Raceway-based production of microalgae for possible use in making biodiesel

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Sadia Tahir

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Abstract

Oils from microalgae are of interest as a potential feedstock for producing renewable transport fuels including gasoline, diesel, biodiesel and jet fuel. For producing feedstock oils, an alga must be capable of being grown easily in readily available seawater and have a high productivity of biomass and oil. This study explored the biomass and lipid production potential of the microalga *Chlorella vulgaris* in seawater media, as a potential producer of feedstock oils. The alga was grown photoautotrophically under various conditions in ~2 L Duran bottles and a pilot scale (~138 L) raceway system. Initially, eight species of microalgae of different classes were assessed under nutrient sufficient growth conditions for the production of biomass and lipids in ~2 L Duran bottles. Two of the promising species (*C. vulgaris* and *Nannochloropsis salina*) were then further evaluated extensively under various conditions (i.e. salinity stress, different levels of nitrogen in growth media, continuous light and light-dark cycling). Based on these assessments *C. vulgaris* stood out as the best alga for further detailed study. *C. vulgaris* was evaluated for biomass production and lipid production. The consumption rates of major nutrients (N and P) were quantified. Biomass was characterized for elemental composition and energy content at the end of the growth cycle. A maximum lipid productivity of ~31 mg L^{-1} d^{-1} was attained in Duran bottle batch culture under nitrogen starvation in continuous light with a lipid content in the biomass of ~66% (dry weight). This appears to be the highest lipid content reported for *C. vulgaris* grown in seawater and demonstrates an excellent ability of this alga to accumulate high levels of oil. Under a 12:12 h light-dark cycle, the lipid content and productivity in Duran bottle batch culture were decreased by 13% and 41%, respectively, relative to the case for continuous illumination. Energy content of the biomass produced in Duran bottle batch culture exceeded 30 kJ g^{-1} both in continuous light and the 12: 12 h light-dark cycle.

Batch and continuous culture kinetics of *C. vulgaris* in the raceway system were assessed. The alga was subjected to various light regimes and nitrogen starvation conditions. Although the N starvation enhanced the lipid accumulation by 42% relative to nutrient sufficient growth in batch culture, the highest biomass and oil productivities were attained under nutrient sufficient conditions in continuous mode of cultivation. Under nutrient sufficiency in continuous culture with a constant illumination of 91 $\mu mol \cdot m^{-2} s^{-1}$, the productivities of biomass and lipid in the raceway were >61 mg L^{-1} d^{-1} and >8 mg L^{-1} d^{-1}, respectively.

This work represents the first detailed study of *C. vulgaris* in a raceway pond in full strength seawater media. Previous studies of this alga were almost always carried out in freshwater media.

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Abbreviations

A	Surface area for light absorption
Acetyl-CoA	Acetyl coenzyme A
ADP	Adenosine diphosphate
ATP	Adenosine triphosphate
A_{xxx}	Spectrophotometric absorbance at *xxx* nm
BG11	A medium formulation for growing cyanobacteria/microalgae
CCALA	Culture Collection of Autotrophic Organisms, Czech Republic
CCAP	Culture Collection of Algae and Protozoa, Argyll, United Kingdom
D	Dilution rate
DCW	Biomass dry cell weight
DF	Dilution factor
DHA	Docosahexaenoic acid
DNA	Deoxyribonucleic acid
EPA	Eicosapentaenoic acid
F	Feed flow rate
FAME	Fatty acid methyl esters
F/2-Si	A medium formulation for growing diatoms
GC	Gas chromatography
G3P	Glyceraldehyde-3-phosphate
HRAP	High Rate Algal Ponds
I	Irradiance
ICP-MS	Inductively coupled plasma mass spectrometry
ICP-OES	Inductively coupled plasma optical emission spectrometry
I_L	Local irradiance at any depth *L* from the surface

ISO	International Organization for Standardization
L	Depth from the surface
LED	Light emitting diode
MBL	A medium formulation for growing cyanobacteria/microalgae
NA	Not available
NADPH	Reduced form of nicotinamide adenine dinucleotide phosphate
ND	Not determined
N_f	Final nitrate concentration
NCMA	Provasoli-Guillard National Center of Marine algae and Microbiota, Maine, USA
N_i	Initial nitrate concentration
NIWA	National Institute of Water and Atmospheric Research Ltd, New Zealand
N_1	Nitrate concentration at time t_1
N11	A medium formulation for growing cyanobacteria/microalgae
N_2	Nitrate concentration at time t_2
PAR	Photosynthetically active radiation (light in the wavelength range of 400-700 nm)
P_b	Biomass productivity
PBR	Photobioreactor
P_f	Final phosphate concentration
PFD	Photon-flux density
P_i	Initial phosphate concentration
P_l	Lipid productivity
ppt	Part per thousand
PUFA	Polyunsaturated fatty acid
P_1	Phosphate concentration at time t_1

P_2	Phosphate concentration at time t_2
q_N	Average biomass specific nitrate consumption rate
q_P	Average biomass specific phosphate consumption rate
RNA	Ribonucleic acid
rpm	Revolutions per minute
RTD	Resistance temperature device
RuBP	Ribulose-1,5-bisphosphate
S	Surface area
t	Duration time of a batch (i.e. the time required to attain the biomass concentration X_f
TAG	Triacylglycerols
UTEX	The Culture Collection of Algae of University of Texas, Austin, USA
V	Volume
V	Volume in the culture vessel
v/v	Volume by volume
w	Weight fraction of the lipids in the biomass
w/w	Weight by weight
w_s	Steady state weight fraction of the lipids in the biomass
x	x-Variable
X	Biomass concentration at any time t
X_i	Initial biomass concentration
X_f	Final biomass concentration
X_s	Steady state biomass concentration
X_1	Biomass concentration at time t_1
X_2	Biomass concentration at time t_2
y	y-Variable

Y_N, $Y_{X/N}$ Biomass yield coefficient on nitrate

Y_P, $Y_{X/P}$ Biomass yield coefficient on phosphate

$Y_{X/L}$ Biomass yield coefficient on light

Greek symbols

μ Specific growth rate