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REVIEW ARTICLE

Maximum-CO_2 Tolerance in Microalgae: Possible Mechanisms and Higher lipid Accumulation

Vaibhav Nagaich*, Sumeet Kumar Dongre, Pushpendra Singh, Mahavir Yadav, Archana Tiwari
School of Biotechnology, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, Madhya Pradesh, Airport Bypass Road, Bhopal - 462033 India

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Corresponding Author

Vaibhav Nagaich

Abstract

Microalgae are belonging to unicellular or simple multicellular photosynthetic microorganisms that have the capability to fix CO_2 from various sources, industrial exhaust gases, with the environment and soluble carbonate salts. Unbalanced production of the environment CO_2 constitutes a most important challenge to worldwide sustainability. Photoautotrophic algal cultures have the possible to lessen the release of CO_2 into the environment by CO_2 fixation, helping alleviate the trend toward global warming. Increased CO_2 concentration improved significantly the growth rate of the species. In this study, the effects of nitrate feeding on microalgal growth and related CO_2 fixation were evaluated, as a affinity to increase carbon fixation. The present study aimed at investigating the mechanisms of carbon dioxide fixation in microalgal cultivation. Biomass composition accessible a prevalence of proteins but also a high amount of lipids. The Rubisco give the high greatest specific reaction rate by the use of high CO_2 and (initially) O_2-free situation. Photosynthetic equipment state transitions that increase ATP generation, up regulation of H+-ATPase pumping protons out of the cell, shutdown of CO_2-concentrating mechanisms, and alteration of membranes' fatty acid composition are presently assumed to be the key mechanisms leading cellular pH homeostasis and hence microalgae's tolerance to high CO_2 levels. The different percentage of carbon dioxide fixation enhances the higher lipid in the microalgae.

Introduction

Due to the consumption of fossil fuels, the atmospheric greenhouse gases such as carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NOx) rises.(Hempel, Petrick et al. 2012). The unbalance overload of CO_2 in the environment having the major problem for the environment. CO_2 fixation by microalgal cultures has the possible to reduce the release of CO_2 into the environment, helping improve the movement toward global warming (Ono and Cuello 2003).

An raise in atmospheric CO2, derived from fossil fuel combustion, poses big challenges to worldwide sustainability(Change 2007). Natural photosynthesis in green plants achieves carbon dioxide (CO2) fixation on a worldwide scale. The incorporation of carbon dioxide (CO2) into the biosphere by the photosynthetic action of plants and microorganisms has been approximate to total to about 1011 tons of CO2 per year(Ramanan, Vinayagamoorthy et al. 2012).

With the fast development of present industry, they require for energy has enlarged substantially in current years, and consequently, unconventional energy sources are being explored. At this time Biodiesel is produced from plant and animal oils. Biodiesel is a important fuel that has grown extremely in popularity over the past decade. With decreasing reserves of fossil fuels, At this time it is more important than ever to search for transportation fuels that can serve as alternatives to crude oil-based fuels such as diesel and gasoline (Sudhakar and Premalatha 2012).

Micro algae can convert CO2 to potential biofuels, foods, feeds and high-value bioactive compounds by using of sun light (Chisti 2007).

The unbalance overload of carbon dioxide in the atmosphere cause major problem in the environment, the microalgae having the useful phenomena above this problem. Micro algae utilize carbon dioxide as sources of nutrients.

Based on these evidence the current work is an attempt to create biodiesel from microalgae and also to apply algae for carbon dioxide sequestration.

Microalgal strains for fixation of CO_2

The various microalgal species have been shown to be able to use carbonates such as Na_2CO_3 and $NaHCO_3$ for cell growth(Huertas, Colman et al. 2000).

Microalgae can fix carbon dioxide from different sources, which can be characterized as

- CO_2 from the environment,
- CO_2 from industrial exhaust gases , and

Fixed CO_2 in the form of soluble carbonates (e.g., $NaHCO_3$ and Na_2CO_3) (Wang, Li et al. 2008).

A number of microalgae species have been studied for CO_2 reduction, such as Chlorella kessleri, Scenedesmus obliquus(de Morais and Costa 2007) , Chlorocuccum littorale(Ota, Kato et al. 2009), Dunaliella tertiolecta, Chlorella vulgaris, Spirulina platensis, Botryococcus braunii(Sydney, Sturm et al. 2010), Nannochloropsis oculata(Chiu, Kao et al. 2009), and Chlorella sp.(Chiu, Kao et al. 2008).

Photosynthesis and growth

Photosynthesis is the important mechanism in which living organisms obtains their energy and nutrients, directly and indirectly. Algal photosynthesis is a unique process by which solar energy is transformed into chemical energy that is stored in organic carbon substance through the cycling of atmospheric CO_2. Photosynthesis takes place in specific organelles called chloroplasts of eukaryotic species, and also in a membrane-bound sac known as a thylakoid of the cyanobacterium due to lack of defined chloroplast structure in the prokaryotic organism. Photosynthesis is commonly conducted in two divide steps—the light and dark reactions(Rubio, Camacho et al. 2003). CO_2 convert in to the organic carbon in algae by two carboxylation pathways C_3 and C_4 carbon fixation pathway. Enzyme Rubisco (ribulose-bisphosphate carboxylase) catalyzes the reaction of RuBP + CO_2 + HO_2 to 2 PGA (phosphoglyceric acid), In the C3 pathway. In Calvin cycle, PGA convert in sugar. It is supposed that mainly algae and higher plants utilize the C3 pathway to fix the inorganic carbon. Some algae and plants evolved another C4 pathway—CO_2 is first transformed into a four-carbon organic compound and then CO_2 released for fixation by Rubisco(Raven, Giordano et al. 2012).

Cell growth is another basic feature of algal cell biology, which, together with photosynthesis and nutrition supplements, determines the maximal potential of the algal biomass production. Cell growth probably consists of two phases—earlier cell proliferation and later improvement in cell volume, both of which directly contribute to algal biomass accumulation(Beardall and Raven 2013).

The photosynthesis is the most useful phenomenon in microalgae, solar energy converted in to chemical energy and the CO_2released for fixation by Rubisco.

Robustness of pH homeostasis in the cell

The fast inhibition of photosynthesis observed under high-CO_2 circumstances could be a consequence of inactivation of the key enzymes of the Calvin cycle due to acidification of the stromal section of the chloroplast(Zarco-Tejada, Catalina et al. 2013) under high-CO_2 stress. This proposal was confirmed by Pronina et al.(Pesheva, Kodama et al. 1994) who recognized, using vital ^{31}P-NMR, that the pH of the cytoplasm in the CO_2-tolerant microalga C. littorale does not fall below 7.0, even during farming under excessive (40 %) CO_2 levels(Miyachi, Iwasaki et al. 2003).

Active transport of H^+

Taking into account these result, it is obvious that efficient control of intracellular pH is crucial for high-CO_2 tolerance. Such control might be achieved by pumping the protons from the cytoplasm into the vacuoles, for example, via utilization of the surplus ATP generated as a result of cyclic electron transport by the ATPase and H^+-pyrophosphates associated with the tonoplast(Rienmüller, Dreyer et al. 2012).

A significant factor of CO_2 tolerance is the ability of microalgae cells to enhance the pH of the medium through active growth via nitrate uptake. Alkalization of the medium is assumed to recompense, to a substantial extent, for the acidification effect of high CO_2 concentrations. This mechanism operates in Emiliania huxleyi(Fukuda, Suzuki et al. 2011).

A sufficient supply of NO_3 - would be essential for proficient acclimation to high CO_2 and carbon capture from flue gases by the microalgal cultures.

Shutdown of the CO_2-concentrating mechanism (CCM)

(Satoh, Kurano et al. 2002) established a drop in intracellular pH within 1 h of transferring C. littorale cells growing in low CO_2 to 40 % CO_2. This effect was eliminated by action of the cells with ethoxzolamide. Farming of the low-CO_2-adapted microalgal cells at eminent CO_2 bring about a substantial refuse in CCM activity. In Chlamydomonas reinhardtii, squalor of CA takes ca. 7 days(Baba and Shiraiwa 2012) and occurs in parallel with inhibition of active transport of bicarbonate(Bhatti and Colman 2008).

Effects on lipid biosynthesis and fatty acid composition

Many research groups are presently affianced in the isolation of novel CO_2-tolerant strains and investigations into their ability to build up storage lipids when sparged with high, or even pure, CO_2(Yoo, Choi et al. 2012). In general, a moderate (2–5 %) increase in CO_2 stimulates both growth and lipid accumulation by microalgal cells(Muradyan, Klyachko-Gurvich et al. 2004). The availability of other carbon sources has a strong effect on lipid accumulation under elevated CO_2. In particular, the possessions of high or low inorganic carbon concentrations (CO_2 and bicarbonate) on neutral lipid and starch accumulation were studied in the model alga Chlamydomonas reinhardtii during nitrogen depletion under photoautotrophic conditions(Gardner, Lohman et al. 2013). Under low CO_2 (0.04 %), carbon limitation resulted in reduced accumulation of both storage products - triacylglycerol (TAG) and starch; at 5 % CO_2, the highest amount of TAG was produced, however under these circumstances rapid TAG accretion was followed by squalor (probably following acclimation to the elevated CO_2 level). Under high bicarbonate supplementation, the cell cycle was arrested and sustainable accumulation of both TAG and starch was recorded. In mixotrophic cultures (grown on an organic carbon source), raising CO_2 levels impaired the algae's capacity for import and assimilation of glycerol(Sforza, Cipriani et al. 2012).

Obviously, lipid (TAG in particular) biosynthesis represents a sink for the excess products of carbon fixation, which is especially important under hectic conditions causing termination of cell division(Solovchenko 2012).

One could further consider that the ability to channel the excess photosynthates to the biosynthesis of energy-rich compounds such as TAG may, in some situations, give to high-CO_2 tolerance of microalgae.

The enhance in CO_2 concentration in microalgae leads the growth and lipid accumulation in microalgae. Chlamydomonas reinhardtii showing the maximum triacylglycerol production.

Conclusion

We are still some way from realizing the absolute potential offered by algal biodiesel. For the purpose of CO_2 sequestration, the use of microalgae is an exclusive technology. Life-cycle analyses suggest that using current methodologies the procedure is trivial in terms of positive energy balance and global warming potential. The actual process of photosynthesis, which can be utilized to fix carbon dioxide and produce useful by-products in a sustainable fashion, has been explained to be feasible and the design of a solar energized photo-bioreactor system for the function of carbon dioxide fixation was illustrated to be technically possible. CO_2 mitigation and biofuels production could be mutual in an economically feasible and environmentally sustainable approach. The possibility of this strategy could be further improved by fixing CO_2 from industrial exhaust gases such as flue gases and by integrating microalgal cultivation.

Table.1-Range of significant attributes (CO_2 and temperature tolerance capacity) of commonly used microalgae

Alga	CO_2 tolerance capacity (%)	Reference
Cyanidium caldarium	100	Seckbach et al., 1971
Eudorina sp. K17	20	Hanagata et al., 1992
Chlorella sp. K35	50	Hanagata et al., 1992
Scenedesmus sp. K34	80	Hanagata et al., 1992
Chlamydomonas sp. MGA 161	15	Miura et al., 1993
Nannochloropsis salina NANNP-2	10	Hamasaki et al., 1994
Chlorella sp. T-1	100	Maeda et al., 1995
Synechococcus elongates	60	Miyairi 1995
Monoraphidium minutum	13.6	Zeiler et al., 1995
Chlorella sp.	40	Sakai et al., 1995
Chlorella sp. UK001	40	Hirata et al., 1996
Euglena gracilis	45	Nakano et al., 1996
Chlorella vulgaris	15	Yun et al., 1997
Dunaliella tertiolecta	15	Nagase et al., 1998
Cyanidium sp.	100	Graham and Wilcox 2000
Chlorella sp.ZY-1	70	Yue and Chen 2005
Spirulina sp.	12	de Morais and Costa 2007a
Scenedesmus obliquus	18	de Morais and Costa 2007a
Chlorella kessleri	18	de Morais and Costa 2007b
Chlorococcum littorale	70	Ota et al., 2009
Chlorella minutissima	15	Sankar et al., 2011
Desmodemus sp.	100	Kativu et al., 2011

Figure.1- Mechanism of CO_2 Fixation

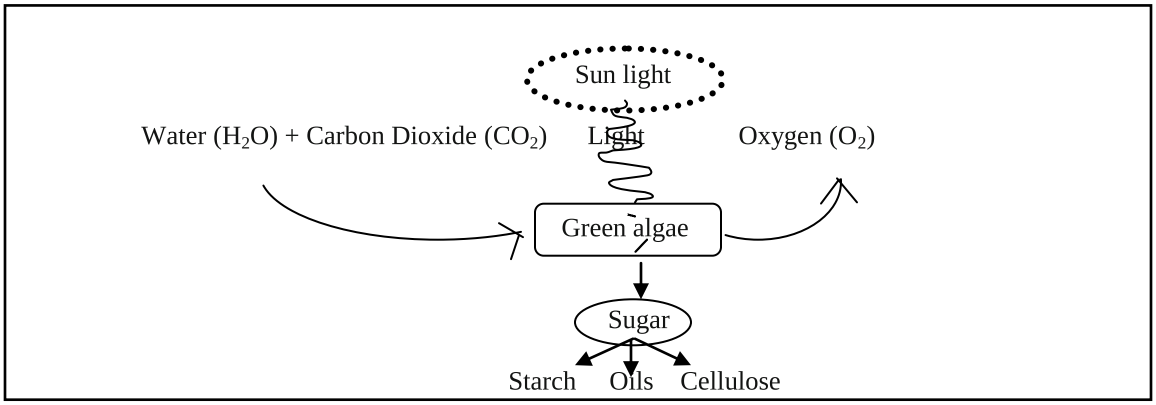

Table.2- Lipid content in the dry biomass of various species of microalgae

Species	**Lipid content (% dry weight)**
Anabaena cylindrical	4–7
Botyococcus braunii	25–80
Chlamydomonas reinhardtii	21
Chlorella vulgaris	14–22
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Dunaliella bioculata	8

Dunaliella primolecta	23
Dunaliella tertiolecta	35.6
Euglena gracilis	14–20
Hormidium sp.	38
Isochrysis sp.	25–33
Nannochloris sp.	30–50
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Pleurochrysis carterae	30–50
Porphyridium cruentum	9–14
Prymnesium parvum	22–38
Scenedesmus dimorphus	16–40
Scenedesmus obliquus	12–14
Schizochytrium sp.	50–77
Spirogyra sp.	11–21
Synechoccus sp.	11
Tetraselmis maculate	8
Tetraselmis sueica	15–23

Future Prospects

To conclude, microalgae can securely be termed as the favorable system for CO2 sequestration compared to forests and other vegetation. These should be chosen over others due to their possible of faster growth, high photosynthetic efficiency, environment friendly operation of effluent nutrients and flue gas, and providing a spectrum of value added mercantile products with no waste by-products. Continued progress of technologies to optimize the microalgae production, wastewater treatment, and biomass processing has the facility to make important contributions towards this object.

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