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Microalgae for the production of biofuels and other value-added products

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ABSTRACT

Microalgae are single-celled aquatic photosynthetic microorganisms with ubiquitous existence including both freshwater and marine habitats. They are considered the fastest-growing organism due to the shortest doubling time. Its mechanism and pathway for using atmospheric carbon dioxide to convert it into biomass are quite different from the other plants and flora. Microalgae biomass is an excellent source of biomolecules such as carbohydrates, proteins, and lipids. They have been considered a great potential in the fields of renewable and sustainable energy production including the biofuels industry. Microalgae are still under-utilized in industrial sectors and microalgae technology is still in the initial stage of commercialization due to the paucity of economic viability and comparatively low fuel prices. This study has deliberated a great potential for a higher return on investment for microalgae biofuels production via an efficient upstream and downstream approach. It will not support and promote sustainability only, but it will also promise an eco-friendly and healthy environment.

Keywords: *Microalgae; biomolecules; biofuels; value-added product; environment.*

1. INTRODUCTION

Microalgae have been considered as an excellent source of renewable and sustainable biofuel production due to their high biomass production rate and can be easily cultivated in any ecological conditions (Schenk, 2021). It has been already reported that one kilogram of microalgal biomass has the ability to absorb 1.8 kilograms of atmospheric carbon dioxide (Mathimani & Pugazhendhi, 2019; Banerjee et al., 2020). According to Rosch et al., (2018), one of the best parts of microalgae cultivation is that it has the ability to survive with inferior climatic conditions. Technical systems, marginal land and a source of sewage with a high amount of carbon dioxide, nitrogen, and phosphorus contents, the microalgae flourish wonderfully.

Microalgae can be grown using wastewater of different sources that contain high amounts of phosphorus and nitrogen because they consume it for their biomass growth (Bigogna et al. 2002; Fatima et al., 2020a; Fatima and Kumar, 2020). A number of microalgae strains have been reported to be cultivated in different stress conditions including herbicide and other organic and inorganic pollutants (Kumar et al., 2021; Jaiswal et al., 2020a; Jaiswal et al., 2021; Nanda et al., 2021). Biofuels production from microalgae biomass has been considered a third-generation biofuel (Sharma and Sharma, 2017; Jaiswal et al., 2020b; Jaiswal and Pandey, 2014). The cultivation of microalgae biomass in a limited area possesses higher costs for its cultivation. However, the development and advances of new technologies have provided efficient systems that can be used to establish an integrated microalgae system for biofuel as well as for food sources. Microalgae are the rich source of protein, carbohydrates and lipids.

The lipids from the algae can be used for the production of biofuels (biodiesel), while the protein can be used as food. Furthermore, the lipids present in microalgae biomass can form the building blocks for both sustainable fuel and the food industry. The carbohydrates present in algae can be used for the production of other valuable chemicals and biofuels such as ethanol (Radakovits et al. 2010). According to Sharma and Sharma, (2017), most of the preceding work on microalgae has only focused on the extraction of a specific product from biomass, so extraction methods have been developed with the same purpose. This also means that the other useful components of microalgae have not yet been exploited for economical beneficiation. According to them, the best way to obtain multiple products from biomass is very critical using soft extraction techniques. For example, the lipid extraction techniques used in most cases destruct and cause denaturation of the proteins available in microalgae. Therefore, the protein is lost and cannot be obtained for other useful purposes. One of the challenges of using microalgae is that the system can be expensive if only used for biofuel production. It also includes the huge investment costs and time-consuming efforts throughout the production process. Some of the steps involved in the microalgae biomass and bio-product production process require a lot of energy, such as mixing the harvested microalgae and removing the cell walls before extracting the desired products (Naruka et al., 2019; Dutta et al., 2020; Jaiswal et al., 2020c). In this review work, we have specifically illustrated the microalgae biofuel production and other valuable product using upstream and downstream processing.

2. UPSTREAM PROCESSING OF MICROALGAE CULTURE

The process of producing biofuels and food from microalgae biomass has been divided into two separate divisions: the upstream process and the downstream process. The upstream process includes the important steps of cultivating and harvesting biomass. The microalgae can be grown through an open pond system in a raceway pond. The closed cultivation system i.e. photobioreactors (PBR) can also be used in the culturing process. The establishment of open ponds implies low investments, less labour intensity, and lower operating costs. However, the use of PBRs is quite expensive and they are equally important to manage and control culture conditions in an open system. In addition, they also help to achieve higher biomass productivity while effectively preventing contamination. There are various types of PBR, such as a green wall, flat plate, tubular; they are used mainly for the production of high-value products (Zijffers et al. 2010). They are also used in hybrid culture systems to supply a high cell density of microalgae to open ponds. A high surface-to-volume ratio is required in PBRs. To provide an optimal light intensity for microalgae cultivation, it is necessary to build complicated and sophisticated constructions to obtain the largest surface area. There is also a great need to pump and mix the microalgae with carbon, light and nutrients. The temperature of the microalgae should be kept. The combined technique of the open pond system and PBRs is useful for both biofuel production and food production. It also helps to meet safety and quality standards in food production.

3. DOWNSTREAM PROCESSING OF MICROALGAE CULTURE

In the downstream processing, the separation of microalgae cells from the culture medium has been carried out. This would be followed by a liquid phase extraction containing the desired high-value polysaccharides, proteins, fatty acids and other compounds. The dry matter content increases in the harvesting and separation phase. The dry matter content in the diluted microalgae solution varies between 0.05–0.75% and 0.3–0.4% in the case of open pond systems and PBR systems, respectively. In the combined system of flocculation, filtration, centrifugation, and sedimentation, the dry matter content ranges from 10–25%. Microalgae biomass needs to be processed shortly after separation to avoid any form of cross-contamination or spoilage. The microalgae can be applied to the spray-dried or even lyophilized to increase its dry matter content. According to Borowitzka, (2013), extraction in different stages has been shown to improve the increase in the content of the desired high-value compounds. Drying of the microalgal biomass may lead to the rupture of complex cell wall membranes that eventually lead to the release of the desired metabolites (Andersson et al. 2020). These high-value compounds could be proteins, carbohydrates, fatty acids, phycobilins, carotenoids, sterols, or polyunsaturated fatty acids. The technique is generally chosen based on the characteristics of the microalgae cell wall and the nature of the desired product. Some of the methods used are high-speed, high-pressure homogenization, pulsed electric field, autoclaving, ultrasound and microwave assistance, and bead mills. The other non-mechanical actions involved in the processes involve organic solvents, osmotic shock, freezing, enzymatic reactions, acids and bases (Demuez et al. 2015). One of the main drawbacks of processing is that its success is highly dependent on specific products and is difficult to deliberate. The fatty acids can be obtained from lyophilized biomass with the help of solvents such as ethanol, hexane or a mixture of 96% hexane-ethanol (Andersson et al. 2014). Techniques such as microwave or ultrasound-assisted extraction would also have been suitable for the extraction process. However, it is necessary to know the characteristics of the different solvents and the compatibility between the different processes with each specific lyophilic compound. It is important to ensure that the process used for protein extraction does not have any denaturing impact on the protein. The combination of processes used in protein extraction is centrifugation, ultrafiltration, solvent extraction, lyophilization, fractionation and chromatographic techniques (Sari et al. 2015). In cases of integrated extraction, it is advisable to extract the protein before extracting the lipids. This would prevent any form of protein spoilage.

4. MICROALGAE BIOMASS FOR BIOFUELS

The type of element, whether in solid, liquid, or gaseous state, can be derived from renewable feedstock and can be used as an energy source, called biofuel. Some of the important parameters to consider during the conversion process are the amount and form of biomass, the economic return of the product, and the type of energy (Maltsev et al. 2017). Agricultural crops are often used as sources of biofuels. There is always strong competition when it comes to turning a product into food and fuel.

This is because the focus is always to use a significant part for fuel production. The cultivation of microalgae has several benefits, including wastewater treatment, high biomass productivity, and the lipid content of the microalgae, the year-round productivity, and the chemical composition of the microalgae biomass (Adeniyi et al. 2018; Jaiswal and Prasath, 2016; Fatima et al., 2020b). An additional benefit is the easy and reliable control of microalgae culture techniques.

4.1. Biodiesel

Biodiesel obtained from microalgae is mainly composed of unsaturated fatty acids. Although, a number of animal and plant-based feedstocks have been reported to produce biodiesel such as fish waste, chicken waste, jatropha seeds, etc., but microalgae have been shown its highly efficient and renewable resource (Dutta et al., 2019; Jaiswal et al., 2014; Jha et al., 2016). They are obtained through the process of transesterification of microalgae lipids for biodiesel production. The microalgal biomass contains a combination of fatty acid profiles that is very useful in providing very viscous oil. It is converted into low molecular weight compounds or fatty acid ethyl esters. During transesterification, the lipid molecules react with alcohol in the presence of a catalyst (acidic, basic, or enzymatic) and provide fatty acid methyl esters and glycerol (Milledge & Heaven, 2013).

4.2. Bio-oil

Bio-oils are obtained through the process of thermochemical conversion that converts biomass into char, gases, and liquid oils at high temperatures and pressure. The bio-oils are quite similar to fuel oil and can be used as substitutes. The bio-oil production process consists of two main phases: pyrolysis and hydrothermal liquefaction (Demirbas, 2010). Pyrolysis is carried out at 350–530 ℃ for the development of a solid, liquid and gaseous part. The liquid part has an aqueous and a non-aqueous phase. The biomass is dried, moistened and maintained at a high temperature (300 ℃) and a higher pressure (10 MPa) during thermochemical liquefaction (Sharma & Sharma, 2017).

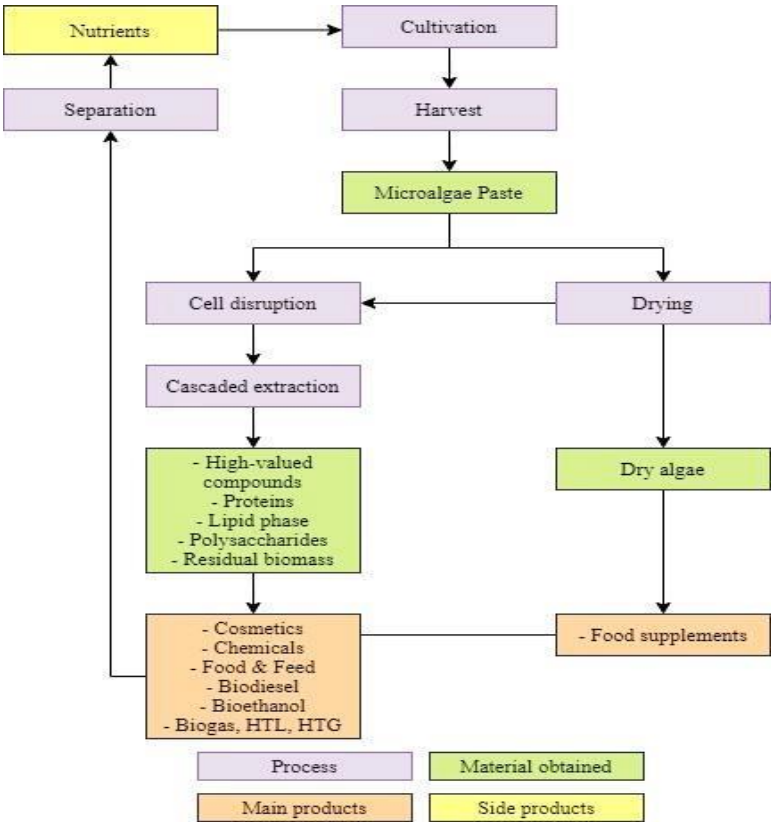

Figure 1. Flow diagram representing the integrated process for the production of biofuels and value-added products from microalgae.

5. CONCLUSIONS

The cultivation of microalgae in different environmental conditions has shown its importance in various applications for human well-being. Numerous investigations have supported the improvement of strains for the easy and efficient generation of biomass. Several investigations have focused on improving particular bio-constituents for application in a specific field. Microalgae lipids have demonstrated their applicability mainly in the field of transportation fuel, i.e., biodiesel. Another, the generation of bio-oils and bio-char, has also gained considerable interest. Several other applications are also notable, including the food product. Upstream and downstream microalgae processing is gaining a lot of interest for renewable and sustainable resources.

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7. DECLARATION

The author declares no conflict of interest.

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