RBES
Revista Brasileira de Engenharia e Sustentabilidade

ISSN 2448-1661
Pelotas, RS, UFPel-Ceng
https://periodicos.ufpel.edu.br/ojs2/index.php/RBES/index
v.9, n.2, p.18-25, dez. 2021

TRENDS OF MICROALGAE RESEARCH IN BRAZIL

MOREIRA, A. B. L.[1]

[1]Universidade Estadual de Goiás

Keywords:microalgae, research and development, scientific production

Abstract
Microalgae is a generic term to classify microscopic algae and have been studied in many countries for a variety of applications, but no research about microalgae trends in Brazil was found. Thus, this study aimed to assess the interests of microalgae research in Brazil through a scientometric approach. The research was performed on the Web of Science choosing "microalga" on title and Brazil as author's address. A total of 605 documents were found, whereas 83.8% were articles and English was the predominant language (93.6%). Brazil has collaborated with 35 countries and the most-collaborative was the United States. The most-productive institutions and authors were from the South and Southeast of Brazil, while women sum 45% of the most-prolific authors. In total, 371 research funding bodies were cited, Biotechnology Applied Microbiology was the most indexed Web of Science category, while Algal Research was the most-prolific journals. The most-cited keywords were biomass, biodiesel and wastewater. It is concluded that microalgae research in Brazil follow the trends of microalgae studies worldwide, there are national and international collaboration and even though the investments in research have decreased the number of publications keeps on growing.

TENDÊNCIAS NA PESQUISA DE MICROALGAS NO BRASIL

Palavra-Chave: microalga, pesquisa e desenvimento, produção científica.

Resumo
Microalga é um termo genérico para classificar algas microscópicas e tem sido estudado em muitos países para uma variedade de aplicações, mas nenhuma pesquisa sobre tendências de microalgas no Brasil foi encontrada. Assim, este estudo teve como objetivo avaliar os interesses da pesquisa em microalgas no Brasil por meio de uma abordagem cienciométrica. A pesquisa foi realizada na Web of Science escolhendo "microalga" no título e Brasil como endereço do autor. Foram encontrados 605 documentos, sendo 83,8% artigos e o inglês como idioma predominante (93,6%). O Brasil já colaborou com 35 países e o que mais colaborou foram os Estados Unidos. As instituições e autores mais produtivos foram do Sul e Sudeste do Brasil, enquanto as mulheres somam 45% dos autores mais prolíficos. No total, 371 instituições de financiamento de pesquisa foram citadas, Biotechnology Applied Microbiology foi a categoria Web of Science mais indexada, enquanto Algal Research foi o periódico mais prolífico. As palavras-chave mais citadas foram biomass, biodiesel and wastewater. Conclui-se que a pesquisa de microalgas no Brasil segue as tendências dos estudos de microalgas em todo o mundo, há colaboração nacional e internacional e embora os investimentos em pesquisa tenham diminuído o número de publicações continua crescendo.

Artigo Submetido dia 12/07/2021

Artigo Aceito dia 17/12/2021

INTRODUCTION

Microalgae is a generic term used to refer to microscopic algae between 5-50μm (UMMALYMA et al., 2017) including more than 300,000 species (ALAM; MOBIN; CHOWDHURY, 2015) that can live in the water column and sediments of fresh, marine, brackish and waste water (CHEAH et al., 2016).

Microalgae cover prokaryotic and eukaryotic, unicellular and multicellular (colonial or filamentous), autotrophic, heterotrophic and mixotrophic, motile or nonmotile organisms (BAHADAR; BILAL KHAN, 2013). The diversity of microalgae, that can reach 1,000,000 species, represents an excellent feedstock to explore (RUMIN et al., 2020).

In the last 20 years microalgae is being used for food and nutrition, cosmetic, chemical, pharmaceutical and biofuel industries (KONUR, 2020). Although all the advantages, there are gaps to scale-up microalgal biorefinery that involves mostly scientific and technological barriers(RUMIN et al., 2020).

Recently, scientometric analysis has been performed to quantify and characterize the microalgal scientific literature worldwide (GARRIDO-CARDENAS et al., 2018), in Europe (RUMIN et al., 2020), in science, technology and medicine, food, biomedicine, bioremediation, ecology (KONUR, 2020), for bioproducts (DE SOUZA et al., 2019), harvesting (NAZARI et al., 2020) and biofuels (ANDREO-MARTÍNEZ et al., 2020).

That being said and to the best of the author's knowledge, no bibliometric analysis of microalgae scenario in Brazil has been published yet. The aim of this work was to assess how the scientific interest in microalgae has evolved in Brazil. In order, we were looking for answers to the ensuing questions: a) when the interest for microalgae started in Brazil? b) Where are the researches taking place and which countries are collaborating with Brazil? c) Where the results are being published and in which knowledge areas? and d) what are the most appellant subjects on microalgal research in Brazil?

MATERIAL AND METHODS

This research was carried out on the Web of Science database (https://webofknowledge.com/) of the Institute for Scientific Information (ISI) during the temporary search period of 1945 and 2020. Data were collected on January 1st of 2021 at 9am using [TITLE: (microalga* *OR* micro-alga* *OR* "micro alga*") *AND* ADDRESS: (Brasil *OR* Brazil)] as Boolean strings and logical operators.

The limitation of this research was based on the database used, once there are other databases that could help on the expansion of the results obtained by this search. Data analysis was carried out using the Microsoft Excel 2016, VOSviewer (VAN ECK, 2013) and Bibliometrix (ARIA; CUCCURULLO, 2017) for RStudio.

RESULTS AND DISCUSSION

Publication Outputs

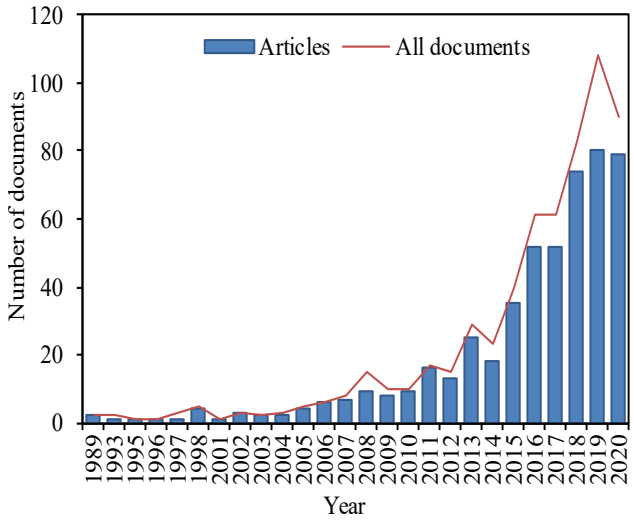
A total of 605 documents regarding to microalgae research in Brazil were identified and once articles were the principal publication type on the Brazilian microalgal scenario (507), they were selected to this analysis. The amount of documents found in this research is lower than the described in other microalgae scientometric investigations (KONUR, 2020).

In this case, the Author's address was a limitation field on the research coverage. On the other hand, microalgae research worldwide have published almost 80.000 articles and Brazil is on a top 20 rank of the most-prolific countries contributing on 0.64% of global paper publication (RUMIN et al., 2020).

The number of documents and articles published by Brazilian researches are shown in Figure 1. It was observed that along 31 years there was an increasing on microalgae publications in Brazil, but between 2015 and 2020 the publication number has doubled. The year of 2019 was the most expressive in number of publication on microalgae research in Brazil (Figure 1).

Brazilian publications in microalgae pictured a total of 8.466 citations, an average of 16.7 citations by each of the 507 articles. Counting the number of publications is a result of the productivity of authors and institutions, while counting the citations is considered an important tool for measure how much the articles are being discussed in other publications (LARSEN; VON INS, 2010).

Figure 1. Number of microalgae publications in Brazil on WoS database



Fonte:

Figure 2. Distribution of Brazilian collaborations on microalgae yield

English was the predominant language on microalgae articles in Brazil representing 93.6% (475 articles) of the total publications and agreeing with the bias that quality papers are published in English (KING, 2004). The other two idioms that Brazilian scientists have been published on the microalgae scenario are Portuguese and Spanish, representing 5.9% (30) and 0.3% (2) of the publications, respectively.

From 1990 to 2000 there were an increasing of 135% on international collaboration in science and the tendency is to increase the speeding (LEYDESDORFF; WAGNER, 2008). Brazil has been collaborated with 35 different countries (Figure 2), whereas the United States was the most-collaborative country, summing 34 articles and followed by European countries (17 countries).

Research Funding Bodies and Institutions

Research funding bodies (RFB) counted 371 and were not found in 111 publications (21.8%). Articles can count on more than one RFB on the funding field, so the sum of the contribution of each RFB is higher than 100%. Between the 10 most-prolific RFB, the main positions are occupied by Brazilian institutions, while the 8th, 9th and 10th are from Europe.

A total of 80% of the RFB only appear in one article, while 12.6% have financed two articles. An amount of 79.4% of the financial support for microalgae research

Table 1. 10 most-prolific institutions

	Institution	NP*	State
1	Federal University of Rio Grande	78	Rio Grande do Sul
2	Sao Paulo University	57	Sao Paulo
3	Parana Federal University	40	Parana
4	Federal University of Rio de Janeiro	36	Rio de Janeiro
5	Federal University of Santa Maria	33	Rio Grande do Sul
6	State University of Campinas	31	Sao Paulo
7	Federal University of Santa Catarina	31	Santa Catarina
8	Federal University of São Carlos	26	Sao Paulo
9	Federal University of Rio Grande Do Sul	26	Rio Grande do Sul
10	Federal University of Bahia	20	Bahia

*NP : Number of Publications.

in Brazil come from institutions not linked to a specific university, but governmental funding bodies (CNPq and CAPES).

An amount of 363 institutions were listed on the author's address field, counting 1.086 appearances on the 507 articles, indicating a high number of institutions collaborating on the same article, evidencing the multi-authored tendency in Brazilian microalgal publications (LEYDESDORFF; WAGNER, 2008).

The 10 most-prolific institutions are listed in Table 1, where the main institutions are located in the South and Southeast of Brazil. A total of 237 (65.2%) institutions appeared only in one article, that can happen due to the grouping of local researchers that publish together in one article.

Authors

A total of 1.693 authors that were listed on Brazilian microalgae articles, while 1.280 (75.6%) of the authors appeared in only once. The 10 most-contributive authors to microalgae research in Brazil are described on the Table 2.

Table 2. 10 most-contributive authors on microalgae research in Brazil

	Author Name	PN*	Gender	Filiation	Region
1	Jorge Alberto Vieira Costa	41	Male	FURG	South
2	Eduardo Jacob-Lopes	28	Male	UFSM	South
3	Leila Queiroz Zepka	22	Female	UFSM	South
4	Michele Gueque de Morais	17	Female	FURG	South
5	André Bellin Mariano	17	Male	UFPR	South
6	Paulo César Abreu	16	Male	FURG	South
7	Roberto Bianchini Derner	15	Male	UFSC	South
8	José Viriato Coelho Vargas	15	Male	UFPR	South
9	Armando Augusto H. Vieira	14	Male	UFSCar	Southeast
10	Nelson Roberto Antoniosi	12	Male	UFG	Center-West

*PN: Publication Number.

It's noted that the most-contributive authors are preferably from the South region of Brazil, except for two (one from the Southeast and another from the Center-West), that can indicate where the most productive research groups are installed. Between the most-prolific authors only 2 were women, inferring that this is an area where men use to publish the most.

Web of Science Categories

The 507 articles were classified in 75 Web of Science categories. Biotechnology Applied Microbiology was listed in 120 articles (23.6%), Environmental Science in 96 studies (18.9%), while Energy Fuels came out in 89 publications (17.5%). From the 75 categories, 36% (27) appear only in one document.

The most significant category in many studies on microalgae is Biotechnology Applied Microbiology, while for microalgae use as biofuels (COELHO; BARBOSA; SOUZA, 2014) the Energy Fuels category is more relevant than Environmental Sciences, which are more related to other uses of microalgae, such as high-value products (CHENG et al., 2020) and bioremediation (KONUR, 2020).

Journals

A total of 219 journals have been publishing Brazilian articles on microalgae scenario, but 61.1% of the journals only showed one publication under the research parameters of this study. The 10 most-productive journals are listed on Table 3. Algal Research (5.5%), Bioresource Technology (5.3%) and Journal of Applied Phycology (4.1%) were the most productive journals, the same reported by other researches (GARRIDO-CARDENAS et al., 2018).

Table 3. 10 most-productive journals on Brazilian microalgae research

	Journal Name	PN*	h-Index	Country
1	Algal Research	28	54	Netherlands
2	Bioresource Technology	27	273	Netherlands
3	Journal of Applied Phycology	21	101	Netherlands
4	Renewable Energy	10	174	Netherlands
5	Water Science and Technology	10	131	United Kingdom
6	Brazilian Archives of Biology and Technology	9	45	Brazil
7	Environmental Technology	9	71	United States
8	Journal of Cleaner Production	9	173	Netherlands
9	Science of the Total Environment	9	224	Netherlands
10	Biomass Bioenergy	8	169	United Kingdom
	Other Journals (209)	367		

*Publication Number.

Keywords

A total of 3.845 author keywords were analyzed to identify the spotlights and trends on microalgae research in Brazil. Microalgae itself was cited 238 times, while biomass (64 citations) was the second most cited keyword, once it is the main product obtained from microalgae to biorefinery. A cloud word with the most cited keywords are shown in Figure 3A.

Figure 3. (A) Word cloud with the most-cited keywords. (B) Author keywords associations on Brazilian microalgae research panorama.

Chlorella was the most cited microalgae genus while cultivation in wastewater is a relevant topic on biomass production. Equally observed in other microalgae studies, energy and biofuels are also trend-topics, whereas biodiesel is the most relevant biofuel type on the studies. Even that Brazil has been successful in the development of sugar cane bioethanol (ADENLE; HASLAM; LEE, 2013), the third generation of biofuels emerges among Brazilian microalgae research.

High lipid microalgae species have been considered a reliable and renewable energy source for a variety of oleaginous co-products, chemicals, food (AXELSSON; GENTILI, 2014) and biodiesel (CHISTI, 2007). *Chlorella* sp., *Scenedesmus* sp. and *Nannochloropsis* sp. are between the most cited microalgae genus and show high lipid content compared to other groups (GONZÁLEZ-GONZÁLEZ et al., 2018).

Another interest area in microalgae research worldwide is harvesting steps (ANTHONY et al., 2013), on what flocculation, coagulation and coagulant are the main author keywords related to microalgae recovery techniques. Bioremediation is also a topic where Brazilian microalgae research is standing out (KONUR, 2020), once the keywords bioremediation and phycoremediation appear discreetly among relevant topics on this review.

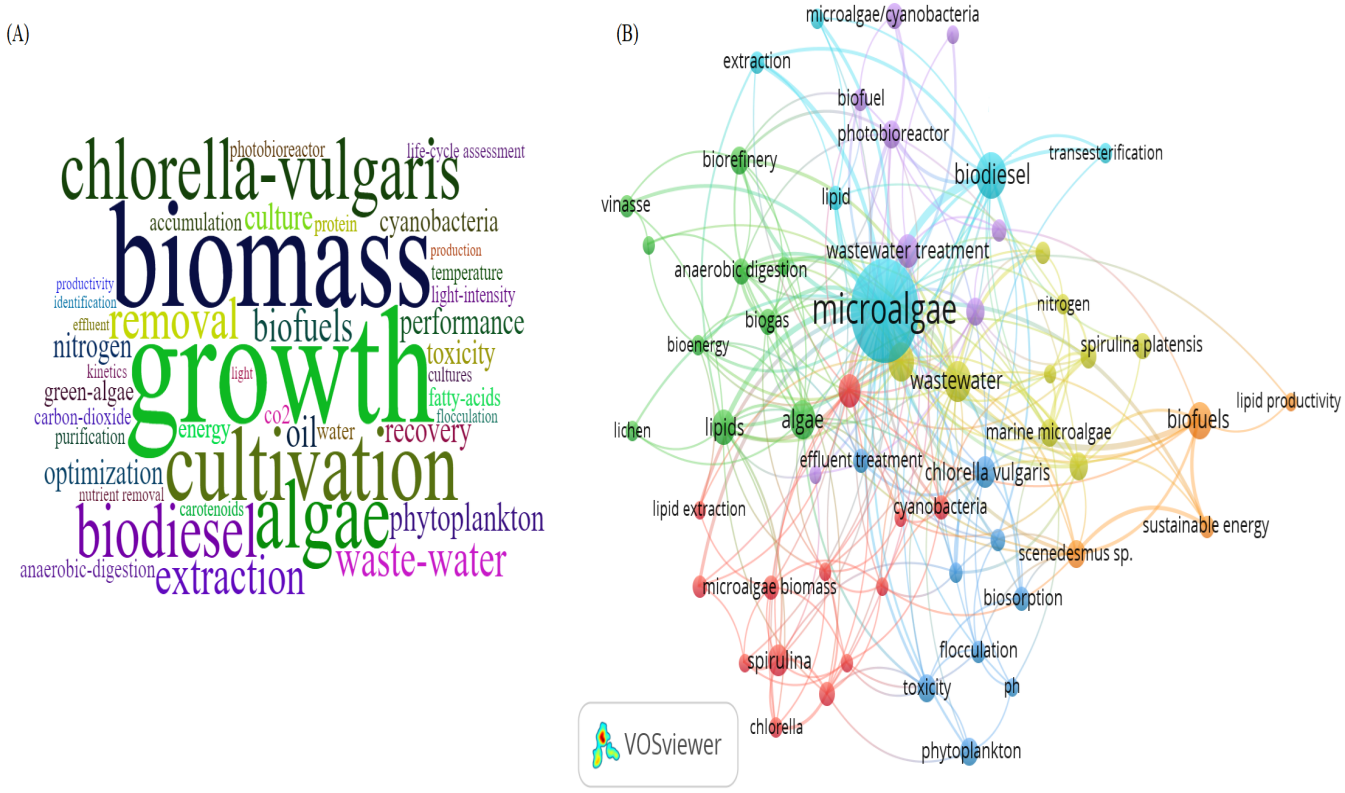
Analyzing the associations between the author keywords 7 clusters were found (Figure 3B), where microalgae biorefinery is mainly related to bioenergy (biofuels), wastewater treatment (bioremediation) and lipid production (biodiesel).

Microalgae is largely connected to the biodiesel production (light blue cluster) once biodiesel manufacture appears in all clusters, underlining the importance of biodiesel on the microalgae research scenario worldwide and in Brazil. In addition, anaerobic digestion and biogas (green cluster) also appear as a concept to bioenergy from microalgae (PERAZZOLI et al., 2016).

The yellow cluster refers to the use of wastewater

on microalgae cultivation (CAI; PARK; LI, 2013; CHEAH et al., 2016; YOUSUF, 2020), in turn is related to nitrogen, that can be a factor for lipid accumulation on microalgae cells (GOH et al., 2019; GONZÁLEZ-GONZÁLEZ et al., 2018; YEN et al., 2013). Variations for microalgae appear as well as the phylum cyanobacteria, the generic classification phytoplankton and marine microalgae, genus *Chlorella* sp., *Scenedesmus* sp. and *Spirulina* sp.

Figure 3. (A) Word cloud with the most-cited keywords. (B) Author keywords associations on Brazilian microalgae research panorama.



CONCLUSION

This study aimed to identify the trends on microalgal research in Brazil and we found that microalgae can be a dynamic feedstock for a variety of bioproducts. Also, Brazilian research follows the tendencies worldwide where microalgae is used as food, pharmaceuticals, chemicals, medicine, remediation and biofuels. A total of 507 were published in Brazil since 1989 and the number of publications has increased year by year. Most of articles were published in English (93.6%) and the South and Southeast of the country are the most-productive regions. Brazilian researchers are collaborating with 35 different countries, seventeen are from Europe, but the USA is the country that collaborates on the most number of articles (34). The articles are mainly classified on the following WoS categories: Biotechnology Applied Microbiology, Environmental Science and Energy Fuels; while the most-prolific journals are Algal Research, Bioresource Technology and Journal of Applied Phycology. Microalgal research in Brazil is focused on topics such as the cultivation on wastewater, which have a connection to remediation and sewage treatment. Biomass is a strong term and the second most-cited keyword once the microalgal biomass is the main feedstock for a variety of uses of microalgae in industry and biorefinery. Biodiesel is a relevant concept in microalgal research in Brazil and worldwide.

LITERATURE CITED

ADENLE, A. A.; HASLAM, G. E.; LEE, L. Global assessment of research and development for algae biofuel production and its potential role for sustainable development in developing countries. **Energy Policy**, v. 61, p. 182–195, 2013.

ALAM, F.; MOBIN, S.; CHOWDHURY, H. Third generation biofuel from Algae. P**rocedia Engineering**, v. 105, n. Icte 2014, p. 763–768, 2015.

ANDREO-MARTÍNEZ, P. et al. Production of biodiesel under supercritical conditions: State of the art and bibliometric analysis. **Applied Energy**, v. 264, n. October 2019, p. 114753, 2020.

ANTHONY, R. J. et al. Effect of coagulant/flocculants on bioproducts from microalgae. **Bioresource Technology**, v. 149, p. 65–70, 2013.

ARIA, M.; CUCCURULLO, C. bibliometrix: An R-tool for comprehensive science mapping analysis. **Journal of Informetrics**, v. 11, n. 4, p. 959–975, 2017.

AXELSSON, M.; GENTILI, F. A single-step method for rapid extraction of total lipids from green microalgae. **PLoS ONE**, v. 9, n. 2, p. 17–20, 2014.

BAHADAR, A.; BILAL KHAN, M. Progress in energy from microalgae: A review. Renewable and Sustainable Energy Reviews, v. 27, p. 128–148, 2013.

CAI, T.; PARK, S. Y.; LI, Y. Nutrient recovery from wastewater streams by microalgae: Status and prospects. **Renewable and Sustainable Energy Reviews**, v. 19, p. 360–369, 2013.

CHEAH, W. Y. et al. Cultivation in wastewaters for energy: A microalgae platform. **Applied Energy**, v. 179, p. 609–625, 2016.

CHENG, Z. et al. A bibliometric-based analysis of the high-value application of Chlorella. **3 Biotech**, v. 10, n. 3, p. 1–14, 2020.

CHISTI, Y. Biodiesel from microalgae. **Biotechnology Advances**, v. 25, n. 3, p. 294–306, 2007.

COELHO, M. S.; BARBOSA, F. G.; SOUZA, M. DA R. A. Z. DE. The scientometric research on macroalgal biomass as a source of biofuel feedstock. **Algal Research**, v. 6, n. PB, p. 132–138, 2014.

DE SOUZA, M. P. et al. Potential of Microalgal Bioproducts: General Perspectives and Main Challenges. Waste and Biomass Valorization, v. 10, n. 8, p. 2139–2156, 2019.

GARRIDO-CARDENAS, J. A. et al. Microalgae research worldwide. **Algal Research**, v. 35, n. May, p. 50–60, 2018.

GOH, B. H. H. et al. Sustainability of direct biodiesel synthesis from microalgae biomass: A critical review. **Renewable and Sustainable Energy Reviews**, v. 107, n. May 2018, p. 59–74, 2019.

GONZÁLEZ-GONZÁLEZ, L. M. et al. Integrated biodiesel and biogas production from microalgae: Towards a sustainable closed loop through nutrient recycling. **Renewable and Sustainable Energy Reviews,** v. 82, n. May 2016, p. 1137–1148, 2018.

KING, D. A. The scientific impact of nations: What different countries get for their research spending. **Nature**, v. 430, p. 311–316, 2004.

KONUR, O. **Handbook of Algal Science, Technology and Medicine**. 1. ed. Elsevier, 2020.

LARSEN, P. O.; VON INS, M. The rate of growth in scientific publication and the decline in coverage provided by science citation index. **Scientometrics**, v. 84, n. 3, p. 575–603, 2010.

LEYDESDORFF, L.; WAGNER, C. S. International collaboration in science and the formation of a core group. **Journal of Informetrics**, v. 2, n. 4, p. 317–325, 2008.

MA, X. et al. Past, current, and future research on microalga-derived biodiesel: a critical review and bibliometric analysis. **Environmental Science and Pollution Research**, v. 25, n. 11, p. 10596–10610, 2018.

NAZARI, M. T. et al. Microalgae harvesting by fungal-assisted bioflocculation. **Reviews in Environmental Science and Biotechnology**, v. 19, n. 2, p. 369–388, 2020.

PERAZZOLI, S. et al. Optimizing biomethane production from anaerobic degradation of Scenedesmus spp. biomass harvested from algae-based swine digestate treatment. **International Biodeterioration and Biodegradation**, v. 109, p. 23–28, 2016.

RUMIN, J. et al. A bibliometric analysis of microalgae research in the world, Europe, and the European Atlantic area. **Marine Drugs**, v. 18, n. 2, 2020.

TAN, J. SEN et al. A review on microalgae cultivation and harvesting, and their biomass extraction processing using ionic liquids. **Bioengineered**, v. 11, n. 1, p. 116–129, 2020.

UMMALYMA, S. B. et al. Bioflocculation: An alternative strategy for harvesting of microalgae – An overview. **Bioresource Technology**, v. 242, p. 227–235, 2017.

VAN ECK, N. J. Waltman L. VOSviewer manual. Leiden: Univeristeit Leiden; 2013. p. 1–53.
YEN, H. W. et al. **Microalgae-based biorefinery - From biofuels to natural products**. Bioresource Technology, v. 135, p. 166–174, 2013.

YOUSUF, A. Fundamentals of Microalgae Cultivation. In: YOUSUF, A. (Ed.). **Microalgae Cultivation for Biofuels Production. London**. Elsevier Inc., 2020. p. 1–9.