analysis and specialization.

The information in (Table 2) offers a comprehensive summary of the renowned academic journals that have

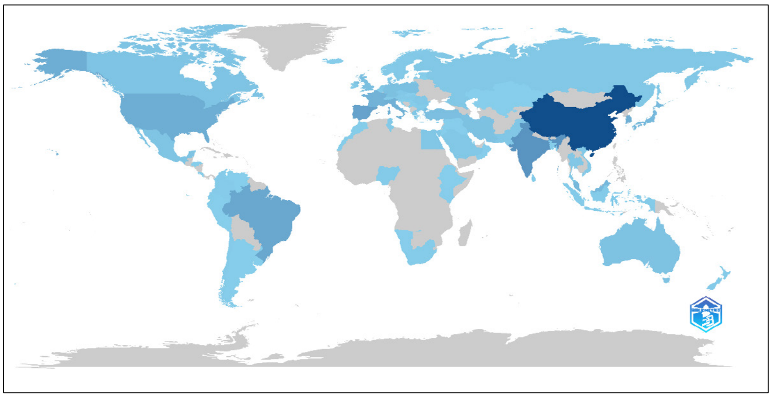

Fig. 1 A geographical atlas of the country's scientific production research is conducted, with darker colors indicating a higher level of scientific output

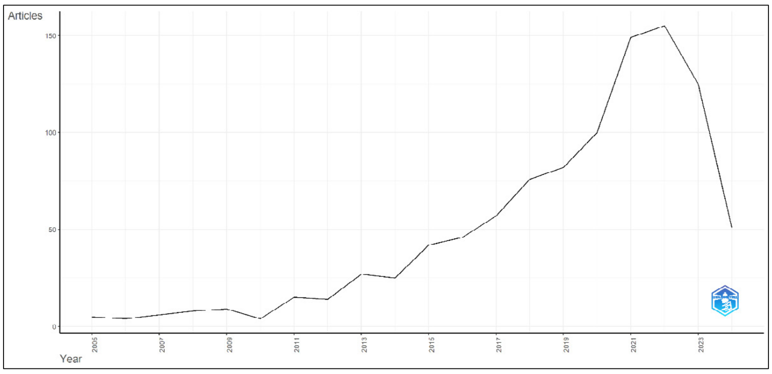

Fig. 2 Annual scientific production for the utilization of microalgae in cosmetics

played a crucial role in publishing innovative studies in inserting microalgae in cosmetics. The allocation of the most often published papers among different sources emphasizes prominent publications that have made substantial contributions to the body of the topic of microalgae and its applications. “Marine Drugs” stands out by having 65 publications, highlighting its importance in publishing research on marine natural products, specifically microalgae. This is consistent with the increasing fascination with marine biotechnology and the possible medicinal uses of substances obtained from the ocean. The journal “Science of the Total Environment” contains 51 articles, which cover a wide range of topics including environmental science, technology, and sustainability studies. The incorporation of microalgae investigation in this publication shows the significance of microalgae in environmental surveillance, pollution management, and ecological durability. “Algal Research-Biomass Biofuels and Bioproducts” is a publication that primarily concentrates on algae-based technology. It contains a total of 50 articles. This publication is essential for academics studying biofuels, biomass, and bioproducts obtained from algae, with a focus on the sector’s innovation and advancement. The “Journal of Applied Phycology” and “Bioresource Technology” have respectively published 32 and 20 papers, demonstrating their significance in applied research and the use of microalgae in biotechnological breakthroughs. These publications focus on research related to the practical applications and technological integration of algae in different industries. The fact that “Molecules”, “Chemosphere”, and “Journal of Hazardous Materials” have a significant number of articles indicates the interdisciplinary character of research on microalgae. These periodicals encompass a wide range of subjects, including chemical sciences and environmental toxicity, and emphasize the various uses and effects of microalgae. Publications such as “Environmental Pollution, “Environmental Science and Pollution Research”, and “Ecotoxicology and Environmental Safety” highlight the significance of microalgae in environmental research, specifically in comprehending and addressing pollution and ecological hazards. The presence of “Water Research” and Water publications highlights the importance of microalgae in aquatic environments and studies connected to water. These sources are crucial for researching water quality, treatment processes, and the ecological roles of microalgae in aquatic systems. “Applied Sciences-Basel”, “Aquatic Toxicology”, and “Applied Microbiology and Biotechnology” emphasize the practical and toxicological aspects of studying microalgae. The topics covered span a broad spectrum, encompassing applied sciences, microbial biotechnology, and toxicological assessments. The publications “Cosmetics”, “Environmental Research”, and “Frontiers in Plant Science” demonstrate the growing interest in the use of microalgae for cosmetic applications, environmental impact studies, and plant science research. These publications showcase the broadening scope of microalgae research into novel and cutting-edge areas. To obtain a more comprehensive comprehension of the influence of these publications, one might check Bradford’s Law, which was first suggested by Bradford (1934). This legislation establishes a clear and structured system of productivity within the domain of scientific publications. Therefore, (Figure 3) demonstrates the implementation of Bradford’s Law in studying the usage of microalgae in personal

Table 2 Sources for the most published articles

Sources	Articles
Marine Drugs	65
Science of the Total Environment	51
Algal research-biomass biofuels and bioproducts	50
Journal of Applied Phycology	32
Bioresource Technology	20
Molecules	20
Chemosphere	19
Journal of Hazardous Materials	18
Environmental Pollution	16
Biotechnology Advances	12
Ecotoxicology and Environmental Safety	12
Environmental Science and Pollution Research	12
Water Research	12
Applied Sciences-Basel	11
Aquatic Toxicology	11
Applied Microbiology and Biotechnology	9
Cosmetics	9
Water	8
Environmental Research	7
Frontiers in Plant Science	7

care products. Just a few journals have a substantial impact in the core zone, which encompasses well-known publications including Marine Drugs, Algal Research-Biomass Biofuels and Bioproducts, Journal of Applied Phycology, and Bioresource Technology. These publications are widely acknowledged as the main avenues for distributing innovative research in this discipline.

The substantial growth in the research domain of algal utilization in cosmetics is conspicuously evident not only in the proliferation of scholarly contributions but also in its global dissemination, as exemplified in (Figure 4) which depicts the scientific output of research on the use of algae in cosmetics across different countries, with the number of published articles reflecting each country's involvement in this field. China is at the forefront with an impressive 538 publications, which demonstrates its strong research infrastructure and substantial investment in biotechnological advancements, likely driven by massive research programs and industrial utilization of microalgae, especially in the field of cosmetics. India is ranked second with 234 publications, demonstrating its increasing interest and ability to use microalgae for cosmetic purposes. This highlights India's active scientific community and its emphasis on exploiting natural resources for sustainable products. Spain, with 174 publications, and Portugal, with 173 articles, are notable contributors due to their well-established expertise in marine research and biotechnology. Brazil and the USA make substantial contributions, with Brazil's emphasis on biodiversity and natural goods and the USA's prominence in biotechnology advancements. South Korea and Italy have shown significant research efforts, with South Korea benefiting from its excellent technological infrastructure and Italy excelling in marine sciences. France, with 107 publications, Malaysia, with 84 articles, and Japan, with 79 papers, provide significant contributions in the fields of biotechnology, rich marine biodiversity, and creative techniques, respectively. The research output from Turkey (59 articles), Poland (57 articles), the UK (56 articles), and Germany (53 articles) demonstrates a wide range of research interests across Europe, utilizing their scientific knowledge and industrial capacities. Iran, Australia, Canada, and Mexico are included in the list with 49, 45, 40, and 37 papers respectively. Each country contributes distinct perspectives and research focuses. In general, the way research outputs are distributed by countries shows that there is a worldwide interest in using microalgae in cosmetics. This emphasizes the significance of international collaboration and knowledge sharing to

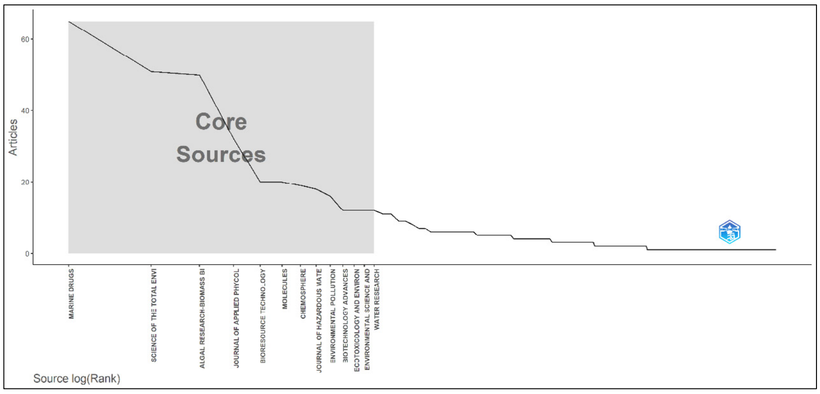

Fig. 3 Bradford's law in microalgal utilization in cosmetics research

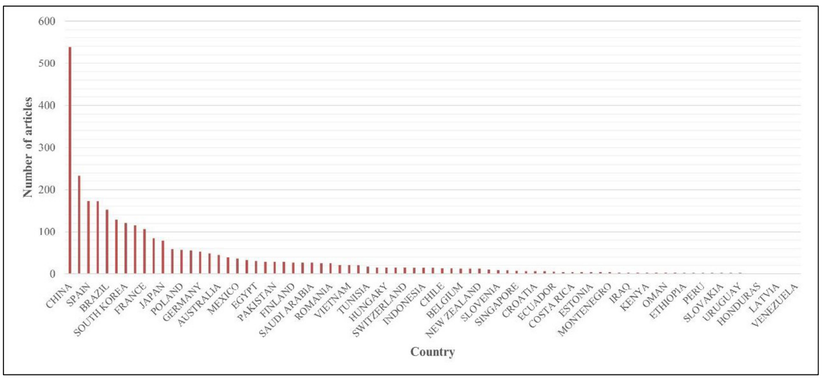

Fig. 4 Research on microalgal utilization in cosmetics by nation's scientific production

promote the progress of sustainable and creative cosmetic products that utilize microalgae.

Additionally, Table 3 presents the most cited works related to microalgae utilization in cosmetics, underscoring their significant contributions to the scientific community. The study by Spolaore et al. (2006) has achieved a remarkable total of 2,679 citations, with an average of 141 citations per year. This influential research has had a substantial impact on the field, likely due to its pioneering findings and foundational concepts in microalgae biotechnology and its applications in cosmetics. Becker (2007) publication has garnered 1,304 citations, averaging 72.44 citations per year. Additionally, Borowitzka (2013) work is widely recognized, with a total of 908 citations and an average of 75.67 citations per year. This article emphasizes significant advancements in applied phycology, particularly highlighting the practical applications of microalgae within the cosmetics industry. Recent publications, such as those by Chew et al. (2017) and Ahmed et al. (2017), have also received considerable acclaim, with 776 and 769 citations, respectively. Both studies exhibit a high citation rate per year (97 and 96.13), indicating their rapid and substantial influence in the field, especially concerning the utilization of microalgae.

The Dominance Factor is a bibliometric metric that measures the level of importance of writers in academic circles. It is calculated by dividing the number of multi-authored publications where an author is the lead author by the total number of multi-authored articles (Kumar and Kumar. 2008). This metric has gained significant recognition in academic literature, as evidenced by research conducted by Firdaus et al. (2019). Additionally, (Figure 5) clearly illustrates the changing trends of prominent authors in the discipline throughout time. Ying GG had a lasting influence from 2007 to 2021, Jeon YJ showed strong domination from 2008 to 2023, and Chang JS had a notable impact from 2015 to 2024. Nevertheless, the academic field has also seen the emergence of new voices that established their influence inside the discipline. This group comprises three individuals: Iqbal HMN, who was significant from 2017 to 2023, Leska B, who was influential from 2014 to 2020, and Vasconcelos V, whose impact stretched from 2019 to 2022. These advancements emphasize the ever-changing prominence of authors in research on microalgae in the cosmetics

Table 3 Most cited articles in the field of microalgae utilization in cosmetics

Paper	Total citations	TC per year	Normalized TC
Spolaore P, 2006, J Biosci Bioeng	2679	141	3.45
Becker EW, 2007, Biotechnol Adv	1304	72.44	3.56
Borowitzka MA, 2013, J Appl Phycol	908	75.67	6.42
Chew KW, 2017, Bioresource Technol	776	97.00	9.55
Ahmed Mb, 2017, J Hazard Mater	769	96.13	9.47
Dann AB, 2011, J Appl Toxicol	639	45.64	4.06
González-Pleiter M, 2013, Water Res	554	46.17	3.92
Shah MMR, 2016, Front Plant Sci	491	54.56	6.99
Del Campo Ja, 2007, Appl Microbiol Biot	478	26.56	1.31
Raposo MFD, 2015, Mar Drugs	406	40.60	4.67
Stengel DB, 2011, Biotechnol Adv	379	27.07	2.41
Koller M, 2014, Algal Res	377	34.27	4.51
Guedes AC, 2011, Mar Drugs	359	25.64	2.28
Raposo MFD, 2013, Mar Drugs	357	29.75	2.53
Yang LH, 2008, Environ Toxicol Chem	355	20.88	3.17

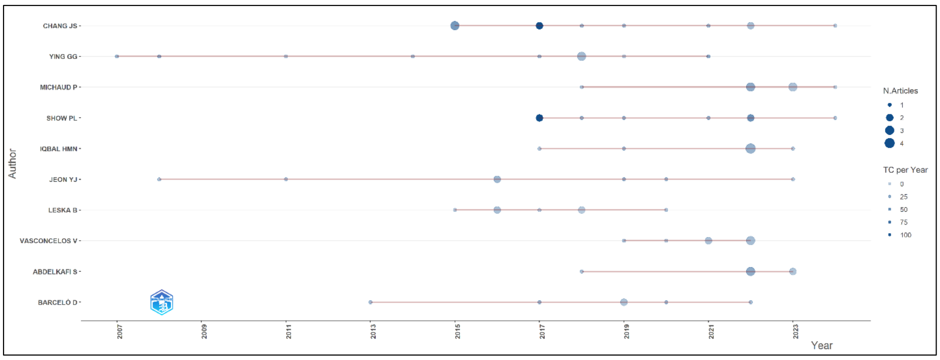

Fig. 5 Authors production over time in the field of adding microalgae in cosmetics research

industry. The idea of "Concentration of Authors' Contribution" is a well-established statistic in the field of bibliometric analysis, as supported by Merediz-Solà and Bariviera (2019).

This metric is based on Lotka's Law (Lotka 1926), which states that the number of authors who produce a certain number of articles is inversely proportional to the square of the number of articles produced. This is often approximated by a fixed ratio, usually 2, to the number of authors who have only produced one article. Lotka's Law is a useful tool for understanding the patterns of author production in many domains. By implementing this legislation in scholarly investigations within particular fields, one can obtain an important understanding of its internal mechanisms. Further analysis of (Figure 6) and a deeper understanding of the source provide further information and insights into the implications. Regarding the exploitation of microalgae in cosmetics, this principle reveals that a significant number of writers have solely written a single work. This implies that numerous individuals contribute to the field, showing that many authors address the use of microalgae in cosmetics without focusing solely on this specific area of study. Their study encompasses a wider range of topics, with the exploitation of microalgae in cosmetics being just one aspect of their interests. The significant number of writers who have only published a single paper indicates that many contributors may have a secondary interest in the use of microalgae in cosmetics, rather than it being their main area of attention. The extent of participation in this field of study can be deducted by analyzing the distribution of writers based on Lotka's Law, which spans from occasional contributors to committed researchers. The distribution of research focus and the varied degrees of expertise among writers within the area can be better understood using this analysis.

Network analysis

Co-citation networks

As presented in (Figure 7) co-citation network showcases the connections and partnerships between authors

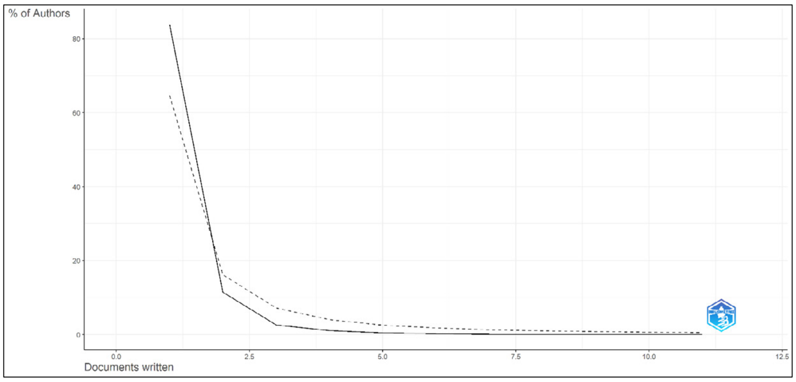

Fig. 6 Authors' productivity in microalgae utilization in cosmetics research through Lotka's law

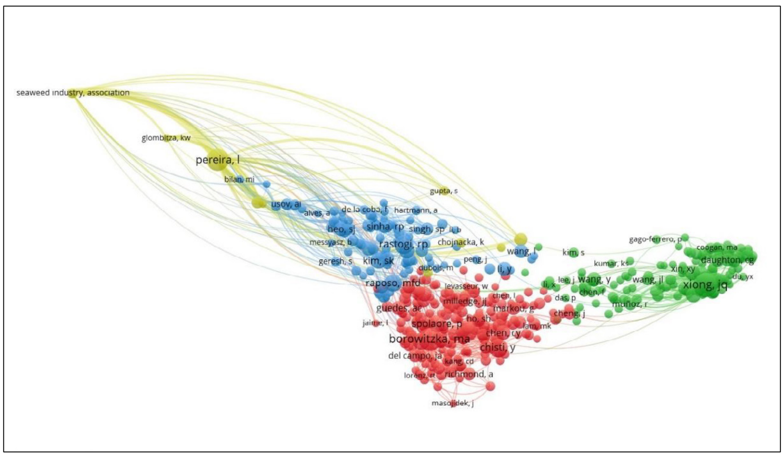

Fig. 7 Microalgae utilization in cosmetics research authors co-citation network (≥ 20 articles)

in the field of microalgae utilization in cosmetics. The network includes authors who have published a minimum of 20 papers, represented by nodes. The size of each node indicates the number of citations received by the respective author. The edges connecting the nodes in the network represent co-citation associations, indicating the frequency with which writers are referenced together. The network is separated into clusters, with each cluster represented by a distinct color, indicating groups of authors who frequently cite each other's work. The main clusters identified are the Red Cluster, which consists of well-known authors such as Borowitzka MA, Chen CY, and Chisti Y indicating a substantial impact and collaboration among these authors; the Green Cluster, where Xiong JG plays a prominent role and connects with other influential researchers; the Blue Cluster, which includes Pereira L, Bilan MI, and Usov AI representing another significant collaborative group; and the Yellow Cluster, which features authors like Glombitza KW emphasizing a distinct focal area. Renowned writers, like Borowitzka MA, Chen CY, Chisti Y, Pereira L, and Xiong JG have a significant impact on the study focus and patterns in the use of microalgae in cosmetics. The network exposes cooperative and impactful connections between scholars, with clearly defined groups denoting specific subfields or research subjects within the larger field. The red cluster, led by Borowitzka MA serves as a prominent center for research, with links across clusters representing interdisciplinary cooperation. Authors such as Pereira L, who establish connections between numerous clusters, have a vital role in facilitating this integrative process. The network's configuration indicates developing patterns and important areas of focus in the study of microalgae application in cosmetics, pinpointing prominent research subjects and providing guidance for future research endeavors. Analyzing the co-citation network offers valuable information about the research community's dynamics, important contributors, possible collaborators, and influential publications that have influenced the field's progress.

Notable authors play a significant role in the co-citation network by influencing interaction dynamics and spreading information across the research network (Lin and Himelboim 2019). Bakshy et al. (2011) support this conclusion by suggesting that influential authors have a strategic advantage in starting conversations, encouraging interaction, and promoting feedback. As a result, they have a greater impact on the spread of information inside the network. The co-citation graph also demonstrates the closeness of specific nodes, suggesting a noticeable "homophily effect." Homophily, which is based on the idea that "similarity leads to connection" (McPherson et al. 2001), occurs when individuals in a certain field of study engage in conversations focused on shared interests or a common research goal (Findlay and Janse van Rensburg. 2018). This conclusion is consistent with the findings of Jiang et al. (2019), who emphasize that homophily in bibliometric networks often stems from underlying disciplinary or thematic affinities. According to Haythornthwaite (1996), researchers can exploit structural gaps by creating research papers that connect separate clusters inside the network. These articles play a vital role in connecting knowledge communities that might otherwise be isolated. Skilled authors who can bridge these gaps in structure serve as information brokers, enabling linkages between different groups in the network. Their essential role grants them a "structural advantage," which improves the exchange of knowledge and interactions within the network, hence strengthening the foundation of scholarly discourse (Burt 1999).

The co-citation network shown in (Figure 8) demonstrates the connections between sources (journals)

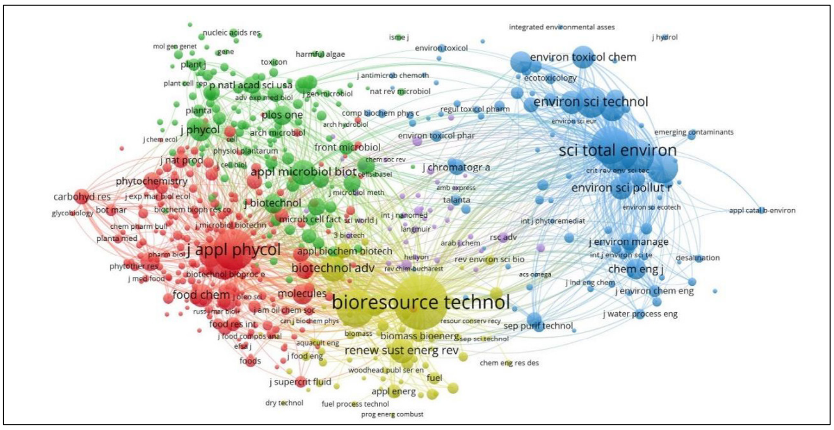

Fig. 8 Microalgal utilization in cosmetics research source co-citation network (≥ 20 articles)

by analyzing their co-citations in the field of microalgae use in cosmetics. The network is divided into multiple clusters, with each cluster being distinguished by distinct colors. These colors represent groups of sources that are commonly mentioned in conjunction with one another. The major clusters identified are: Red Cluster, which includes sources such as “Journal of Applied Phycology” (J Appl Phycol), “Food Chemistry” (Food Chem), and “Carbohydrate Research” (Carbohydr Res), suggesting significant influence and interconnectivity among these journals; Green Cluster, which includes sources like “Applied Microbiology and Biotechnology” (Appl Microbiol Biotechnol), “Frontiers in Microbiology” (Front Microbiol), and “Plant Journal” (Plant J), indicating a strong focus on microbiology and plant sciences within the field; Blue Cluster, which contains sources such as “Science of the Total Environment” (Sci Total Environ), “Environmental Science & Technology” (Environ Sci Technol), and “Environmental Pollution” (Environ Pollut), highlighting the environmental aspect of algal research; and Yellow Cluster, featuring sources like “Bioresource Technology” (Bioresource Technol), “Renewable and Sustainable Energy Reviews” (Renew Sust Energ Rev), and “Biomass & Bioenergy” (Biomass Bioenerg), emphasizing the biotechnological and energy-related aspects of algal research. The co-citation network exposes the cooperative and impactful connections between various research sources in the realm of microalgae usage in cosmetics. The existence of separate clusters indicates the presence of specialized subfields or research topics within the larger field, with specific sources serving as important connectors between different research areas. The red cluster, centered around J Appl Phycol and Food Chem, represents a prominent research hub. This suggests a cohesive set of journals that are regularly cited together, highlighting their collective significance in the subject. Clusters with interconnections imply multidisciplinary interactions, where knowledge and approaches from diverse subfields are combined. Journals like Bioresource Technol, which are associated with many clusters, have a vital role in facilitating this integrative process. The configuration of the network indicates developing patterns and central areas of focus in the study of using microalgae in cosmetics. Identifying outstanding research subjects and guiding future research directions can be facilitated by the prominence of specific journals and clusters. Analyzing the co-citation network offers valuable information about the research community’s dynamics, enabling the identification of important contributors, potential collaborators, and influential works that impact the field’s progress. The results highlight the restricted scholarly interactions among these groups, which indicates a situation known as “orthodox core-heterodox periphery,” as addressed by Glötzl and Aigner (2018). In this situation, a small number of highly cited “orthodox journals” have a significant presence in each cluster, whereas “heterodox journals” are located on the outskirts. This suggests that there is a clear hierarchy in terms of influence and involvement inside the network.

Collaboration networks

The collaboration network depicted in (Figure 9) demonstrates the connections and partnerships between authors in the field of microalgae use in cosmetics who have jointly produced a minimum of two articles. The major clusters identified are the Yellow Cluster, which includes authors such as Silva J, Gaspar H, Martins A, and Alves C, forming a highly interconnected group indicating frequent collaboration within this cluster; the Blue Cluster, which includes authors like Barreia L, Maia I, Domingues P, Pereira H, and

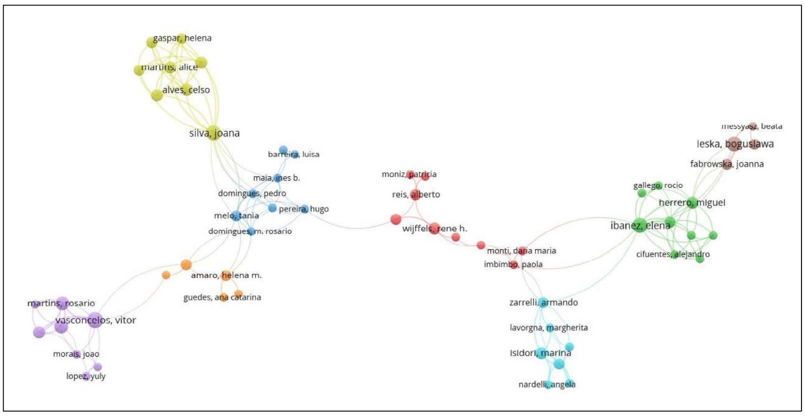

Fig. 9 Microalgae utilization in cosmetics research authors’ collaboration network (≥ 2 articles)

Melo T, showing strong internal collaboration among its members; the Red Cluster, featuring authors such as Moniz P, Reis A, and Wijffels R, showing tight collaboration within its smaller group; the Green Cluster, containing authors like Ibanez E, Herrera M, and Cifuentes A, indicating significant collaboration in the field; the Brown Cluster, including authors such as Messyasz B, Leska B, and Fabrowska J, showing collaboration among a few key authors; the Orange Cluster, featuring authors like Amaro H, and Guedes A indicating a collaborative subgroup within the network; and the Purple Cluster, containing authors such as Martins R, Vasconcelos V, and Morais J, indicating another subgroup of frequent collaborators. The network identifies prominent authors based on their central positions and the density of connections surrounding them. Notable authors such as Silva J, Ibanez E, and Moniz P, are recognized as central Figures within their respective clusters, suggesting their influential role in the research community. The collaboration network exposes interdependent connections between researchers in the domain of microalgal utilization in cosmetics. The presence of distinct clusters implies the existence of specialized subfields or research groups within the larger domain. Additionally, certain authors play a crucial role as central nodes, fostering collaboration within and between these groups. The yellow cluster, led by Silva J, is a prominent center of collaboration, suggesting a highly networked group of academics that often collaborate, highlighting their collective significance in the area. The network displays linkages between several clusters, illustrating interdisciplinary partnerships and the incorporation of information from other subfields. Key authors, such as Silva J, and Moniz P, play a vital role in facilitating these connections by bridging clusters. The network's configuration indicates the existence of collaborative subgroups that concentrate on various aspects of using microalgae in cosmetics. The prominence of specific authors and clusters aids in identifying key research subjects and prospective opportunities for future collaboration. Analyzing the collaboration network provides valuable information about the research community's dynamics, enabling the identification of important contributors, possible partners, and influential works that impact the field's progress.

Table 4 delineates preeminent institutions conducting research on microalgae uses in cosmetics, illustrating worldwide involvement in this domain. The Chinese Academy of Sciences is the most prolific institution, producing 74 publications, followed by Universidade do Porto with 53 papers, and the Centre National de la Recherche Scientifique with 43 articles. Additional notable contributions are Universidade de Sao Paulo with 32 articles and Consejo Superior de Investigaciones Científicas with 29 papers. This data highlights the active participation of institutions in Asia, Europe, and Latin America, including the Chinese Academy of Sciences, National Cheng Kung University, Universidade do Porto, and Tecnologico de Monterrey. The significant contributions from these regions demonstrate robust international collaboration and the formation of research networks centered on microalgae in cosmetics. These findings emphasize the essential importance of institutional support in promoting research and show the worldwide significance of scientific investigation in this domain.

Table 4 Presents the papers that universities frequently produce regarding the use of microalgae in cosmetics

Affiliation	Articles
Chinese Academy of Sciences	74
Universidade do Porto	53
Centre National de la Recherche Scientifique (CNRS)	43
Universidade de São Paulo	32
Consejo Superior de Investigaciones Científicas (CSIC)	29
Consiglio Nazionale delle Ricerche (CNR)	25
Indian Institute of Technology System (IIT System)	25
National Cheng Kung University	25
Wageningen University and Research	21
Ege University	19
Shenzhen University	18
Universidade de Aveiro	17
Tecnológico de Monterrey	16
CSIC - Centro de Investigación y Desarrollo Pascual Vila (CID-CSIC)	14
Universidad de Cádiz	14
Universidade de Lisboa	14
Université de Sfax	14
Universiti Putra Malaysia	14
University of Helsinki	14

In addition, (Figure 10) illustrates the collaboration network among countries engaged in research on the application of microalgae in cosmetics, emphasizing nations with a minimum of two published publications. The People's Republic of China is distinguished as the foremost leader, possessing the greatest quantity of partnerships and publications in this domain. Additional significant nodes comprise the United States, India, Brazil, and Spain. International connections signify joint endeavors, with longer lines denoting more robust or regular alliances. Significant cooperation is evident between China and the USA, China and India, and the USA and Brazil. The network comprises clusters arranged by geographic closeness or research focus, with European nations like Spain, Portugal, and Germany constituting a regional cluster that signifies close collaboration. China's leading position underscores its preeminent role in microalgae research for cosmetics, largely attributable to significant investments in biotechnology and a diverse range of research institutions. The network exhibits significant worldwide collaboration, highlighting the value of international connections in furthering research. The participation of nations such as the USA and India signifies a global interest in this sector, whilst European countries are shaped by EU-funded initiatives that advocate for sustainable and creative cosmetic components. Brazil and South Korea, albeit less prominent than China or the USA, are making substantial contributions to this research area, indicating their increasing significance. This network map offers significant insights into the global research landscape concerning microalgae applications in cosmetics, emphasizing principal contributors and collaborative efforts that foster innovation. (Figure 11) elaborates on the pattern of international cooperation, visually illustrating the dynamics of collaboration within this study domain. In this diagram, color intensity denotes the number of publications, whereas brown lines indicate collaboration links. This picture provides a thorough global overview, depicting the varied levels of connectivity among nations and the possibility for enhanced international collaborations in this academic field.

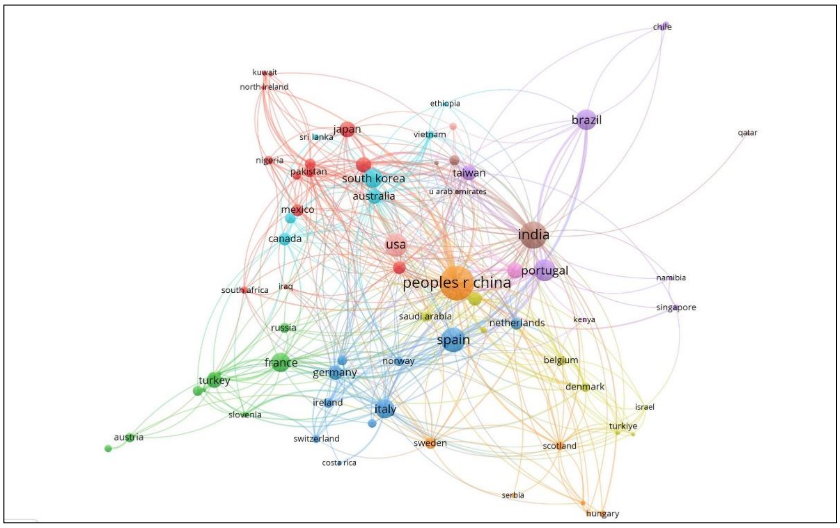

Fig. 10 Collaboration network among nations producing microalgal utilization in cosmetics research (≥ 2 articles)

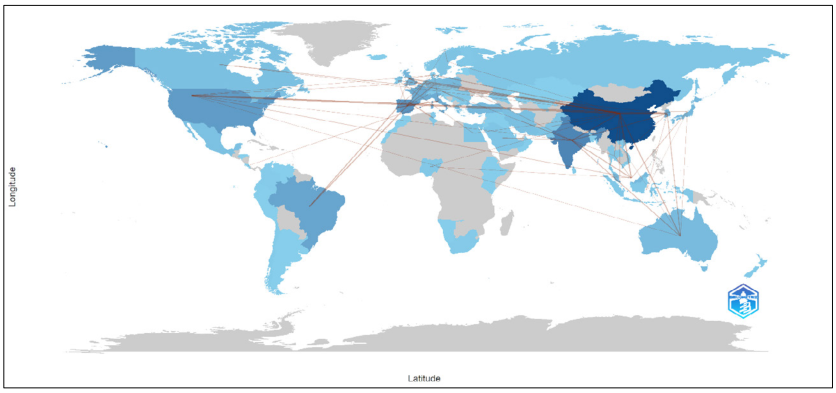

Fig. 11 Country collaboration map among countries concerned about microalgal utilization in cosmetics research

The utilization of keywords and co-occurrence network research techniques

The Keyword Co-occurrence Network (KCN) methodology is commonly used in several study fields to analyze the structure of knowledge and research trends within literature. This approach involves establishing a network where keywords are depicted as nodes, and the links between keywords indicate their prevalence together in the literature. By examining KCNs, academics can identify increasing and declining research patterns, uncover intersections and links among various subject areas, and contribute to the advancement of industrial practices. An analysis of KCNs provides a significant understanding of the elements and organization of information in literature. This helps academics, educators, and industry leaders discover study areas and current knowledge trends in their domains. In addition, the inclusion of keywords is a commonly used technique in academic research to summarize the main ideas of a paper, mostly due to their brief and precise character (Chen et al. 2008). Where (Figure 12) displays a visually attractive word cloud that was created using the keywords provided by the authors. This word cloud serves as a succinct and enlightening instrument for condensing textual information. The size and proximity of each word within the cloud indicate its value, enabling quick identification of the most significant and frequently used terms (Liao et al. 2019). The term that stands out the most is “personal care products,” highlighting their significant relevance in this particular domain. Additional noteworthy terms encompass “microalgae,” “antioxidant activity,” “pharmaceuticals,” and “waste-water treatment,” indicating that these are prominent areas of concentration. Notable species of microalgae such as “*C. vulgaris*,” “*H. pluvialis*,” and “*Spirulina platensis*” are commonly cited due to their significance in cosmetic uses. The inclusion of terms like “biomass,” “extraction,” and “toxicity” further signifies significant research areas concerning the manufacturing and safety of cosmetic components derived from microalgae. This visualization offers a concise summary of the primary subjects and patterns in the study of using microalgae for cosmetic purposes. The industry’s keenness on integrating microalgae-derived compounds in “personal care products” highlights the significance of these substances due to their advantageous qualities. The frequent reference to “antioxidant activity” emphasizes the possible health advantages of these components, while the use of phrases such as “waste-water treatment” indicates a concern for sustainable and eco-friendly approaches. Furthermore, the co-occurrence network depicted in (Figure 13) illustrates the connections between author-provided terms in the field of microalgal usage in cosmetics research. Specifically, it highlights keywords that occur together at least four times. The keywords “microalgae,” “cosmetics,” “skin care products,” and “antioxidant activity” are highly significant and frequently appear together with other terms, making them central nodes. The network is partitioned into clusters, with each cluster being denoted by distinct colors, thereby grouping keywords that are connected. For instance, one cluster may prioritize “biofuel production” and “biomass,” while another highlights “antioxidant activity” and “skin care products.”

In order to fully understand the complex connections between keywords, authors, and sources in the field of microalgal use in cosmetics research, a three-field plot, also known as a Sankey diagram, was used to provide comprehensive context. This visualization tool allows for the depiction of patterns and connections among these basic elements, with the size of the boxes in the diagram directly reflecting the quantities of keywords, authors, or sources. The interconnectivity of research in this sector is well illustrated in (Figure 14). Keywords such as “microalgae,” “cosmetics,” and “antioxidant activity” are prominently featured in the literature, suggesting their significance and frequent occurrence. Authors are associated with several

Fig. 12 Keyword-based wordcloud of the most frequent microalgal utilization in cosmetics research terms

keywords, indicating their varied research interests. The progression from keywords to sources elucidates the journals that are producing research on these themes with the highest frequency. The fact that microalgal research in cosmetics is multidisciplinary is highlighted by this interconnection, which involves major contributions from several scientific disciplines. This observation underscores the crucial significance of these keywords in the discourse, accentuating their dominance in the field. Furthermore, the graphic illustrates discrepancies in the implementation of keywords. Certain authors have utilized a comprehensive array of keywords, which showcases the wide range of their research interests, whereas others have opted for more precise and distinctive keywords.

While (Figure 15) depicts a visual representation of the prominent trends in the field of microalgae usage in cosmetics research. The graph shows a clear change in the use of microalgae in different topics. The use of microalgae in cosmetics, specifically in "personal care products," was prominent between 2017 and 2022 with a frequency of 200 terms. Similarly, the use of "microalgae" was notable from 2018 to 2022 with a frequency of 150 terms. However, there has been a shift towards the use of microalgae in emerging themes such as "pharmaceuticals," which has gained prominence from 2014 to 2021 with a frequency of 100 terms. These emerging subjects can be accurately described as "trending topics" or "hotspots" in the field of scholarly publications that concentrate on the use of microalgae in cosmetics research. The appearance of these subjects might be understood as a manifestation of the ever-changing and progressive character of research in this sector. It supports the idea that popular topics usually indicate areas or locations that are experiencing fast growth and change within a specific field of study (Neff and Corley 2009; Van Eck and

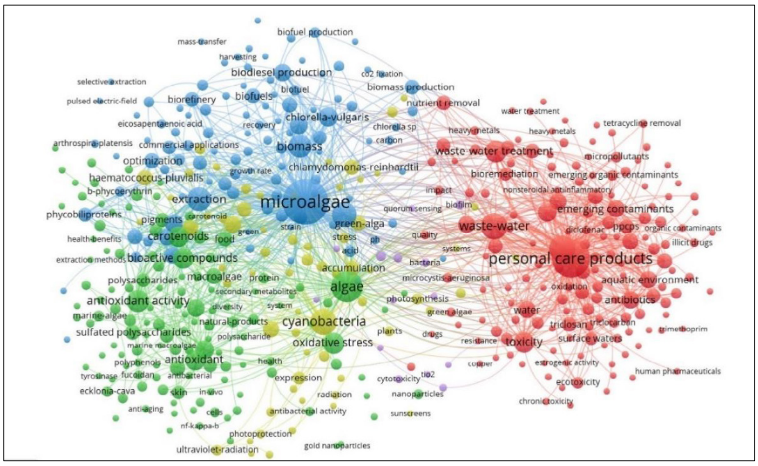

Fig. 13 Co-occurrence network for author-provided microalgal utilization in cosmetics research keywords (≥ 4 keywords)

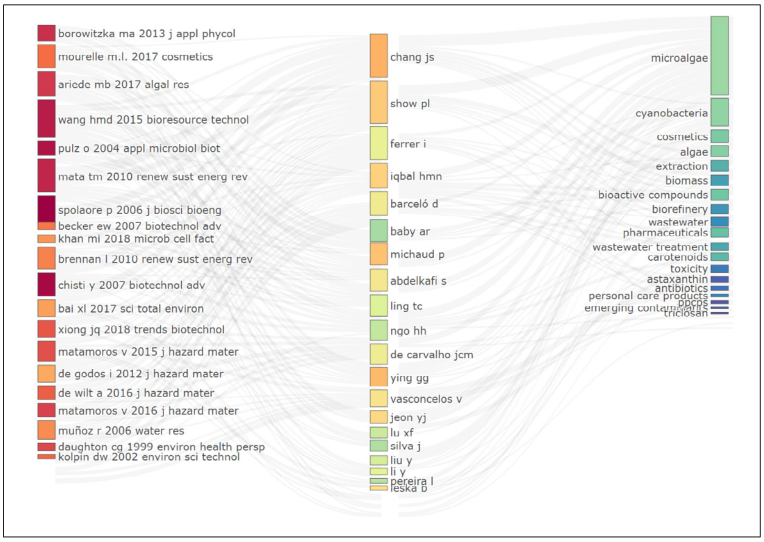

Fig. 14 Sankey diagram for microalgal utilization in cosmetics research flow (each column from left to right source, author, keywords)

Waltman. 2014). Fluctuations or rapid increases in keywords can also work as signs of "potential fronts," indicating areas of research that are gaining momentum and developing (Mostafa 2023). Researchers have proposed that knowledge in a particular field often consists of a sequence of problems that emerge, gain importance over time, and then eventually diminish (Qian et al. 2019).

Thematic maps

Furthermore, (Figure 16) presents a thematic/strategic map illustrating the research conducted on microalgal utilization in cosmetics. The graphic is divided by a dashed line, which represents the average values of both axes. This division creates four unique quadrants, each reflecting specific thematic areas. The magnitude of the bubbles in the graph is directly proportional to the frequency of keywords in scholarly articles. According to Cobo et al. (2011), the first quadrant, positioned in the upper right, is distinguished by a high concentration and importance, indicating well-established topics that are prominent both within and outside the field, commonly referred to as "motor themes." Transitioning to the second quadrant, located in the upper left, the themes found here demonstrate a high level of concentration but a low level of centrality. This indicates strong internal connections but little exterior impact, leading to their classification as "highly-developed-and-isolated themes." In the third quadrant, which is the bottom left quadrant, themes are characterized by both low density and centrality. This indicates that there are weak internal and external linkages. As a result, these themes are referred to as "emerging-or-declining themes." Finally, the fourth quadrant, located on the lower right, consists of themes characterized by low density and high centrality. These motifs indicate little internal growth but large outward linkages and are referred to as "basic-and-transversal themes." For that (Figure 16) examined motor themes, including "personal care products," "waste-water

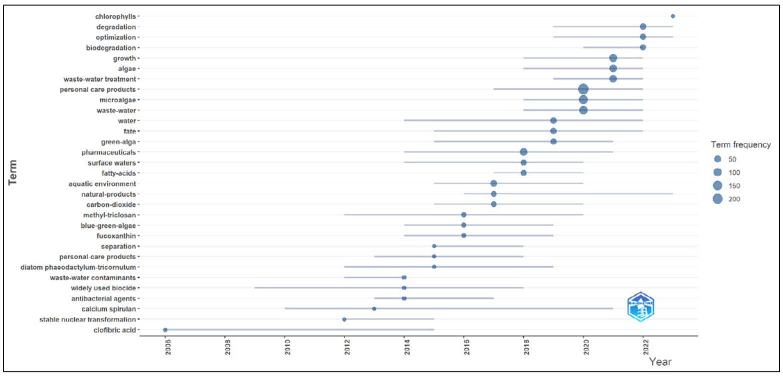

Fig. 15 Microalgal utilization in cosmetics research trending topics over time

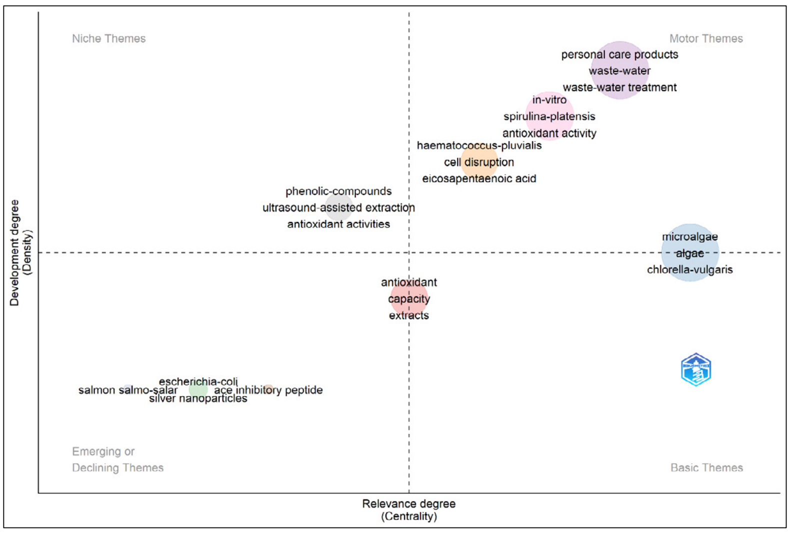

Fig. 16 Microalgae utilization in cosmetics research thematic/strategic map

treatment," "*H. pluvialis*," and "antioxidant activity," which have been extensively studied and are of great significance. This underscores their importance in current research and their potential to drive future advancements. Study disciplines that are highly focused and extensively developed, such as "ultrasonic-assisted extraction" and "antioxidant activities," are regarded as niche subjects. Nevertheless, their broader significance may be constrained, as they just pertain to specific research domains that enhance the comprehensiveness of the subject. Foundational themes, denoted by terminology like "microalgae," "algae," and "*C. vulgaris*," are fundamental and widely relevant, but may lack significant advancements. These issues are fundamental to the research field and offer essential background information. Themes such as "*Escherichia coli* inhibitory peptide" and "silver nanoparticles" are experiencing either a rise or a fall in popularity. This suggests that they are either emerging as new topics of research or diminishing in significance. It proposes potential new avenues of research or areas that are receiving less focus. This strategic map provides a comprehensive overview of the current state and future potential of research on the utilization of microalgae in the cosmetics industry. The tool highlights significant focal points, developing trends, and essential concepts, aiding researchers in finding viable topics for further investigation and collaboration.

Discussion

Overview of microalgae utilization in cosmetics

Microalgae have become increasingly important in various businesses, especially in the cosmetics sector, due to their prospective applications (De Luca et al. 2021). The growing interest stems from the significant presence of bioactive compounds in them, including proteins, polysaccharides, lipids, and pigments, which offer various benefits for skin care and cosmetic products. Microalgae are highly remarkable for their rapid growth and high biomass production capacity (Cagney and O'Neill. 2024). They function as an abundant source of organic compounds, such as antioxidants, vitamins, minerals, and essential fatty acids (Wu et al. 2021). The cosmetics industry highly values these bioactive compounds for their capacity to provide anti-aging, moisturizing, and UV-protective advantages. The present scientometric investigation entailed a comprehensive scrutiny of scholarly works about the utilization of microalgae in cosmetics from 2005 to 2024. The data was acquired via the Web of Science. The analysis employed bibliometric methodologies to assess publishing trends, citation patterns, co-authorship networks, and keyword co-occurrence, providing a comprehensive assessment of the research landscape in both quantitative and qualitative terms. Table 5 highlights the adaptability of several microalgae species within the cosmetic sector. Species such as *Chlorella* and *Spirulina* are abundant in chlorophyll, carotenoids, proteins, and vitamins, providing diverse benefits including anti-aging, antioxidant, and moisturizing effects. These compounds, recognized for their capacity to mitigate oxidative stress and enhance skin health, are increasingly desired in formulations

Table 5 Overview of microalgae species, their bioactive compounds, and potential applications in cosmetics

Microalgae species	Compounds	Potential uses in cosmetics	References
Chlorella	Chlorophyll, Carotenoids, Proteins, Vitamins	Anti-aging, Antioxidant, Moisturizing, Skin Whitening	(Leong et al. 2024)
Spirulina	Phycocyanin, Chlorophyll, Proteins, Vitamins	Anti-aging, Antioxidant, Photoprotection, Skin Conditioning	(Mourelle et al. 2017)
Haematococcus pluvialis	Astaxanthin, Carotenoids	Anti-aging, Antioxidant, Sunscreen, Skin Whitening	(Saini et al. 2024)
Dunaliella salina	Beta-carotene, Carotenoids	Anti-aging, Antioxidant, Skin Whitening, Moisturizing	(Stoyneva-Gärtner et al. 2020)
Aphanizomenon flosaquae	Phycocyanin, Chlorophyll, Proteins	Anti-aging, Antioxidant, Skin Conditioning, Soothing	(Saini et al. 2024)
Arthrospira platensis	Ferulic acid, cafeic acid	Anti-melanogenesis	(Sahin. 2018)
Scenedesmus rubescens	Amino acids (alanine and glycine), vitamin b3	Photoprotection, anti-melanogenesis, anti-aging	(Campiche et al. 2018)
Coelastrella rubescens	Carotenoids and MAAs	Photoprotection	(Zaytseva et al. 2021)
Chlamydomonas reinhardtii	Carotenoids (neoxanthin, violaxanthin, lutein,	Anti-melanogenesis	(Sedjati et al. 2020)
Nannochloropsis oculata	Carotenoids, pigments	Antioxidant	(Gkioni et al. 2022)
Chlorella	Polysaccharides	Moisturizing and thickener agent	(Jain et al. 2005)
Arthrospira platensis	Exopolysaccharides	Antioxidant	(de Jesus Raposo et al. 2015)
Porphyridium sp.	Sulfated polysaccharides		
Odontella aurita	Chrysolaminarin	Antioxidant	(Xia et al. 2014)
Dunaliella salina	ß-carotenes	Antioxidant	(Hamed. 2016)
Spirulina, Porphyridium	phycoerythrobilin	Antioxidant, Pigment for eye-liner and lipsticks	
Dunaliella salina	β-Cryptoxanthin	Anti-inflammatory Promote Hyaluronan synthesis	(Tang and Suter. 2011)
Anabaena vaginicola	Lycopene	Antioxidant Anti-ageing Sunscreen	(Hashtroudi et al. 2013)
Nannochloropsis oceanica	Phytohormones	Anti-aging	(Michelet et al. 2012)
Chlorella	Polysaccharides	Moisturizing and thickener agent	(Jain et al. 2005)

intended to restore skin vitality and diminish indications of aging. Research conducted by (Leong et al. 2024) and (Mourelle et al. 2017) substantiates the effectiveness of these species, particularly in mitigating skin damage and enhancing general skin health. Moreover, the elevated concentrations of astaxanthin and carotenoids in *H. pluvialis* render it a powerful component for sunscreens and anti-aging formulations. Astaxanthin exhibits significant antioxidant properties that confer photoprotection and anti-aging benefits, as indicated by (Saini et al. 2024). *Dunaliella salina*, recognized for its beta-carotene content, aids in skin whitening and moisturizing, hence justifying its incorporation in cosmetic products aimed at various skin care requirements. Polysaccharides derived from *Chlorella* and *Arthrospira platensis* are distinguished by their moisturizing and thickening characteristics, rendering them suitable for hydrating formulations. Furthermore, the anti-melanogenesis attributes of some species, such as *Scenedesmus rubescens* and *Chlamydomonas reinhardtii*, underscore the potential of microalgae in formulations aimed at inhibiting melanin synthesis and mitigating hyperpigmentation concerns. The explicit incorporation of species such as *Anabaena vaginicola* and *Nannochloropsis oceanica*, recognized for their lycopene and phytohormones respectively, underscores the potential of microalgae in enhancing skin repair, anti-aging, and sunscreen properties. The varied chemicals in microalgae make them interesting candidates for sustainable and effective cosmetic uses.

Key insights from the scientometric analysis of microalgae utilization in cosmetics

The purpose of this study was to visually portray and map the research conducted on the use of microalgae in cosmetics. Simultaneously, it sought to examine the evolutionary path of scholarly papers in this discipline while uncovering the intellectual core that distinguishes it. We used scientometric networks as a methodological framework to analyze a dataset of 1,000 academic publications on the use of microalgae in cosmetics research. The dataset covered a period of 20 years, from 2005 to 2024. The authorship of these papers is attributed to 4,269 academicians hailing from 79 distinct nations. By employing a bibliometric approach, we ensured the impartiality of our conclusions by basing them on empirical facts, as opposed to relying on subjective techniques. This strategy enabled us to bypass the inherent biases linked to sample selection, which often plague traditional research methodologies (Linnenluecke et al. 2020). Our goal was to overcome the constraints of conventional research methods, which frequently overlook the dynamic connections between authors, scholarly publications, and the journals in which they are published. Chen and Leydesdorff (2014) emphasized the crucial importance of these links in understanding the significant advancements in intellectual development and the path of knowledge within a research field as time progresses. This study is the first comprehensive bibliometric examination of the use of microalgae in cosmetics research. It includes all published documents from the important period of 2005 to the present. Through our diligent work, we have been able to accurately identify notable researchers, important journals, and significant trends and themes in this complex area.

A comprehensive analysis of co-citation networks, including authors and journal sources, has revealed a hub-and-spoke structure in the research networks of microalgal usage in cosmetics, similar to small-world networks. This structural characteristic indicates the existence of a small number of influential entities that have significant influence inside the network. These organizations are widely acknowledged as leading academic institutions in the field of microalgal usage in cosmetics research. They play a crucial role in spreading and exchanging information within the network, connecting important groups, as previously stated by Park et al. (2015). On the other hand, small-world networks, which are characterized by nodes that are densely coupled and closely grouped, enable the effective distribution of information (Shirky 2008). In addition, Smith and Graham (2019) argue that small-world networks exhibit resilience, as the elimination of nodes has a negligible effect on network dynamics. Another nottable observation pertains to the collaboration patterns among institutions and nations, which are influenced by characteristics such as cultural proximity, geographical distance, and specialized patterns. This finding supports prior research, as demonstrated by the study conducted by Prieto-Gutiérrez and Segado-Boj (2019), which examined collaborative tendencies among authors from Asia. Moreover, our categorization of universities as the principal research entities, with research institutions as secondary, aligns with previous study findings (Chen and Liu. 2020).

This comprehensive dataset encompasses 1000 academic research documents from 381 distinct sources, including journals and books. The dataset's impressive annual growth rate of 13% indicates a slightly burgeoning interest in its subject matter. With an average document age of 4.79 years and an average citation count of 48.25 per document, it reflects a contemporary and highly referenced body of work. The dataset includes a substantial 60,940 references, providing a broad context for the research. Additionally, the dataset contains valuable content analysis elements such as 2,888 Keyword-plus terms and 2,674 author-generated keywords. It involves 4,269 authors, 19 of whom have single-authored documents, emphasizing diversity in authorship. Collaboration is common, with an average of 5.32 co-authors per document, and 29.9% of collaborations being international. The dataset comprises various types of publications, including 605 articles, 31 articles that are also book chapters, 3 articles with early access, and 14 articles presented as proceedings papers. Additionally, there are 335 reviews, 5 reviews that are also book chapters, and 7 reviews with early access, showcasing a multifaceted dataset ideal for in-depth exploration of its chosen research domain. In addition, a thorough examination of the most influential sources for microalgal utilization in cosmetics research publications, with a primary focus on the number of articles published in each journal. Publications from a variety of periodicals are included in the dataset, including 65 from Marine Drugs, 51 from Science of the Total Environment, 50 from Algal Research-Biomass Biofuels and Bioproducts, 32 from the Journal of Applied Phycology, 20 from Bioresource Technology, and 20 from Molecules. Additionally, this list includes a wide variety of journals, such as those that specialize in sustainable development, science, environment, and cosmetics, which is indicative of the multifaceted nature of microalgal utilization in cosmetics research. To expand on the overview and key insights of this research, the findings hold significant implications for the strategies of marketing utilized in the cosmetics industry. Marketers may translate the increasing scientific interest in microalgae as a growing market opportunity for cosmetics that incorporate such sustainable ingredients. By tapping into the rising consumer demand for natural and sustainable beauty products, marketers can highlight the ecological benefits and unique properties found in microalgae in promotional campaigns.

Limitations and future research

Although this study has made valuable contributions, it is important to highlight numerous limitations. Our research differs from Holub and Johnson (2018), in that we solely rely on a single database, rather than combining data from several sources. This technique may result in more cautious citation and relationship counts compared to alternative sources such as Scopus and Google Scholar. It is important to mention that most of the documents included in sites like the Web of Science are also included in Scopus (Gavel and Iselid. 2008). In addition, Google Scholar is known for its comprehensive approach to considering citations from many sources such as blogs, unpublished presentations, and related resources (Neuhaus et al. 2006). Future research could investigate the integration of additional databases to support and validate our findings. Furthermore, similar to previous research, such as the study conducted by Qian et al. (2019), we restricted our search to publications that were published in the English language. This linguistic limitation may limit the scope of our coverage, and future research should consider including articles in other languages, especially those from highly productive countries like China, to evaluate the applicability of our results across various linguistic contexts.

Researchers and academics can use this information to find important channels for publishing their work and stay informed about the newest advancements in this ever-changing field of research. Several important factors should be considered while considering future research projects. Our study conducted a comprehensive bibliometric analysis of 20 years of research publications on the use of microalgae in cosmetics. Future investigations could consider using a topic modeling approach to uncover hidden patterns in the textual data of microalgae utilization in cosmetics research, as demonstrated by Chen et al. (2020). This methodology can reveal hidden topic frameworks inherent in scholarly papers, therefore providing further insights into the field. Furthermore, our study utilized a co-citation network method, which is a well-established technique in literature. However, it is important to recognize Skupin's assertion that this approach might occasionally hide important connections (Skupin 2009). Hence, future research endeavors could involve doing a comparative examination of the co-citation techniques utilized in our work with other strategies. This comparative investigation aims to validate the findings and enhance our understanding of the intellectual landscape in the field of microalgal use in cosmetics research.

Conclusions

To summarize, the application of microalgae in cosmetics has experienced significant growth and development in the last twenty years. Our scientometric analysis shows that the field of research on using microalgae for cosmetic purposes is lively and active. We observed a significant annual growth of 13% in the number of publications, indicating a growing interest in this area. The dataset covers the period from 2005 to 2024 and includes 1,000 papers from 381 sources. It highlights the current importance of the topic, with an average document age of 4.79 years and an average of 48.25 citations per document. The study reveals a significant amount of information, with 60,940 references, 2,888 Keyword-plus phrases, and 2,674 author-generated keywords, demonstrating the vast scope of research. Collaboration is an important aspect, with an average of 5.32 co-authors per document and 29.9% of collaborations being international, indicating a strong worldwide network. The interdisciplinary nature of this research is further shown by influential journals such as Marine Drugs and Science of the Total Environment. In summary, this study validates the considerable promise of microalgae in the creation of environmentally friendly and efficient cosmetic products. The acquired insights establish a strong basis for forthcoming research, product development, and innovation, directing the development of original goods and promoting ongoing collaboration in this auspicious domain.

Conflict of interest statement The authors have no declared conflicts of interest.

Data Availability Statement Data will be made available on request.

References

Ahmed MB, Zhou JL, Ngo HH, Guo W, Thomaidis NS, Xu J (2017) Progress in the biological and chemical treatment technologies for emerging contaminant removal from wastewater: a critical review. J Hazard Mater 323:274-298

Ambati RR, Gogisetty D, Aswathanarayana RG, Ravi S, Bikkina PN, Bo L, Yuepeng S (2019) Industrial potential of carotenoid pigments from microalgae: Current trends and future prospects. Crit Rev Food Sci Nutr 59(12):1880-1902

Avila-Robinson A, Wakabayashi N (2018) Changes in the structures and directions of destination management and marketing research: A bibliometric mapping study, 2005–2016. J Destin Mark Manag 10:101-111

Bakshy E, Hofman JM, Mason WA, Watts DJ (2011) Everyone's an influencer: quantifying influence on twitter. In: Proceedings of the fourth ACM international conference on web search and data mining, 2011. pp 65-74

Becker EW (2007) Micro-algae as a source of protein. Biotechnol Adv 25(2):207-210

Benckendorff P (2009) Themes and trends in Australian and New Zealand tourism research: A social network analysis of citations in two leading journals (1994–2007). J Hospit Tourism Manag 16(1):1-15

Boichenko M, Zinchenko V (2022) Наукометрія, бібліометрія і інфометрія: облік наукових досліджень і прогрес науки під кутом зору філософії стратегії глобального стійкого розвитку. Filosofiya Osvity Philos Educ 28(1):119-138

Borowitzka MA (2013) High-value products from microalgae their development and commercialisation. J Appl Psychol 25:743-756

Bradford SC (1934) Sources of information on specific subjects. Engineering 137:85-86

Burt RS (1999) The social capital of opinion leaders. The annals of the american academy of political and social science 566(1):37-54

Cagney MH, O'Neill EC (2024) Strategies for producing high value small molecules in microalgae. Plant Physiol Biochem:108942

Callon M, Courtial JP, Laville F (1991) Co-word analysis as a tool for describing the network of interactions between basic and technological research: The case of polymer chemsitry. Scientometrics 22:155-205

Campiche R, Sandau P, Kurth E, Massironi M, Imfeld D, Schuetz R (2018) Protective effects of an extract of the freshwater microalga *Scenedesmus rubescens* on UV-irradiated skin cells. Int J Cosmet Sci 40(2):187-192

Carballo-Cárdenas EC, Tuan PM, Janssen M, Wijffels RH (2003) Vitamin E (α-tocopherol) production by the marine microalgae *Dunaliella tertiolecta* and *Tetraselmis suecica* in batch cultivation. Biomol Eng 20(4-6):139-147

Cardozo KH, Guaratini T, Barros MP, Falcão VR, Tonon AP, Lopes NP, Campos S, Torres MA, Souza AO, Colepicolo P (2007) Metabolites from algae with economical impact. Comp Biochem Physiol C Toxicol Pharmacol 146(1-2):60-78

Chen C, Leydesdorff L (2014) Patterns of connections and movements in dual-map overlays: A new method of publication portfolio analysis. J Assoc Inf Sci Technol 65(2):334-351

Chen C, Song I-Y, Yuan X, Zhang J (2008) The thematic and citation landscape of data and knowledge engineering (1985–2007). Data Knowl Eng 67(2):234-259

Chen X, Liu Y (2020) Visualization analysis of high-speed railway research based on CiteSpace. Transp Policy 85:1-17

Chen X, Zou D, Xie H (2020) Fifty years of british journal of educational technology: A topic modeling based bibliometric perspective. Br J Educ Technol 51(3):692-708

Chew KW, Yap JY, Show PL, Suan NH, Juan JC, Ling TC, Lee D-J, Chang J-S (2017) Microalgae biorefinery: high value products perspectives. Bioresour Technol 229:53-62

Cobo MJ, López-Herrera AG, Herrera-Viedma E, Herrera F (2011) An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. J Informetr 5(1):146-166. doi:https://doi.org/10.1016/j.joi.2010.10.002

Couteau C, Coiffard L (2018) Chapter 15 - Microalgal Application in Cosmetics. In: Levine IA, Fleurence J (eds) Microalgae in Health and Disease Prevention. Academic Press, pp 317-323. doi:https://doi.org/10.1016/B978-0-12-811405-6.00015-3

Cuccurullo C, Aria M, Sarto F (2016) Foundations and trends in performance management. A twenty-five years bibliometric analysis in business and public administration domains. Scientometrics 108:595-611

de Jesus Raposo MF, De Morais AMB, De Morais RMSC (2015) Marine polysaccharides from algae with potential biomedical applications. Mar Drugs 13(5):2967-3028

de Jesus Raposo MF, de Morais RMSC, de Morais AMMB (2013) Health applications of bioactive compounds from marine microalgae. Life Sci 93(15):479-486

De Luca M, Pappalardo I, Limongi AR, Viviano E, Radice RP, Todisco S, Martelli G, Infantino V, Vassallo A (2021) Lipids from microalgae for cosmetic applications. Cosmetics 8(2):52

Derrien A, Coiffard LJ, Coiffard C, De Roeck-Holtzhauer Y (1998) Free amino acid analysis of five microalgae. J Appl Phycol 10:131-134

Ding Y (2011) Scientific collaboration and endorsement: Network analysis of coauthorship and citation networks. J Informetr 5(1):187-203

Dussably J, Mshvildadze V, Pichette A, Ripoll L (2022) Microalgae and diatom potential pharmaceutical and cosmetic resources–Review. J Biomed Res Environ Sci. 2022 Sep 23:3(9):1082-1092. doi: 10.37871/jbres1559

Fang Y, Yin J, Wu B (2018) Climate change and tourism: A scientometric analysis using CiteSpace. J Sustain Tour 26(1):108-126

Findlay K, Janse van Rensburg O (2018) Using interaction networks to map communities on Twitter. Int J Mark Res 60(2):169-189

Firdaus A, Razak MFA, Feizollah A, Hashem IAT, Hazim M, Anuar NB (2019) The rise of "blockchain": bibliometric analysis of blockchain study. Scientometrics 120:1289-1331

Gavel Y, Iselid L (2008) Web of Science and Scopus: a journal title overlap study. Online information review 32(1):8-21

Gkioni MD, Andriopoulos V, Koutra E, Hatziantoniou S, Kornaros M, Lamari FN (2022) Ultrasound-assisted extraction of *Nannochloropsis oculata* with ethanol and betaine: 1, 2-propanediol eutectic solvent for antioxidant pigment-rich extracts retaining nutritious the residual biomass. Antioxidants 11(6):1103

Glötzl F, Aigner E (2018) Orthodox Core–Heterodox periphery? Contrasting citation networks of economics departments in Vienna. Rev Polit Econ 30(2):210-240

Grossman A (2016) Nutrient acquisition: the generation of bioactive vitamin B12 by microalgae. Curr Biol 26 (8):R319-R321

Gruzd A, Wellman B, Takhteyev Y (2011) Imagining Twitter as an imagined community. Am Behav Sci 55(10):1294-1318

Guedes AC, Amaro HM, Barbosa CR, Pereira RD, Malcata FX (2011) Fatty acid composition of several wild microalgae and cyanobacteria, with a focus on eicosapentaenoic, docosahexaenoic and α-linolenic acids for eventual dietary uses. Food Res Int 44(9):2721-2729

Hamed I (2016) The evolution and versatility of microalgal biotechnology: A review. Comprehen Rev Food Sci Food Saf 15(6):1104-1123

Hashtroudi MS, Shariatmadari Z, Riahi H, Ghassempour A (2013) Analysis of *Anabaena vaginicola* and *Nostoc calcicola* from Northern Iran, as rich sources of major carotenoids. Food Chem 136(3-4):1148-1153

Haythornthwaite C (1996) Social network analysis: An approach and technique for the study of information exchange. Lib Inf Sci Res 18(4):323-342

Hjørland B (2013) Citation analysis: A social and dynamic approach to knowledge organization. Inf Process Manag 49(6):1313-1325

Holub M, Johnson J (2018) Bitcoin research across disciplines. Info Soc 34(2):114-126

Hood WW, Wilson CS (2001) The literature of bibliometrics, scientometrics and informetrics. Scientometrics 52:291-314

Jain R, Raghukumar S, Tharanathan R, Bhosle N (2005) Extracellular polysaccharide production by thraustochytrid protists. Mar Biotechnol 7:184-192

Jiang Y, Ritchie BW, Benckendorff P (2019) Bibliometric visualisation: An application in tourism crisis and disaster management research. Curr Issues Tour 22(16):1925-1957

Khan GF, Wood J (2016) Knowledge networks of the information technology management domain: A social network analysis approach. Commun Assoc Inf Syst 39(1):18

Kim MC, Chen C (2015) A scientometric review of emerging trends and new developments in recommendation systems. Scientometrics 104:239-263

Knoke D, Yang S (2019) Social network analysis. SAGE publications, Kumar S, Kumar S (2008) Collaboration in research productivity in oil seed research institutes of India. In: Proceedings of fourth international conference on webometrics, informetrics and scientometrics. Humboldt-Universitat zu Berlin, Institute for Library and Information (Vol. 28)

Law J, Bauin S, Courtial J, Whittaker J (1988) Policy and the mapping of scientific change: A co-word analysis of research into environmental acidification. Scientometrics 14(3-4):251-264

Leong HJ-Y, Teoh M-L, Beardall J, Convey P (2024) Green beauty unveiled: Exploring the potential of microalgae for skin whitening, photoprotection and anti-aging applications in cosmetics. J Appl Phycol. doi:10.1007/s10811-024-03345-4

Leu S, Boussiba S (2014) Advances in the production of high-value products by microalgae. Ind Biotechnol 10(3):169-183

Liao H, Tang M, Li Z, Lev B (2019) Bibliometric analysis for highly cited papers in operations research and management science from 2008 to 2017 based on essential science indicators. Omega 88:223-236

Lin J-S, Himelboim I (2019) Political brand communities as social network clusters: winning and trailing candidates in the GOP 2016 primary elections. J Polit Mark 18(1-2):119-147

Linnenluecke MK, Marrone M, Singh AK (2020) Conducting systematic literature reviews and bibliometric analyses. Aust J Manag 45(2):175-194

Lotka AJ (1926) The frequency distribution of scientific productivity. J Wash Acad Sci 16(12):317-323

Manirafasha E, Ndikubwimana T, Zeng X, Lu Y, Jing K (2016) Phycobiliprotein: Potential microalgae derived pharmaceutical and biological reagent. Biochem Eng J 109:282-296

Martínez-Ruiz M, Martínez-González CA, Kim D-H, Santiesteban-Romero B, Reyes-Pardo H, Villaseñor-Zepeda KR, Meléndez-Sánchez ER, Ramírez-Gamboa D, Díaz-Zamorano AL, Sosa-Hernández JE (2022) Microalgae bioactive compounds to topical applications products-a review. Molecules 27(11):3512

McPherson M, Smith-Lovin L, Cook JM (2001) Birds of a feather: Homophily in social networks. Annu Rev Sociol 27(1):415-444

Merediz-Solà I, Bariviera AF (2019) A bibliometric analysis of bitcoin scientific production. Res Int Bus Finance 50:294-305

Michelet JF, Olive C, Rieux E, Fagot D, Simonetti L, Galey JB, Dalko-Csiba M, Bernard BA, Pereira R (2012) The anti-ageing potential of a new jasmonic acid derivative (LR2412): in vitro evaluation using reconstructed epidermis episkin™. Exp Dermatol 21(5):398-400
Moed HF, Glänzel W, Schmoch U (2004) Handbook of quantitative science and technology research. The use of publications and patent statistics in studies of S&T systems. Dordrecht: Kluwer academic publisher.
Morocho-Jácome AL, Ruscinc N, Martinez RM, de Carvalho JCM, Santos de Almeida T, Rosado C, Costa JG, Velasco MVR, Baby AR (2020) (Bio) Technological aspects of microalgae pigments for cosmetics. Appl Microbiol Biotechnol 104:9513-9522
Mostafa MM (2023) Twenty years of wikipedia in scholarly publications: a bibliometric network analysis of the thematic and citation landscape. Qual Quant:1-31
Mourelle ML, Gómez CP, Legido JL (2017) The potential use of marine microalgae and cyanobacteria in cosmetics and thalassotherapy. Cosmetics 4(4). doi:10.3390/cosmetics4040046
Neff M, Corley E (2009) 35 years and 160,000 articles: A bibliometric exploration of the evolution of ecology. Scientometrics 80(3):657-682
Neuhaus C, Neuhaus E, Asher A, Wrede C (2006) The depth and breadth of Google Scholar: An empirical study. portal: Libraries and the Academy 6(2):127-141
Park SJ, Lim YS, Park HW (2015) Comparing Twitter and YouTube networks in information diffusion: The case of the “Occupy Wall Street” movement. Technol Forecast Soc Change 95:208-217
Prieto-Gutiérrez JJ, Segado-Boj F (2019) Annals of library and information studies: a bibliometric analysis of the journal and a comparison with the top library and information studies journals in Asia and worldwide (2011–2017). Ser Libr 77(1-2):38-48
Priyadarshani I, Rath B (2012) Commercial and industrial applications of micro algae–A review. J Algal Biomass Util 3(4):89-100
Qian J, Law R, Wei J (2019) Knowledge mapping in travel website studies: a scientometric review. Scand J Hospit Tour 19(2):192-209. doi:10.1080/15022250.2018.1526113
R-Development-Core-Team (2021) R: A language and environment for statistical computing. R foundation, for statistical computing, Vienna, Austria (wwwR- proje ct org) (2021)
Sahin SC (2018) The potential of arthrospira platensis extract as a tyrosinase inhibitor for pharmaceutical or cosmetic applications. South Afr J Bot 119:236-243
Saini KC, Rani A, Gupta SK, Sharma P (2024) Algae a potential source in cosmetics: current status, challenges, and economic implications. Indian J Microbiol. doi:10.1007/s12088-024-01263-0
Salinas-Ríos K (2022) Bibliometrics, a useful tool within the field of research. J Basic Appl Psychol Res 3(6):9-16
Sasounian R, Martinez RM, Lopes AM, Giarolla J, Rosado C, Magalhães WV, Velasco MVR, Baby AR (2024) Innovative approaches to an eco-friendly cosmetic industry: a review of sustainable ingredients. Clean Technol 6(1):176-198
Sedjati S, Pringgenies D, Fajri M (2020) Determination of the pigment content and antioxidant activity of the marine microalga *Tetraselmis suecica*. Jordan J Biol Sci 13(1):55-58
Shiau W-L, Dwivedi YK, Yang HS (2017) Co-citation and cluster analyses of extant literature on social networks. Int J Inf Manag 37(5):390-399
Shirky C (2008) Here comes everybody: The power of organizing without organizations. Penguin Press
Skupin A (2009) Discrete and continuous conceptualizations of science: Implications for knowledge domain visualization. J Informetr 3(3):233-245
Smith N, Graham T (2019) Mapping the anti-vaccination movement on facebook. Inf Commun Soc 22(9):1310-1327
Spence DP, Owens KC (1990) Lexical co-occurrence and association strength. J Psycholinguist Res 19:317-330
Spolaore P, Joannis-Cassan C, Duran E, Isambert A (2006) Commercial applications of microalgae. J Biosci Bioeng 101(2):87-96
Statista (2024) Beauty and personal care - global | statista market forecast. https://www.statista.com/outlook/cmo/beauty-personal-care/worldwide. Accessed 2024-07-14 21:56:12 2024
Stoyneva-Gärtner M, Uzunov B, Gärtner G (2020) Enigmatic microalgae from aeroterrestrial and extreme habitats in cosmetics: the potential of the untapped natural sources. Cosmetics 7(2). doi:10.3390/cosmetics7020027
Tang G, Suter PM (2011) Vitamin A, nutrition and health values of algae: *Spirulina*, *Chlorella* and *Dunaliella*. J Pharm Nutr Sci 1(2):111-118
Van Eck NJ, Waltman L (2014) Visualizing bibliometric networks. In: Measuring scholarly impact: Methods and practice. Springer, pp 285-320
van Eck NJ, Waltman L (2019) VOSviewer (Version 1.6. 13). computer program, Available at: https://www vosviewer com/download [Accessed: 15 February 2022]
Vinkler P (2010) Indicators are the essence of scientometrics and bibliometrics: Comments to the book entitled “Bibliometrics and Citation Analysis, from the science citation index to cybermetrics” from Nicola De Bellis. Scientometrics 85(3):861-866
Wakefield R (2008) Networks of accounting research: A citation-based structural and network analysis. Br Account Rev 40(3):228-244
Wan M, Hou D, Li Y, Fan J, Huang J, Liang S, Wang W, Pan R, Wang J, Li S (2014) The effective photoinduction of *Haematococcus pluvialis* for accumulating astaxanthin with attached cultivation. Bioresour Technol 163:26-32
Wang H-MD, Chen C-C, Huynh P, Chang J-S (2015) Exploring the potential of using algae in cosmetics. Bioresour Technol 184:355-362
Wetzstein A, Feisel E, Hartmann E, Benton Jr W (2019) Uncovering the supplier selection knowledge structure: a systematic citation network analysis from 1991 to 2017. J Purchas Supply Manag 25(4):100519
Wu J, Gu X, Yang D, Xu S, Wang S, Chen X, Wang Z (2021) Bioactive substances and potentiality of marine microalgae. Food Sci Nutr 9(9):5279-5292
Xia S, Gao B, Li A, Xiong J, Ao Z, Zhang C (2014) Preliminary characterization, antioxidant properties and production of chrysolaminarin from marine diatom *Odontella aurita*. Mar Drugs 12(9):4883-4897
Yang G-C, Li G, Li C-Y, Zhao Y-H, Zhang J, Liu T, Chen D-Z, Huang M-H (2015) Using the comprehensive patent citation network (CPC) to evaluate patent value. Scientometrics 105:1319-1346
Yang S, Han R, Wolfram D, Zhao Y (2016) Visualizing the intellectual structure of information science (2006–2015): Introducing

author keyword coupling analysis. J Informetr 10(1):132-150

Yarkent Ç, Gürlek C, Oncel SS (2020) Potential of microalgal compounds in trending natural cosmetics: A review. Sustain Chem Pharm 17:100304

Zaytseva A, Chekanov K, Zaytsev P, Bakhareva D, Gorelova O, Kochkin D, Lobakova E (2021) Sunscreen effect exerted by secondary carotenoids and mycosporine-like amino acids in the aeroterrestrial chlorophyte *Coelastrella rubescens* under high light and UV-A irradiation. Plants 10(12):2601

Zong Q-J, Shen H-Z, Yuan Q-J, Hu X-W, Hou Z-P, Deng S-G (2013) Doctoral dissertations of library and information science in China: A co-word analysis. Scientometrics 94:781-799

Zou X, Yue WL, Le Vu H (2018) Visualization and analysis of mapping knowledge domain of road safety studies. Accid Anal Prev 118:131-145

Zupic I, Čater T (2015) Bibliometric methods in management and organization. Organ Res Methods 18(3):429-472

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