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Research review paper

Extraction of oil from microalgae for biodiesel production: A review

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ABSTRACT

The rapid increase of CO_2 concentration in the atmosphere combined with depleted supplies of fossil fuels has led to an increased commercial interest in renewable fuels. Due to their high biomass productivity, rapid lipid accumulation, and ability to survive in saline water, microalgae have been identified as promising feedstocks for industrial-scale production of carbon-neutral biodiesel. This study examines the principles involved in lipid extraction from microalgal cells, a crucial downstream processing step in the production of microalgal biodiesel. We analyze the different technological options currently available for laboratory-scale microalgal lipid extraction, with a primary focus on the prospect of organic solvent and supercritical fluid extraction. The study also provides an assessment of recent breakthroughs in this rapidly developing field and reports on the suitability of microalgal lipid compositions for biodiesel conversion.

Contents

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1. Introduction

The search for sustainable and renewable fuels is becoming increasingly important as a direct result of climate change and rising fossil-fuel prices. Current commercial production of biodiesel or fatty acid methyl ester (FAME) involves alkaline-catalyzed transesterification of triglycerides found in oleaginous food crops with methanol. However, cultivation of these food crops for biodiesel (mainly rapeseed in Europe and soybean in the US) is no longer sustainable as it requires substantial arable land and consumes large amounts of freshwater (Chisti, 2007).

Microalgae are currently considered to be one of the most romising alternative sources for biodiesel (Sheehan et al., 1998). Since many microalgal strains can be cultivated on non-arable land in a saline water medium, their mass farming does not place additional strains on food production (Widjaja et al., 2009). Their high photosynthetic rates, often ascribed to their simplistic unicellular structures, enable microalgae not only to serve as an effective carbon sequestration platform but also to rapidly accumulate lipids in their biomass (up to 77% of dry cell mass). Even using a conservative scenario, microalgae are still predicted to produce about 10 times more biodiesel per unit area of land than a typical terrestrial oleaginous crop (Chisti, 2007; Rosenberg et al., 2008; Sheehan et al., 1998; Shenk et al., 2008).

There are, however, various technological and economic obstacles which have to be overcome before industrial-scale production of microalgal biodiesel can take place. The selection and successful outdoor large-scale cultivation of a robust microalgal strain, which has optimum neutral lipid content, possesses an elevated growth rate, and is immune towards invasion by local microbes, remain a major upstream challenge (Sheehan et al., 1998). On the other hand, the development of an effective and energetically efficient lipid extraction process from the microalgal cells is critical for the successful upscaling of the downstream processes. Despite the routine use of laboratory-scale extraction protocols to determine microalgal lipid contents, the variables affecting lipid extraction from microalgal cells are not well understood and no method for industrial-scale extraction is currently established (Halim et al., 2011).

This paper attempts to address the knowledge gap surrounding microalgal lipid extraction by summarizing and critiquing recent studies in the field. We report on the suitability of microalgal lipid compositions for biodiesel conversion and review the different conventional downstream bioprocessing steps required for microalgal biodiesel production. We then examine the technologies currently available for laboratory-scale microalgal lipid extraction, paying special attention to the use of organic solvent extraction and supercritical fluid extraction. We conclude with an assessment on how different cellular pre-treatment processes can effect microalgal lipid extraction as well as with an update on the recent advances in the field, such as the development of a simultaneous microalgal lipid extraction-methylation method and the establishment of a novel 'single-step' microalgal lipid extraction method by OriginOil, Inc.

2. Microalgal lipid composition

A fatty acid (FA) molecule consists of a hydrophilic carboxylate group attached to one end of a hydrophobic hydrocarbon chain (Fig. 1). Fatty acids are constituents of lipid molecules (both neutral and polar) and designated based on their two most important features 'the total number of carbon atoms in the hydrocarbon chain: the number of double bonds along the hydrocarbon chain'. Saturated fatty acids have no double bond, while unsaturated fatty

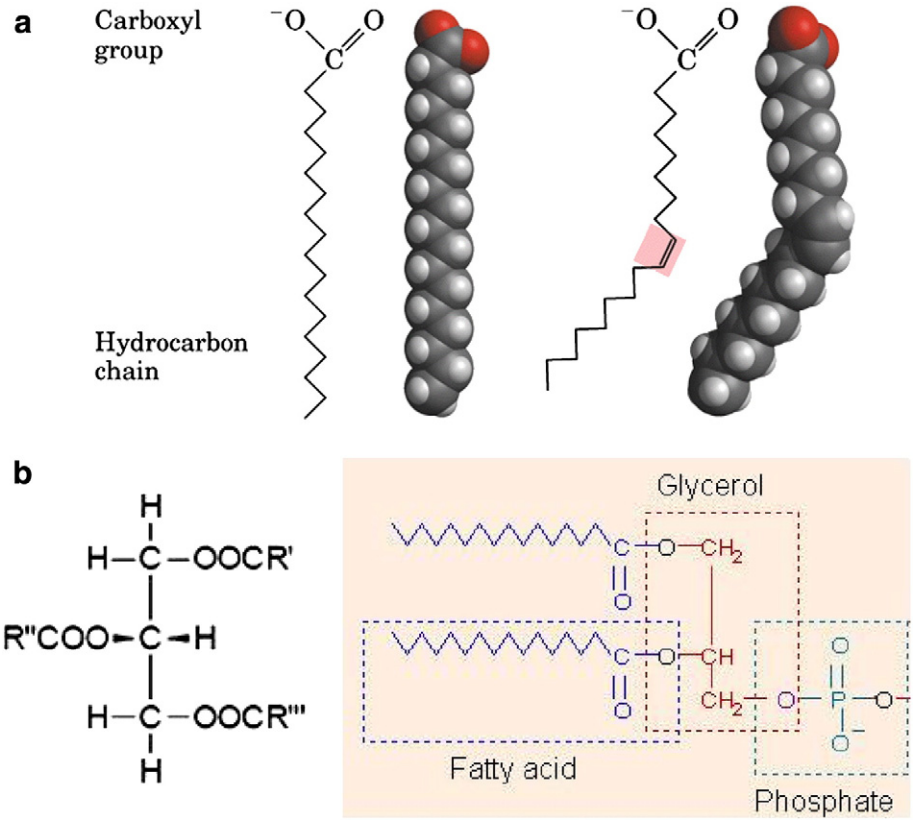

Fig. 1. (a) Fatty acid chains. Saturated fatty acid (C18:0 or stearic acid) on the left. Unsaturated fatty acid (C18:1 or oleic acid) on the right. Oleic acid is of cis-isomerism. (b) Lipid molecules. Triacylglycerol (neutral lipid) on the left. Phospholipid (polar lipid) on the right. R′, R″, R‴ in the triacylglycerol molecule represent fatty acid chains. Phospholipid molecule is negatively charged.
Modified from Nelson and Cox (2000).