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Biodiesel production potential of wastewater treatment high rate algal pond biomass

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HIGHLIGHTS

- Year-round biodiesel production potential from WWT HRAP biomass is investigated.
- Biomass FAME profile is highly complex resulted in production of low-quality biodiesel.
- 3.2 ± 0.5 ton/ha/year raw biodiesel can be produced from WWT HRAP biomass.
- CO_2 addition increases biodiesel productivity while does not affect its quality.

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ABSTRACT

This study investigates the year-round production potential and quality of biodiesel from wastewater treatment high rate algal pond (WWT HRAP) biomass and how it is affected by CO_2 addition to the culture. The mean monthly pond biomass and lipid productivities varied between 2.0 ± 0.3 and 11.1 ± 2.5 g VSS/m^2/d, and between 0.5 ± 0.1 and 2.6 ± 1.1 g/m^2/d, respectively. The biomass fatty acid methyl esters were highly complex which led to produce low-quality biodiesel so that it cannot be used directly as a transportation fuel. Overall, 0.9 ± 0.1 g/m^2/d (3.2 ± 0.5 ton/ha/year) low-quality biodiesel could be produced from WWT HRAP biomass which could be further increased to 1.1 ± 0.1 g/m^2/d (4.0 ton/ha/year) by lowering culture pH to 6–7 during warm summer months. CO_2 addition, had little effect on both the biomass lipid content and profile and consequently did not change the quality of biodiesel.

1. Introduction

Increasing fossil fuel consumption has accelerated global warming and caused several environmental problems such as air pollution and changing marine ecosystem (Sheehan et al., 1998). To reduce the environmental problems associated with use of transportation fuels, replacement of petro-diesel by premium quality biodiesel derived from a renewable feedstock such as algal has been suggested for several decades (Mehrabadi et al., 2015; Sheehan et al., 1998). Of all renewable biofuel resources, microalgae have been highlighted due to: 1) high biomass and lipid productivities (up to 100× greater than oil seeds), 2) temperature tolerance, 3) ability to grow on wasteland and wastewater, 4) ability to bio-fix high amounts of CO_2 (1.7–2.4 tons of CO_2 per one ton of microalgae biomass), and 5) relatively simple life cycle (Nascimento et al., 2015; Sheehan et al., 1998). It has been predicted, based on small-scale controlled experiments, that 7–60 ton/ha/year biodiesel could potentially be produced from pure fresh/seawater algae (Moazami et al., 2011; Pienkos, 2007). These values are much higher than the potential values for oil seed-based biodiesel: ~0.4 ton/ha/year from soybean, ~0.7 ton/h/year from canola, ~2 ton/ha/year from jatropha, ~4.5 ton/ha/year from palm (Ardebili et al., 2011; Eryilmaz et al., 2016).

Biodiesel production from algae involves six sequential steps (Iyer, 2016; Moazami et al., 2011) including: 1) species selection (in terms of biomass and lipid productivities as well as suitability of lipids for biodiesel production), 2) algal cultivation, 3) biomass harvesting, concentrating and dewatering (optional), 4) lipid extraction (optional) and purification, 5) biodiesel production through esterification of the lipid fraction, and 6) biodiesel purification.

To date, despite intensive efforts, there are still several obstacles to efficient production of algal biodiesel, which have prevented it

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from being economic and competitive with petro-diesel. The low lipid content (typically <30 wt%) of algal biomass, the high cost of nutrient fertilisers and high energy demands for biomass harvest and dewatering are the main obstacles (Hannon et al., 2010; Slade and Bauen, 2013; Xu et al., 2011). In addition, there are several technological limitations for lipid extraction, purification and esterification (Hannon et al., 2010; Schlagermann et al., 2012; Xu et al., 2011). However, to lower production costs, different strategies including genetic engineering of algal lipid synthesis pathway to improve lipid content and profile, using wastewater as a nutrient source for cultivation of pure species, cultivation of easily settleable species, applying wet extraction methods, and enzymatic esterification to improve biodiesel yield have been employed (Antczak et al., 2009; Chinnasamy et al., 2010; Goettel et al., 2013; Park et al., 2013).

A number of studies have shown that 30–50% of the total energy demand for algal biodiesel production is from the cultivation and harvesting of biomass (Kang et al., 2015; Xu et al., 2011). While biodiesel production from pure algal biomass is still uneconomic, one opportunity to lower biodiesel production costs is where the algal-bacterial biomass is produced as an essentially free by-product of wastewater treatment in high rate algal ponds (Craggs et al., 2013; Mehrabadi et al., 2015). Wastewater treatment high rate algal ponds (WWT HRAPs) are shallow, paddlewheel-mixed open raceway ponds which are designed to optimise natural biological treatment processes (Mehrabadi et al., 2015). In fact, in such system cultivation and harvest costs are covered by treatment function. Hence, it is of interest to see whether the lipid content of such free feedstock is higher or lower than pure algal cultures, how it varies seasonally, and based on the fatty acid profile what the quality of the biodiesel produced from it would be. In addition, since WWT HRAP biomass is a consortium of different algal and bacterial species (Doma et al., 2016; Mehrabadi et al., 2016), the biomass lipids may be varied. It would result in higher downstream processing costs and consequently further diminish the potential for low-cost, high quality biodiesel production. To reduce the algal lipid variability, culturing under nutrient starvation conditions has been suggested (Xu et al., 2016). While as the main goal of WWT HRAP is wastewater treatment, there is little opportunity within this context to substantially alter the lipid content of such biomass. Therefore, to improve the quality biodiesel production potential in WWT HRAP, there is a need to find strategies to improve productivity, content and profile of the WWT HRAP biomass lipid without impacting pond treatment performance. Hence, the aims of this study are first to investigate the production potential of biodiesel from WWT HRAP biomass by measuring productivity, lipid content and lipid profile of biomass produced in two identical pilot-scale WWT HRAPs over one year, and second to assess the potential to improve biodiesel production and quality by CO_2 addition to the algal mix culture.

2. Materials and methods

2.1. Experimental set-up

To assess potential of WWT HRAP for biodiesel production three sets of experiment were conducted at the Ruakura Research Centre, Hamilton, New Zealand (37°47′S, 175°19′E). In experiment 1 (Exp. 1) two identical pilot-scale WWT HRAPs (West (WHRAP) and East (EHRAP)) were operated in parallel and sampled weekly over a year (July 2013-August 2014). The ponds culture depth, surface area and mean surface water velocity were 30 cm, 31.8 m^2 and 0.15 m/s, respectively. The ponds were fed with 0.5–1.0 m^3/day of primary settled domestic wastewater at hourly intervals from the Ruakura sewer. The pond hydraulic retention time (HRT) was changed with season from 8 days in winter to 5 days in summer. It is noteworthy that based on the literatures (Park and Craggs, 2011; Park et al., 2013) optimal HRT, in summer, is 4 days and therefore, either longer or shorter HRT may reduce biomass productivity in WWT HRAP. To avoid free ammonia inhibition and carbon limitation, the maximum pH of the HRAPs was kept below 8 during the daytime by CO_2 addition, if necessary. The ponds were operated with no control of the dominant algal species or of the zooplankton population.

Experiment 2 and 3 (Exp. 2&3) were conducted to investigate the effect of CO_2 addition on quality and quantity of the biodiesel could be produced from such free biomass. Both experiments were conducted under outdoor conditions in summer (Exp. 2, January 2014) lasted for 21 days and winter (Exp. 3, July-August 2014) lasted for 30 days. Fifteen replicate foil-wrapped plastic mesocosms (water depth of 0.3 m; volume of 16 L; surface area of 0.06 m^2) were used in each experiment and the cultures were sampled twice a week. The wastewater treatment high rate algal mesocosms (WWT HRAMs) were inoculated from adjacent pilot-scale WWT HRAP dominated by *Pediastrum* sp., *Micractinium* sp. and *Coelastrum* sp. in summer and by *Micractinium* sp., *Ankistrodesmus falcatus*, *Mucidosphaerium* sp. and *Monoraphodium* sp. in winter. The cultures were fed semi-continuously with primary settled domestic wastewater on 4 and 8 days hydraulic retention time in summer and winter, respectively. The mesocosms were supplemented by a mixture of air and CO_2 (with mole fractions of 0.04% CO_2, 0.5% CO_2 (control), 2% CO_2, 5% CO_2, 10% CO_2) using a gas diffuser placed on the bottom of the buckets while cultures were mixed continuously by individual magnetic stirrer. To have replication, each three mesocosms were sparged by air:CO_2 mixture. Over the course of study, daily climate data (temperature, solar radiation, evaporation and rainfall) were downloaded from NIWA's National Climate Database (http://cliflo-niwa.niwa.co.nz/).

2.2. Nutrient concentrations

During the sampling period (weekly for the ponds and twice per week for the HRAMs), the influent and effluent of WWT HRAPs/HRAMs were filtered through Whatman GF/F filters (with 0.7 μm pore size) and then the concentrations of ammonium (NH_4^+-N) and dissolved reactive phosphorous (PO_4^{3-}-P) were determined colorimetrically (APHA, 2008) using a spectrophotometer (HACH RD2008, Germany).

2.3. Algal species composition

During the sampling period (weekly for the ponds and twice per week for the HRAMs), a well-mixed sub-sample of HRAP/HRAM effluents was settled in an Utermöhl chamber (diameter: 25 mm-volume: 10 ml) and viewed on a microscope Leica DM 2500, equipped with a Leica DFC 420 digital camera (Leica Microsystem, Switzerland). Microalgae species were identified to species level, where possible, based on the taxonomic descriptions (John et al., 2011).

2.4. Biomass productivity

The biomass productivity (g VSS/m^2/d) was calculated, during the sampling period, based on the volatile suspended solids (VSS) concentration as described in Park et al. (2013). To determine the VSS a known volume (50 ml) of the pond/mesocosm effluent was filtered onto a pre-rinsed, pre-combusted and pre-weighed Whatman GF/F filter (with 0.7 μm pore size) and then dried in an oven (at 80 °C overnight). The sample was then combusted at 550 °C for 1 h in muffle furnace (F.E.KILN, RTC1000, Bartlett Instrument Company, UK). The weight loss was recorded as VSS concentration.