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THE EFFECT OF RED, BLUE, AND WHITE LIGHT ON THE PRODUCTIVITY OF CHLORELLA VULGARIS

PENGARUH CAHAYA MERAH, BIRU, DAN PUTIH TERHADAP PRODUKTIVITAS CHLORELLA VULGARIS

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ABSTRACT
Chlorella vulgaris is a microalgae known as a photoautotrophic organism with high potential to produce biomass, bioenergy, and bioactive compounds. Chlorella vulgaris has attracted international attention due to its potential to produce biofuel, high-quality biomass, and compounds of economic value. Microalgae photosynthesis is strongly influenced by light; the spectrum and intensity of light directly affect the chlorophyll content, and biomass productivity. The purpose of this study was to determine the effect of different colors of red light (630–700 nm), blue (430-490 nm), white (380-750 nm) on the productivity of Chlorella vulgaris. The research method consists of making AF6 media, Chlorella vulgaris propagation, measuring growth rates, measuring chlorophyll a & b content, and measuring biomass. The results of this study are that white light lighting shows the highest specific growth rate, red light lighting shows the highest biomass, while blue light lighting shows the highest chlorophyll a and b content. The conclusion of this study is that there are differences in Chlorella vulgaris productivity under red, blue, and white light. This research is expected to contribute to the development of microalgae cultivation technology, particularly Chlorella vulgaris. Further research is expected to test combinations of two or more light colors, such as red and blue combinations, to achieve more optimal overall productivity
Keywords: biomass; Chlorella vulgaris; chlorophyll; productivity; light color

ABSTRAK
Chlorella vulgaris merupakan mikroalga yang dikenal sebagai organisme fotoautotrof dengan potensi tinggi dalam menghasilkan biomassa, bioenergi, dan senyawa bioaktif. Chlorella vulgaris telah menarik perhatian internasional karena potensinya dalam menghasilkan bahan bakar hayati, biomassa berkualitas tinggi, serta senyawa yang memiliki nilai ekonomi. Proses fotosintesis pada mikroalga sangat dipengaruhi oleh cahaya, dimana spektrum dan intensitas cahaya secara langsung mempengaruhi kandungan klorofil dan produktivitas biomassa. Penelitian ini bertujuan untuk mengetahui pengaruh perbedaan warna cahaya merah (630–700 nm), biru (430–490 nm), dan putih (380–750 nm) terhadap produktivitas Chlorella vulgaris. Metode penelitian meliputi pembuatan media AF6, perbanyakan kultur Chlorella vulgaris, pengukuran laju pertumbuhan, pengukuran kandungan klorofil a dan b, serta pengukuran biomassa. Hasil penelitian menunjukkan bahwa pencahayaan putih menghasilkan laju pertumbuhan spesifik tertinggi, pencahayaan merah menghasilkan biomassa tertinggi, sedangkan pencahayaan biru menghasilkan kandungan klorofil a dan b tertinggi. Kesimpulan penelitian ini menunjukkan bahwa terdapat perbedaan produktivitas Chlorella vulgaris pada perlakuan cahaya merah, biru, dan putih. Penelitian ini diharapkan dapat memberikan kontribusi dalam pengembangan teknologi budidaya mikroalga, khususnya Chlorella vulgaris. Penelitian selanjutnya diharapkan dapat menguji kombinasi dua atau lebih warna cahaya, seperti kombinasi cahaya merah dan biru, untuk memperoleh produktivitas yang lebih optimal secara keseluruhan.
Kata Kunci: biomassa; Chlorella vulgaris; klorofil; produktivitas; warna cahaya

1. INTRODUCTION

The rapidly growing global population is driving an increased demand for energy to meet daily needs. Indonesia's energy requirements are steadily rising, growing at an average annual

rate of 7% and with current demand fulfillment at 94%, the country must urgently seek alternative sources, specifically new and renewable energy, to satisfy this ever-increasing domestic demand (Sudaryanti et al., 2017). Microalgae, particularly Chlorella vulgaris have attracted international attention due to their potential to produce biofuels, high quality biomass, and economically valuable compounds. Global energy consumption is increasing by approximately 2,2% annually (Tarumanegara et al., 2024). Chlorella vulgaris are recognized as potential candidates for renewable energy production due to their high growth rates, significant lipid content, and capacity to produce various types of biofuels, such as biodiesel, bioethanol, biogas, and biohydrogen (Ashour et al., 2024).

Chlorella vulgaris is a photoautotroph so it requires light as an energy source for cell growth and the synthesis of various important substances involved in it. Light source characteristics such as wavelength and intensity are one of the critical factors that influence the production of Chlorella vulgaris and microalgae in general (Novianti et al., 2017). Microalgal photosynthesis is strongly influenced by light. Light spectrum and intensity directly affect lipid content, energy conversion efficiency, and biomass productivity. Understanding the impact of light type on the productivity of Chlorella vulgaris is crucial for developing optimal bioproduction methods. Three primary light spectra frequently used in microalgal growth research are red (630–700 nm), blue (430–490 nm), and white (380–750 nm). A major challenge in enhancing Chlorella vulgaris productivity is determining the most efficient light spectrum for photosynthesis (Novianti et al., 2017).

2. METHODS

2.1. Time and Location

This research was conducted from February to March 2026 at the Virology Laboratory of Universitas Aisyiyah Yogyakarta.

2.2. Tools and Material

The tools used in this study included 1 L culture bottles, red, blue, and white LED lights, aerator, air tubing, UV-Vis spectrophotometer, centrifuge, 100 ml bottles, micropipettes, volumetric pipettes, tubes, microtubes, test tubes, test tube rack, analytical balance, beaker, Erlenmeyer flask, graduated cylinder, vortex mixer, microscope, autoclave, drying oven, hot plate stirrer, gauze, cotton wool, lux meter, volumetric flask, and cuvette. The materials used in this study included *Chlorella vulgaris* culture obtained from the SR Any home-based culture facility in the Special Region of Yogyakarta, AF6 medium, distilled water, 90% methanol, and 70% alcohol.

2.2.1. Preparation of AF6 Medium

The preparation of AF6 medium began with the preparation of nine 1-L culture bottles, which were then sterilized using an autoclave. Once sterilized, each bottle was filled with 990 mL of distilled water. The next step involved preparing stock solutions for each ingredient listed in Tables 1, 2, and 3 each ingredient was dissolved separately in distilled water within a 100-mL volumetric flask. The prepared stock solutions were then measured according to the quantities specified in the tables and added individually to the culture bottles containing the 990 mL of distilled water (Provasoli, 1960).

Table 1. Composition of AF6 Medium

No	Stock Solution	Concentration: g L-1 Deionized water (dH2O)	Amount
1	MES	Add the reagent directly to the medium	400 mg
2	NaNO3	140 g	1.0 mL

No	Stock Solution	Concentration: g L-1 Deionized water (dH2O)	Amount
3	NH4NO3	20 g	1,1 mL
4	MgSO4.7H2O	80 g	0,375 mL
5	KH2PO4	10 g	1.0 mL
6	K2HPO4	5 g	1.0 mL
7	CaCl2.2H2O	29,4 g	0,34 mL
8	Fe citrate	See the composition below	0,222 mL
9	Biotin	0,1 g	20 µL
10	Thiamine HCL	0,1 g	0,1 µL
11	Vitamin B6	0,1 g	10 µL
12	Vitamin B12	0,1 g	10 µL
13	P IV Metal Mix	See the composition below	5.0 µL

Table 2. Composition of Fe citrate solution

NO	Component	Amount
1	Ferric citrate	9.0 g
2	Citric acid	9.0 g

Table 3. Composition of PIV Metal Mix

NO	Component	Amount
1	Na2EDTA.2H2O	1.0 g
2	FeCl3.6H2O	196 mg
3	MnCl2.4H2O	36.0 mg
4	ZnSO4.7H2O	22.0 mg
5	CoCl2.6H2O	4.0 mg
6	Na2MoO4.2H2O	2,5 mg

2.2.2. Propagation *Chlorella vulgaris*

Chlorella vulgaris was first re-cultured for 7 days as a rejuvenation step. After 7 days, a 100 ml aliquot of the culture was taken to inoculate each 1 L culture bottle containing AF6 medium. Prior to inoculation, the volume of AF6 medium in each bottle was reduced by 100 ml—from 990 ml to 890 ml—and then 100 ml of the *Chlorella vulgaris* culture was added, resulting in a total culture volume of 990 ml per bottle. Each bottle was then sealed with sterile gauze and fitted with an air tube connected to an aerator.

The nine culture bottles were assigned to three different lighting treatment groups, each consisting of three replicate bottles. The first group (top position) was exposed to white light, the second group (middle position) to red light, and the third group (bottom position) to blue light, with light intensities ranging from 500 to 1,500 lux (Nurhanifah *et al*., 2019).

2.2.3. Measurement of the Specific Growth Rate of *Chlorella vulgaris*

Over a 14-day observation period, with measurements taken every 24 hours, a 2 mL sample of the culture was withdrawn from each of the nine flasks, and its absorbance was measured using spectrophotometer at wavelength of 680 nm (Metsoviti *et al*., 2019). The specific growth rate was calculated using the formula.

$\mu_{exp} = \ln(\alpha_2-\alpha_1)/(t_2 - t_1)$

where α1 and α2 are the absorbance readings at the beginning and end of the exponential growth phase, and (t1) – (t2) is the time interval between observations (days).

2.2.4. Measurement of Chlorophyll a and b content

Chlorophyll a and b content in *Chlorella vulgaris* was measured using a spectrophotometer. On days 2, 4, 6, 8, 10, 12, and 14, 2 mL sample was collected from each lighting treatment and centrifuged at 5,000 rpm for 10 minutes. The supernatant was discarded, leaving only the pellet; subsequently, 1.5 mL of 90% methanol was added, and the mixture was stored in a refrigerator overnight. Afterward, the sample was centrifuged again at 5,000 rpm for 5 minutes, the supernatant was collected, and its absorbance was measured using spectrophotometer at wavelengths of 665 nm (chlorophyll a) and 645 nm (chlorophyll b) (Rizzi *et al*., 2021). Chlorophyll content was calculated using the formula provided by (Sari *et al*., 2024).

Chlorophyll a (mg/L)=$12.7(A_{665})-2.69(A_{645})$

Chlorophyll b (mg/L)=$22.9(A_{645})-4.68(A_{665})$

2.2.5. Biomass Dry Weight Measurement

In measuring the dry weight of biomass, 2 ml samples were taken on days 2, 4, 6, 8, 10, 12, and 14 to be centrifuged at 5,000 rpm for 10 minutes. The supernatant was removed until only the pellet remained, then weighed using an analytical balance. After the sample was weighed, it was dried using an oven at 40°C for 30 minutes, after which the sample was weighed again to obtain the scale results after being oven-treated (Wulandari *et al*., 2025). The dry weight of biomass is calculated using the formula

Biomass (g/l) = $\frac{[B]-[A]}{sample\ volume}$ x 1.000

A: Weight after oven drying

B: Weight before oven drying

2.2.6. Data Analysis

The data were processed using analysis of variance (ANOVA), preceded by tests for normality and homogeneity. Subsequently, if differences were found, further analysis was conducted using the Tukey test based on a significance level of $p < 0.05$ (or a 95% confidence level). Data processing was performed using SPSS version 31.0.2.0 (126) (Novianti *et al*., 2017).

3. RESULTS AND DISCUSSIONS

3.1. Specific Growth Rate of Chlorella vulgaris

Light is a key factor in the growth of *Chlorella vulgaris* as a photoautotrophic organism, serving as the energy source for photosynthesis. White, red, and blue LED lamps were used as light sources to substitute for sunlight during the cultivation of *Chlorella vulgaris* (Novianti *et al*., 2019).

Microalgae are photosynthetic microorganisms that utilize light as their primary energy source for photosynthesis. Variations in light intensity affect photosynthetic efficiency and chlorophyll content factors that play a crucial role in determining growth and productivity (Sohani *et al*., 2023).

The growth rate of *Chlorella vulgaris* was monitored every 24 hours over a 14-day period for each light color treatment, with three replicates performed for each. Absorbance values from the three replicates were averaged daily for each treatment, and the resulting mean values were plotted on a graph, as shown in Figure 1.

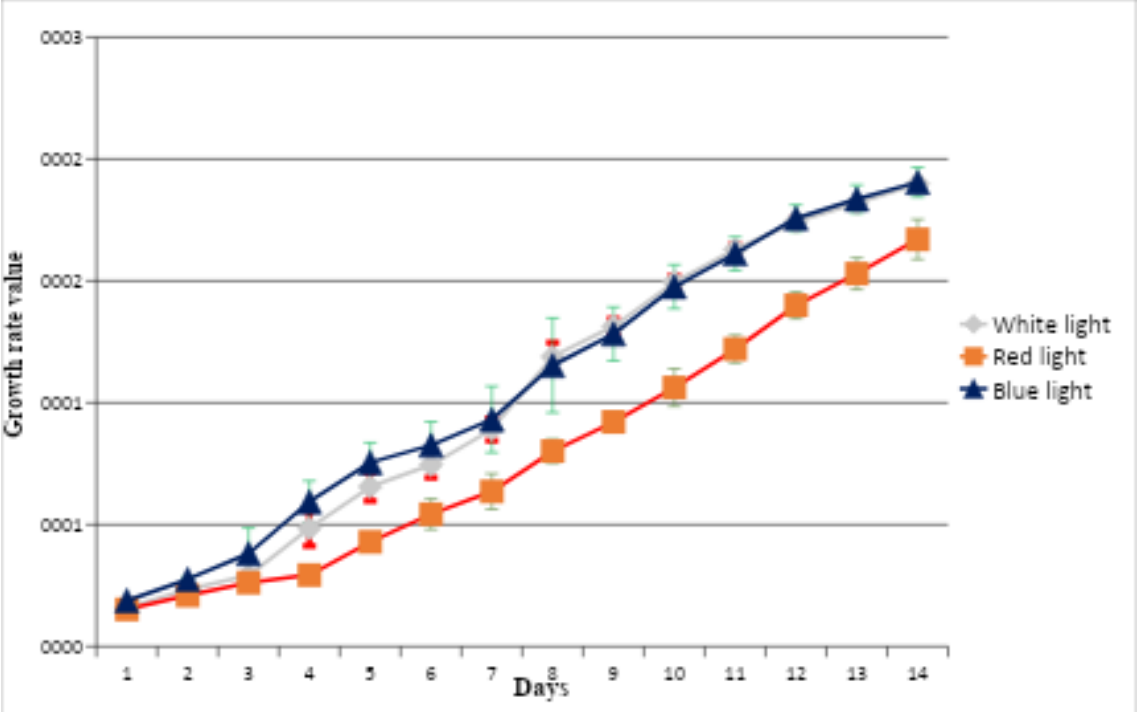

Figure 1. Growth rate graph of *Chlorella vulgaris* under different light colors.

The mean daily absorbance values for each light color treatment were substituted into the specific growth rate formula specified in the research methods section to obtain the specific growth rate for each observation period. These values were then averaged over the 14 day period for each light color treatment, and the results are presented in **Table 4.**

Table 4. Average specific growth rate of *Chlorella vulgaris* under different lighting treatments

Treatment	Mean Specific Growth Rate (cells/ml/day)
White Light	0,043
Red Light	0,032
Blue Light	0,038

Table 5. Specific growth rate: ANOVA test results

	Mean Square	F	Sig
Between Groups	.317	.947	.397

Growth rate is a parameter describing the speed of microalgal cell proliferation per unit of time (Utomo *et al*., 2024). Research results (**Figure 1**) indicate that white light yields the highest specific growth rate due to its characteristics as polychromatic light. Unlike monochromatic light, white light provides the full range of wavelengths required for various metabolic processes. The simultaneous availability of blue and red spectra in white light enables cells to absorb photon energy more comprehensively. This creates a balance between photosynthetic activity and cell division, resulting in a specific growth rate that surpasses that of single-color light treatments (Czyzeweski *et al*., 2026).

Excessively high light intensity can cause photoinhibition in *Chlorella vulgaris*, thereby reducing both the growth rate and cell density (Baiee and Salman, 2016). Conversely, excessively low light intensity leads to *light-limiting* conditions where photosynthetic pigments

cannot optimally absorb photons; consequently, the organic compounds produced are sufficient only to sustain cell growth (Metsoviti *et al*., 2019).

Based on the analysis of the mean specific growth rates of *Chlorella vulgaris* under each light color treatment (**Table 4**), the white light treatment produced the highest specific growth rate at 0.043 cells/mL/day, followed by blue light, while the red light treatment yielded the lowest specific growth rate at 0.032 cells/mL/day. These results demonstrate that white light is the most effective color for supporting the specific growth rate of *Chlorella vulgaris* compared to red and blue light.

This aligns with the view (Steenbergen, 1975, cited in Lama, 2020) that white light possesses the most complete light components resulting from a combination of various rays and the highest light intensity, thereby delivering greater energy than other light colors. White light bulbs possess photon energy referring to the discrete light particles that act as entities with a fixed energy level that is nearly double the photon energy found in blue and red light, this is one of the reasons why the specific growth rate under red and blue light treatments is slower compared to that under white light treatment (Lama, 2020).

ANOVA results indicate that light color did not significantly affect the specific growth rate of *Chlorella vulgaris* ($F = 0.947$; $p = 0.397$; $p > 0.05$). Although descriptive differences in mean values were observed among treatments—specifically white light (0.043 cells/mL/day), blue light (0.038 cells/mL/day), and red light (0.032 cells/mL/day) these differences were not statistically significant. This lack of significance was due to high data variability among replicates within each treatment, as reflected by the standard deviation values: white light (±0.029), blue light (±0.082), and red light (±0.041). The standard deviation for the blue light treatment actually exceeded its mean value, indicating inconsistent growth responses among the replicate bottles in that group. This high variability likely stemmed from uneven light intensity distribution across culture bottles even when positioned side-by-side since minor differences in distance or the angle of light exposure at the laboratory scale can alter the photon flux received by individual bottles. Furthermore, the limited number of replicates (three per treatment) contributed to low *statistical power* in detecting actual differences between treatments (Young *et al*., 2022).

3.2. Chlorophyll a and b Content of *Chlorella vulgaris*

Chlorophyll is the primary pigment responsible for capturing light energy for photosynthesis. According to (Chen *et al*., 2025) chlorophyll-a and chlorophyll-b are the two main pigments playing a crucial role in the photosynthesis of microalgae, including *Chlorella vulgaris*. Chlorophyll-a functions as the primary pigment, absorbing light energy at wavelengths of approximately 430 nm and 662 nm and participating directly in the photochemical reactions of Photosystem II. Meanwhile, chlorophyll-b which absorbs light at approximately 453 nm and 642 nm acts as an accessory pigment that broadens the light absorption spectrum, enabling the microalgae to continue photosynthesizing efficiently even under low-light conditions or different spectral conditions.

Data on chlorophyll-a and chlorophyll-b content were obtained by measuring absorbance with a spectrophotometer every two days over a 14 day observation period. The resulting absorbance values were then calculated using the formulas for chlorophyll-a and chlorophyll-b content specified in the research methodology section, yielding content values for each light color treatment and replicate. The values from the three replicates were averaged for each light color treatment, and the mean results are presented graphically in **Figure 2** and **Figure 3**.

Statistical analysis of chlorophyll-a and chlorophyll-b content was performed using a (*one-way* ANOVA) test with SPSS software. The data used consisted of the mean chlorophyll-a and chlorophyll-b content values derived from the three replicates for each light color

treatment, obtained every two days throughout the 14 day observation period. The results of the ANOVA test are presented in **Table 6** and **Table 7**.

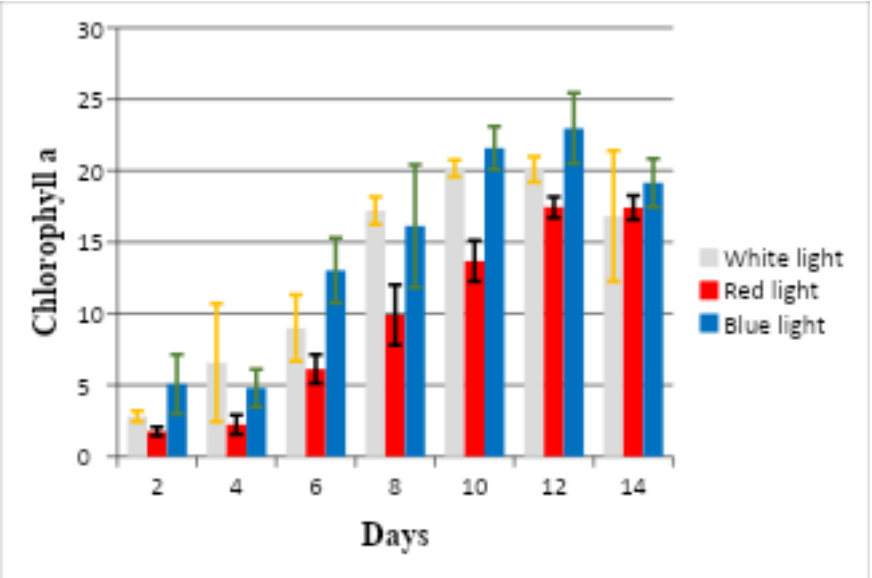

Figure 2. Graph of Chlorophyll a content under different colored light illumination

Table 6. Chlorophyll a content ANOVA test results

	Mean Square	F	Sig
Between Groups	44.0115	.887	.429

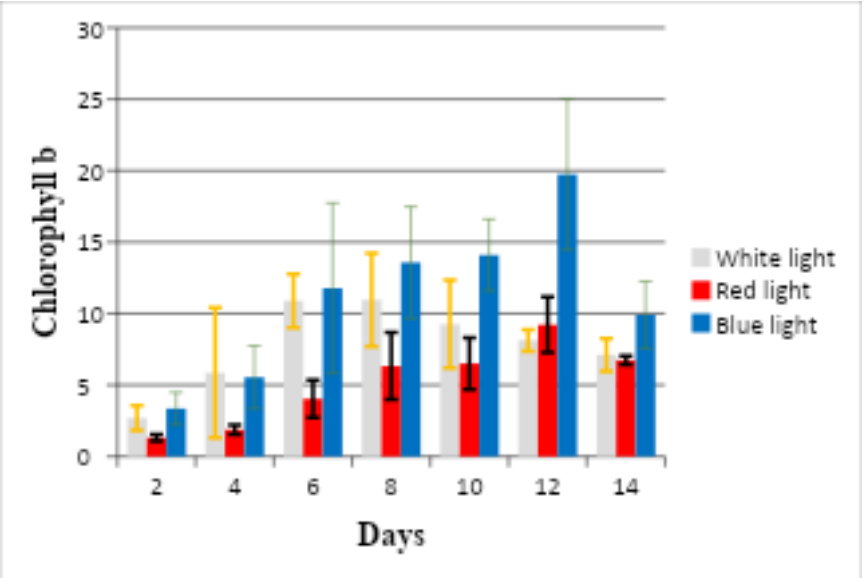

Figure 3. Graph of Chlorophyll b content under different colored lighting

Table 7. Chlorophyll b content ANOVA test results

	Mean Square	F	Sig
Between Groups	63.179	4.010	.036

The research results (**Figure 2** and **Figure 3**) indicate that for *Chlorella vulgaris* cultures subjected to different light source treatments, the white light treatment yielded the highest

chlorophyll a content on day 12 and the highest chlorophyll b content on day 8. In contrast, the red and blue light treatments resulted in peak chlorophyll a and b levels on day 12.

The graphs reveal that blue light had the greatest influence on chlorophyll a and b production compared to white and red light. This aligns with findings by (Baidya *et al*., 2021) who reported maximum chlorophyll a and b content under blue light treatment and minimum levels under red light treatment. This is attributed to the fact that blue light is absorbed more effectively than red light, specifically, blue light absorption is approximately 1.28 times higher than that of red light.

Blue light has wavelength of approximately 450 nm, implying higher photon energy compared to red light. This higher energy renders blue light more efficient at activating photochemical reactions particularly in Photosystem II (PSII), the initial stage of photosynthesis. Optimal PSII activation enhances electron flow and the generation of chemical energy (ATP and NADPH) required for organic compound synthesis. In response to this increased photosynthetic activity, *Chlorella vulgaris* cells boost their light absorption capacity. One adaptive mechanism involves increasing the synthesis of photosynthetic pigments, namely chlorophyll a and chlorophyll b. Chlorophyll a serves as the primary pigment in photosynthetic reactions, while chlorophyll b acts as an accessory pigment that broadens the light absorption spectrum (Lysenko *et al*., 2021).

Statistical analysis of chlorophyll a and b content in *Chlorella vulgaris* began with normality and homogeneity tests using SPSS, which confirmed that the data were normally distributed and homogeneous. The analysis proceeded with an ANOVA test. Based on the results presented in Tables 6 and 7, chlorophyll a content showed a p-value > 0.05, indicating no significant difference among the light color treatments. Conversely, the ANOVA results for chlorophyll b content showed a p-value < 0.05, indicating a significant difference among the light color treatments. This is likely because the light intensity range of 500–1,500 lux was insufficient to induce major changes in the chlorophyll a content of *Chlorella vulgaris*, as the primary photosynthetic pigment, chlorophyll a tends to be maintained at stable levels. However, at these intensities, chlorophyll b acting as an accessory pigment was more responsive to changes in light quality, thereby exhibiting significant differences across treatments. The increase in chlorophyll *b* represents a cellular adaptation to enhance light energy absorption efficiency under low to moderate light intensities (Zuorro *et al*., 2025).

Chlorophyll a functions as reaction center pigment due to its vital role in photosynthesis, it is more protected and consistently maintained by the cell, resulting in less variation across treatments compared to chlorophyll b. Proteins are also crucial structural and metabolic components of algal cells; consequently, the content of chlorophyll a is linked to thylakoid membrane proteins, which are more resistant to changes in light intensity and quality (Metsoviti *et al.,* 2019). Chlorophyll b is an accessory pigment (*antenna pigment*) responsible for capturing and transferring light energy to chlorophyll a. This pigment is far more sensitive to changes in the light spectrum composition than chlorophyll a. Research by (Guo & Fang., 2020) demonstrated that blue light can specifically influence chlorophyll b synthesisresulting in higher levelswhereas chlorophyll b content is lower under red light; this aligns with findings showing that *Chlorella vulgaris* exposed to blue light exhibits the highest chlorophyll b content.

3.3. Dry Biomass Weight of *Chlorella vulgaris*

Dry weight serves as a direct parameter for measuring the total accumulated biomass of microalgae, encompassing carbon, protein, and lipid components. The biomass productivity of *Chlorella vulgaris* is highly dependent on the efficiency of light absorption specifically within the red (630–660 nm) and blue (430–460 nm) LED spectra, which align with the absorption peaks of chlorophyll a and b to facilitate optimal photosynthesis. Biomass dry weight represents the total mass of the microalgae after the complete removal of water content.

Measuring biomass dry weight is a method used to determine microalgal abundance within a body of water (Hakiki, 2016).

Data on *Chlorella vulgaris* biomass dry weight were obtained through measurements taken every two days over a 14-day observation period. The obtained values were calculated using the formula specified in the research methodology section, yielding biomass dry weight values for each light color treatment across all replicates. Values from the three replicates were averaged at each observation point and subsequently averaged again over the entire 14 day period for each light color treatment, resulting in a single mean biomass dry weight value per treatment, as presented in **Table 8**.

Table 8. Average Dry Biomass Weight of *Chlorella vulgaris* under Different Colored Light Illumination

Lighting Treatment	Average Dry Biomass Weight of *Chlorella vulgaris* (g/L)
White light	6,32
Red light	6,35
Blue Light	6,28

Table 9. Biomass dry weight ANOVA test results

	Mean Square	F	Sig
Between Groups	0.11	.002	.998

Regarding the biomass dry weight of *Chlorella vulgaris* (**Table 8**), it was observed that red light illumination yielded the highest biomass dry weight, whereas blue light illumination resulted in the lowest. This aligns with research by (Novianti et al., 2017) on *Chlorella vulgaris*, which demonstrated that red LED lighting produces higher cell densities than green or blue LED, this is because the red spectrum is more effectively utilized by chlorophyll during photosynthesis, thereby triggering greater biomass accumulation.

Red light facilitates the highest biomass production because it consists of photons with moderate energy sufficient to activate photosystems II and I without inducing the photooxidative stress associated with high energy blue light and is more readily and fully utilized by chloroplasts for CO_2 fixation and carbohydrate production, leading to increased biomass accumulation (Novianti *et al*., 2017).

ANOVA results (**Table 9**) indicate no significant difference in biomass dry weight among the light color treatments ($p > 0.05$). Unlike the previous parameter, the lack of statistical significance regarding biomass dry weight stems from the fact that light intensity plays a more dominant role than light color quality in determining biomass productivity. Light intensity is known to exert a greater influence than light quality on the growth rate and biomass production of *Chlorella vulgaris*, specifically, increasing light intensity consistently enhances the specific growth rate as well as the productivity of biomass, proteins, and lipids. This is supported by findings that higher light intensity directly boosts the average growth of *Chlorella vulgaris*, whereas variations in light color have a comparatively minor impact on biomass production (Metsoviti *et al*., 2019). Given that the light intensity used in this study ranged from 500 to 1,500 lux across all treatments, differences in light color alone were insufficient to produce statistically significant variations in biomass dry weight. Research by (Chriswardana *et al*., 2022) explains that the optimization of *Chlorella vulgaris* biomass is determined not only by light color but is also significantly influenced by light intensity and color temperature. Under suboptimal light conditions, differences in red, white, and blue spectra resulted in varying mean biomass levels, though the differences were not statistically significant.

The study results indicate that white light treatment yielded the highest specific growth rate compared to red and blue light; however, the highest dry biomass weight was

actually obtained under red light treatment. This suggests a non linear relationship between specific growth rate and dry biomass accumulation, attributed to high intracellular water content in white light cultures, consequently, despite faster cell growth, the resulting dry weight was relatively lower because the cells tended to be more dilute or had higher water content. A high growth rate reflects the speed of cell division rather than the solid content within the cell. Cells divide more rapidly, yet individual cells tend to be smaller and more hydrated because energy is directed toward reproduction rather than the accumulation of reserves (Esteves *et al*., 2020). While white light was shown to increase lipid and photosynthetic pigment content, it did not proportionally increase the overall dry weight of the cells. Rapidly growing cells under white light exhibited larger volumes but higher water proportions, resulting in relatively low dry weight, this aligns with findings by (Gao *et al*., 2024), who noted that larger cells resulting from intense light exposure tend to have more dilute intracellular chlorophyll, indicating that an increase in cell volume is not always accompanied by a proportional increase in dry matter content.

Blue light produced the highest levels of chlorophyll a and b compared to white and red light. Mechanistically, chlorophyll synthesis is regulated by cryptochromes (blue light receptors) the greater accumulation of chlorophyll under blue light compared to red light implies an active role for cryptochromes in this process (Zhang *et al*., 2022). Blue light can significantly increase the chlorophyll content of microalgae, indicating that the blue spectrum is more effective at stimulating the biosynthesis of photosynthetic pigments (Duarte & Costa, 2018).

4. CONCLUSION

In the cultivation of *Chlorella vulgaris*, white light yields the highest specific growth rate, blue light produces the highest chlorophyll a and b content, and red light results in the highest biomass dry weight. These variations across parameters stem from the distinct metabolic pathways activated by each light spectrum, consequently, no single light color excels across all productivity parameters. Red light is the most recommended for *Chlorella vulgaris* cultivation because it generates the highest biomass dry weight factor most critical for biomass production, animal feed, and biofuel feedstock applications. Future research should investigate combinations of two or more light colors such as red and blue to achieve optimal overall productivity across all parameters.

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