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EVALUATION OF GROWTH RATE AND CHLOROPHYLL CONTENT OF CABBAGE MICROGREENS UNDER DIFFERENT LED LIGHT SPECTRA

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ABSTRACT

Microgreens are high-value horticultural commodities that are increasingly in demand due to their rich nutritional content and short harvesting period. One of the critical factors in microgreen cultivation is lighting, particularly the use of LED technology, which enables spectral manipulation according to the physiological requirements of plants. However, plant responses to light spectra are variety-specific, necessitating a thorough evaluation of the interaction between cultivar and LED spectrum to achieve optimal results. This study aimed to investigate the interaction effects between cabbage cultivars (Brassica oleracea var. Capitata) and LED spectra on plant height growth rate and chlorophyll content in microgreens. The experiment was conducted using a factorial Completely Randomized Design (CRD) with two factors: cultivar (Talenta F1, Takada F1, Summer Autumn, and Scarlet) and LED spectrum (white, blue, red, and a red–blue combination at 80%:20%). A total of 16 treatments were applied, each replicated twice. Observed parameters included plant height growth rate (cm/day) and chlorophyll content (unit). Data were analyzed using ANOVA at a 5% significance level, followed by Duncan's Multiple Range Test (DMRT) when significant differences were detected. The results revealed a significant interaction between cultivar and LED spectrum for both observed parameters. The red spectrum (s_3) exerted the greatest influence on plant height growth rate, with the highest values recorded in Talenta F1 (0.40 cm/day) and Scarlet (0.31 cm/day). Conversely, the red–blue combination (s_4) produced the highest chlorophyll content, particularly in Scarlet (49.15 units) and Talenta F1 (40.35 units), indicating the synergistic effectiveness of combined spectra in supporting photosynthetic pigment synthesis. The Summer Autumn cultivar exhibited a positive response to the blue spectrum, while Takada F1 demonstrated flexibility under both white and red–blue spectra. The coefficients of variation (CV) were 15.47% for growth and 14.29% for chlorophyll, reflecting moderate variability and representative data quality.

Key words: Cabbage Cultivars, LED spectrum, Microgreens.

INTRODUCTION

According to the World Health Organization (WHO), the recommended daily intake of fruits and vegetables is 400 g per capita to meet nutritional requirements and reduce the risk of non-communicable diseases (WHO, 2023). However, data from the National Food Agency (2022) indicate that the average fruit and vegetable consumption among Indonesians was only 237.5 g per capita in 2022, reflecting a decline in public interest and awareness regarding adequate nutritional intake (BPS, 2022).

Another challenge is the limited availability of agricultural land, particularly in urban areas, coupled with time constraints that hinder individuals from independently cultivating crops. Furthermore, unpredictable agronomic conditions driven by climate change may reduce both yield and crop quality. Therefore, it is essential to develop cultivation systems supported by accessible everyday technologies (Novyanti *et al*., 2024).

Microgreens are vegetables harvested approximately 7–14 days after germination, characterized by higher concentrations of nutrients and vitamins compared to conventionally grown vegetables (Maulida Fajrin *et al*., 2023). These plants contain elevated levels of bioactive compounds such as antioxidants, vitamins, flavonoids, and carotenoids relative to their mature counterparts (Maulida Fajrin *et al*., 2023). The high nutritional content of microgreens is attributed to ongoing catabolic processes, which provide nutrients for plant growth through hydrolytic reactions of seed reserves. Additionally, during the microgreen stage, increased growth hormone activity enhances phenolic compound synthesis (Andriani & Murtisiwi, 2018). Microgreens have emerged as a promising horticultural commodity due to their superior nutritional value, short cultivation cycle, and economic potential in urban farming systems. Cabbage (Brassica oleracea) is one of the promising varieties for microgreen production, given its high antioxidant, vitamin C, and chlorophyll content. Chlorophyll plays a crucial role in photosynthesis and serves as an indicator of plant physiological quality.

Light is a critical environmental factor influencing microgreen growth and chlorophyll accumulation. Light Emitting Diode (LED) technology has become an efficient alternative for plant illumination, offering adjustable spectral compositions to optimize growth. Blue and red LED spectra are particularly important for photosynthesis, morphogenesis, and pigment synthesis. Research by Zhang *et al*. (2021) demonstrated that a combination of red and blue spectra enhances growth rate and chlorophyll content in Brassicaceae species, including cabbage.

Microgreen development is strongly affected by light intensity (Maulida Fajrin *et al*., 2023). LED-based growing lights are widely used to improve microgreen quality without causing damage. For photosynthesis activation, the appropriate type and quantity of light are essential. Chlorophyll absorbs light within the red (600–700 nm) and blue (400–500 nm) wavelength ranges, suggesting that these spectra enhance photosynthetic efficiency in microgreen cultivation. Rahmani *et al*. (2021) reported that red light is more effective during the generative phase, whereas blue light is more beneficial during the vegetative phase.

Nutritional content in purple cabbage microgreens is significantly higher than in mature vegetables, with vitamin E (α-tocopherol) levels 113-fold greater, ascorbic acid (vitamin C) 6-fold higher, and β-carotene 260-fold higher compared to mature purple cabbage (Choe *et al*., 2018). Similarly, green cabbage microgreens contain 133-fold more vitamin E, 12-fold more vitamin C, and 218-fold more β-carotene than mature green cabbage (Kamal *et al*., 2020). The unique pigmentation of purple cabbage further increases consumer appeal.

Moreover, plant varieties exhibit distinct physiological responses to different light spectra. A study by Lee *et al*. (2022) revealed significant differences in chlorophyll accumulation and biomass between red and green cabbage varieties when exposed to varying LED spectra. Consequently, evaluating the interaction between LED spectral composition and cabbage varieties in microgreen cultivation is crucial to establish technical recommendations for enhancing productivity and crop quality.

MATERIALS AND METHODS

This experiment was conducted at the Agronomy Laboratory, Faculty of Agriculture, UNSIKA, from May to August 2025. The materials used included soil as the growing medium, cabbage seed varieties (Talenta F1, Takada F1, Summer Autumn, and Scarlet), distilled water, 80% ethanol, Folin–Ciocalteu reagent, sodium carbonate, labeling paper, plastic zipper bags, plastic bottles, aluminum PE foam foil, and aluminum foil.

The study employed an experimental method using a completely randomized design (CRD) with a factorial arrangement. Sixteen treatments were applied, consisting of two factors, each replicated twice. The first factor was cabbage variety (S), comprising four levels:

v0 = Green cabbage Talenta F1
v1 = Green cabbage Takada F1
v2 = Green cabbage Summer Autumn
v3 = Purple cabbage Scarlet

The second factor was LED light spectrum (K), comprising four levels:

s1 = White LED spectrum (15 W)
s2 = Blue LED spectrum (15 W)
s3 = Red LED spectrum (15 W)
s4 = Red 80% + Blue 20% LED spectrum (15 W)

Each experimental unit consisted of 25 sample plants. To determine the interaction effects between the two factors on the observed variables, the data were statistically analyzed using an F-test at the 5% significance level. If significant interactions were detected, Duncan's Multiple Range Test (DMRT) at the 5% level was performed to identify the best treatment combinations (Gomes & Gomes, 2020). The primary observation parameters in this experiment were:

Plant growth rate

Measurement of plant height growth rate was conducted to evaluate the growth process of microgreens. The calculation of plant height growth rate was based on the increase in microgreen height from the day of sowing until the harvest stage. The growth rate of plant height was determined using the following formula:

Plant Growth Rate = $(S_2 - S_1)/T$

Where:

S_2: Plant height at the second measurement (cm)
S_1: Plant height at the first measurement (cm)
T: Interval between measurements (days) (Hardoyo, 2019)

Chlorophyll content

Chlorophyll analysis was conducted using a SPAD Chlorophyll Meter to measure chlorophyll levels in leaves without causing tissue damage. The instrument operates by clamping the leaf between its sensors, transmitting light through the leaf at specific wavelengths, and recording the absorbance values in SPAD units. Chlorophyll sampling was performed three times at different leaf positions: the basal, middle, and apical regions. The results can generally be categorized into three levels—low, medium, and high. However, in this study, measurements were taken only at the middle part of the leaf, with two replications.

Experimental procedures

The cultivation of microgreens was carried out in four main stages: preparation of the growing medium, installation of experimental units, seed preparation and maintenance, and harvesting. Growing medium preparation: Soil was prepared in trays with a depth of 3 cm, then sun-dried until constant weight was achieved to eliminate pests and pathogens.

1. Experimental unit installation: The units were constructed using boxes lined with aluminum PE foam foil, which served to reflect light and reduce heat. Each unit was equipped with LED lamps according to treatment: white LED (3118 lux), blue LED (2113 lux), red LED (952 lux), and a combination of red (80%) and blue (20%) LED (1269 lux). The lamps were positioned approximately 60 cm above the soil surface and operated for 16 hours daily, from 17:00 to 09:00.
2. Seed preparation and maintenance: Seeds free from chemical treatment were soaked for approximately 15 minutes to break dormancy, then directly sown into the soil medium without nursery or spacing, as the crop cycle was only 7–14 days. Maintenance included daily watering and monitoring for pest and disease symptoms, with control measures applied when necessary.
3. Harvesting: Microgreens were harvested at 7–13 days after sowing, depending on the variety. Harvesting was performed by cutting the basal stem. Plants were considered ready for harvest when cotyledons were fully developed, the first true leaves had emerged, and a single upright stem was established.

RESULTS AND DISCUSSION

Plant height growth rate

Analysis of variance at the 5% significance level revealed a significant interaction between cabbage varieties and LED light spectra on the mean growth rate of microgreen plant height. The subsequent Duncan's Multiple Range Test (DMRT) at the 5% level (Table 1) indicated that the red LED spectrum (s_3) generally exerted the greatest influence on enhancing growth rate across most varieties. The highest values were recorded in Talenta F1 (0.40 cm day^{-1}) and Scarlet (0.31 cm day^{-1}). These findings are consistent with previous studies reporting that red light plays a crucial role in stem elongation and the enhancement of photosynthetic activity in young plants. Mahardhika *et al*. (2024) emphasized that illumination within the wavelength range of 610–760 nm is highly effective in supporting photosynthesis, as red light is absorbed by phytochrome pigments that regulate plant size and developmental processes.

The Summer Autumn variety exhibited a distinct response, with the blue LED spectrum (s_2)

producing the highest growth rate (0.32 cm day^{-1}) (Table 1). This indicates that the variety is more responsive to blue light, which is generally associated with chlorophyll formation and leaf structural development. Ainunnisa (2021) reported that blue light maintains optimal growth during the seedling stage, while Fajrin *et al*. (2023) emphasized that blue light is the most efficiently absorbed wavelength in photosynthesis, thereby accelerating plant growth. In contrast, the combined spectrum of red (80%) and blue (20%) (s_4) did not yield optimal results across all varieties, with the lowest growth rate recorded in Scarlet (0.19 cm day^{-1}). This suggests that the spectral proportion in such combinations may not be universally suitable for all cultivars. Agnestika *et al*. (2017) highlighted that differences in pigment composition among plant varieties influence their capacity to absorb visible light.

The Takada F1 variety demonstrated the highest growth under both white light (s_1) and the red–blue combination (s_4), with growth rates of 0.29 cm day^{-1} and 0.28 cm day^{-1}, respectively. This indicates that Takada F1 possesses greater flexibility in adapting to a wider range of light spectra (Table 1). Ariesna *et al*. (2014) noted that white light enhances stomatal aperture size, thereby increasing photosynthetic activity and contributing to higher growth rates. The coefficient of variation (CV) of 15.47% reflects a moderate level of variability in the data, suggesting that the results are sufficiently representative to describe the effects of treatments on plant growth.

Table 1. Mean Plant Height Growth Rate of Microgreen Cabbage Varieties (Brassica oleracea var. Capitata) under Different Light Spectra

Plant Variety (V)	Plant Height Growth Rate (cm day^{-1})			
	LED Spectra (S)			
	s_1 (White)	s_2 (Blue)	s_3 (Red)	s_4 (Red 80% : Blue 20%)
v_0 (Talenta F1)	0,23 b B	0,21 c C	0,40 a A	0,23 c B
v_1 (Takada F1)	0,29 a A	0,20 d C	0,22 c B	0,28 b A
v_2 (Summer Autumn)	0,29 a C	0,32 a A	0,30 c B	0,22 a D
v_3 (Scarlet)	0,21 c C	0,23 b B	0,31 b A	0,19 d D
KK (%)	15,47			

Note: Mean values followed by the same letters (uppercase letters across rows and lowercase letters within columns) are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Overall, both cabbage variety and LED spectrum play critical roles in determining the effectiveness of microgreen growth. Red light tends to promote vertical elongation, whereas blue light contributes more significantly to physiological quality, particularly chlorophyll synthesis. Therefore, the appropriate selection of cultivar and light spectrum is essential for optimizing microgreen production under artificial lighting technologies.

Chlorophyll analysis

Analysis of variance at the 5% significance level revealed a significant interaction between LED light spectra and cabbage microgreen varieties (*Brassica oleracea* var. *Capitata*) on mean chlorophyll content (Table 2). The subsequent Duncan's Multiple Range Test (DMRT) at the 5% level indicated that the combined spectrum of red (80%) and blue (20%) (s_4) generally exerted the greatest influence on chlorophyll accumulation across most varieties. The highest values were recorded in Scarlet (49.15 units) and Talenta F1 (40.35 units) (Table 2). These findings are consistent with previous reports that the combination of red and blue spectra enhances photosynthetic efficiency by stimulating chlorophyll biosynthesis and enzymatic activities that support the metabolism of young plants. Rosyida *et al*. (2022) further noted that blue light, when combined with red LED spectra, contributes to the restoration of impaired physiological functions such as nitrogen reduction, while simultaneously promoting chlorophyll formation and increasing chloroplast activity.

The Takada F1 variety exhibited a distinct response, with the white LED spectrum (s_1) producing the highest chlorophyll content (41.95 units) (Table 2). This suggests that the variety is more responsive to full-spectrum light resembling natural sunlight. White light is known to support a balance between vegetative growth and the synthesis of photosynthetic pigments, making it suitable for varieties with adaptive physiological characteristics. According to Fajrin et al. (2023), white light comprises multiple wavelengths that collectively promote chlorophyll formation in plants. Conversely, the Summer Autumn variety showed the lowest chlorophyll content across all spectra, with the lowest value recorded under red light (s_3) at 28.95 units (Table 2). This indicates that the variety has low sensitivity to monochromatic light, particularly red, which is generally less effective in stimulating chlorophyll biosynthesis without the complementary effect of blue light. Hasna *et al*. (2025) reported that varietal responses to light spectra vary considerably, with certain genotypes exhibiting reduced sensitivity to red wavelengths.

Table 2. Mean Chlorophyll Content of Cabbage Microgreens (Brassica oleracea var. Capitata) across Different LED Spectra

Varietas Tanaman (S)	Analisis Klorofil (Unit)			
	LED Spectra (K)			
	s_1 (Putih)	s_2 (Biru)	s_3 (Merah)	s_4 (Merah 80% : Biru 20%)
v_0 (Talenta F1)	39,5 b B	38,7 a C	33,7 c C	40,35 b A
v_1 (Takada F1)	41,95 a A	35,6 b C	34,95 b C	39 b B

v_2 (Summer Autumn)	37,15 d A	32,7d B	28,95 d C	33,85 c B
v_3 (Scarlet)	41,2 a C	36,7 b D	43,95 a B	49,15 a A
KK (%)		14,29		

Note: Mean values followed by the same letters (uppercase letters across rows and lowercase letters within columns) are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level

The Scarlet variety demonstrated high flexibility to light treatments, with elevated chlorophyll levels observed under red light (43.95 units) and the red–blue combination (49.15 units). This suggests that Scarlet can efficiently utilize different light spectra for chlorophyll synthesis. Meanwhile, blue light (s_2) produced the lowest chlorophyll content in most varieties, except Talenta F1, which recorded a relatively high value (38.7 units). This indicates that Talenta F1 responds positively to blue light, which plays a critical role in leaf structural development and green pigment formation. Hasna *et al*. (2025) further emphasized that genotypic variation influences LED light responses, with some genotypes showing enhanced chlorophyll accumulation under blue light, confirming that light responsiveness is variety-specific and genetically determined. The coefficient of variation (CV) of 14.29% reflects a moderate level of variability, suggesting that the data are sufficiently representative to describe the effects of treatments on chlorophyll content in cabbage microgreens. Overall, both variety and LED spectrum play crucial roles in determining the effectiveness of chlorophyll biosynthesis. The red–blue combination spectrum tends to support optimal chlorophyll formation, while white light provides favorable results for varieties that are physiologically adaptive to full-spectrum illumination. Therefore, the appropriate selection of variety and light spectrum is essential for optimizing the physiological quality of cabbage microgreens under artificial lighting technologies.

CONCLUSION

Based on the results of this study, it can be concluded that there is a significant interaction between cabbage varieties and LED light spectra on the mean plant height growth rate and mean chlorophyll content of microgreens. The red LED spectrum (s_3) was found to be the most effective in promoting vertical growth, particularly in the Talenta F1 and Scarlet varieties. In contrast, the red–blue combination spectrum (s_4) contributed most substantially to chlorophyll synthesis, with the highest values observed in Scarlet. The Summer Autumn variety exhibited a unique response to blue light, which supported leaf structural development and green pigment formation, while the Takada F1 variety demonstrated flexibility in adapting to both white light and the red–blue combination spectrum.

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