EFFECTS OF DIFFERENT LIGHT SPECTRUMS ON GROWTH AND PROXIMATE BIOCHEMICAL COMPOSITION OF Chaetoceros calcitrans AND MARINE Chlorella sp.

GREGORY TAN GUAN YUAN

IB 2020 26

EFFECTS OF DIFFERENT LIGHT SPECTRUMS ON GROWTH AND PROXIMATE BIOCHEMICAL COMPOSITION OF *Chaetoceros calcitrans* AND MARINE *Chlorella* sp.

By

GREGORY TAN GUAN YUAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

December 2019

COPYRIGHT

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

EFFECTS OF DIFFERENT LIGHT SPECTRUMS ON GROWTH AND PROXIMATE BIOCHEMICAL COMPOSITION OF *Chaetoceros calcitrans* AND MARINE *Chlorella* sp.

By

GREGORY TAN GUAN YUAN

December 2019

Chairman : Sanjoy Banerjee, PhD
Institute : Bioscience

The growth and biochemical composition of microalgae is influenced by light, CO_2, nutrients, temperature, pH and mixing. The spectral quality of light source plays an important role in the growth of microalgae and their biochemical composition. Light emitting diodes (LEDs) are an alternative for replacing sunlight and less energy efficient conventional lights as the spectral wavelengths of LEDs can be customized according to species requirements and they consume much less energy.

The aim of this study is to examine the growth, proximate biochemical composition and fatty acid profile of *Chaetoceros calcitrans* and marine *Chlorella* sp. In the first phase, microlagae were cultivated in small scale photobioreactors (1 L) and exposed to five different spectrums from LEDs – blue, white, green, yellow, red and fluorescent lamp (FL) as the control. In *C. calcitrans*, yellow light demonstrated the highest ($p < 0.05$) specific growth rate. Protein content was found to be the highest in the FL-control treatment followed by blue and red light, and lowest in yellow light. Lipid content in *C. calcitrans* was also found to be amongst the highest in yellow along with blue and green light but lowest in white light. Green light treatment had the highest carbohydrate content over the other treatments whereas the lowest was found in white light. The fatty acid content was also found to be influenced by light spectrums. *Chaetoceros calcitrans* produced highest amounts of ω3 essential fatty acids under red light whereas it was green light for poly-unsaturated fatty acids (PUFAs). Based on the high specific growth rate and lipid production from the first phase, yellow light was selected for the second phase of the experiment which was conducted in flat panel photobioreactors (FP-PBR; 60 L). In phase 2, no significant difference was found in cell density and biomass upon harvest in both yellow and FL-control. However, yellow light demonstrated a higher protein content over FL-control, but showed no

significant difference in lipid and carbohydrate. Yellow light also produced the highest PUFAs and ω3 fatty acids.

As seen for *C. calcitrans*, yellow light also demonstrated a higher specific growth rate in marine *Chlorella* sp. in phase 1. The highest protein content in *Chlorella* sp. was found in red light while the lowest was in FL-control treatment. However, FL-control showed the highest lipid content. Lowest carbohydrate content was found in red light. In *Chlorella* sp., red light produced higher amounts of ω3 and PUFAs and green light promoted the synthesis of ω6 fatty acids. Based on the high specific growth rate of *Chlorella* sp. from the phase 1, yellow light was selected for phase 2 of the experiment which was conducted in flat panel photobioreactors (FP-PBR; 60 L). In phase 2, no significant differences were found in cell density and biomass upon harvesting in both yellow and FL-control. However, yellow light only demonstrated a higher protein content over FL-control, and was significantly lower in lipid and carbohydrate content. Yellow light also produced the highest PUFAs and ω3 fatty acids in *Chlorella* sp.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KESAN SPEKTRUM CAHAYA BERBEZA TERHADAP PERTUMBUHAN DAN KOMPOSISI BIOKIMIA PROXIMASI *Chaetoceros calcitrans* DAN *Chlorella* sp. MARIN

Oleh

GREGORY TAN GUAN YUAN

Disember 2019

Pengerusi : Sanjoy Banerjee, PhD
Institut : Biosains

Pertumbuhan dan komposisi biokimia mikroalga dipengaruhi oleh cahaya, karbon dioksida, nutrien, suhu, pH dan peredaran. Kualiti spektrum sumber cahaya memainkan peranan penting dalam pertumbuhan mikroalga dan komposisi biokimia mereka. Pancaran cahaya diod (LED) adalah sumber cahaya alternatif untuk menggantikan cahaya matahari dan lampu konvensional yang kurang cekap dan panjang gelombang spektrum LED boleh diubahsuaikan mengikut keperluan spesies dan mereka menggunakan tenaga yang kurang.

Tujuan kajian ini adalah untuk mengkaji pertumbuhan, komposisi biokimia proksima dan profil asid lemak *Chaetoceros calcitrans* dan *Chlorella* sp. marin. Pada fasa pertama, mikrolalga dikultur dalam fotobioreaktor kecil (1 L) dan terdedah kepada lima spektrum LED yang berlainan - biru, putih, hijau, kuning, merah dan lampu pendarfluor sebagai kawalan. Bagi *Chaetoceros calcitrans*, cahaya kuning menunjukkan kadar pertumbuhan spesifik ($p < 0.05$) yang tertinggi. Kandungan protein *C. calcitrans* didapati paling tinggi dalam rawatan kawalan diikuti oleh cahaya biru dan merah, dan paling rendah dalam cahaya kuning. Kandungan lipid dalam *C. calcitrans* juga didapati tertinggi dalam cahaya kuning bersama dengan biru dan hijau tetapi paling rendah dalam cahaya putih. Rawatan cahaya hijau mempunyai kandungan karbohidrat tertinggi berbandingkan rawatan lain manakala yang paling rendah didapati dalam cahaya putih. Kandungan asid lemak juga didapati dipengaruhi oleh spektrum cahaya. *Chaetoceros calcitrans* menghasilkan ω3 asid lemak penting yang tertinggi di bawah cahaya merah manakala cahaya hijau untuk asid lemak poli tidak jenuh. Berdasarkan kadar pertumbuhan spesifik dan pengeluaran lipid yang tinggi dari fasa pertama, cahaya kuning dipilih untuk eksperimen fasa kedua yang dijalankan di dalam fotobiooreaktor panel rata (60 L). Dalam fasa 2, tidak mempunyai perbezaan yang ketara dalam ketumpatan sel dan biomas semasa penuaian di antara

kuning dan kawalan. Walau bagaimanapun, cahaya kuning menunjukkan kandungan protein yang lebih tinggi berbanding dengan kawalan, tetapi tidak menunjukkan perbezaan ketara dalam lipid dan karbohidrat. Cahaya kuning juga menghasilkan asid lemak poli tidak jenuh dan asid lemak ω3 yang tertinggi.

Seperti yang dilihat untuk *C. calcitrans*, cahaya kuning juga menunjukkan kadar pertumbuhan spesifik yang lebih tinggi di dalam *Chlorella* sp. marin dalam fasa 1. Kandungan protein tertinggi dalam *Chlorella* sp. didapati dalam cahaya merah manakala yang paling rendah adalah kawalan. Walau bagaimanapun, kawalan menunjukkan kandungan lipid tertinggi. Kandungan karbohidrat yang paling rendah didapati dalam cahaya merah. Dalam *Chlorella* sp., cahaya merah menghasilkan ω3 dan asid lemak poli tidak jenuh yang lebih tinngi dan cahaya hijau menggalakkan sintesis asid lemak ω6. Berdasarkan kadar pertumbuhan spesifik *Chlorella* sp. yang tinggi dari fasa 1, cahaya kuning dipilih untuk dijalankan dalam eksperimen fasa 2 menggunakan fotobioreaktor panel rata. Dalam fasa 2, tidak terdapat perbezaan yang ketara dalam ketumpatan sel dan biomas semasa penuaian di antara kuning dan kawalan. Walau bagaimanapun, cahaya kuning hanya menunjukkan kandungan protein yang lebih tinggi berbanding dengan kawalan, dan lebih rendah ketara dalam kandungan lipid dan karbohidrat. Cahaya kuning juga menghasilkan asid lemak poli tidak jenuh dan asid lemak ω3 yang tertinggi dalam *Chlorella* sp.

ACKNOWLEDGEMENTS

I would like to acknowledge everyone who played a role in my academic accomplishments. First of all, my family, who supported me with love and understanding. Without you, I could never have attained this current level of success. Secondly, my committee members – Dr. Sanjoy Banerjee, Dato' Dr. Mohamed Shariff Mohamed Din, Professor Dr. Fatimah Md Yusoff and Dr. Helena Khatoon, each of whom has provided patient advice and guidance throughout the research process. Thank you all for your unwavering support.

I would also like to extend my gratitude towards my funders in this research project – Putra Grant (9441700), MyBrain15 and Science and Technology Research Partnership for Sustainable Development Program (SATREPS).

Last but not least, to my fellow colleagues – Pearl Kwan Penz Penz, Alexander Zachariah De Silva, Rashidah Abdul Razak, Muhammad Talba Ahmad and Nurul Farahin Abdul Wahab who have helped and encouraged me through challenging times.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Sanjoy Banerjee, PhD
Research Fellow
Institute of Bioscience
Universiti Putra Malaysia
(Chairman)

Mohamed Shariff Mohamed Din, PhD
Professor Dato'
Faculty of Veterinary Medicine
Universiti Putra Malaysia
(Member)

Fatimah Md. Yusoff, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Helena Khatoon, PhD
Assistant Professor
Department of Aquaculture
Faculty of Fisheries
Chittagong Veterinary and Animal Sciences University
Bangladesh
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 08 October 2020

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature:	
Name of Chairman of Supervisory Committee:	Dr. Sanjoy Banerjee
Signature:	
Name of Member of Supervisory Committee:	Professor Dato' Dr. Mohamed Shariff Mohamed Din
Signature:	
Name of Member of Supervisory Committee:	Professor Dr. Fatimah Md. Yusoff
Signature:	
Name of Member of Supervisory Committee:	Assistant Professor Dr. Helena Khatoon

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ALA	a-linolenic acid
ALR	Airlift reactor
Ast	Astaxanthin
BBM	Bold Basal medium
BG-11	Blue green medium
BSA	Bovine serum albumin
Car	Carotenoids
Chl	Chlorophyll
cm-LED	colour-mixed-LED
d.c.	Duty cycles
DHA	Docosahexaenoic acid
DO	Dissolved oxygen
DPA	Docosapentaenoic
DW	Dry weight
EPA	Eicosapentaenoic acid
FAME	Fatty acid methyl esters
FID	Flame ionization detector
FL	Fluorescent lamps
FP-PBR	Flat panel photobioreactor
GC	Gas chromatography
GC-MS	Gas chromatography-mass spectrometry
HPLC	High-performance liquid chromatography
LC-PUFA	Long-chain polyunsaturated fatty acids
LED	Light emitting diode

LHP	Light harvesting protein-pigments
Lut	Lutein
Lyc	Lycopene
MUFA	Monounsaturated fatty acids
PAR	Photosynthetic active radiation
PBR	Photobioreactor
PCE	Power conversion efficiency
PCR	Polymerase chain reaction
pc-LED	Phosphor-converted-LED
PEP	Phosphoenolpyruvate
pH	Potential of hydrogen
Phy	Phycocyanin
PPFD	Photosynthetic photon flux density
PUFA	Polyunsaturated fatty acids
ROS	Reactive oxygen species
SE	Standard error
SFA	Saturated fatty acids
SGR	Specific growth rate
OD	Optical density
TCA	Trichloroacetic acid
UV	Ultra-violet
Zea	Zeaxanthin
β-car	β-carotene

LIST OF NOTATIONS

µmol	Micromole
m^2	Square meter
m	Meter
cm	Centimeter
µm	Micrometer
nm	Nanometer
mm^2	Square millimeter
cm^3	Cubic centimeter
s	Seconds
$m^{-2}h^{-1}$	Square meter per hour
kWh^{-1}	Kilo watts per hour
%	Percent
g	Grams
kg	Kilogram
pg	Picogram
mg	Milligram
L	Liter
µL	Microliter
mL	Milliliter
C_t	Concentration at time
C_0	Initial concentration
e^{mt}	Exponential with the function of specific growth and time
lux	One lumen per square meter
°C	Celsius
ppt	Parts per thousand
λ_e	Emission peak

λ	Wavelength
W	Watt
InGaN	Indium gallium nitride
AlGaInP	Aluminium gallium indium phosphide
FWHM	Full width at half maximum
€	Euro currency
$\mu molm^{-2}s^{-1}$	Micromole per square meter per second
$\mu mol\text{-}ph\ s^{-1}\ W^{-1}$	Micromole of photon per second per watt
h	Hour
Wm^{-3}	Watts per cubic meter
N	Normality
min	Minutes
rpm	Revolution per minute
X_2	Final cell density
X_1	Initial cell density
$t_2 - t_1$,	Time/duration of exposure
R^2	Proportion of the variance for a dependent variable in a regression model
$\mu g\ mL^{-1}$	Microgram per milliliter
m	Slope standard curve
A	Absorbance
c	y-intercept
p	Significant level
n	Number of replicates
ω3	Omega 3
ω6	Omega 6
kHz	Kilohertz

CHAPTER 1

INTRODUCTION

1.1 Background of study

Microalgae are fast-growing microorganisms (Gordon and Polle, 2007) found in a wide range of habitats including marine, freshwater, and brackish water (Abbott et al., 1992; Wehr, 2002). They are characterized by their high productivity per unit area in comparison with higher photosynthetic plants (Carvalho et al., 2011). This notable photosynthetic efficiency is dominated by the advantages of their reduced internal physiological competitiveness, instant reproduction cycles, narrow nutrient requirements and adaptation to a wide range of radial intensities, temporal and spectral distributions (Gordon and Polle, 2007). Microalgae are widely used as a food source for fish (Reitan et al., 1994), crustacean (Preston et al., 1992), and bivalve (Frankish et al. 1991) larvae due to their high nutritional value in proximate composition as well as fatty acids. Essential fatty acids plays an important role in the initial growth of aquaculture larvae and juvenile development (Renaud et al., 1999).

Microalgae cultivation can be carried out in open ponds or closed-system photobioreactors (Singh and Sharma, 2012). Essential factors such as light, pH, CO_2, and the medium's nutrient content have to be finely attuned (Koc et al., 2013) for the optimum growth of microalgae. However, light would be the most imperative factor as it is generated by electricity in closed-photobioreactor culture systems hence affecting the production cost of biomass (Koc et al., 2013). Visible light encompasses different spectral wavelengths and is found to influence the physiological changes in cell size, reproduction and biochemical composition such as protein, polysaccharides, lipids, fatty acids, pigments and other derived compounds (Rivkin, 1989; Koc et al., 2013). For instance, biomass of *Spirulina platensis* was found to be similar when cultivated using white LED, flourescent and natural light with different spectral properties (Chen and Lee, 2012). These finding prove that alternative light sources can be used for the cultivation of microalgae. In general, many species of microalgae have higher carbon fixation rates in their cells (Rivkin, 1989), increasing their biomass when exposed to blue light. On the contrary, red light promotes cell division (Koc et al., 2013). However, responses are still species specific under different circumstances.

Photon flux density is the amount of photons in μmol striking a surface of 1 m^2 in 1s. The significance of providing an optimum photon flux density in microalgae cultures is because dense cultures are often challenging to maintain as they have the tendency to reflect, refract, and absorb light, thus impeding it from reaching the entire depth of the photobioreactor (Koc et al., 2013). If high light intensities are engaged to counter mutual shading in dense cultures, installation of a cooling system might be necessary as the light source could accelerate high temperatures which may inhibit growth and even kill cells (Park and Lee, 2000). This would eventually add on to biomass production costs. Excessive light may have negative effects on microalgae (or plants)

where photons cannot be further absorbed by photoreceptors, a phenomenon known as photo-saturation (Koc et al., 2013). This could subsequently lead to photo-inhibition and photo-oxidation, resulting in photosynthesis retardation and even damaging cells; although the photons exist within the photosynthetic active radiation (PAR) range which falls between 380 and 750 nm (Koc et al., 2013). Contrarily, photosynthesis will also be deterred if light intensities are too low as a consequence of shading; henceforth reducing biomass production (Koc et al., 2013).

The PAR is an important factor in photosynthesis as microalgae utilizes the spectral wavelengths within its range (Koc et al., 2013). The PAR affects microalgal production and has to be given due considerations in the design of lighting systems for photobioreactors (Koc et al., 2013). LED's application in photobioreactors (PBRs) demonstrated a great advancement over existing indoor agricultural lighting (Yeh and Chung, 2009). The incorporation of LED lights into PBR designs was initiated in the early 1990s (Lee and Palsson, 1994). LEDs are amongst the preeminent alternatives available in the current lighting technology to be adopted by PBRs (Fu et al., 2012). Higher luminous efficiency, lower energy consumption, and longer life span are some of the major advantages LEDs can offer over other light sources (Chen and Lee, 2012). LEDs are light and small enough to fit into virtually any culture system, such as plant incubators and photobioreactors (Chen and Lee, 2012), and they permit the alteration of spectral quality as well as quantity in optimizing illumination. LEDs have narrow spectral bands between 20-30 nm (Chen et al., 2010), producing desirable wavelengths at higher energy conversion efficiency (Yam and Hassan, 2005). LEDs can also minimize abiotic stresses rising from excessive illumination upon cells and they are easily obtainable. Their small structure, low energy consumption, and ease of installation make LEDs more environmental-user friendly than other light sources (Koc et al., 2013). In addition, LEDs do not produce as much heat as other types of lights, thus preventing overheating of the culture (Koç et al., 2009). Therefore, LED lighting technology is a practicable option for microalgal cultivation, especially in speeding up the production rate of biomass and specific biochemical compounds (Schulze et al., 2014).

Photobioreactors (PBRs) precedes the benefits of open systems as it assures higher culture purity, reduces the use of water, CO_2 loss and better control over environmental conditions such as pH, temperature, light and other factors (Singh and Sharma, 2012). Besides, they also permit higher biomass quantity and fine biopharmaceutical production (Singh and Sharma, 2012). Commercial microalgae cultivations are commonly carried out in open-pond systems (Chen et al., 2010). However, the performance of open-pond cultures is usually less satisfactory. This is because culture conditions including UV-radiation exposure, biological contamination, natural light intensities and distributions are difficult to control (Chen et al., 2008). These limitations are often observed throughout variations in diurnal cycles, weathers, seasons and solar spectrums (Chen et al., 2010). The maximum average productivity for outdoor open algal ponds is 1 g DW $m^{-2}h^{-1}$, while in closed algal photobioreactors the productivity increases to 2-3 g DW $m^{-2}h^{-1}$ (Weisz, 2004). To overcome constraints, LEDs are being integrated into closed photobioreactor systems to ensure continuous, sufficient and stable light supply (Chen et al., 2010). Most of laboratory-scale

photobioreactors are illuminated using fluorescent lamps, which entails a higher power consumption and operating cost (Chen et al., 2010). Hence, by replacing fluorescent lamps with multi-LED light, electricity consumption may be reduced up to 50 % from 40.32 to 20.16 kWh^{-1} (Chen et al., 2010).

1.2 Problem Statement

Microalgae have recently received much attention as a new biomass source for protein, lipid, fatty acids, amino acids, vitamins and pigments which can be used as high value products. This makes microalgae a potentially rich source of chemical products with applications in food, animal feed, nutritional, cosmetic and pharmaceutical industries. High quality biomasses at cheaper costs are necessary to make products viable for commercial applications. One of the important factors in achieving high density productive microalgal culture is light. The growth of microalgae and the nutritional composition of microalgal biomass are known to be greatly dependent on the light source. Sunlight is a cheap and natural source of light normally utilized for microalgae cultivation. However, limited availability due to diurnal cycles and seasonal variations impedes the viability of commercial production. To circumvent these issues, artificial lights are commonly integrated into microalgae cultures. This would ensure uninterrupted production since continuous and controlled illumination will increase microalgal productivity. Artificial lights have limitations as well due to their spectral properties. Therefore, appropriate light sources having specific spectrum should be identified for the illumination of cultures in order to achieve optimum growth. A number of studies have been conducted on light regimes (Carvalho et al., 2011), nutrient manipulation (Mandalam and Palsson, 1998; Ramos et al., 2011), salinity manipulation (Fazeli et al., 2006) and cellular engineering (Beckmann et al., 2009) in optimizing microalgal growth, lipid accumulation (Bartley et al., 2013) and pigmentation (Ramos et al., 2011). However, few studies have been conducted on the effects of different light quality on microalgal growth and proximate composition (Abiusi et al., 2014).

Open pond cultures using natural light tend to have higher risks of failure associated with contamination, less- or uncontrollable culture conditions like direct UV irradiation exposure, low light intensity, uneven light distribution (Chen et al. 2008) and low cell density (Chen et al., 2010); therefore it is crucial to look into alternative culture systems to minimize the risk factors. Closed photobioreactor culture systems may be the solution to the problems as mentioned above. However, types of lights integrated in the PBRs and their spectral quality on how it affects the physiological properties of cells is yet to be investigated.

1.3 Significance of Study

Microalgae are significant commercially as they are cultured for food, valuable compounds, bio-remediation, pharmaceuticals, aquaculture and biofuel purpose (Lorenz and Cysewski, 2000; Brown, 2002; Sharma et al., 2013; Velichkova et al., 2014). The purpose of this study is to examine the growth rates and proximate composition of two commercially significant microalgae species *Chaetoceros calcitrans* and marine *Chorella* sp. exposed to different light spectrums. Thus, a flat panel photobioreactor culture system (FP-PBR; Patent pending UI2014700185) with light sources from LEDs and fluorescent lamps (as control) composed of different spectral qualities, was adapted to maximize the biomass productivity (Fu et al., 2012) and lipid composition (Chen et al., 2010) of microalgae. Since spectral ranges and distribution of LEDs can be customized, it will provide significant results of the physiological changes induced by their light qualities and to compare the results with other light treatments (e.g. fluorescent lamps). The responses of microalgae to light qualities are species dependent (Gorai et al., 2014; Hultberg et al., 2014; Schulze et al., 2014); thus, specific wavelengths of energy-saving LEDs can be chosen selectively (Blanken et al., 2013), while increasing or maintaining product yields in expressions of the biomass itself or biomass-derived compounds. The intention behind spectral selection is to eliminate energy wastage used to irradiate wavelengths which are photosynthetically less efficient (Abiusi et al., 2014). This study would benefit commercial farms in microalgal production as the understanding of light quality effect on the growth and biochemical composition of microalgal species may help increase production in biomass and its derivatives more efficiently.

1.4 Objectives

This study was undertaken specifically with the following objectives:

1. To determine the growth of *Chaetoceros calcitrans* and marine *Chlorella* sp. cultivated under different light spectrums in photobioreactors.
2. To analyse the proximate composition and fatty acid profiles of the two microalgae species cultivated under different light spectrums in photobioreactors.

REFERENCES

Abbott, I. A., Isabella, A., & Hollenberg, G. J. (1992). Marine algae of California. Stanford University Press: California.

Abdulkadir, S., & Tsuchiya, M. (2008). One-step method for quantitative and qualitative analysis of fatty acids in marine animal samples. J. Exp. Mar. Biol. Ecol., 354(1): 1-8.

Abiusi, F., Sampietro, G., Marturano, G., Biondi, N., Rodolfi, L., D'Ottavio, M., & Tredici, M. R. (2014). Growth, photosynthetic efficiency, and biochemical composition of *Tetraselmis suecica* F&M- M33 grown with LEDs of different colors. Biotechnol. Bioeng., 111(5): 956-964.

Ahmad, M. T., Shariff, M., Md. Yusoff, F., Goh, Y. M., & Banerjee, S. (2018). Applications of microalga *Chlorella vulgaris* in aquaculture. Reviews in Aquaculture: 1-19. doi: https://doi.org/10.1111/raq.12320

Alabi, A. O., Tampier, M., & Bibeau, E. (2009). Microalgae technologies and processes for biofuels-bioenergy production in British Columbia: current technology, suitability & barriers to implementation: final report. British Columbia Innovation Council: British Columbia.

Atta, M., Idris, A., Bukhari, A., & Wahidin, S. (2013). Intensity of blue LED light: a potential stimulus for biomass and lipid content in fresh water microalgae *Chlorella vulgaris*. Bioresour. Technol., 148: 373-378.

Ayehunie, S., Belay, A., Baba, T. W., & Ruprecht, R. M. (1998). Inhibition of HIV-1 Replication by an Aqueous Extract of *Spirulina platensis* (*Arthrospira platensis*). J. Acquir. Immune Defic. Syndr. (JAIDS), 18(1): 7-12.

Barbosa, M. J., Janssen, M., Ham, N., Tramper, J., & Wijffels, R. H. (2003). Microalgae cultivation in air- lift reactors: Modeling biomass yield and growth rate as a function of mixing frequency. Biotechnol. Bioeng., 82(2): 170-179.

Bartley, M. L., Boeing, W. J., Corcoran, A. A., Holguin, F. O., & Schaub, T. (2013). Effects of salinity on growth and lipid accumulation of biofuel microalga *Nannochloropsis salina* and invading organisms. Biomass Bioenerg., 54: 83-88.

Becker, E. W. (2007). Microalgae as a source of protein. Biotechnology advances, 25(2), 207-210.

Becker, W. (2004). Microalgae In Human and Animal Nutrition. In A. Richmond (Ed.), Handbook Of Microalgal Culture: Biotechnology And Applied Phycology (pp. 312-351). Oxford: Blackwell Science.

Beckmann, J., Lehr, F., Finazzi, G., Hankamer, B., Posten, C., Wobbe, L., & Kruse, O. (2009). Improvement of light to biomass conversion by de-regulation of light-harvesting protein translation in *Chlamydomonas reinhardtii*. J. Biotechnol., 142(1): 70-77.

Begum, H., Yusoff, F. M., Banerjee, S., Khatoon, H., & Shariff, M. (2016). Availability and utilization of pigments from microalgae. Crit. Rev. Food Sci. Nutr., 56(13): 2209-2222.

Blanken, W., Cuaresma, M., Wijffels, R. H., & Janssen, M. (2013). Cultivation of microalgae on artificial light comes at a cost. Algal Res., 2(4): 333-340.

Borowitzka, M. A. (1988). Fats, oils and hydrocarbons. In M. A. Borowitzka, and L. J. Borowitzka (Eds.), Micro-algal biotechnology (pp. 257-287). Cambridge: Cambridge University Press.

Brown, M. R. (2002). Nutritional value and use of microalgae in aquaculture. Avances en Nutrición Acuícola VI. Memorias del VI Simposium Internacional de Nutrición Acuícola, 3: 281-292.

Brown, M. R., Jeffrey, S. W., & Garland, C. D. (1989). Nutritional aspects of microalgae used in mariculture; a literature review. Hobart: CSIRO Marine Laboratories.

Brown, M. R., Jeffrey, S. W., Volkman, J. K., & Dunstan, G. A. (1997). Nutritional properties of microalgae for mariculture. Aquaculture, 151(1-4): 315-331.

Brown, M. R., Mular, M., Miller, I., Farmer, C., & Trenerry, C. (1999). The vitamin content of microalgae used in aquaculture. J. Appl. Phycol., 11(3): 247-255.

Bussell, A. N., & Kehoe, D. M. (2013). Control of a four-color sensing photoreceptor by a two-color sensing photoreceptor reveals complex light regulation in cyanobacteria. Proc. Natl. Acad. Sci. U.S.A., 110(31): 12834-12839.

Chen, C. Y., Chen, Y. C., Huang, H. C., Huang, C. C., Lee, W. L., & Chang, J. S. (2013). Engineering strategies for enhancing the production of eicosapentaenoic acid (EPA) from an isolated microalga Nannochloropsis oceanica CY2. Bioresour. Technol., 147: 160-167.

Carvalho, A. P., Silva, S. O., Baptista, J. M., & Malcata, F. X. (2011). Light requirements in microalgal photobioreactors: an overview of biophotonic aspects. Appl. Microbiol. Biotechnol., 89(5): 1275-1288.

Chen, C. Y., Saratale, G. D., Lee, C. M., Chen, P. C., & Chang, J. S. (2008). Phototrophic hydrogen production in photobioreactors coupled with solar-energy-excited optical fibers. Int. J. Hydrog. Energy, 33(23): 6886-6895.

Chen, F., Liu, Z., Li, D., Liu, C., Zheng, P., & Chen, S. (2012). Using ammonia for algae harvesting and as nutrient in subsequent cultures. Bioresour. Technol., 121: 298-303.

Chen, H. B., Wu, J. Y., Wang, C. F., Fu, C. C., Shieh, C. J., Chen, C. I., Wang C.Y. & Liu, Y. C. (2010). Modeling on chlorophyll a and phycocyanin production by *Spirulina platensis* under various light-emitting diodes. Biochem. Eng. J., 53(1): 52-56.

Chen, Y. C. (2003). Immobilized *Isochrysis galbana* (Haptophyta) for long-term storage and applications for feed and water quality control in clam (*Meretrix lusoria*) cultures. J. Appl. Phycol., 15(5): 439-444.

Chen, Y. C., & Lee, M. C. (2012). Double-power double-heterostructure light-emitting diodes in microalgae, *Spirulina platensis* and *Nannochloropsis oculata*, cultures. J. Mar. Sci. Tech.-Japan, 20(2): 233-236.

Chisti, Y. (2007). Biodiesel from microalgae. Biotechnol. Adv., 25(3): 294-306.

Choi, B., Lim, J. H., Lee, J., & Lee, T. (2013). Optimum conditions for cultivation of *Chlorella* sp. FC-21 using light emitting diodes. Korean J. Chem. Eng., 30(8), 1614-1619.

Christaki, E., Florou-Paneri, P., & Bonos, E. (2011). Microalgae: a novel ingredient in nutrition. Int. J. Food Sci. Nutr., 62(8): 794-799.

Cordoba-Matson, M. V. (2013). Evaluation of growth, cell size and biomass of *Isochrysis* aff. *galbana* (T-ISO) with two LED regimes. The All Results Journals: Biol., 4(1): 7-15.

Cornet, J. F. (1998). Le technoscope: les photobioréacteurs. Biofutur., 176: 1-10.

Crawford, M. H. (2009). LEDs for solid-state lighting: performance challenges and recent advances. IEEE J. Sel. Top. Quantum Electron., 15(4): 1028-1040.

Del Campo, J. A., García-González, M., & Guerrero, M. G. (2007). Outdoor cultivation of microalgae for carotenoid production: current state and perspectives. Appl. Microbiol. Biotechnol., 74(6): 1163-1174.

Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. T., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. Anal. Chem., 28(3): 350-356.

Dunstan, G. A., Volkman, J. K., Barrett, S. M., Leroi, J. M., & Jeffrey, S. W. (1993). Essential polyunsaturated fatty acids from 14 species of diatom (Bacillariophyceae). Phytochemistry, 35(1): 155-161.

Fazeli, M.R., Tofighi, H., Samadi, N., Jamalifar, H., & Fazeli, A. (2006). Carotenoids accumulation by *Dunaliella tertiolecta* (lake Urmia isolate) and *Dunaliella salina* (CCAP 19/18 & WT) under stress conditions. DARU J. Pharm. Sci., 14(3): 146-150.

Frankish, K. R., Goard, L. J., & O'Connor, W. A. (1991). The development of hatchery rearing techniques of the Sydney rock oyster (*Saccostrea commercialis*). In Internal Report (28p.). NSW Fisheries: Brackish Water Fish Culture Research Station Salamander Bay.

Fu, W., Gudmundsson, O., Feist, A. M., Herjolfsson, G., Brynjolfsson, S., & Palsson, B. Ø. (2012). Maximizing biomass productivity and cell density of *Chlorella vulgaris* by using light-emitting diode-based photobioreactor. J. Biotechnol., 161(3): 242-249.

Fu, W., Guðmundsson, Ó., Paglia, G., Herjólfsson, G., Andrésson, Ó. S., Palsson, B. Ø., & Brynjólfsson, S. (2013). Enhancement of carotenoid biosynthesis in the green microalga *Dunaliella salina* with light-emitting diodes and adaptive laboratory evolution. Appl. Microbiol. Biotechnol., 97(6): 2395-2403.

Gorai, T., Katayama, T., Obata, M., Murata, A., & Taguchi, S. (2014). Low blue light enhances growth rate, light absorption, and photosynthetic characteristics of four marine phytoplankton species. J. Exp. Mar. Biol. Ecol., 459: 87-95.

Gordon, J. M., & Polle, J. E. (2007). Ultrahigh bioproductivity from algae. Appl. Microbiol. Biotechnol., 76(5): 969-975.

Gostan, J., Lechuga-deveze, C., & Lazzara, L. (1986). Does blue light affect the growth of *Chaetoceros protuberans* (Bacillariophyceae)?. J. Phycol., 22(1): 63-71.

Gouveia, L., & Oliveira, A. C. (2009). Microalgae as a raw material for biofuels production. Journal of Industrial Microbiology & Biotechnology, 36(2): 269-274.

Grimm, B., Porra, R. J., Rüdiger, W., & Scheer, H. (Eds.). (2006). Chlorophylls and bacteriochlorophylls: biochemistry, biophysics, functions and applications (Vol. 25). Springer Science & Business Media.

Guedes, A. C., Amaro, H. M., & Malcata, F. X. (2011). Microalgae as sources of carotenoids. Mar. Drugs, 9(4): 625-644.

Guil-Guerrero, J. L., Navarro-Juárez, R., López-Martınez, J. C., Campra-Madrid, P., & Rebolloso-Fuentes, M. (2004). Functional properties of the biomass of three microalgal species. J. Food Eng., 65(4): 511-517.

Guillard, R. R., & Ryther, J. H. (1962). Studies on marine planktonic diatoms. 1. *Cyclotella nana* Hustedt and *Detonulla confervaceae* (Cleve) Gran. Can. J. Microbiol., 8(2): 229-239.

Harjunowibowo, D., Ding, Y., Omer, S., & Riffat, S. (2018). Recent active technologies of greenhouse systems—a comprehensive review. Bulg. J. Agric. Sci., 24: 158-70.

Harrison, P. J., Conway, H. L., Holmes, R. W., & Davis, C. O. (1977). Marine diatoms grown in chemostats under silicate or ammonium limitation. III. Cellular chemical composition and morphology of *Chaetoceros debilis*, *Skeletonema costatum*, and *Thalassiosira gravida*. Mar. Biol., 43(1): 19-31.

Harrison, P. J., Thompson, P. A., & Calderwood, G. S. (1990). Effects of nutrient and light limitation on the biochemical composition of phytoplankton. J. Appl. Phycol., 2(1): 45-56.

Hasle, G. R. & Syvertsen, E. E. (1996). Marine Diatoms. In C. R. Tomas, (Ed.) Identifying Marine Diatoms And Dino-flagellates (pp. 5-385). San Diego, CA: Academic Press.

Hernández-Becerril, D. U. 1996. A morphological study of *Chaetoceros* species (Bacillariophyta) from the plankton of the Pacific Ocean of Mexico. Bull. Nat. Hist. Mus. London (Bot.), 26:1-73.

Hernández-Becerril, D. U. 1991. The morphology and tax-onomy of the planktonic diatom *Chaetoceros coarctatus* Lauder (Bacillariophyceae). Diatom Res., 6: 281-287.

Hills, C., & Nakamura, H. (1978). Food From Sunlight. Planetary Survival For Hungry People. How To Grow Edible Algae And Establish A Profitable Aquaculture (383p.). California: University of the Trees Press.

Huang, G., Chen, F., Wei, D., Zhang, X., & Chen, G. (2010). Biodiesel production by microalgal biotechnology. Appl. Energy, 87(1): 38-46.

Hultberg, M., Jönsson, H. L., Bergstrand, K. J., & Carlsson, A. S. (2014). Impact of light quality on biomass production and fatty acid content in the microalga *Chlorella vulgaris*. Bioresour. Technol., 159: 465-467.

Hu, Q., Guterman, H., & Richmond, A. (1996). A flat inclined modular photobioreactor for outdoor mass cultivation of photoautotrophs. Biotechnol. Bioeng., 51(1): 51-60.

Jacob-Lopes, E., Scoparo, C. H. G., Lacerda, L. M. C. F., & Franco, T. T. (2009). Effect of light cycles (night/day) on CO_2 fixation and biomass production by microalgae in photobioreactors. Chemical Engineering and Processing: Process Intensification, 48(1): 306-310.

Jeong, H., Lee, J., & Cha, M. (2013). Energy efficient growth control of microalgae using photobiological methods. Renew. Energy, 54: 161-165.

Jiang, Y., Chen, F., & Liang, S. Z. (1999). Production potential of docosahexaenoic acid by the heterotrophic marine dinoflagellate *Crypthecodinium cohnii*. Process Biochem., 34(6-7): 633-637.

Johkan, M., Shoji, K., Goto, F., Hahida, S. N., & Yoshihara, T. (2012). Effect of green light wavelength and intensity on photomorphogenesis and photosynthesis in *Lactuca sativa*. Environ. Exp. Bot., 75: 128-133.

Kanazawa, A., & Teshima, S. I. (1977). Biosynthesis of fatty acids from acetate in the prawn, *Penaeus japonicus*. Kagoshima: Memoirs of Faculty of Fisheries Kagoshima University, 28: 21-26.

Katsuda, T., Lababpour, A., Shimahara, K., & Katoh, S. (2004). Astaxanthin production by *Haematococcus pluvialis* under illumination with LEDs. Enzyme Microb. Technol., 35(1): 81-86.

Keeling, P. J. (2013). The number, speed, and impact of plastid endosymbioses in eukaryotic evolution. Annu. Rev. Plant Biol., 64: 583-607.

Kianianmomeni, A., & Hallmann, A. (2014). Algal photoreceptors: in vivo functions and potential applications. Planta, 239(1): 1-26.

Kim, T. H., Lee, Y., Han, S. H., & Hwang, S. J. (2013). The effects of wavelength and wavelength mixing ratios on microalgae growth and nitrogen, phosphorus removal using Scenedesmus sp. for wastewater treatment. Bioresour. Technol., 130: 75-80.

Koc, C., Anderson, G. A., & Kommareddy, A. (2013) Use of red and blue light-emitting diodes (LED) and fluorescent lamps to grow microalgae in a photobioreactor. Isr. J. Aquacult., 65: 797.

Koç, C., Vatandaş, M., & Koç, A. B. (2009). LED Lighting Technology and Using in Agriculture (pp. 153-158). In 25th National Congress Mechanization and Energy in Agriculture. Turkey: Isparta.

Kommareddy, A., & Anderson, G. (2003). Study of light as a parameter in the growth of algae in a photo-bio reactor (PBR). In 2003 ASAE Annual Meeting (1p.). Boston: American Society of Agricultural and Biological Engineers.

Lavens, P., & Sorgeloos, P. (1996). Manual on the production and use of live food for aquaculture. In FAO Fisheries Technical Paper 361 (295p.). Rome: FAO.

Lee, C. G., Kang, D. H., Lee, D. B., & Lee, H. Y. (2013). Pretreatment for simultaneous production of total lipids and fermentable sugars from marine alga, *Chlorella* sp. Appl. Biochem. Biotechnol., 171(5): 1143-1158.

Lee, C. G., & Palsson, B. Ø. (1994). High- density algal photobioreactors using light- emitting diodes. Biotechnol. Bioeng., 44(10): 1161-1167.

Lee, C. G., & Palsson, B. Ø. (1996). Photoacclimation of *Chlorella vulgaris* to red light from light- emitting diodes leads to autospore release following each cellular division. Biotechnol. Prog., 12(2): 249-256.

Liu, J., Sun, Z., Gerken, H., Huang, J., Jiang, Y., & Chen, F. (2014). Genetic engineering of the green alga *Chlorella zofingiensis*: a modified norflurazon-resistant phytoene desaturase gene as a dominant selectable marker. Appl. Microbiol. Biotechnol., 98(11): 5069-5079.

Liu, J., Sun, Z., Zhong, Y., Gerken, H., Huang, J., & Chen, F. (2013). Utilization of cane molasses towards cost-saving astaxanthin production by a *Chlorella zofingiensis* mutant. J. Appl. Phycol., 25(5): 1447-1456.

Lorenz, R. T., & Cysewski, G. R. (2000). Commercial potential for *Haematococcus* microalgae as a natural source of astaxanthin. Trends Biotechnol., 18(4): 160-167.

Lowry, O. H., Rosebrough, N. J., Farr, A. L., & Randall, R. J. (1951). Protein measurement with the Folin phenol reagent. J. Biol. Chem., 193(1): 265-275.

Mandalam, R. K.,& Palsson, B. Ø. (1998). Elemental balancing of biomass and medium composition enhances growth capacity in high-density *Chlorella vulgaris* cultures. Biotechnol. Bioeng., 59: 605-611.

Marchetti, J., Bougaran, G., Jauffrais, T., Lefebvre, S., Rouxel, C., Saint-Jean, B., Lukomska, E., Robert, R., & Cadoret, J. P. (2013). Effects of blue light on the biochemical composition and photosynthetic activity of *Isochrysis* sp.(T-iso). J. Appl. Phycol., 25(1): 109-119.

Marriott, M. F., & Blankenship, R. E. (2011). Evolution of photosynthesis. Annual Review of Plant Biology, 62: 515-548.

Marsh, J. B., & Weinstein, D. B. (1966). Simple charring method for determination of lipids. J. Lipid Res., 7(4): 574-576.

Martínez, F., & Orús, M. I. (1991). Interactions between glucose and inorganic carbon metabolism in *Chlorella vulgaris* strain UAM 101. Plant Physiol., 95(4): 1150-1155.

Maruyama, I., Nakao, T., Shigeno, I., Ando, Y., & Hirayama, K. (1997). Application of unicellular algae *Chlorella vulgaris* for the mass-culture of marine rotifer *Brachionus*. Hydrobiologia, 358(1-3): 133-138.

Matsumoto, M., Sugiyama, H., Maeda, Y., Sato, R., Tanaka, T., & Matsunaga, T. (2010). Marine diatom, *Navicula* sp. strain JPCC DA0580 and marine green alga, *Chlorella* sp. strain NKG400014 as potential sources for biodiesel production. Biotechnol. Appl. Biochem., 161(1-8): 483-490.

McQuoid, M.R., Hobson, L.A., 1996. Diatom resting stage. J. Phycol., 32: 889–902.

Mercado, J. M., del Pilar Sánchez-Saavedra, M., Correa-Reyes, G., Lubián, L., Montero, O., & Figueroa, F. L. (2004). Blue light effect on growth, light absorption characteristics and photosynthesis of five benthic diatom strains. Aquat. Bot., 78(3): 265-277.

Metting, F. B. (1996). Biodiversity and application of microalgae. J. Ind. Microbiol. Biotechnol., 17(5-6): 477-489.

Mohsenpour, S. F., Richards, B., & Willoughby, N. (2012). Spectral conversion of light for enhanced microalgae growth rates and photosynthetic pigment production. Bioresour. Technol., 125, 75-81.

Mohsenpour, S. F., & Willoughby, N. (2013). Luminescent photobioreactor design for improved algal growth and photosynthetic pigment production through spectral conversion of light. Bioresour. Technol., 142, 147-153.

Morimura, Y. (1959). Synchronous culture of *Chlorella*: I. Kinetic analysis of the life cycle of *Chlorella ellipsoidea* as affected by changes of temperature and light intensity. Plant Cell Physiol., 1(1): 49-62.

Munawer, K. M., & Mazharuddin, K. M. (2011). Enhancement of engineering in production of phenolic compounds (antioxidants) in *Spirulina plantensis* under different IAA regimes. Int. J. Eng. Sci. Technol., 3: 3004-3009.

Nigam, P. S., & Singh, A. (2011). Production of liquid biofuels from renewable resources. Prog. Energy Combust. Sci., 37(1): 52-68.

Ogbonna, J. C., Soejima, T., & Tanaka, H. (1999). An integrated solar and artificial light system for internal illumination of photobioreactors. J. Biotechnol., 70(1): 289-297.

Olle, M., & Viršile, A. (2013). The effects of light-emitting diode lighting on greenhouse plant growth and quality. Agr. Food Sci., 22(2): 223-234.

Osman, S. M., Seng, C. T., Hong, L., San, C. T., & Ahmad, A. (2017). Variations in growth and fatty acid composition of mangrove-isolated *Chlorella* strains. Journal of Sustainability Science and Management, 12(2): 17-25.

Ötleş, S., & Pire, R. (2001). Fatty acid composition of *Chlorella* and *Spirulina* microalgae species. J. AOAC Int., 84(6): 1708-1714.

Paradiso, R., Meinen, E., Snel, J. F. H., Marcelis, L. F. M., van Ieperen, W., & Hogewoning, S. W. (2011). Light use efficiency at different wavelengths in rose plants. In Proceedings of the International Symposium on High Technology for Greenhouse Systems 893 (pp. 849-855). Québec City, Canada: GreenSys2009.

Park, K. H., & Lee, C. G. (2000). Optimization of algal photobioreactors using flashing lights. Biotechnol. Bioproc. E., 5(3): 186-190.

Pérez-Pazos, J. V., & Fernández-Izquierdo, P. (2011). Synthesis of neutral lipids in *Chlorella* sp. under different light and carbonate conditions. CT&F-Ciencia, Tecnología y Futuro, 4(4): 47-58.

Preston, N. P., Burford, M. A., Coman, F. E., & Rothlisberg, P. C. (1992). Natural diet of larval *Penaeus merguiensis* (Decapoda: Penaeidae) and its effect on survival. Mar. Biol., 113(2): 181-191.

Priyadarshani, I., & Rath, B. (2012). Commercial and industrial applications of micro algae–A review. J. Algal Biomass Utln., 3(4): 89-100.

Pulz, O., & Gross, W. (2004). Valuable products from biotechnology of microalgae. Appl. Microbiol. Biotechnol., 65(6): 635-648.

Ramos, A. A., Polle, J., Tran, D., Cushman, J. C., Jin, E., & Varela, J. C. (2011). The unicellular green alga *Dunaliella salina* Teod. as a model for abiotic stress tolerance: genetic advances and future perspectives. Algae, 26(1): 3-20.

Ravelonandro, P. H., Ratianarivo, D. H., Joannis- Cassan, C., Isambert, A., & Raherimandimby, M. (2008). Influence of light quality and intensity in the cultivation of *Spirulina platensis* from Toliara (Madagascar) in a closed system. J. Chem. Technol. Biotechnol., 83(6): 842-848.

Reis Batista, I., Garcia, A. B., Van Dalen, P., Kamermans, P., Verdegem, M., & Smaal, A. C. (2015). Culturing *Chaetoceros muelleri* using simplified media with different N sources: effects on production and lipid content. Eur. J. Phycol., 50(1): 92-99.

Reitan, K. I., Bolla, S., & Olsen, Y. (1994). A study of the mechanism of algal uptake in yolk- sac larvae of Atlantic halibut (*Hippoglossus hippoglossus*). J. Fish Biol., 44(2): 303-310.

Renaud, S. M., Parry, D. L., & Thinh, L. V. (1994). Microalgae for use in tropical aquaculture I: Gross chemical and fatty acid composition of twelve species of microalgae from the Northern Territory, Australia. J. Appl. Phycol., 6(3): 337-345.

Renaud, S. M., Thinh, L. V., & Parry, D. L. (1999). The gross chemical composition and fatty acid composition of 18 species of tropical Australian microalgae for possible use in mariculture. Aquaculture, 170(2): 147-159.

Rendon, S. M., Roldan, G. J. C., & Voroney, R. P. (2013). Effect of carbon dioxide concentration on the growth response of *Chlorella vulgaris* under four different LED illumination. International Journal of Biotechnology for Wellness Industries, 2(3): 125-131.

Rivkin, R. B. (1989). Influence of irradiation and spectral quality on carbon metabolism of phytoplankton. I. Photosynthesis, chemical composition and growth. Mar. Ecol. Prog. Ser., 55: 291-304.

Saavedra, M. D. P. S., & Voltolina, D. (1994). The chemical composition of *Chaetoceros* sp.(Bacillariophyceae) under different light conditions. Comparative Biochemistry and Physiology Part B: Comparative Biochemistry, 107(1): 39-44.

Saavedra, M. D. P. S., & Voltolina, D. (1996). Effect of blue-green light on growth rate and chemical composition of three diatoms. J. Appl. Phycol., 8(2): 131-137.

Saavedra, M. D. P. S., & Voltolina, D. (2006). The growth rate, biomass production and composition of *Chaetoceros* sp. grown with different light sources. Aquacult. Eng., 35(2): 161-165.

Schulze, P. S., Barreira, L. A., Pereira, H. G., Perales, J. A., & Varela, J. C. (2014). Light emitting diodes (LEDs) applied to microalgal production. Trends Biotechnol., 32(8): 422-430.

Sharma, P., Khetmalas, M. B., & Tandon, G. D. (2013). Biofuels from green microalgae. In Biotechnology: Prospects and Applications (pp. 95-112). New Delhi: Springer.

Shevchenko, O. G., Orlova, T. Yu. & Hernández-Becerril, D. U. (2006). The genus *Chaetoceros* (Bacillariophyta) from Peter the Great Bay, Sea of Japan. Bot. Mar., 49: 236-258.

Shu, C. H., Tsai, C. C., Liao, W. H., Chen, K. Y., & Huang, H. C. (2012). Effects of light quality on the accumulation of oil in a mixed culture of *Chlorella* sp. and *Saccharomyces cerevisiae*. J. Chem. Technol. Biotechnol., 87(5): 601-607.

Singh, R. N., & Sharma, S. (2012). Development of suitable photobioreactor for algae production–A review. Renew. Sust. Energ. Rev., 16(4): 2347-2353.

Slocombe, S. P., Ross, M., Thomas, N., McNeill, S., & Stanley, M. S. (2013). A rapid and general method for measurement of protein in micro-algal biomass. Bioresour. Technol., 129: 51-57.

Soletto, D., Binaghi, L., Lodi, A., Carvalho, J. C. M., & Converti, A. (2005). Batch and fed-batch cultivations of *Spirulina platensis* using ammonium sulphate and urea as nitrogen sources. Aquaculture, 243(1-4): 217-224.

Spolaore, P., Joannis-Cassan, C., Duran, E., & Isambert, A. (2006). Commercial applications of microalgae. J. Biosci. Bioeng., 101(2): 87-96.

Stadnichuk, I. N., Bulychev, A. A., Lukashev, E. P., Sinetova, M. P., Khristin, M. S., Johnson, M. P., & Ruban, A. V. (2011a). Far-red light-regulated efficient energy transfer from phycobilisomes to photosystem I in the red microalga *Galdieria sulphuraria* and photosystems-related heterogeneity of phycobilisome population. Biochimica et Biophysica Acta (BBA)-Bioenergetics, 1807(2): 227-235.

Stadnichuk, I. N., Yanyushin, M. F., Zharmukhamedov, S. K., Maksimov, E. G., Muronets, E. M., & Pashchenko, V. Z. (2011b). Quenching of phycobilisome fluorescence by orange carotenoid protein. In Doklady Biochemistry and Biophysics Vol. 439(1) (pp. 167-170). Florida: Maik Nauka/Interperiodica.

Stolz, P. and Obermayer, B. (2005). Manufacturing microalgae for skin care. Cosmetics and Toiletries, 120(3): 99-106.

Sudibyo, H., Pradana, Y. S., Samudra, T. T., Budiman, A., & Suyono, E. A. (2017). Study of cultivation under different colors of light and growth kinetic study of *Chlorella zofingiensis* Dönz for biofuel production. Energy Procedia, 105: 270-276.

Suh, I. S., & Lee, C. G. (2003). Photobioreactor engineering: design and performance. Biotechnol. Bioproc. E., 8(6): 313.

Sunesen, I., Hernández-Becerril, D. U. & Sar, E. A. (2008). Marine diatoms from Buenos Aires coastal waters (Argentina). V. Species of the genus *Chaetoceros*. Rev. Biol. Mar. Oceanogr., 43: 303-326.

Takaichi, S. (2011). Carotenoids in algae: distributions, biosyntheses and functions. Mar. Drugs, 9(6): 1101-1118.

Tennessen, D. J., Bula, R. J., & Sharkey, T. D. (1995). Efficiency of photosynthesis in continuous and pulsed light emitting diode irradiation. Photosynth. Res., 44(3): 261-269.

Teo, C. L., Atta, M., Bukhari, A., Taisir, M., Yusuf, A. M., & Idris, A. (2014). Enhancing growth and lipid production of marine microalgae for biodiesel production via the use of different LED wavelengths. Bioresour. Technol., 162: 38-44.

Tredici, M. R., Carlozzi, P., Zittelli, G. C., & Materassi, R. (1991). A vertical alveolar panel (VAP) for outdoor mass cultivation of microalgae and cyanobacteria. Bioresour. Technol., 38(2): 153-159.

Tsao, J. Y., Coltrin, M. E., Crawford, M. H., & Simmons, J. A. (2010). Solid-state lighting: an integrated human factors, technology, and economic perspective. Proceedings of the IEEE, 98(7): 1162-1179.

Tzovenis, I., De Pauw, N., & Sorgeloos, P. (2003). Optimisation of T-ISO biomass production rich in essential fatty acids: II. Effect of different light regimes on the production of fatty acids. Aquaculture, 216(1-4): 223-242.

US DOE. (2013). Solid-State Lighting Research and Development. Multi- Year Program Plan, Office of Energy Efficiency & Renewable Energy. Washington D.C.: United States Department of Energy

Vanlandingham, S. L. (1968). Catalogue of the fossil and recent genera and species of diatoms and their synonyms, Part II. In *Bacteriastrum* through *Coscinodiscus* (pp. 494-1086). Lehre: Verlag von J. Cramer.

Vasumathi, K. K., Premalatha, M., & Subramanian, P. (2012). Parameters influencing the design of photobioreactor for the growth of microalgae. Renewable and Sustainable Energy Reviews, 16(7): 5443-5450.

Vega, J. M. P., Roa, M. A. C., Saavedra, M. D. P. S., Ramírez, D. T., & Dávalos, C. R. (2010). Effect of culture medium and nutrient concentration on fatty acid content of *Chaetoceros muelleri*. Rev. Latinoam. Biotecnol. Amb. Algal, 1: 6-15.

Velichkova, K., Sirakov, I., & Stoyanova, S. (2014). Biomass production and wastewater treatment from aquaculture with *Chlorella vulgaris* under different carbon sources. Scientific Bulletin. Series F. Biotechnologies, 18: 83-88.

Volkman, J. K., Brown, M. R., Dunstan, G. A., & Jeffrey, S. W. (1993). The biochemical composition of marine microalgae from the class Eustigmatophyceae. J. Phycol., 29(1): 69-78.

Volkman, J. K., Dunstan, G. A., Jeffrey, S. W., & Kearney, P. S. (1991). Fatty acids from microalgae of the genus *Pavlova*. Phytochemistry, 30(6): 1855-1859.

Volkman, J. K., Jeffrey, S. W., Nichols, P. D., Rogers, G. I., & Garland, C. D. (1989). Fatty acid and lipid composition of 10 species of microalgae used in mariculture. J. Exp. Mar. Biol. Ecol., 128(3): 219-240.

Walne, P.R. (1974). Culture o f Bivalve Molluscs. In Fishing News (Books) Ltd. (173 p.), Great Britain: Surrey.

Wang, B., Lan, C. Q., & Horsman, M. (2012). Closed photobioreactors for production of microalgal biomasses. Biotechnol. Adv., 30(4): 904-912.

Wang, C. Y., Fu, C. C., & Liu, Y. C. (2007). Effects of using light-emitting diodes on the cultivation of *Spirulina platensis*. Biochem. Eng. J., 37(1): 21-25.

Wehr, J. D. (2002). Freshwater algae of North America: ecology and classification. Massachusetts: Academic Press.

Weisz, P. B. (2004). Basic choices and constraints on long-term energy supplies. Phys. Today, 57(7): 47-52.

Werner, D., 1977. Introduction with a note on taxonomy. In: D. Werner (Ed.), The Biology of Diatoms, Botan. Monogr., Vol. 13 (pp. 1-17). Berkeley: Univ. Calif. Press.

Widell, S. (1987). Purification of plasmalemma with aqueous polymer two- phase partition. Physiologia Plantarum, 69(4): 727-730.

Wood, A. M., Everroad, R. C., & Wingard, L., M. (2005). Measuring Growth Rates In Microalgal Cultures. In R. A. Andersen, (Ed.), Algal Culturing Techniques (pp. 269-286). Burlington: Elsevier.

Xu, B., Cheng, P., Yan, C., Pei, H., & Hu, W. (2013). The effect of varying LED light sources and influent carbon/nitrogen ratios on treatment of synthetic sanitary sewage using *Chlorella vulgaris*. World J. Microbiol. Biotechnol., 29(7): 1289-1300.

Yam, F. K., & Hassan, Z. (2005). Innovative advances in LED technology. Microelectron. J., 36(2): 129-137.

Yan, C., Zhang, L., Luo, X., & Zheng, Z. (2013). Effects of various LED light wavelengths and intensities on the performance of purifying synthetic domestic sewage by microalgae at different influent C/N ratios. Ecol. Eng., 51: 24-32.

Yeh, N., & Chung, J. P. (2009). High-brightness LEDs–Energy efficient lighting sources and their potential in indoor plant cultivation. Renewable and Sustainable Energy Reviews, 13(8), 2175-2180.

Yoshioka, M., Yago, T., Yoshie-Stark, Y., Arakawa, H., & Morinaga, T. (2012). Effect of high frequency of intermittent light on the growth and fatty acid profile of *Isochrysis galbana*. Aquaculture, 338: 111-117.

Yun, Y. S., & Park, J. (2001). Attenuation of monochromatic and polychromatic lights in Chlorella vulgaris suspensions. Appl. Microbiol. Biotechnol., 55(6): 765-770.

Zhang, B. Y., Geng, Y. H., Li, Z. K., Hu, H. J., & Li, Y. G. (2009). Production of astaxanthin from *Haematococcus* in open pond by two-stage growth one-step process. Aquaculture, 295(3-4): 275-281.

Zhao, Y., Wang, J., Zhang, H., Yan, C., & Zhang, Y. (2013). Effects of various LED light wavelengths and intensities on microalgae-based simultaneous biogas upgrading and digestate nutrient reduction process. Bioresour. Technol., 136: 461-468.

Zhu, J., Rong, J. and Zong, B. (2013). Factors in mass cultivation of microalgae for biodiesel. Chinese J. Catal., 34(1): 80-100.

Zijffers, J. W. F., Janssen, M., Tramper, J., & Wijffels, R. H. (2008). Design process of an area-efficient photobioreactor. Mar. Biotechnol., 10(4), 404-415.