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Optimization of Cultivation Settings of Chlorella Grown in Indoor Photobioreactor and Assessment as Superfood

Optimalisasi Pengaturan Budidaya Chlorella pada Fotobioreaktor dalam Ruangan sebagai Superfood

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ABSTRACT

Microalgae are microorganisms with great potential as a superfood. Microalgae can serve as an alternative food source. One of their ecosystems is freshwater, where they can be cultivated on a small scale using indoor farming systems, especially in urban areas. This is because microalgae can live anywhere as long as their growth factors are fulfilled. This becomes a bright spot for agriculture in Indonesia, where land is becoming increasingly limited, causing millennial farmers to struggle with conventional cultivation. Therefore, indoor farming systems with IoT can become an alternative solution that supports food security and more effective microalgae cultivation. Microalgae are photosynthetic unicellular organisms influenced by several factors, including pH and light intensity. pH plays an important role in enzyme activity and nutrient availability, while light intensity affects biomass, cell density, and nutritional content. Both factors are crucial in determining biomass, cell density and protein content. However, studies on the combined effect of pH and light intensity on protein content in microalgae are still limited. Thus, this research aims to investigate the influence of pH and light intensity on protein content in an indoor farming system with IoT. The findings are expected to contribute valuable knowledge about optimal pH and light conditions for maximizing protein content in microalgae cultivation as a superfood. Then, according to the result, the combined interaction is 7 pH and 3000 lux light intensity is the optimal for cultivation of microalgae, which is much higher than other combines.

Key words: Biochemical, chlorella, light, photobioreactor, *microalgae*, superfood

ABSTRACT

Mikroalga merupakan mikroorganisme dengan potensi besar sebagai superfood. Mikroalga dapat berfungsi sebagai sumber pangan alternatif. Salah satu ekosistemnya adalah perairan tawar, di mana mikroalga dapat dibudidayakan dalam skala kecil menggunakan sistem pertanian dalam ruangan, terutama di perkotaan. Hal ini karena mikroalga dapat hidup di mana saja selama faktor pertumbuhannya terpenuhi. Hal ini menjadi titik terang bagi pertanian di Indonesia, di mana lahan semakin terbatas, menyebabkan petani milenial kesulitan dengan budidaya konvensional. Oleh karena itu, sistem pertanian dalam ruangan dengan IoT dapat menjadi solusi alternatif yang mendukung ketahanan pangan dan budidaya mikroalga yang lebih efektif. Mikroalga merupakan organisme uniseluler fotosintetik yang dipengaruhi oleh beberapa faktor, termasuk pH dan intensitas cahaya. pH berperan penting dalam aktivitas enzim dan ketersediaan nutrisi, sementara intensitas cahaya memengaruhi biomassa, kepadatan sel, dan kandungan nutrisi. Kedua faktor tersebut krusial dalam

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menentukan biomassa, kepadatan sel, dan kandungan protein. Namun, studi tentang efek gabungan pH dan intensitas cahaya terhadap kandungan protein mikroalga masih terbatas. Oleh karena itu, penelitian ini bertujuan untuk menyelidiki pengaruh pH dan intensitas cahaya terhadap kandungan protein dalam sistem pertanian dalam ruangan dengan IoT. Temuan ini diharapkan dapat memberikan kontribusi pengetahuan tentang kondisi pH dan cahaya optimal untuk memaksimalkan kandungan protein dalam budidaya mikroalga sebagai superfood. Selanjutnya, berdasarkan hasil, interaksi gabungan tersebut menunjukkan bahwa pH 7 dan intensitas cahaya 3000 lux merupakan kondisi optimal untuk budidaya mikroalga, yang jauh lebih tinggi dibandingkan kombinasi lainnya.

Key words: biochemical, chlorella, fotobioreaktor, mikroalga, superfood

INTRODUCTION

Chlorella is a unicellular green microalga from the division Chlorophyta, commonly found in freshwater habitats such as ponds, lakes, and rivers, though some species also occur in marine or terrestrial environments. It has a spherical shape, measures 2–10 µm in diameter, and appears bright green due to chlorophyll a and b. Each cell contains a cup-shaped chloroplast, nucleus, and pyrenoid, with a thick cell wall composed of cellulose. Chlorella reproduces asexually through autosporulation and is valued for its rapid growth, high nutritional content, and applications in food, biofuel, and wastewater treatment (Becker, 1994). Chlorella is among the most extensively studied microalgae due to its characteristics, namely rapid growth, high adaptability, as well as the ability to produce numerous beneficial compounds such as carbohydrate, protein, lipid, chlorophyll, essential amino acids, antioxidants, and other bioactive substances. These compounds have been associated with various health benefits, including immune support, detoxification, and lipid regulation upon consumption. Those characteristics have made *Chlorella* a promising source of superfood due to its nutrient-dense status as well as health modulation effects upon consumption (Nadathur et al., 2016). Children who suffer from malnutrition and are at risk of food insecurity require serious attention in the form of providing nutritional sources, one of which is protein. Efforts to meet this protein shortage can be made from plant and animal proteins, as well as microorganisms. One microorganism that can be used as a protein source is microalgae, as it has rapid regeneration, is not dependent on the season, and does not require extensive land (Rofidah, 2017). One of the microalgae that can be used as a source of protein is *Chlorella* sp. Therefore, adoption of *Chlorella* production and consumption must be advocated to the general population through the development of simple cultivation technology that is easily adopted at home as well as optimization of cultivation parameters.

Optimization of microalgae cultivation includes optimizing many culture parameters such as pH and light intensity. The aim of this research is to find the appropriate setup that maximizes the biomass yield as well as the content of the beneficial compounds (e.g., carbohydrate, protein, and lipid) (Zhuang et al., 2018). pH is closely related to enzymes functioning. *Chlorella* tends to adapt to wide ranges of pH, but the optimal point tends to be near neutral (pH 7.0) (Sakarika and Komaros, 2016). Meanwhile, the intensity of light is crucial to optimize due to *Chlorella's status* as an autotroph that self-produces its energy through photosynthesis (Ye et al., 2018). Hence both factors must be carefully optimized to achieve optimal cultivation technology.

These qualities make microalgae not only valuable as a nutritional supplement but also as a functional ingredient in food, feed, and even pharmaceutical applications. Furthermore, its ability to

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grow in a wide range of environmental conditions, including varying pH and light regimes, makes it a suitable candidate for optimization studies in controlled environments such as photobioreactors and indoor vertical farms. Previous studies have shown that environmental parameters like light intensity and pH can significantly influence the metabolic profile of *Chlorella* sp., affecting not just biomass accumulation but also the synthesis of specific compounds such as lipids, proteins, and carbohydrates. For instance, moderate light levels have been associated with higher chlorophyll and protein production, while stress conditions such as high light or suboptimal pH may trigger lipid accumulation as a protective mechanism (Ho et al., 2021). Understanding how these stress responses are modulated by different combinations of light and pH could inform strategic manipulation of growth conditions to enhance the yield of desired bioactive components, depending on the intended application whether for food, nutraceuticals, or biofuels.

In the context of sustainability, microalgae cultivation especially indoors offers distinct advantages over traditional crops. It requires less land, can utilize non-arable areas, and has high areal productivity compared to conventional agriculture (Sarker and Kaparaju., 2023). Moreover, microalgae can contribute to carbon capture and wastewater treatment while simultaneously producing valuable biomass. These co-benefits align well with global efforts to transition toward circular bioeconomy models and climate-resilient food systems (Ahmad et al., 2020). Therefore, optimizing the growth parameters of *Chlorella* sp. Indoor cultivation not only supports food innovation but also offers scalable solutions for environmental and resource management.

This study seeks to bridge the knowledge gap by examining the combined effects of pH and light intensity on the growth performance and biochemical composition of *Chlorella* sp. within an indoor farming framework. By exploring both short-term and long-term responses, the research aims to identify optimal conditions that maximize productivity while maintaining high nutritional value. The results are expected to inform future designs of compact, sustainable microalgae cultivation systems tailored for urban implementation and climate-smart agriculture. In doing so, this work contributes to the broader discourse on alternative proteins, functional foods, and the future of urban food production.

MATERIALS AND METHODS

Location and time

This research was conducted from March to June 2025 in the Laboratory of Biotechnology, Faculty of Agriculture, University of Pembangunan Nasional "Veteran" Jawa Timur, Indonesia. Microalgae cultivation was done in a customized indoor photobioreactor placed in a closed room with the temperature ~28 °C, relative humidity 90%, and artificial lighting provided by IoT-controlled LED lamps.

Materials

The pure culture of *Chlorella* sp. isolate was obtained from an online merchant. The cultivation was done through Bold Basal Medium (BBM) which the composition and preparation followed a procedure from UTEX Culture Collection of Algae (https://utex.org). Other materials used including HCl, NaOH, acetone, ascorbic acid, Biuret reagent, Bovine Serum Albumin (BSA), phenol (5%), glucose, sulfuric acid (H_2SO_4), methanol, chloroform, and ethanol (70%).

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Microalgae cultivation was facilitated by a customized indoor photobioreactor as shown in Figure 1. The photobioreactor was designed as a multileveled, circular-arranged erlenmeyer flask, with IoT-controlled central lighting from LED lamps. The aeration was produced by an electrical aerator and distributed through a silicon tubing network to the medium in the flasks.

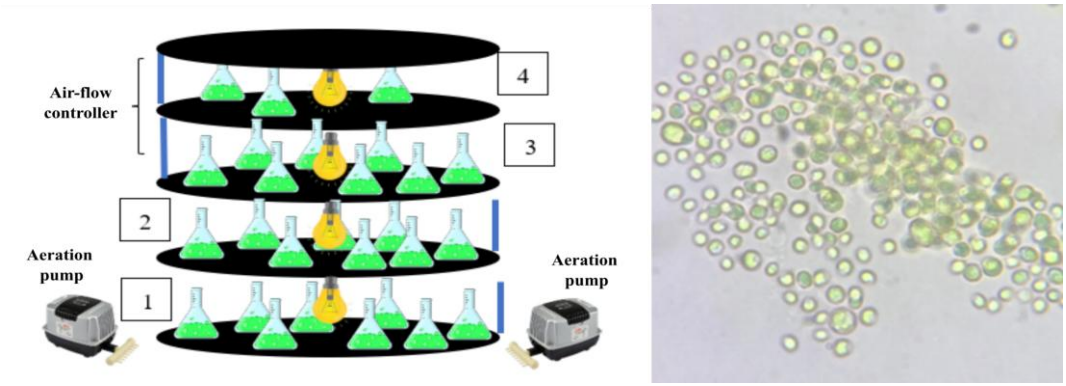

Figure 1. Photobioreactor design (left) and microscopic view of *Chlorella* sp. isolate under 400x magnification (right)

Experimental design

The study was designed as a two-factors factorial experiment of a Completely Randomized Design (CRD). The factors assessed were pH of the medium (P) and light intensity (L). The pH was set as pH 7.5, 7.0, and 6.5, while the light intensity was set at 1,000; 3,000; and 5,000 lux. The combination of both factors were replicated three times, yielding a total of 27 experimental units. Each unit was represented by a flask containing BBM medium and microalgae inoculum. The cultivation was run for 14 days. The parameters assessed were: optical density (680 nm), dry biomass, cell density (cfu/mL), and biochemical contents, namely chlorophyll, carbohydrate, protein, and lipid contents.

Cultivation preparation and maintenance

The BBM medium was prepared following the procedure. Prior to autoclaving, the pH was set by using HCl or NaOH as per the pH set in the treatments. The *Chlorella* inoculum was prepared by culturing the isolate in standard BBM for 2-3 days, on a shaker (150 rpm) and 3000 lux lightning. The final microalgae suspension was adjusted at OD = 0.1 (680 nm) and set as inoculum. The photobioreactor was cleaned from dust and surface-sprayed with ethanol (70%). After all preparations were set, the photobioreactor system was installed by arranging the flask containing the medium and inoculum (500 mL, ratio 4 : 1) in the installation, as well as installing the lighting and aeration system in place. The cultivation was run for 14 days with continuous aeration and light photoperiod of 12 : 12 (light : dark). The maintenance was conducted daily through cleaning the area around the bioreactor as well as checking for the possible contamination of the culture.

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Biomass harvesting

Figure 2. Harvesting biomass of *Chlorella* sp.

In 14 days, the cultivation was stopped and the biomass was harvested by turning off the photobioreactor and transporting the microalgae culture to the lab for further processing. Harvesting was carried out by concentrating the suspension by naturally settling the biomass overnight. The microalgae biomass suspension would collect at the bottom of the media, and the remaining upper media was removed with a measuring pipette to discard until 100 mL of the initial 500 mL suspension remained. At this stage, the suspension could be directly used for phytochemical analysis of the microalgae. Meanwhile, to measure the dry biomass weight, the microalgae suspension was further concentrated using a centrifuge at 5000 rpm for 15 minutes to obtain the solid phase (pellet).

Growth and biomass assessment

The growth and biomass accumulation was assessed in the forms of optical density (OD), cell density, and dry biomass weight. The OD measured daily indicates the relative density of microalgae cells based on measurements using a spectrophotometer. Microalgae OD measurements were performed at a wavelength of 680 nm (Santos-Ballardo et al., 2015). OD measurements were performed daily (1-14 days after planting) by sampling the microalgae suspension and measuring its absorbance using a spectrophotometer. Empty BBM media was used as a blank. The cell density (cfu/mL) was measured by determining when the standard curve on optical density had been obtained. Then, microalgae were cultured for 14 days and measured OD = 0,1. Dilution was then carried out by serial dilution taken at the 10-4th sampling and viewed through a hemacytometer on a microscope. The data results were then calculated by counting the colonies that grew per large box which would be counted for a total of 5 large boxes and observed several times with a ratio of 10-4. (Kawachi, 2005).Meanwhile, the dry biomass weight was measured by using an analytical balance. Microalgae biomass from 100 ml of suspension was obtained from the pellet resulting from centrifugation at a speed of 5,000 rpm for 15 minutes. After that, the pellet was filtered using filter paper and dried using an oven at a temperature of 70-80 °C until a constant weight was achieved, characterized by the formation of dry microalgae biomass in the form of powder on the filter paper.

Biochemical content assessment

The biochemical content of *Chlorella* was assessed in the form of chlorophyll, carbohydrate, protein, and lipid contents. The chlorophyll content was assessed by using the method from

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Cannavaro et al. (2024) with a modification of chlorophyll extraction carried out using organic solvents/acetone with 2 repetitions (duplo). The microalgae suspension was first centrifuged, then the pellet was taken and 5 ml of acetone (80%) was added. The suspension was then homogenized for 1 minute and incubated at 40 °C using a water bath. The suspension was then cooled and re-centriguged at 6000 rpm for 5 minutes, the supernatant was then taken and transferred into a new tube. The remaining pellet was then extracted again using the same method, the supernatants in the first and second extractions were then mixed and their absorbance was measured using a spectrophotometer at a wavelength of 645 nm and a wavelength of 663 nm.

The carbohydrate content was determined by using the spectrophotometric-based phenol-sulfuric acid method as described in Tomas et al. (2018). First, a standard glucose solution (100 ppm) was prepared by weighing 0.001 g of glucose in 10 ml of distilled water. The glucose solution was then diluted in a glucose standard series of 0, 10, 20, 30, 40, 50, and 60 ppm. After that, 0.5 ml of phenol (5%) was vortexed and 2.5 ml of concentrated sulfuric acid was added. The test sample was then incubated at room temperature for 30 minutes and then the absorbance (485 nm) was measured. The carbohydrate content of the test sample was calculated using the previously prepared glucose standard curve.

The protein content was assessed by The protein content in microalgae was tested using the biuret method. The biuret method is carried out by creating a standard curve at various concentrations. First, a standard series with Bovine Serum Albumin (BSA) was prepared, namely 0, 1000, 2000, 3000, 4000, and 5000 ppm. Then, 4 ml of biuret reagent was added to the tube and shaken until homogeneous. Let stand for 30 minutes at room temperature. Then, the standard series was observed for absorbance using a spectrophotometer at a wavelength of 550 nm and a linear regression was performed. Second, the sample analysis was also carried out in the same way by centrifuging the sample for 5 minutes at a speed of 4000 rpm, then the supernatant was discarded. The settled pellet was given 4 ml of biuret reagent and vortexed. The same thing was done by incubating for 30 minutes and centrifuging again. The supernatant was taken with a pipette and then its absorbance was observed using a spectrophotometer with a wavelength of 550 nm. Then plot it with the BSA standard curve.

The lipid content was determined by This lipid content analysis was carried out using the gravimetric method. The gravimetric method is a quantitative analysis technique that measures the mass of a substance after going through a series of separation and purification processes. Extracting 5 ml of lipid from the sample using an organic solvent, namely 2 ml of methanol and 1 ml of chloroform on a pellet and storing it at room temperature for 24 hours, then vortexing for 2 minutes and adding 1 ml of chloroform and 1 ml of aquadest, then centrifuging for 10 minutes at 2000 rpm. After that, discard the supernatant and weigh the wet weight of the lipid. The lipid solvent was evaporated using heating in an oven at 104 °C for 30 minutes so that pure lipid remains that can be weighed constantly. The difference in mass before and after extraction will indicate the amount of lipid contained in the sample. Then the results of the wet weight and dry weight data are entered into the formula: (Anggraini et al., 2016).

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Data collection and analysis

The data was collected and analyzed by using analysis of variance (ANOVA). Should there be any significance, the data was followed by post-hoc Tukey's HSD test. Both ANOVA and Tukey tests were performed at significance level 95%. The mean square of the ANOVA was presented in a table. The growth curve in OD across pH and light intensity combinations were presented in a graph. The OD at 1, 7 and 14 days, as well as all parameters assessed were presented as column graphs with standard error.

RESULTS AND DISCUSSION

The results of this study indicate that both pH and light intensity had a significant influence on the growth and biochemical composition of *Chlorella* sp. cultivated under indoor farming conditions. The most notable findings were observed in cell density, biomass production, and all measured phytochemical parameters, including chlorophyll, carbohydrates, lipids, and proteins, which are all important indicators of the nutritional potential of microalgae as a superfood. Statistical analysis showed that pH significantly affected OD at day 1 and day 7, but had no significant effect by day 14. This suggests that pH influenced early-stage growth, especially during the adaptation and exponential phase, but later growth may have reached a saturation point or entered the stationary phase where pH was no longer the limiting factor. Cell density and biomass, however, remained significantly affected by pH, indicating that the pH environment plays a crucial role in the cumulative productivity of microalgae, likely due to its impact on enzymatic activity and nutrient solubility during the entire cultivation period. Light intensity had a more pronounced effect than pH on almost all parameters, particularly chlorophyll and protein contents. Light intensity had a more pronounced effect than pH on almost all parameters. It significantly influenced OD at day 1 and 7, and strongly affected cell density, biomass, and especially chlorophyll and protein contents. This confirms the vital role of light as the main energy source for photosynthesis. The increased chlorophyll content under higher light intensities suggests an adaptive response to capture more light energy, while higher protein levels may indicate enhanced metabolic activity. Interestingly, carbohydrate and lipid accumulation also increased significantly with light, supporting previous studies that report microalgae can shift towards energy storage molecules under stress or high light exposure.

Table 1. The mean square values of ANOVA of several microalgae growth and biochemical characteristics

Source of variation	DF	OD 7	OD 14	Cell density	Biomass
pH	2	0.165*	0.026ns	1.914*	0.380*
Intensity	3	0.067*	0.253ns	5.045*	0.364*
pH x intensity	4	0.026ns	0.135ns	2.124*	0.179*
Error	18	0.074	0.576	4.316	0.088
Total	26	0.031	1.205	5.750	0.927
		Chlorophyll	**Carbohydrate**	**Lipid**	**Protein**
pH	2	46.34*	1.5 x10*	0.013*	0.001*
Intensity	3	584.56*	1.0 x10*	0.078*	0.003*
pH x intensity	4	177.68*	1.5 x10*	0.001*	0.000*
Error	18	14.75	0.001	0.001	0.000
Total	26	823.33	1.3 x10	0.094	0.006

Remarks: * = indicates significance at confidence level 95%.

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While the interaction between pH and light intensity was not significant for OD and only slightly significant for biomass and phytochemical contents. Carbohydrate and lipid accumulation also increased significantly with light, supporting earlier findings that microalgae accumulate energy-storage compounds under high light stress (Panahi et al., 2016). It still showed potential influence, particularly in carbohydrate and chlorophyll content. This indicates that while each factor individually drives growth and composition, their combination can fine-tune specific metabolite profiles, which is essential when optimizing microalgae for specific nutritional or industrial targets. Overall, this study supports the hypothesis that both pH and light intensity play a critical role in determining the growth performance and biochemical characteristics of Chlorella sp., especially under indoor farming conditions. The findings align with the concept of microalgae as a sustainable superfood, where targeted manipulation of cultivation parameters can enhance the yield and quality of bioactive compounds. Furthermore, this research highlights the potential of controlled indoor farming to produce high value microalgae biomass in urban settings, even under limited land and environmental constraints.

Growth Rate of *Chlorella* sp.

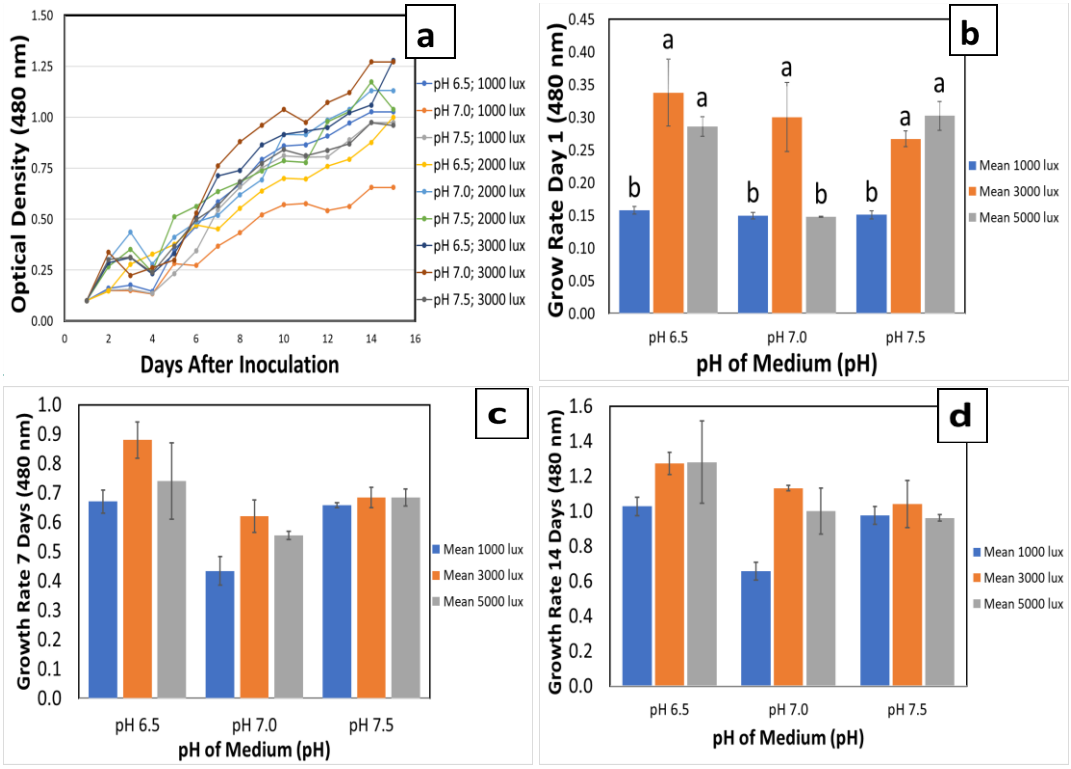

Figure 3. a.) A growth rate of microalgae *Chlorella* sp. By day 1 to days 14, b.) Diagram of growth rate by day 1 after inoculation, there is an interaction by factor pH medium and light intensity, c.) Diagrams of growth rate by 7 days after inoculation, d.) Diagram of growth rate by days 14

The growth pattern of *Chlorella sp.* over 14 days clearly shows that the combination of pH 7.0 and 3000 lux produced the highest optical density, followed closely by pH 6.5 under the same light intensity. This indicates that neutral to slightly acidic pH, when paired with moderate to high light intensity, provides highly favorable conditions for photosynthetic activity and biomass accumulation. In contrast, the lowest growth was consistently observed under 1000 lux, especially at pH 7.0 and 7.5,

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highlighting that insufficient light limits energy availability regardless of pH. These results reinforce that light intensity is a dominant factor, but also that pH modulates how efficiently that light is utilized. Short-term and long-term observations (day 1, 7, and 14) further confirm a clear interaction between light and pH. On day 1, pH 6.5 with 3000 lux showed the most rapid initial growth, while higher light at 5000 lux began to show signs of diminishing returns at higher pH, possibly due to photoinhibition. By day 7, pH 6.5 continued to perform best under 3000 lux, whereas pH 7.5 showed a leveling trend across all intensities, suggesting a broader tolerance over time. After 14 days, pH 6.5 consistently supported strong growth across all light treatments, while pH 7.5 again showed uniformity, likely due to adaptive stress responses. These trends highlight that while 3000 lux and pH 6.5–7.0 are optimal, *Chlorella sp.* remains highly adaptable under a range of controlled indoor conditions.

Density and Biomass

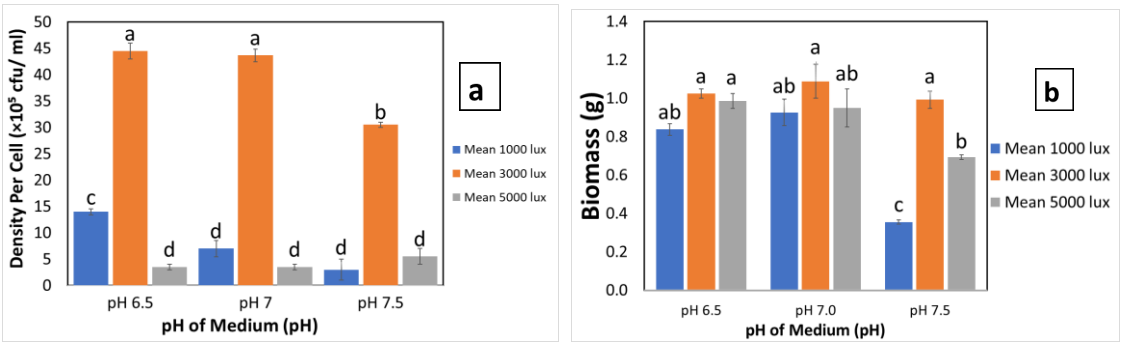

Figure 4. a.) Diagram of density cell by microalgae *Chlorella* sp., b.) Diagram of biomass weight by all combines of microalgae *Chlorella* sp.

The bar charts on cell density and biomass yield of *Chlorella sp.* reveal a clear synergy between light intensity and pH, where 3000 lux consistently promoted the highest performance across both parameters. In terms of cell density, 3000 lux resulted in the greatest proliferation, especially at pH 6.5 and 7.0, suggesting that moderate light intensity combined with slightly acidic to neutral conditions creates an ideal environment for active cell division (Wijayasekera et al., 2020). Meanwhile, extremely low (1000 lux) and high (5000 lux) light intensities limited growth across all pH levels likely due to insufficient energy for photosynthesis at low light and potential photoinhibition under excess irradiance (Rivi et al., 2020). This trend was mirrored in the biomass data, where 3000 lux again produced the highest yields, particularly at pH 7.0, supporting the idea that neutral pH allows flexibility in light response. Although 5000 lux occasionally produced comparable biomass, it still underperformed relative to 3000 lux, likely due to stress-related energy trade-offs for photo-protective mechanisms. Furthermore, at pH 7.5, the sharp drop in biomass under 1000 lux emphasizes the compounded limiting effect of low light and alkaline stress. Altogether, these findings confirm that both parameters interact significantly, with optimal biomass and cell proliferation achieved under 3000 lux and pH 6.5 - 7.0, reinforcing the importance of balanced environmental conditions for maximizing productivity in controlled systems.

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Biochemical of *Chlorella* sp.

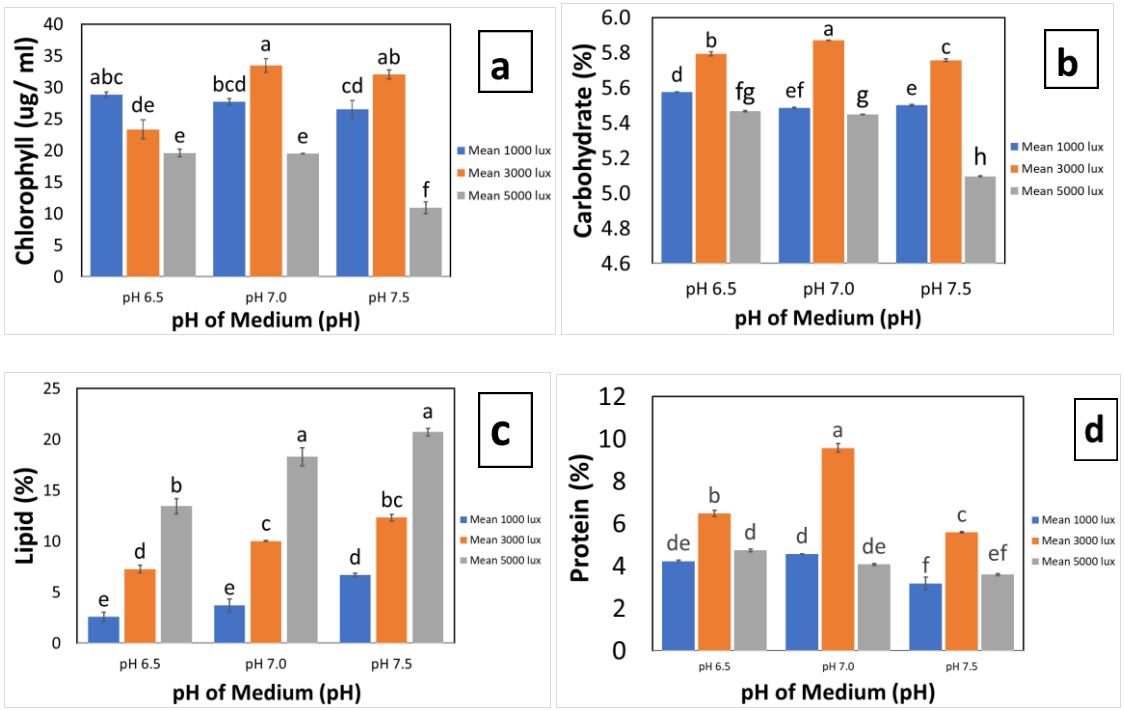

Figure 5. a.) Diagram of chlorophyll content of microalgae *Chlorella* sp., b.) Diagram carbohydrate content of microalgae *Chlorella* sp., c.) Diagram of lipid content of microalgae *Chlorella* sp., d.) Diagram of protein content of microalgae *Chlorella* sp.

The biochemical profiles of *Chlorella sp.* were strongly influenced by the interplay between pH and light intensity, with each metabolite showing distinct optimal conditions. Chlorophyll concentration peaked at pH 7.0 under 3000 lux (~34 µg/mL), indicating that a neutral pH and moderate light intensity are ideal for chlorophyll biosynthesis. Conversely, 5000 lux resulted in the lowest chlorophyll levels across all pH treatments, suggesting photoinhibition at high light intensities, particularly at pH 7.5. A similar trend was observed for carbohydrate content, which reached its maximum (5.87%) under the same optimal condition pH 7.0 and 3000 lux. Carbohydrate accumulation declined under both lower (1000 lux) and higher (5000 lux) intensities, reinforcing that moderate light supports carbon assimilation without triggering stress responses. Notably, both chlorophyll and carbohydrate production were optimized under identical conditions, highlighting a strong correlation between photosynthetic efficiency and carbon metabolism. In contrast, lipid content exhibited a different pattern. The highest lipid yield (>20%) was recorded under 5000 lux at pH 7.0 and 7.5, showing that elevated light intensity promotes lipid biosynthesis, particularly under neutral to slightly alkaline conditions. This shift suggests that *Chlorella sp.* redirects energy toward lipid storage under high-light stress, possibly as a protective or energy-reserve mechanism, which is valuable for biofuel applications.

Protein content, however, aligned more closely with chlorophyll and carbohydrate trends. The highest protein level (~10%) was observed at pH 7.0 with 3000 lux, while both lower and higher intensities resulted in reduced protein synthesis. This decline at 5000 lux further supports the idea of photo-inhibition affecting nitrogen metabolism or shifting cellular priorities. These results confirm

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that pH 7.0 and 3000 lux provide optimal conditions for maximizing chlorophyll, carbohydrate, and protein content, while higher light (5000 lux) promotes lipid accumulation. These insights highlight the importance of fine-tuning environmental parameters to target specific metabolic outputs in *Chlorella sp.*, depending on whether the goal is food-grade biomass or lipid-rich material for industrial use.

CONCLUSION

1. Both pH and light intensity are key factors influencing the growth and biochemical composition of *Chlorella* sp. in indoor cultivation systems.
2. Light intensity had a stronger overall effect, significantly enhancing optical density, biomass, and phytochemical contents, including chlorophyll, protein, carbohydrates, and lipids. pH influenced early-stage growth and contributed to overall productivity, especially through enzyme related metabolic processes.
3. The optimal condition was achieved at pH 7.0 with 3000 lux, followed closely by pH 6.5 at the same light intensity.
4. These results highlight the potential of controlled indoor systems for producing high-quality microalgae biomass.

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