Photobioreactor production of microalgae for potential fuel oils

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Abstract

This work focussed on a detailed characterization of the freshwater microalga *Chlorella vulgaris* as a producer of potential fuel oils. Uniquely, growth and oil production of *C. vulgaris* were characterized in full strength seawater-based media, something that has not been previously reported. *C. vulgaris* was selected for a detailed study after a screening of six potential oil producing microalgae. For photoautotrophic growth, always under carbon sufficiency and at normal growth temperature, the characterization study covered: the biomass growth rate; lipid content in the biomass; productivities of the lipids and the biomass; the biomass loss in the dark; the lipid/biomass yields on macronutrients; and the energy content of the biomass. The above key production parameters were characterized in a purpose-built tubular photobioreactor (~80 L) and in stirred tank photobioreactors (~7.5 L) under conditions of nitrogen sufficiency and at various levels of nitrogen limitation. Production was evaluated in both batch and continuous cultures at various dilution rates using indoor light to mimic sunlight. The production temperature mimicked the relatively warm conditions that would be encountered in a potential production system located outdoors in a tropical climate.

In seawater media at 25–27 °C, *C. vulgaris* was shown to have a crude oil productivity of >37 mg L^{-1} d^{-1} and the energy content of the biomass could exceed 25 kJ g^{-1}, depending on the culture conditions. Both these values were high compared with the reported data for this alga in freshwater media. Compared with continuously illuminated culture, day–night cycling of irradiance reduced oil productivity by ~31%, but the energy content of the biomass were reduced by only about 8%. In seawater, the alga could be grown as rapidly and stably as in freshwater. The lipid content of the biomass commonly exceeded 30% by dry weight and in exceptional cases a lipid content of more than 50% (by weight)

was achieved. Biomass calorific values of ≥27 kJ g^{-1} could be attained in some cases. Nitrogen starvation enhanced the lipid contents of the biomass by >3-fold relative to the lipid contents for the nonstarved case. Steady-state continuous cultures were shown to be possible. Both batch and continuous operations were feasible, especially in stirred tanks, but the culture was more failure prone, or relatively less productive, in the tubular photobioreactor.

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Abbreviations

A	Area illuminated by light (m^2)
A_{xxx}	Spectrophotometric absorbance at a wavelength of xxx nm
BR n	Corning stirred photobioreactor run n
C	Biomass concentration at time t (g L^{-1})
C_0	Biomass concentration at time zero (g L^{-1})
D	Dilution rate (d^{-1})
DCW	Dry cell weight (g L^{-1})
DHA	Docosahexaenoic acid
DNA	Deoxyribonucleic acid
DO	Dissolved oxygen
d	Diameter (m)
EPA	Eicosapentaenoic acid
F	Flow rate of the feed (mL d^{-1})
I	Irradiance (μmol m^{-2} s^{-1})
k	First-order rate constant for biomass loss (h^{-1})
LED	Light emission diodes
ND	Not determined
N_f	Final concentration of nitrate (mg L^{-1})
N_i	Initial concentration of nitrate (mg L^{-1})
PAR	Photosynthetically active radiation
PBR n	Tubular photobioreactor run n
P_f	Final concentration of phosphate (mg L^{-1})
P_i	Initial concentration of phosphate (mg L^{-1})

PTFE	Poly (tetrafluoroethylene), or Teflon
Q_L	Final lipid productivity (g $L^{-1}d^{-1}$)
Q_X	Final biomass productivity (g $L^{-1}d^{-1}$)
q_L	Specific lipid production rate (d^{-1})
q_N	Specific nitrate consumption rate (mg $g^{-1}d^{-1}$)
q_P	Specific phosphate consumption rate (mg $g^{-1}d^{-1}$)
RNA	Ribonucleic acid
RTD	Resistance temperature detector, a type of temperature sensor
RUBISCO	Ribulose-1,5-bisphosphate carboxylase/oxygenase
RuBPCase	Ribulose-1,5-bisphosphate carboxylase/oxygenase
SARDI	South Australia Research and Development Institute
STR n	Stirred tank bioreactor (BioFlo) run n
TL	Total lipids
t	Duration of a batch (d)
t_f	Time at the end of a batch (d)
t_i	Time at the beginning of a batch (d)
V	Working volume of the reactor, or volume (L)
X_f	Final concentration of biomass (g L^{-1})
X_i	Initial concentration of biomass (g L^{-1})
$Y_{L/Light}$	Lipid yield on light (g μmol^{-1})
$Y_{L/N}$	Lipid yield coefficients on nitrate (g mg^{-1})
$Y_{L/P}$	Lipid yield coefficients on phosphate (g mg^{-1})
$Y_{X/Light}$	Biomass yield coefficient on light (g μmol^{-1})
$Y_{X/N}$	Biomass yield coefficient on nitrate (g mg^{-1})
$Y_{X/P}$	Biomass yield coefficient on phosphate (g mg^{-1})

y	Weight fraction of lipids in the biomass
ICP-MS	Inductively coupled plasma mass spectrometry
ICP-OES	Inductively coupled plasma optical emission spectrometry