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Bioplastic Production from Microalgae and Applications: A Review

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Abstract

Production of plastic waste has been increasing on a global scale, resulting in an elevation in plastic waste pollution. There is a critical need to develop novel methods to scale down plastic waste pollution. Recycling the plastic scraps alone is not a complete solution for the rising problem. A key component of sustainability is reducing the use of plastics made from fossil fuels. Bio-based plastics are becoming more popular as a substitute for fossil-based polymers on the market. Researchers have found that biological feedstocks can be better utilized for the production of plastic goods in comparison to a fossil-based approach. Therefore, the production of bioplastics from microalgae is aninnovative approach that should be further investigated and enhanced. The current study focuses on assessing the present status of microalgae-based bioplastic production technologies and identifying the specific areas that require optimization for better productivity. A wide range of applications, including biomedical, agricultural, and packaging industries, employ biopolymers. A circular economy approach to microalgal-based bioplastic production is considered in this review to provide insight into current knowledge and future directions.

Keywords: Bioplastic, Microalgae, Biomedical, Agriculture, Packaging

Introduction

The demand for traditional petroleum-based synthetic polymers has dramatically expanded as a result of population growth over the past two decades. These synthetic polymers were produced around the globe at a rate of 359 million tonnes annually in 2018, according to Plastics Europe (2019). In order to manufacture synthetic polymers and plastic goods, including low-density polyethylene, high-density polyethylene, polyethylene terephthalate, polyvinyl chloride, poly-propylene and polystyrene, this resource holds around 4% of the world's total oil production. Unfortunately, the main issues with these synthetic polymers are their emission of greenhouse gases (GHGs), non-biodegradability, detrimental effects on both terrestrial and marine ecosystems, and environmental persistence (Ranganadha & Chandrasekhar, 2021; Rambabu *et al*., 2023). Researchers are interested in the manufacture of biopolymer as an alternative and biodegradable plastic for everyday requirements (Ranganadhareddy, 2022). Three generations represent the historical evolution of biopolymers. However, the limitations of first- and second-generation biopolymers continue the usage of plastic blends based on petrochemicals, which may cause some plastics to partially degrade into microplastics that can continue to harm the environment. Third-generation biopolymers concentrate on utilizing natural resources derived from plant-based material to ensure that they may quickly biodegrade without leaving behind microplastic fragments or other byproducts that could build up in the environment (Antar *et al*., 2021). Bioplastics are produced using natural resources from terrestrial crops (such as potato and maize); however, this method is not long-term viable given the conflict between food and fuel, the necessity for arable land, and the substantial water and nutrient consumption. Due to its high biomass productivity, capacity to absorb 1.8 lbs of carbon dioxide, and ability to release more than 75% of oxygen into the atmosphere, microalgae have been widely studied for their potential as alternative plant-based resources (Assunção & Malcata, 2020). Additionally, compared to the development of terrestrial crops, the cost of growing microalgae is lower since they may be grown in a variety of challenging environmental conditions using wastewater resources. These microalgae, which are made up of carbohydrates, proteins, lipids, and carotenoids, are bioprocessed to create products that are naturally derived (Thanigaivel *et al*., 2022). Chlorella sp. and Spirulina sp. microalgae have produced microalgae-based bioproducts that have reached the market from several industry sectors (Yong *et al*., 2021). Microalgae are regarded as the world's greatest sustainable biomass feedstock for making biopolymers as opposed to synthetic polymers derived from petroleum (Junior *et al*., 2020). According to recent studies, biopolymers derived from algae have better mechanical properties than those derived from petroleum (Subhash *et al*., 2022). Additionally, algae-based biopolymers can be altered by including additives, plasticizers, and compatibilizers to improve the intermolecular forces of interaction between different compounds and increase material strength, flexibility, and durability (Rai *et al*., 2021). By analyzing the synthesis of biopolymers from microalgae, this study seeks to give a thorough understanding of the present state-of-the-art advancement of algae-based biopolymers towards a sustainable circular economy. The study also covered research on the circular bioeconomy of

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algae in light of the present difficulties facing the biopolymer sector. Additionally, scale-up concerns and culture system running costs were thoroughly covered to give a better understanding of the difficulties encountered in the production of algal biomass. The life cycle assessment (LCA) was examined, however, to help researchers see the advantages of algae-based biopolymers over traditional petroleum-based ones.

Biopolymers from Algal Biomass

Microalgae are eukaryotic photosynthetic organisms that can thrive in both freshwater and saltwater. Red algae, green algae, and brown algae are classified by color. Microalgae are seaweeds that range in size from microscopic to 200 feet (Casas & Matamoros, 2021). Microalgae have a straightforward cell structure and depend on sunlight, carbon dioxide, water, and nutrients for photosynthetic development (Ranganadha *et al*., 2020). Microalgae are quickly expanding photosynthetic organisms that develop in the 0.02 to 2000 m size range (Hossein *et al*., 2022). They can produce up to 70% of the oxygen in the atmosphere by using greenhouse gases in their autotrophic complex. Lipids (13–47%), proteins (17–47%), carbs (19–45%), and carotenoids (11–13%) make up the majority of the bioactive components in microalgae (Mehariya *et al*., 2021). The primary element that qualifies algae as a possible feedstock for the biopolymer sector is their quick biomass productivity, which is 5 to 10 times quicker than that of typical food crops (Kushwaha *et al*., 2022). Agricultural and horticultural polymers, food industry packaging polymers, and other industries benefit from the biodegradability of algae-based bioplastics for a variety of uses (Saratale *et al*., 2021). PHAs, which can be made from microalgae cells, are one of the developed biodegradable polymers as shown in **Figure 1**.

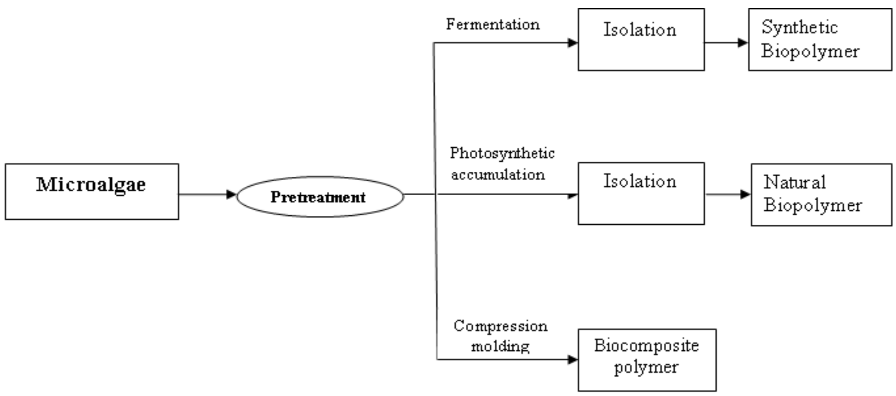

Figure 1. Biopolymer synthesis from microalgae (Devadas *et al*., 2021)

PHAs are produced by microalgae from neutral lipids that have accumulated in their cells; this process calls for carefully controlled culture conditions employing sugarcane vinasse and molasses, or waste frying oil (Bhatia *et al*., 2019). PHAs typically melt between 169ºC and 180ºC (Ranganadha *et al*., 2019). PHAs can be produced from microalgae in two ways: (i) under conditions of environmental stress during cultivation; and (ii) by using the protein in microalgae biomass and putting it through thermo-mechanical polymerization (Chong *et al*., 2021). Phosphorus and nitrogen deficiency can be used to induce the accumulation of PHAs in microalgae under environmental stress culture conditions (Ranganadhareddy, 2022). This was in agreement with Zhang *et al*. (2019), who demonstrated that under phosphate-limited conditions, spirulina has the capacity to synthesize homopolymers such as Polyhydroxtbutyratye, a family of PHAs. The backbone of biopolymers in PHBs, as opposed to PHAs, is a short-chain homopolymer of hydroxybutyrate with four carbon atoms. In addition, PHBs are typically combined with polyesters, which boost the material's stiffness and brittleness, with elongation at break values of 1 GPa and under 15%, respectively (Dang *et al*., 2022). Actually, a number of PHA-based products, including Biogreen, Nodax, Biopol, and Degr Pol, have already been commercialized for a variety of applications (Zhou *et al*., 2022).

Properties of Polyhydroxyalkanoates

PHAs have a variety of physical-chemical features that, according to a review by Popa *et al*. (2022), contribute to further possible applications. PHBs, for instance, have material properties that are comparable to or even superior to those of petrochemical-based plastics, which have melting points between 110ºC and 170ºC. In reality, PHB has strong gas barrier properties, a high crystallinity of up to 70%, and is easily degraded or destroyed, making it appropriate for a variety of industrial applications. PHBs polymerase can also go through the polymerization step to create long-chain PHB polymers, which can be used to create algal bioplastics (Liu *et al*., 2022; Ranganadha, 2022). Alternately, algae bioplastic can be created using the protein found in the biomass of microalgae via thermomechanical polymerization. According to Rai (2021), the small size and high protein content of microalgae make the microalgae biomass itself appropriate for plastic conversion. As a result, this feature makes plastic fabrication particularly suitable without any prior treatment, enabling more efficient and scalable production.

Applications

Biomedical Field

In contrast to other applications, biomedical applications have garnered exceptional attention for the utilization of biopolymers because to its greater entity significance (Akhtartavan *et al.,* 2019). As surgical sutures that promote integrated damaged tissue coalescence, biodegradable polymers are increasingly being drawn to applications that solve medical issues in specifics, such as orthopedic and vascular grafting surgical implants (Mahendiran *et al*., 2021). The remarkable longevity and sturdiness of these sutures, which are easily sterilizable, allow them to work throughout tissue regeneration before being either physically removed or allowed to disintegrate quickly in the body. Because they provide strong knot toughness and outstanding flexibility, poly-(glycolic acid), poly-(L-lactic acid), and their copolymers are widely employed as sutures (Behera *et al.,* 2022). Biopolymer-based bone fixation implants provide unhindered dynamic bone healing and don't need to be removed surgically following bone repair because the entire implanted fixture dissolves. Due to their superior biocompatibility, pharmacokinetics, and immunogenicity compared to their synthetic counterparts, biopolymer nanoparticles are potentially rated as significant materials for drug delivery systems, aiding the process of drug release and absorption (Ranganadha *et al.,* 2021). Biopolymers with poly (hydroxy acid) and poly (ortho ester) groupings are frequently used in drug delivery methods. Given their strength, flexibility, and resistance to wear and tear, polyurethanes are referred to as a blood-compatible category (Iolanda *et al.,* 2021). These qualities are crucial for grafting scaffolds that resemble artificial blood vessels. Because of their inherent ability to degrade naturally and their ability to improve soil, biopolymers have garnered attention in the agricultural field and have had a significant impact on the creation of mulches and plant containers. Mulches encourage plant development because their polymer films retain moisture, prevent the growth of weeds, maintain the ideal soil temperature, and, most importantly, degrade through photodegradation, which eliminates the need for removal and the associated expenses (Daniel *et al.,* 2020).

Agriculture

By using mulch in agricultural areas, cultivation processes are reduced, preventing further root damage and plant stunting or destruction. Additionally, there has beena noticeable and reasonable reduction in the amount of water and soil nutrients needed. Mulch is produced using polymer films composed of poly-(vinyl chloride), low density polyethylene, poly-(vinyl alcohol), or polybutylene (Abd El-malek *et al.,* 2020). These films are modified in a certain way, either with the help of soil microorganisms or by adding specific particulate matter that encourages film termination, such that disintegration is only permitted after the crop-growing time has concluded. Polycaprolactone has a similar characteristic and is used to make containers for agricultural plants. These containers often take a long time to decompose, giving tree seedlings enough time to develop.

Packaging Industry

The physical features of packaging polymers, which allow for adjustments in the molecular weight, chemical composition, and processing conditions in an effort to obtain desired qualities, have drawn a lot of attention. The commodities that will be packed as well as its storage environment dictate these necessary qualities. It has been established that combining the characteristics of various biopolymers into a biodegradable film can be used to create packaging materials whose end results are quite distinguishable from those of synthetic ones, though the latter have a slight advantage over their bio-derived counterparts (Mostafavi & Zaeim, 2020). In order to create viable packaging films, a variety of biopolymers based on polysaccharides, including starch, cellulose, etc., as well as a number of copolymers of polyesters and polyethylene, are being used. The degrading characteristics of laminated packaging are now improved by blending natural fillers like starch with synthetic polymers. Bags for groceries and mail, storage containers, disposable dishes, glasses, and silverware, as well as textiles, are just a few of the packaging options derived from biopolymer sources (Alexandrovich *et al.,* 2018). When it comes to foods and condiments, biopolymer packaging meets the expectation of maintaining the product's quality and palatability from the point of manufacture to the point of consumption.

Conclusion

Algal biomass offers enormous potential for the manufacture of biopolymers, as was addressed in the review. The production process is, however, hampered by a few bottlenecks. Algal growth in photobioreactors demands significant expenditures for large-scale production. A sustainable method for growing algae on a large scale with lower production costs may be developed. There are problems with both the large-scale production of biopolymers and the disposal of waste biomass. In this regard, models encouraging the bioeconomy might be developed using the concepts of the circular economy. Additionally, utilizing neural network optimization techniques, research may be done to establish the best conditions for algae growth and fermentation in bioreactors. It is feasible to screen microalgal species to find the optimal algal biomass for the manufacture of biopolymers. The purpose of this review is to emphasize the significance of algal biomass and its value in the production of biopolymers. Furthermore, new advancements in biopolymer synthesis techniques using algal biomass were presented. The subject of biomedical sciences has a lot of potential for biopolymeric materials. Additionally, the use of different chemicals may limit the applications for microalgae products, such as in food packaging and medical fields. As a result, additional research is required to improve the procedure for industrial applications and reduce the need for additives through more innovative design.

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References

Akhtartavan, S., Karimi, M., Karimian, K., Azarpira, N., Khatami, M., & Heli, H. (2019). Evaluation of a self-nanoemulsifying docetaxel delivery system. *Biomedicine*

& Pharmacotherapy, *109*, 2427-2433. doi:10.1016/j.biopha.2018.11.110

Alexandrovich, S. O., Yurievna, V. S., Olegovich, P. I., Yurievna, K. N., Ilyinichna, V. L., & Pavlovna, Y. T. (2018). Provision of Microbiological Safety in The Food Industry Based on Special Technological Supporting Solutions. *International Journal of Pharmaceutical Research & Allied Sciences*, *7*(1), 103-113.

Antar, M., Lyu, D., Nazari, M., Shah, A., Zhou, X., & Smith, D. L. (2021). Biomass for a sustainable bioeconomy: An overview of world biomass production and utilization. *Renewable and Sustainable Energy Reviews*, *139*, 110691. doi:10.1016/j.rser.2020.110691

Assunção, J., & Malcata, F. X. (2020). Enclosed "non-conventional" photobioreactors for microalga production: A review. *Algal Research*, *52*, 102107. doi:10.1016/j.algal.2020.102107

Behera, S., Priyadarshanee, M., Vandana, & Das, S. (2022). Polyhydroxyalkanoates, the bioplastics of microbial origin: Properties, biochemical synthesis, and their applications. *Chemosphere*, *294*, 133723. doi:10.1016/j.chemosphere.2022.133723

Bhatia, S. K., Gurav, R., Choi, T. R., Jung, H. R., Yang, S. Y., Moon, Y. M., Song, H. S., Jeon, J. M., Choi, K. Y., & Yang, Y. H. (2019). Bioconversion of plant biomass hydrolysate into bioplastic (polyhydroxyalkanoates) using Ralstoniaeutropha 5119. *Bioresource Technology*, *271*, 306-315. doi:10.1016/j.biortech.2018.09.122

Casas, M. E., & Matamoros, V. (2021). Analytical challenges and solutions for performing metabolomic analysis of root exudates. *Trends in Environmental Analytical Chemistry*, *31*, e00130. doi:10.1016/j.teac.2021.e00130

Chong, J. W. R., Yew, G. Y., Khoo, K. S., Ho, S. H., & Show, P. L. (2021). Recent advances on food waste pretreatment technology via microalgae for source of polyhydroxyalkanoates. *Journal of Environmental Management*, *293*, 112782. doi:10.1016/j.jenvman.2021.112782

Dang, B. T., Bui, X. T., Tran, D. P. H., Hao Ngo, H., Nghiem, L. D., Hoang, T. K., Nguyen, P. T., Nguyen, H. H., Vo, T. K., Lin, C., et al. (2022). Current application of algae derivatives for bioplastic production: A review. *Bioresource Technology*, *347*, 126698. doi:10.1016/j.biortech.2022.126698

Daniel, S., Amanda, L., Adriana, L., & Mario, D. (2020). Approaching the environmental problem of microplastics: Importance of WWTP treatments. *Science of the Total Environment*, 740, 140016. doi:10.1016/j.scitotenv.2020.140016

Devadas, V. V., Khoo, K. S., Chia, W. Y., Chew, K. W., Munawaroh, H. S. H., Lam, M. K., Lim, J. W., Ho, Y. C., Lee, K. T., & Show, P. L. (2021). Algae biopolymer towards sustainable circular economy. *Bioresource Technology*, *325*, 124702. doi:10.1016/j.biortech.2021.124702

El-Malek, F. A., Farag, A., Omar, S., & Khairy, H. (2020). Polyhydroxyalkanoates (PHA) from Halomonaspacifica ASL10 and Halomonassalifodiane ASL11 isolated from Mariout salt lakes. *International Journal of Biological Macromolecules*, *161*, 1318-1328. doi:10.1016/j.ijbiomac.2020.07.258

Hossein, F., Materazzi, M., Errigo, M., Angeli, P., & Lettieri, P. (2022). Application of ultrasound techniques in Solid-Liquid fluidized bed. *Measurement*, *194*, 111017. doi:10.1016/j.measurement.2022.111017

Iolanda, C., Claudia, P., Rachele, I., Angela, C., Corsaro, M. M., Giovanni, S., & Cinzia, P. (2021). The power of two: An artificial microbial consortium for the conversion of inulin into Polyhydroxyalkanoates. *International Journal of Biological Macromolecules*, *189*, 494-502. doi:10.1016/j.ijbiomac.2021.08.12

Junior, W. G. M., Gorgich, M., Corrêa, P. S., Martins, A. A., Mata, T. M., & Caetano, N. S. (2020). Microalgae for biotechnological applications: Cultivation, harvesting and biomass processing. *Aquaculture*, *528*, 735562. doi:10.1016/j.aquaculture.2020.735562

Kushwaha, A., Yadav, A. N., Singh, B., Dwivedi, V., Kumar, S., Goswami, L., & Hussain, C. M. (2022). Life cycle assessment and techno-economic analysis of algae-derived biodiesel: Current challenges and future prospects. *Waste-to-Energy approaches towards zero waste*, 343-372. doi:10.1016/B978-0-323-85387-3.00003-3

Liu, R., Li, S., Tu, Y., Hao, X., & Qiu, F. (2022). Recovery of value-added products by mining microalgae. *Journal of Environmental Management*, *307*, 114512. doi:10.1016/j.jenvman.2022.114512

Mahendiran, B., Muthusamy, S., Sampath, S., Jaisankar, S. N., Popat, K. C., Selvakumar, R., & Krishnakumar, G. S. (2021). Recent trends in natural polysaccharide based bioinks for multiscale 3D printing in tissue regeneration: A review. *International Journal of Biological Macromolecules*, *183*, 564-588. doi:10.1016/j.ijbiomac.2021.04.179

Mehariya, S., Goswami, R. K., Karthikeysan, O. P., & Verma, P. (2021). Microalgae for high-value products: A way towards green nutraceutical and pharmaceutical compounds. *Chemosphere*, *280*, 130553. doi:10.1016/j.chemosphere.2021.130553

Mostafavi, F. S., & Zaeim, D. (2020). Agar-based edible films for food packaging applications - A review. *International Journal of Biological Macromolecules*, *159*, 1165-1176. doi:10.1016/j.ijbiomac.2020.05.123

Plastics Europe, E. P. R. O. (2019). Plastics—The Facts 2019. An Analysis of European Plastics Production, Demand and Waste Data. *Plastic Europe https://www. plasticseurope. org/en/resources/publications/1804-plastics-facts-2019*.

Popa, M. S., Frone, A. N., & Panaitescu, D. M. (2022). Polyhydroxybutyrate blends: A solution for biodegradable packaging?. *International Journal of Biological Macromolecules*, *207*, 263-277. doi:10.1016/j.ijbiomac.2022.02.185

Rai, P., Mehrotra, S., Priya, S., Gnansounou, E., & Sharma, S. K. (2021). Recent advances in the sustainable design and applications of biodegradable polymers. *Bioresource Technology*, *325*, 124739. doi:10.1016/j.biortech.2021.124739

Rambabu, K., Avornyo, A., Gomathi, T., Thanigaivelan, A., Show, P. L., & Banat, F. (2023). Phycoremediation for carbon neutrality and circular economy: Potential, trends, and challenges. *Bioresource Technology*, *367*, 128257. doi:10.1016/j.biortech.2022.128257

Ranganadha, A. R. (2022). A Review on Production of Polyhydroxyalkanoates in Microorganisms. *Journal of Biochemical Technology*, *13*(1), 1-6. doi:10.51847/Uo3EEbmgID

Ranganadha, A. R., Sravani, K., Sanjana, N., & Chandrasekhar, Ch. (2021). Production of biopolymer from bacteria – A Review. *Environmental and Earth Sciences Research Journal*, *8*(2), 91-96. doi:10.18280/eesrj.080205

Ranganadha, A. R., & Chandrasekhar, Ch. (2021). Production of Polyhydroxtbutyratye from marine source-A Review. *Indial Journal of Ecology*, *48*(6), 1829-1836.

Ranganadha, R. A., Krupanidhi, S., Venkateswarulu, T. C., Bharath, K. R., Sudhakar, P., & Vidyaprabhakar, K. (2019). Molecular characterization of a biopolymer producing bacterium isolated from sewage sample. *Current Trends in Biotechnology and Pharmacy*, *13*(3), 325-335.

Ranganadha, R. A., Vidyaprabhakar, K., Venkateswarulu, T. C., Krupanidhi, S., Nazneen Bobby, Md., Abraham, P. K., Sudhakar, P., & Vijetha, P. (2020). Statistical optimization of Polyhydroxtbutyratye (PHB) production by novel Acinetobacternosocomialis RR20 strain Using Response Surface Methodology. *Current Trends in Biotechnology and Pharmacy*, *14*(1), 62-69.

Ranganadhareddy, A. (2022). Production of Polyhydroxyalkanoates from Microalgae-A Review. *Journal of Biochemical Technology*, *13*(2). doi:10.51847/NeYIasA2Ix

Saratale, R. G., Cho, S. K., Saratale, G. D., Avinash A. K., Gajanan S. G., Kumar, M., Ram Naresh, B., Gopalakrishnan, K., Kim, D. S., Sikandar, I. M., et al. (2021). A comprehensive overview and recent advances on polyhydroxyalkanoates (PHA) production using various organic waste streams. *Bioresource Technology*, *325*, 124685. doi:10.1016/j.biortech.2021.124685

Subhash, G. V., Rajvanshi, M., Kumar, G. R. K., Sagaram, U. S., Prasad, V., Govindachary, S., & Dasgupta, S. (2022). Challenges in microalgal biofuel production: A perspective on techno economic feasibility under biorefinery stratagem. *Bioresource Technology*, *343*, 126155. doi:10.1016/j.biortech.2021.126155

Thanigaivel, S., Priya, A. K., Dutta, K., Rajendran, S., & Vasseghian, Y. (2022). Engineering strategies and opportunities of next generation biofuel from microalgae: A perspective review on the potential bioenergy feedstock. *Fuel*, *312*, 122827. doi:10.1016/j.fuel.2021.122827

Yong, J. J. J. Y., Chew, K. W., Khoo, K. S., Show, P. L., & Chang, J. S. (2021). Prospects and development of algal-bacterial biotechnology in environmental management and protection. *Biotechnology Advances*, *47*, 107684. doi:10.1016/j.biotechadv.2020.107684

Zhang, C., Show, P., & Ho, S. H. (2019). Progress and perspective on algal plastics – A critical review. *Bioresource Technology*, *289*, 121700. doi:10.1016/j.biortech.2019.121700

Zhou, Y., Kumar, V., Harirchi, S., Vigneswaran, V. S., Rajendran, K., Sharma, P., Tong, Y. W., Binod, P., Sindhu, R., Sarsaiya, S., et al. (2022). Recovery of value-added products from biowaste: A review. *Bioresource Technology*, *360*, 127565. doi:10.1016/j.biortech.2022.127565