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Heterotrophic microalgae cultivation to synergize biodiesel production with waste remediation: Progress and perspectives

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HIGHLIGHTS

- Synergising heterotrophic cultivation of microalgae with wastewater treatment.
- Integrated biorefinery in a closed loop approach.
- Heterotrophic cultivation is amenable for higher biomass and lipid productivity.
- Multidisciplinary approach enables value addition to co-products.

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ABSTRACT

Microalgae are inexhaustible feedstock for synthesis of biodiesel rich in polyunsaturated fatty acids (PUFA) and valuable bioactive compounds. Their cultivation is critical in sustaining the global economy in terms of human consumption of food and fuel. When compared to autotrophic cultivation, heterotrophic systems are more suitable for producing high cell densities of microalgae for accumulation of large quantities of lipids (triacylglycerols) which can be converted into biodiesel. Consorted efforts are made in this communication to converge recent literature on heterotrophic cultivation systems with simultaneous wastewater treatment and algal oil production. Challenges faced during large scale production and limiting factors which hinder the microalgae growth are enumerated. A strategic deployment of integrated closed loop biorefinery concept with multi-product recovery is proposed to exploit the full potential of algal systems. Sustainable algae cultivation is essential to produce biofuels leading to green future.

1. Introduction

Microalgae are highly diverse and specialized group of microorganisms which synthesize good amounts of triacylglycerols (TAG) in the form of storage lipids under adverse environmental conditions (Sheehan et al., 1998). They can grow very fast and are capable of producing several folds higher biomass compared to terrestrial crops and trees, requires low and marginal land and other resources, produces higher lipid and carbohydrates (Singh et al., 2011). Recently, significant attention has been directed towards algae based biodiesel in both basic and applied areas of research. The flexibility of algae to switch their nutritional mode based on substrate availability and light condition is one of the inherent evolutionary advantage which compounds vital importance. In the context of substrate, algae can fix atmospheric CO_2 as well as can consume the organic molecules and micronutrients. Autotrophically algae gain energy through light by fixing atmospheric CO_2. However, low biomass yields, requirement of cultivation systems with large surface area and shallow depth for better access of light, are some of the inherent disadvantages. In the absence of light, the photosynthetic process gets suppressed and algae gain energy from alternative organic processes that convert sugar into lipids (Perez-Garcia et al., 2010). The growth of algae can be significantly denser, allowing for greater yield, because light does not need to penetrate the algae. Microalgae use organic molecules as primary energy and carbon source through heterotrophic nutritional mode and facilitate high biomass productivities which provide an economical feasibility for large scale production (Behrens, 2005; Perez-Garcia et al., 2011). Cost effectiveness, relative simplicity in operations and easy maintenance are the main attractions of the heterotrophic growth approach (Perez-Garcia et al., 2011). Microalgae can also function

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under mixotrophic nutrition by combining both the autotrophic and heterotrophic mechanisms by assimilating available organic compounds as well as atmospheric CO_2 as carbon source.

Economical way of algal cultivation for oil based fuel depends on the source of water, fertilizers and organic carbon source used (Yang et al., 2000). Integrating biofuel production, CO_2 mitigation using industrial flue gas emissions and wastewater treatment is highly selective strategy in enhancing the cost effectiveness and environmental sustainability of algal cultivation. There are many products in the agricultural, chemical or food industry that could be produced using more sustainable inputs and which can be produced locally with a lower impact on natural resources. Co-producing some of these products together with biofuels helps in creation of a self sustaining economy and generates newer job opportunities over an extended period of time (Mata et al., 2010). This communication comprehensively provides the state of art in current knowledge and recent developments on heterotrophic cultivation of microalgae by synergizing biodiesel production in conjunction with waste remediation. This review also focuses on challenges faced during downstream processing, feasibility of large scale cultivation systems and attempts to provide solution to these problems by outlining a closed loop biorefinery concept.

2. Assimilation of carbon through various metabolisms

Photosynthetically fixed CO_2 in the form of glucose serves as sole energy source for all the metabolic activities of the algal cells (Chang et al., 2011). Major advantage of the autotrophic nutritional mode is the algal oil production at the expense of atmospheric CO_2. Photosynthesis process takes place in the chloroplasts and is dominated by light and dark reactions (Fig. 1a). In photosynthetic light reactions, incorporation of one CO_2 to glucose requires three ATP and two NADPH which are generated as a result of light absorption, charge separation, water-splitting and proton gradient. The dark reaction (Calvin cycle) consists of three phases i.e. CO_2 fixation, reduction and regeneration. In first phase, autotrophic CO_2 fixation is accomplished by the enzyme ribulose bisphosphate carboxylase/oxygenase (Rubisco), forming two molecules of 3-phosphoglyceraldehyde (PGA) which is then reduced to glyceraldehyde 3 phosphate. RuBP is regenerated from G3P and carbohydrates such as fructose and glucose are produced as a form of energy. To synthesize fructose or glucose from CO_2, the cycle must operate for six times to yield the desired hexoses and reform the six RuBP molecules. These glucose molecules under nutrient limiting and stress conditions will favor the lipid biosynthesis which also helps to cope up from the stress. Large scale microalgae cultivation systems (such as open/raceway ponds) are usually operated under photoautotrophic conditions (Mata et al., 2010).

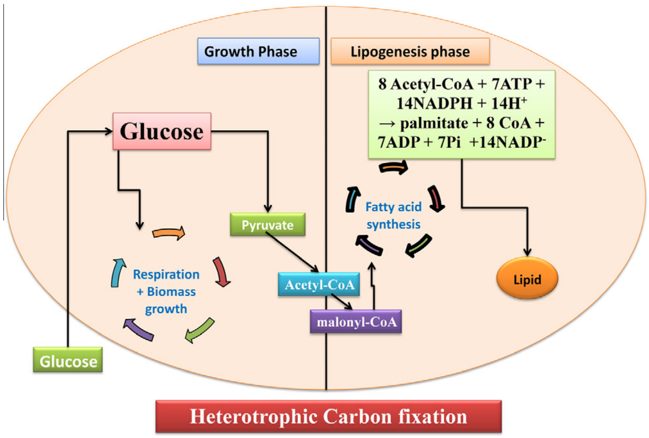

Fig. 1b. Heterotrophic cultivation.

Heterotrophic nutrition takes place both in the presence and absence of light (Fig. 1b). This unique ability is shared by several species of microalgae (Perez-Garcia et al., 2011). Light and carbon acts as an energy source in photo-heterotrophic nutrition mode whereas the sole source of energy during dark conditions is organic carbon. Photo-heterotrophic nutritional mode avoids the limitations of light dependency which is the major obstruction for gaining high cell density in large scale photo-bioreactors. The mixotrophs utilize organic carbon, therefore light energy is not limiting factor for the biomass growth (Chang et al., 2011). In mixotrophic mode, acetyl-CoA pool will be maintained from both the carbon source i.e. CO_2 fixation (Calvin cycle) and extra cellular organic carbon (Fig. 1c). Mixotrophic cultures show reduced photo inhibition and improved growth rates over autotrophic and heterotrophic cultures. The advantages of the mixotrophic nutrition is its independency on both photosynthesis and growth substrates (Kong et al., 2012). Mixotrophism is often observed in the ecological water bodies where the homeostatic structure and function of a living system is supported by chemical, physical and organic activity of the biota, which balances the ecological status (Venkata Mohan, 2010). In fed-batch strategy, the lipid productivity is usually up to 20 times higher under heterotrophic nutritional mode than photoautotrophic cultivation.

Growth of heterotrophic algae remains constant as carbon and nutrients are available but productive growth of autotrophic

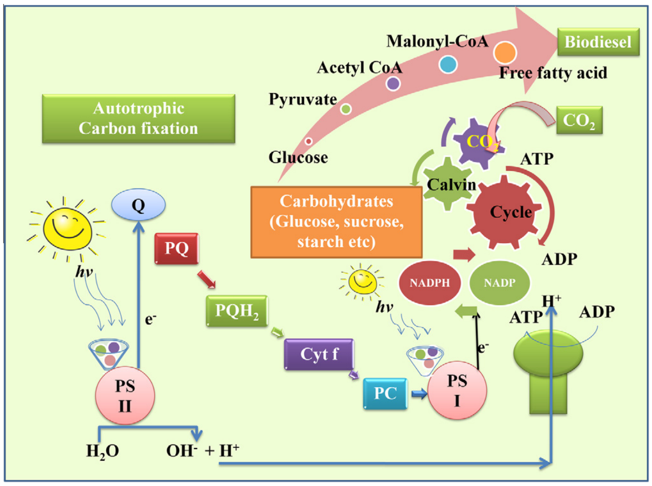

Fig. 1a. Autotrophic cultivation.

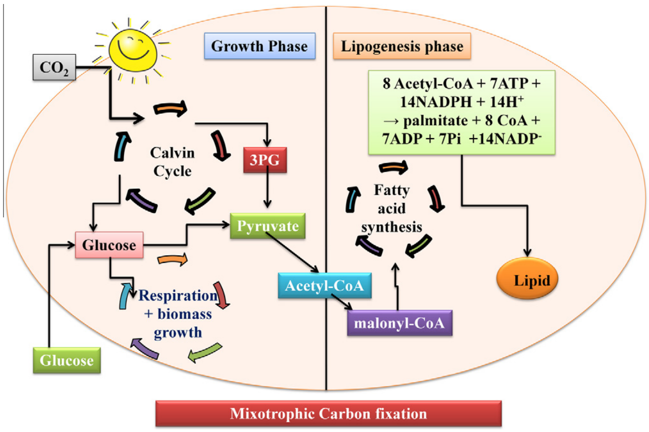

Fig. 1c. Mixotrophic cultivation.

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