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Effects of CO_2 sequestration on lipid and biomass productivity in microalgal biomass production

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HIGHLIGHTS

- Algal technology strategies successfully monitored effects of CO_2 sequestration.
- In comparison with ambient CO_2, 1% (v) of CO_2 addition promoted algal growths.
- Average logarithmic growth rate was 60% higher.
- CO_2 removal across species is analogous to lipid build ups; highest in *Chlorella.*

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ABSTRACT

The study is focused on the technology and manipulation of production strategies for the cultivation of biomass from four strains of microalgae. Species of microalgae studied are: *Chlorella vulgaris*, *Dunaliella*, *Scenedesmus quadricauda* and *Synechococcus* spp. The effects of the rate and amount of CO_2 removal from the atmosphere and sequestration with dissolved oxygen on lipid production from accumulated biomass were studied. Also, the rate of sequestration of both total and dissolved carbon was investigated. Daily measurements of total, organic and inorganic carbon sequestrated, optical densities, proximate analysis and kinetic parameters of the growing and cultivated microalga were monitored and carried out during the two phases of cultivation: dark and light phases. The values of maximum rate of carbon (IV) oxide removed, r_{max} varied from 11.73 mg L^{-1} min^{-1} to 18.84 mg L^{-1} min^{-1} from *Chlorella vulgaris* to *Synechoccocus* spp. Important parameters such as biomass productivity, maximum pH values obtained at cultivation, lipid content of the produced biomass and the hydraulic detection time for all four strains of microalgae were considered and presented in comparison and with their individual and collective effects. The ratios of the rate of CO_2 absorption constant and the constant for the CO_2 desorption rate (k1/k2) occurred highest in *Dunaliella* suggesting that with a high uptake of CO_2, the algal strain is more effective in CO_2 sequestration. The best biomass producer in this study was the *C. vulgaris* (X_{max} = 5400 mg L^{-1} and Px = 35.1 mg L h^{-1}) where biomass productivity is P_x and the maximum cellular concentration is X_{max}. *C. vulgaris* has the highest lipids productivity of 27% while Synechoccocus has the least (11.72%). In general, biomass productivity may be inversely related; this fact may be explained by greater metabolic involvement of lipid biosynthesis. This pioneer study may be advanced further to developing models for strategic manipulation and optimisation approach in micro algal biomass cultivation.

1. Introduction

There are dwindling growths in the economy of most oil producing nations due to instability in the global market oil prices. In addition, the constant depletion of oil reserves has intensified the worldwide demand for renewable energy resources. The attendant consequences provoke environmental concerns in terms of increased greenhouse gases which also affects mitigating climate change strategies. These are current burning global issues for the climatic, economic and technological preferences for renewable energy technologies and resources [1,2]. The urgent revolution in engineering CO_2 free fuel resources have been positioned by various designs and modeling strategies for sustainability. The adverse effects of climate change, national and global economic and climatic impacts with rising competition in the fossil fuel market

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by the great oil and gas players in control of the world economies have presented unquestionable repercussions for this paradigm shift [3–5]. In consideration of these, climate change phenomenon virtually represents the highest time-constrained catalyst for the development of green energy technologies globally. This is of great interest because a recline in CO_2 emission according to the International Panel on Climate Change Report [3] between ±25% and ≤40% on the attainment of 2020 and 80% up to 90% by the year 2050 was projected to be sufficient in limiting the global continuous rise in temperature to at least less than 2 °C. Current research interests are then directed towards unrelenting search for potential energy resources from diverse sources. These are transformed through physical, chemical and biochemical processes into liquid, gaseous and solid fuels for domestic and industrial needs. Studies have identified various feedstocks as alternative sources. These may range from energy crops, bio-degradable wastes (plants and animal wastes), photosynthetic organisms of various kinds, diatoms, sea weeds and recently diverse aquatic plants; micro and macro algae are also identified as bio-oil sources.

1.1. Potential of microalgae as green energy feedstock

As diverse and largely basic, simple organism, autotrophic in nature, multi-cellular and unicellular in form and shape, algae have the capability to considerably produce and thus manufacture lipids, starch, food and biomass per hectare more than most continental and terrestrial floras (plants and organisms) [6]. They can be grown on any marginal land, tanks, tubes, dams, lagoons and ponds (open or closed). Competition with food chain and with other plants for nutrients does not exist. They are photosynthetically cultivated with energy from sunlight; nutrients and carbon sources (CO_2); can also be cultivated in raceway ponds, marginal shallow lagoons or in contained ponds. Sometimes, plastic tubes in the form of photo-bioreactors are employed and these offer more productivity rate than the open ponds. Several studies have been conducted using closed photo-bioreactors for higher yields, cost effective production and uncontaminated outputs especially from homogeneous algal biomass. Beer et al. [6] performed such experiment and attained with high yields. The economic viability of production of bio-value products especially lipids by algae also depends largely on the type of technology employed, manipulation of strategies and the benefit/cost ratio (techno-economics) of the adopted technology. Irrespective of the biological innovations and the technological manipulation strategies adopted, the open secret lies in the fact that the marketplace for commercial viability remains to elicit the enthusiastic approach for driving the economic base for huge capital energy projects since the whole attention are still developmental and hugely capital intensive [6].

Feedstocks from microalgae and its process value added products are of research interests in the recent energy scenario. Their expeditious growth rate, in addition to their comparatively high lipids, carbohydrates, food and other nutrients production and relatively short period of production are good indicators. These properties make them unique and exceptional sources for biofuel production, biodiesel, bio-methane, bio-kerosene and other value products, precursors and intermediate platform chemicals. According to Skjanes et al. [7], an efficient algal fuel commercialisation programme has to take into consideration, the following: (1) that the project is economically viable to produce fuels via microalgal technology, (2) that there is need for optimisation of maintenance and operational costs and (3) that maximization of oil-rich production through manipulation of production strategies for each desired product from algae. Originally, algae were looked at as 'aquatic plants' but over the years, have been separately classified because they lack key characteristics as true plants: they have no false roots, leaves, stems, no embryos and their sizes range from 'one-celled', tiny organisms to 'multi-celled', large plant-like organisms. They may be prokaryotic in nature which include: cyanobacteria or eukaryotic: red algae, diatoms, and green algae [8]. The attention is more in utilizing the latter in the bio-energy precursor's production for lipids, starch and hydrogen and for conversion to alcohols, fuel surrogates and fuel cells respectively. In comparison with other continental biofuel feedstocks, algae not only can transform energy from the sun into fuels (chemical energy) at high level efficiency, they can also thrive well in any brackish water environment [6]. The underlying force supporting all synthetic process of biofuel production in transforming solar energy into biomass is the photosynthetic process which also is responsible for the carbon-carbon interaction in the form of lipids and carbohydrates. These are the building block of fats and oil and/or hydrogen [7,9].

1.2. Contribution of CO_2 in algal biomass and lipid production

Microalgae are organisms which are photosynthetically imbued with considerable simple growth, simple requirements relative to other biodiesel and biomass sources. As a promising biodiesel production feedstock, it is scientifically proven that when excess ambient CO_2-enriched air is bubbled in, it favours the production of oily substances. Carbon source presents nearly 60% of minerals/nutrients needed and likewise the costs. Algae transform light, carbon-dioxide (CO_2) and water into biomass and oxygen photosynthetically. Other nutritional requirements needed may be accounted for in effluents/flare gases or from industrial wastes. The challenges of waste control and management are converted into specific raw materials (waste to wealth) and thus yielding added value in the final end products [10,11]. The potential advantage of this type of conversion process to a CO_2 neutral fuel carrier outweighs that needed for the same production from other known sources. Problems of air pollution emanating from CO_2 evolution in addition to the global depleting energy requirements are already unsettling the world. Issues of greenhouse emission especially from fossil fuel utilization are tragedies in our ecosystems. With escalating energy needs, industrialization and population overflow, urgent remedial action is ultimately necessary. Apart from greenhouse gases, other air contaminants are on the increase as well. These are SOx, NOx, VOCs, CO, H_2S particulate matter and others. Biomass from algae or other sources do not contribute to greenhouse gas emission and other contaminants but mitigates them. Renewable energy conservation and sustainability are the panacea to these global environmental issues and challenges. It is an acceptable necessity to curtail emissions through reduced human and industrial activities. This is necessary to avert the impending doom that global warming and effects of greenhouse pose to our ecosystem [12]. With reduction in transportation and engine emissions which contributes up to 27% of global primary energy [12] by the use of renewable biofuels and energy from biomass, a significant progress in the mitigation strategy may be attained. The use of bioenergy in whatever form has been reported to contribute net zero value of CO_2, SOx and other atmospheric contaminants more than fossil petroleum fuels [13]. Attention towards deploying biofuels from algae has generated a lot of recent research interests and thus will develop into viable and cost-effective algal production and utilization system.

1.3. Microalgal biomass technologies

Microalgal technology uses energy from sunlight: can be conducted in an open or closed pond or in photobioreactors which can be flat plated, tubular and or similar designs. Unlike the cultivation of other oil crops, their growths are extremely fast and the biomass production rates are doubled phenomenally every 24 h