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Review

Applications of de-oiled microalgal biomass towards development of sustainable biorefinery

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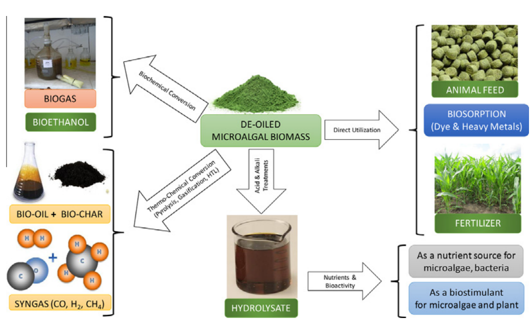
HIGHLIGHTS

- Strategies for the valorisation of de-oiled microalgal biomass (DMB) are reviewed.
- Different processes to further recover energy from DMB are outlined.
- Use of DMB hydrolysate as a nutrient source for biological growth are described.
- Direct DMB utilization without pre-treatments are illustrated.
- Reviewed insights and perspectives on future applications of DMB.

GRAPHICAL ABSTRACT



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ABSTRACT

In view of commercialization of microalgal biofuel, the de-oiled microalgal biomass (DMB) is a surplus by-product in the biorefinery process that needs to be exploited to make the process economically attractive and feasible. This DMB, rich in carbohydrates, proteins, and minerals, can be used as feed, fertilizer, and substrate for the production of bioethanol/bio-methane. Further, thermo-chemical conversion of DMB results into fuels and industrially important chemicals. Future prospects of DMB also lie with its conversion into novel biomaterials like nanoparticles and carbon-dot which have biomedical importance. The lowest valued application of DMB is to use it for adsorption of dyes and heavy metals from industrial effluents. This study reviews how DMB can be utilized for different applications and in the generation of valuable co-products. The value addition of DMB would thereby improve the overall cost economics of the microalgal bio-refinery.

Contents

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1. Introduction

Depleting fossil fuel reserves have induced researchers to focus on alternative, renewable forms of energy. Recent trends suggest the development of biofuels from feedstock that do not compete with food crops, avoiding the food vs. fuel debate.

Microalgae are widely seen as tiny bags of biofuels mitigating environmental carbon dioxide, a major cause of global warming, by converting it into high energy biomass *via* a photochemical reaction. The high energy content of such biomass is due to its carbohydrates, proteins and lipids that can be converted into biofuels like biodiesel, bioethanol, biohydrogen and biomethane (Maurya et al., 2014, 2016b). Lab and pilot scale studies for the enhancement of biodiesel, biogas, biohydrogen, and bioethanol production have been reported in many studies worldwide, emphasizing that energy crisis is global. Microalgae have their own advantages, including high productivity, lipid accumulation, ability to grow on wastewater, a non-requirement for arable land and non-competitiveness with food crops. However, there are bottlenecks which still hinder their development as a strong technology that is viable both economically and technically. Some of these bottlenecks are the lack of promising lipid bearing algal strains, non-standardized cultivation and harvesting methods, arduous cell lysis and lipid extraction methods, etc. (Amaro et al., 2011). Besides these problems, cost reduction of microalgal biofuels is one avenue that has seen much research lately. A multitude of strategies employed for development of alternate microalgal biofuels makes calculating the economics for a particular process tedious since most of the processes are highly interlinked.

If we look at microalgal biofuels, biodiesel has garnered attention for its applicability as an automobile fuel (Amaro et al., 2011). The microalgae industry is broadly concerned about the two fundamental hurdles that hinder its biofuels: low productivity and high costs. If produced at an industrial scale, the microalgal biodiesel process would generate huge amounts of de-oiled microalgal biomass (DMB) (Maurya et al., 2016a). After oil extraction, the high cost of biodiesel can be suitably offset by the effective use of biomass residues in further energy recovery and other applications. This residual biomass after lipid extraction has been a subject of numerous studies for their utilization in various fields (Rashid et al., 2013). In the current scenario, the economic feasibility of commercial microalgal biodiesel is still a matter of investigation. In the last few years, different reports have been published on the applications of this residual biomass; however, the amount of work needed is still extensive. There are different terms describing residual biomass, i.e. algal biomass residues (ABR) (Park and Li, 2012), de-fatted algae (Vardon et al., 2012), oil extracted algae, lipid extracted microalgal biomass residues (LMBRs) (Yang et al., 2010; Maurya et al., 2016a,b), post extracted algae residue (PEAR) (Bryant et al., 2012), spent microalgal biomass (SMAB) (Rashid et al., 2013) and de-oiled algal biomass (DAB) (Maurya et al., 2014; Chandra et al., 2015). Therefore, to avoid any confusion, DMB term has been uniformly used for further discussions throughout this review.

Fig. 1 represents the different conversion routes of DMB and the interlinking nature of these routes. Biomethane, biohydrogen, bioethanol and nutrients for biological growth media could be produced by biochemical conversion of DMB. The nitrogen, phosphorus and mineral enriched slurry after anaerobic digestion can be used as a fertilizer. The hydrolysate of DMB could be used as a fermentation medium for the production of lactic acid, polyhydroxyalkanoates (PHAs) and bioethanol (Section 4.1). Bio-oil, biochar, and syngas could be recovered from DMB by thermochemical conversion routes like pyrolysis, hydrothermal liquefaction, and gasification (Section 4.2). DMB could also be used directly as high protein animal feed, biosorbent to remove dye and heavy metals from wastewater and as a fertilizer for crops (Section 4.3).

This review provides a comprehensive coverage of the various uses DMB could be put to, organized according to the various applications. It would also give the readers an opportunity to read about the many ongoing efforts and several recent economic analysis to reduce production cost, and how these efforts could lead to higher market availability and lower price of microalgae.

2. De-oiled microalgal biomass composition

DMB is a rich source of carbohydrate and proteins with good mineral content (Maurya et al., 2016b). Different upstream processing methods like cultivation, harvesting, and lipid extraction affect the composition of DMB. Also, different chemical and biological pretreatments on DMB have been applied to enhance the availability of these complex molecules in a simple form. In cultivation method, microalgae can be grown heterotrophically, autotrophically and mixotrophically, in fresh or marine water, under nitrogen depletion or replete conditions and all these cultivation factors affect the composition of DMB. After lipid extraction, residual microalgal biomass contains mainly carbohydrate and protein, which can be determined by carbon: nitrogen (C/N) ratio. High C/N ratio is beneficial for the production of biomethane, bioethanol,