ACADEMIC REVIEW: THE APPLICATION OF ARTIFICIAL LICHENS ON A BIOREFINERY CONTEXT

Alice D. R. Pesconi[1], Murilo P. G. Leal[1], Layde T. de Carvalho[1,3], Gabriel L. Arruda[1], Grazielle S. S. Andrade[2], José Eduardo H. Branco[1], Bruno C. Gambrato[4] & Ana Karine F. de Carvalho[1]

[1] Engineering School of Lorena, University of São Paulo–EEL-USP, Lorena, Brazil.
[2] .Federal University of Alfenas – UNIFAL, Poços de Caldas, Brazil
[3]Centre RAPSODEE, IMT Mines Albi – Carmaux, Albi, France
[4]Volta Redonda University Center – UNIFOA, Volta Redonda, Brazil
** Corresponding author's email address: anacarvalho@usp.br*

ABSTRACT

The development of artificial lichens through the symbiosis of fungi and algae has emerged as a promising innovation within biorefineries. This review paper explores the various applications of artificial lichens, emphasizing their role in enhancing the efficiency of biomass harvesting and biofuel production. Key trends identified include the development of mycoalgae biofilms, co-culture techniques for fungi and microalgae, and the integration of sustainable extraction methods for bioactive compounds. The review highlights the potential of artificial lichens to reduce operational costs and improve the economic viability of biorefinery processes. Additionally, the use of green extraction technologies, such as microwave heating and ultrasound-assisted extraction, is discussed for their effectiveness in minimizing toxic solvent use and improving energy efficiency. The article concludes by emphasizing the importance of multidisciplinary approaches to overcoming challenges and maximizing the potential of artificial lichens in industrial applications. This comprehensive review aims to provide insights into the sustainable advancement of biotechnology through the innovative use of artificial lichens.

Keywords: Artificial Lichens. Biorefinery. Mycoalgae Biofilms. Bioactive Compounds. Biofuels.

1 INTRODUCTION

The advancement of biological technologies has spurred increasing interest in exploring new materials and sustainable processes for industrial applications. Among these innovations, artificial lichens have emerged as a promising approach within the context of biorefineries[1]. These synthetic organisms, formed through the symbiosis of fungi and algae[2], replicate the characteristics of natural lichens, offering several advantages in the field of biotechnology.

Artificial lichens possess a unique capability to form robust biofilms[3], facilitating the harvesting and industrial processing of microalgae, thereby enhancing the production of high-value bioproducts[4,5]. Furthermore, the utilization of greener and more sustainable extraction methods[6], such as microwave heating and ultrasound-assisted extraction, has demonstrated efficiency in obtaining bioactive compounds, minimizing the use of toxic solvents, and improving energy efficiency.

This review article aims to explore the applications of artificial lichens within the biorefinery context, analyzing recent advances, sustainable methods for extracting bioactive compounds, and applied biofilm technologies. The review seeks to provide a comprehensive understanding of the challenges and opportunities presented by this innovative research area, emphasizing the importance of multidisciplinary approaches for the sustainable advancement of biotechnology.

2 MATERIAL & METHODS

Firstly, a targeted search was conducted on Google Scholar using the keywords "Artificial Lichens + Biorefinery" and "Artificial Lichens + Bioproducts". The resulting articles were then selected based on their titles and abstracts, considering the review theme 'The Application of Artificial Lichens in a Biorefinery Context'. Only five articles were selected from this initial search as primary sources, namely: 1. Consortium Growth of Filamentous Fungi and Microalgae: Evaluation of Different Cultivation Strategies to Optimize Cell Harvesting and Lipid Accumulation; 2. Mycoalgae biofilm: Development of a Novel Platform Technology Using Algae and Fungal Cultures; 3. The Application of Microbial Consortia in a Biorefinery Context: Understanding the Importance of Artificial Lichens; 4. Towards Greener Approaches in the Extraction of Bioactives from Lichens; 5. Use of Fungal Mycelium as Biosupport in the Formation of Lichen-like Structure: Recovery of Algal Grown in Sugarcane Molasses for Lipid Accumulation and Balanced Fatty Acid Profile.

Their bibliographic references were then compiled into a spreadsheet, with each author's name and each cited article constituting individual cells, as shown in Table 1."Following the creation of this database, which included all references from the five primary articles, the data were imported into Microsoft SQL Server. An analysis was performed to identify the most frequently cited authors within these five primary articles collectively. The resulting table of the most cited authors facilitated the construction of a graph illustrating the most frequently cited authors in the bibliographic references of the selected primary articles (Figure 1).

Table 1 Table Example for the Construction of the Database

Reference	Consortium Growth of Filamentous Fungi and Microalgae: Evaluation of Different Cultivation Strategies to Optimize Cell Harvesting and Lipid Accumulation			
	Author 1	Author 2	Author 3	Article
1	Henderson R.K.	Parsons S.A.	Jefferson B.	Successful removal of algae through the control of zeta potential
2	Mata T.M.	Martins A.A.	Caetano N.S.	Microalgae for biodiesel production and other applications: A review
3	Pragya N.	Pandey K.K.	Sahoo P.K.	A review on harvesting, oil extraction and biofuels production technologies from microalgae

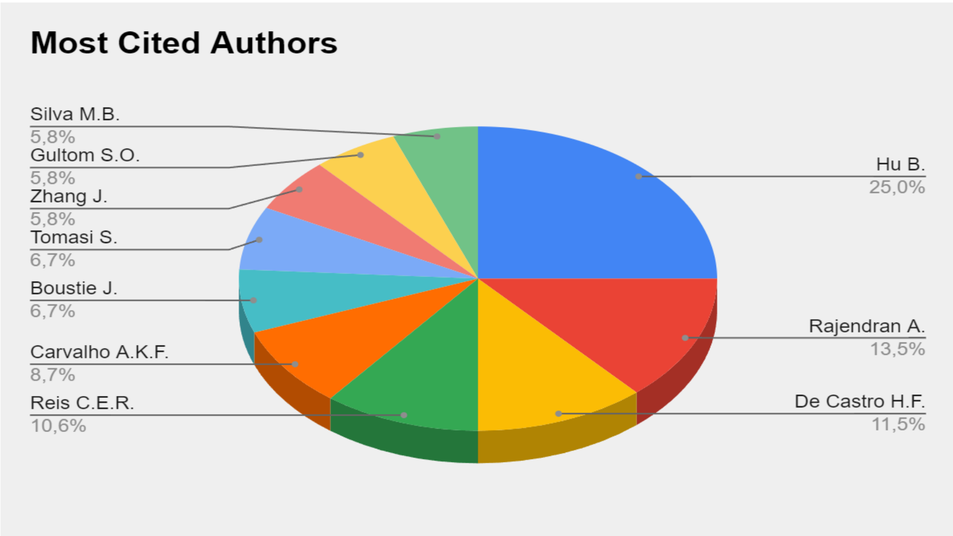

Figure 1 Most Cited Authors

Based on the most frequently cited authors in the primary articles, the spreadsheet was consulted again to identify articles cited by at least three of the primary articles. This allowed for the creation of Table 02, which lists the secondary articles identified [2,7,8,9].

Table 2 Secondary Articles

Article	Times Cited
Review of microalgae harvesting via co-pelletization with filamentous fungus	4
A new cultivation method for microbial oil production: Cell pelletization and lipid accumulation by *Mucor circinelloides*	4
A novel method to harvest microalgae via co-culture of filamentous fungi to form cell pellets	3
Ionic effects on microalgae harvest via microalgae-fungi co-pelletization	3

Finally, both primary and secondary articles were analyzed to identify the main trends within this research area, utilizing OpenAI's ChatGPT as an auxiliary tool in this process.

3 RESULTS & DISCUSSION

Based on the analysis of the primary and secondary articles, the main research trends within the theme "The Application of Artificial Lichens in a Biorefinery Context" were identified as follows:

3.1. Development of Mycoalgae Biofilms

Several studies focus on the creation of artificial biofilms[3,5] that mimic natural lichens by combining filamentous fungi with microalgae. These biofilms, known as "mycoalgae," are efficient in harvesting microalgal biomass and can be used in various industrial applications, including biofuel production and bioremediation. 3.2. Co-culture of Fungi and Microalgae

The symbiotic interaction between fungi and microalgae is explored[1,4,5,7,9] to enhance the efficiency of microalgae harvesting and lipid production. This symbiosis promotes the flocculation and sedimentation of microalgae, facilitating biomass recovery.

3.3. Applications in Biorefineries

Artificial lichens have been studied as a promising solution for biorefineries[1,5]. Microbial consortia that simulate natural lichens are utilized to optimize biomass harvesting and biofuel production, demonstrating potential to reduce operational costs and increase the economic viability of these processes.

3.4. Sustainable Methods for Extracting Bioactive Compounds

The extraction of bioactive compounds from lichens is a field of great interest, with an emphasis on greener and more sustainable methods[1], such as microwave heating, ultrasound-assisted extraction, and supercritical carbon dioxide extraction. These methods aim to reduce the use of toxic solvents and improve energy efficiency and the purity of the extracted compounds.

3.5. Integration of Biofilm Technologies in Industrial Processes

Research is focused on integrating biofilm technologies into industrial processes[3,5], such as biofuel production and bioremediation. The formation of cellular pellets through the co-culture of fungi and microalgae facilitates the harvesting and industrial processing of microalgae, making these processes more efficient and economically viable.

3.6. Challenges and Opportunities

Although promising, these methods face significant challenges[1], including the need to optimize cultivation conditions and adapt extraction methods for different types of lichens and biocompounds. Multidisciplinary approaches are essential to overcome these challenges and better understand the mechanisms of action of bioactive compounds.

In summary, research on artificial lichens is advancing on several fronts, from the development of new biofilm technologies to sustainable methods for extracting biocompounds, with a clear focus on industrial and sustainable applications.

4 CONCLUSION

In conclusion, the exploration and application of artificial lichens within biorefineries represent a significant advancement in sustainable biotechnology. The synthesis of these organisms through the symbiosis of fungi and algae has shown considerable potential in enhancing the efficiency and economic viability of biomass harvesting and biofuel production[4,5]. The development of mycoalgae biofilms[3] and the co-culture of fungi and microalgae[7,9] are pivotal trends, demonstrating their capability to mimic natural processes and optimize industrial applications.

Furthermore, the integration of green extraction methods[6], such as microwave heating and ultrasound-assisted extraction, underscores the progress towards more sustainable and environmentally friendly practices in obtaining bioactive compounds. These methods not only reduce the use of toxic solvents but also improve energy efficiency and compound purity.

The analysis has highlighted the critical role of multidisciplinary approaches[1] in overcoming the existing challenges in the cultivation and extraction processes of artificial lichens. By leveraging the synergistic effects of different scientific disciplines, it is possible to enhance the understanding and utilization of bioactive compounds, paving the way for new industrial applications and innovations.

Overall, the research on artificial lichens is advancing on multiple fronts, offering promising solutions for biorefineries and contributing to the broader goals of sustainability and environmental stewardship. Continued exploration and collaboration across scientific fields will be essential to fully realize the potential of artificial lichens in biotechnological applications.

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ACKNOWLEDGEMENTS

The authors acknowledge to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq project number 420432/2023-0) for the financial support, and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP project number 2019/12940-4) and University of São Paulo (USP).