

Cultivation of three lettuce varieties under low light intensity controlled environment in tropical urban area

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ABSTRACT

Lettuce (*Lactuca sativa*) is a leafy vegetable that is widely consumed due to its high nutritional content. The growth and yield of lettuce plants are significantly influenced by light intensity. Despite its potential, information about the intensity required for plants to grow optimally, specifically in urban areas, is still limited. Therefore, this study aims to evaluate the morphological and physiological growth and yield of 3 lettuce varieties under the intensity of sunlight and artificial light. The procedures were carried out using a split-plot design with 3 replications. The main plot comprised 55% shade (S55% + SL), 80% shade (S80% + SL), and 100% shade combined with artificial light from Light Emitting Diode (LED) lights (S100%+LED), which served as low-intensity light. Meanwhile, the subplots were 3 varieties of lettuce, including Romaine *Lactuca sativa* L. VAR. Longifolia (V1), Grand rapids *Lactuca sativa* L. VAR. new grand rapids (V2), and siamak *Lactuca sativa* L. VAR. Augustuna (V3). The results showed that shading intensity of 80% (S80% +SL) and 100% (SD100%+LED) inhibited plant growth, particularly in leaves and roots. Microclimate conditions, such as air temperature and light intensity, were lower due to the influence of shade. In conclusion, 3 lettuce varieties cannot grow optimally under low intensity shade, and 100% shade (SD100%+LED) is not suitable for the specific needs of plant to promote optimal growth and yield of lettuce.

Keywords: Artificial light; Light emitting diode; Light stress; Shade intensity.

Crescimento de três variedades de alface sob baixa intensidade luminosa em ambiente controlado tropical urbano

RESUMO

A alface (*Lactuca sativa*) é uma hortaliça folhosa amplamente consumida devido ao seu elevado valor nutricional. A intensidade luminosa desempenha um papel crucial no crescimento e na produtividade da alface. No entanto, as informações sobre a intensidade de luz ideal para o cultivo de alface, especialmente em ambientes urbanos, ainda são limitadas. Este estudo teve como objetivo avaliar o crescimento morfológico e fisiológico, bem como a produtividade, de três variedades de alface cultivadas sob diferentes intensidades de luz solar e luz artificial. O experimento foi conduzido em delineamento de parcelas subdivididas com três repetições. As parcelas principais consistiram em três condições de luz: 55% de sombreamento (S55% + SL), 80% de sombreamento (S80% + SL) e 100% de sombreamento suplementado com luz artificial proveniente de lâmpadas LED (S100% + LED), representando condições de baixa luminosidade. As subparcelas compreenderam três variedades de alface: Romana (*Lactuca sativa* L. var. longifolia) (V1), Grand Rapids (*Lactuca sativa* L. var. New Grand Rapids) (V2) e Siamak (*Lactuca sativa* L. var. Augustuna) (V3). Os resultados indicaram que 80% de sombreamento (S80% + SL) e 100% de sombreamento com suplementação de LED (S100% + LED) inibiram significativamente parâmetros de crescimento, incluindo o desenvolvimento de folhas e raízes. Além disso, esses tratamentos reduziram fatores microclimáticos, como temperatura do ar e intensidade luminosa. Em conclusão, as três variedades de alface não apresentaram crescimento ideal em condições de baixa luminosidade, e o sombreamento de 100% com suplementação de LED mostrou-se inadequado para promover crescimento e produtividade ótimos.

Palavras-chave: Luz artificial; Diodo emissor de luz; Estresse luminoso; Intensidade de sombreamento.



1. Introduction

Population growth and decreased agricultural land in urban areas have led to the development of urban farming systems with methods that are more efficient and adaptable. In addition, the availability of land for cultivation is becoming increasingly limited, with cultivation activities being carried out indoors. One of plants that can be developed in urban areas with indoor cultivation practices is lettuce (*Lactuca sativa* L.). Several studies have shown that lettuce is a leafy vegetable that is widely consumed, particularly for its nutritional content and health benefits. It is also widely cultivated in urban farming systems using hydroponics, vertical farming, and indoor farming. Cultivation of lettuce in urban areas can supply local communities with fresh vegetables, reduce dependence on supplies from outside the area, and contribute to local food security. In indoor farming systems, environmental factors, such as light intensity, have a significant influence on the growth and yield. However, some lettuce varieties show different responses to limited environmental conditions. This indicates that it is important to evaluate the response of each variety to low light intensity and identify the most adaptive for indoor cultivation systems.

Plant cultivation in urban areas is faced with the challenge of limited land and light due to dense buildings. Environmental conditions with limited light have a negative effect on the growth and development of plants. In addition, microclimatic conditions, specifically high light intensity, have been reported to be major limiting factors. Excessive lighting conditions can cause stress to plants, leading to a decrease in quality and yield (Ferrante and Mariani, 2018). According to Songserm et al. (2024), light is an essential factor in the photosynthesis process and can have a significant effect on plant morphology.

An effective solution that can be applied to the control of light intensity is the use of shading. In the current study, experiments were carried out using shade at levels of 50% and 80% to reduce direct exposure to sunlight, as well as 100% shade with Light Emitting Diode (LED) light source. The use of LED lights in 100% shade is intended as an additional light source that could be controlled according to plant needs. The use of shade aims to create a microclimate that is more suitable for lettuce growth, while LED lights are used to provide additional lighting in a specific spectrum optimal for photosynthesis and vegetative growth of lettuce (Mohamed et al., 2021). In addition, the use of artificial light technology, such as LED lamps, is a solution to support plant growth in limited sunlight. Artificial light sources, such as light-emitting diodes (LEDs), have been widely used in indoor agriculture because the light spectrum can be modified to suit the specific needs of plants. LED lights offer advantages, such as energy

efficiency, long life, and the ability to adjust the spectrum. Lighting with specific spectrums, such as red and blue, has been shown to be effective in increasing photosynthesis, growth, and yield quality of lettuce (Tarakanov et al., 2022).

Cultivating lettuce in urban areas with LED lighting not only has the potential to increase productivity but also allows the environmental conditions of plants to be controlled. LED lighting technology is one of the best innovations due to its control and high energy efficiency. The combination of an optimal light spectrum and appropriate intensity enables LED lamps to support plant growth more effectively. Spectra such as blue and red light can facilitate more optimal plant growth (Modarelli et al., 2022). In addition to spectrum, light intensity affects photosynthetic rate and plant productivity (Chen et al., 2021). A lower intensity can inhibit growth, while high levels cause stress or damage. This indicates that lighting specific to plant needs for the growth process is important to increase yields. However, studies addressing these light variations in lettuce cultivation remain highly limited.

The use of shading and the combination of blue and red light in this study was chosen because it has not been extensively applied for lettuce growth in urban areas. A total of 3 lettuce varieties were selected due to their distinct morphological characteristics and physiological responses to environmental growing conditions. These differences are important to investigate to determine the most adaptive variety for cultivation systems under shading conditions. Previous studies have rarely compared multiple varieties under integrated shading and LED conditions. Therefore, this study aims to evaluate the effect of 50%, 80%, and 100% shade with LED lighting on morphological and physiological growth and yield of 3 lettuce varieties. The results are expected to provide more accurate guidance and environmentally sustainable vegetable cultivation practices in urban areas.

2. Material and Methods

This study was conducted at an outdoor agricultural study facility in Jakabaring (104°46'44" E, 3°01'35" S), Palembang, South Sumatra, Indonesia, from June to July 2024. The study site was a tropical lowland, which was confirmed by the high rainfall, air humidity, air temperature, and duration of sunshine (Figure 1).

This study was conducted under shade nets of 3 different shading intensities of 4 m (length) × 2 m (width) × 4 m (height). Shading with intensity S55%+SL (55% artificial shade) with light intensity of approximately 400 to 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$, S80%+SL (80% artificial shade) with light intensity of approximately 100 to 150 $\mu\text{mol m}^{-2} \text{s}^{-1}$, and S100%+LED.

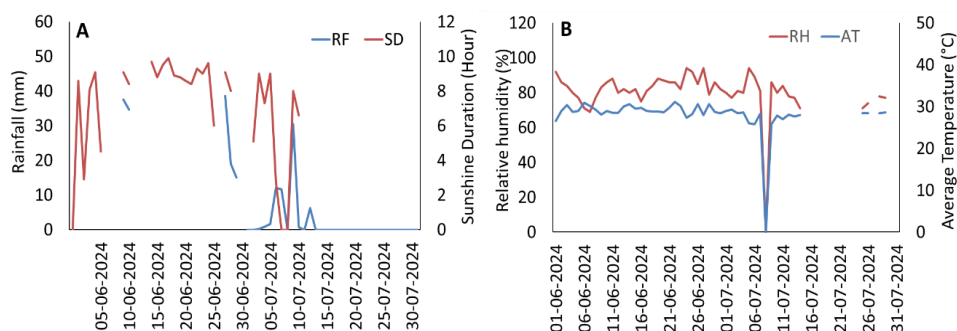


Figure 1. Agroclimatic characteristics of the research site include sunshine duration (SD) and rainfall (RF) (A), and relative humidity (RH) and average temperature (AT) (B). (Source: Indonesian Agency for Meteorology, Climatology, and Geophysics).

The S100%+LED treatment was fully covered with black plastic to prevent any sunlight penetration with light intensity of approximately $200\text{--}250\ \mu\text{mol m}^{-2}\ \text{s}^{-1}$. In addition, shade was designed with a 14-inch (diameter) and 6 m (length) PVC as an air ventilator. Light source in shade (S100%+LED) was supplied by 50-watt purple LED lamps, with a total of 8 lamps installed in a $32\ \text{m}^3$ space and lighting duration of 12 hours per day. LED used was the SMD2835 type, emitting purple light with wavelengths ranging from 395 nm to 420 nm. Each replication was installed with 2 lamps, which were placed at a distance of 55 cm from plant canopy.

Lettuce seeds were transplanted 14 days after sowing, and the seedlings were planted in pots measuring 27.5 cm (height) x 27.5 cm (diameter). This pot was planted with a mixture of substrate, namely mineral soil, topsoil, and a mixture of cow dung (1:3 v/v), which was arranged under the shade net. Subsequently, in S-100% shade, the pots were arranged on a rack, which consisted of 2 rows measuring 3.75 m (length) x 0.8 m (width) x 1.8 m (height) (Figure 2). During the study process, fertilization was carried out with NPK Mutiara fertilizer 16:16:16 at a dose of 5 grams/pot at 7 DAT (day after transplanting).

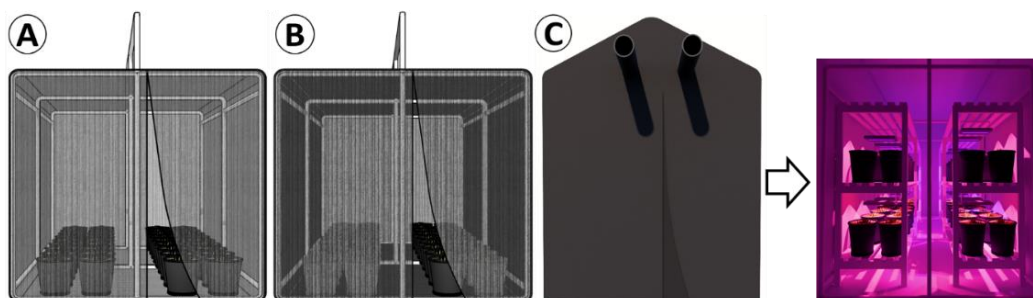


Figure 2. The illustration of cultivation place, shade intensity 55% shade (S55% + SL) (A), shade intensity 80% shade (S80% + SL) (B), and shade intensity 100% (S100%+LED) inside and outside (C).

The data collected included lettuce growth, physiological responses, yield, and microclimatic conditions. Plant growth data consisted of daily leaf expansion measurements (length and width), as well as weekly vegetative growth parameters such as plant height, number of leaves, canopy area, and leaf width. Physiological data included chlorophyll content. Yield was measured at the end of the experiment and included the fresh and dry weight of leaves, stems, and roots. The morphological characteristics of leaves, stems, and roots were also observed. Daily leaf expansion was measured from the time leaves were fully open until growth had stagnated. Meanwhile, microclimate data included soil and air temperature, relative humidity, and light intensity.

A gram of fresh leaf tissue was extracted in 100 mL of 80% (v/v) acetone. The absorbance of the extracting

solution at 646 nm and 663 nm was measured by a spectrophotometer (UV-3150, Shimadzu Corporation, Kyoto, Japan). Chlorophyll content was calculated according to Harborne's (1973) equations. Soil temperature was measured using a KW0600308 thermometer (Krisbow, Inc., Jakarta, Indonesia). Air temperature and humidity were measured using a Tzone TempU07B data logger, PC logger, storage, humidity, and temperature recorder. Light intensity was measured using a Benetech GM1030 lux meter data logger, light lux meter, spectrometer, and photometer tester. The dry weight of each plant organ was obtained by drying in a $105\ ^\circ\text{C}$ oven for 24 hours. Meanwhile, the materials used in this study included lettuce seeds, Panah Merah, 3 varieties of Romaine lettuce *Lactuca sativa* L. VAR. Longifolia, Grand Rapids lettuce *Lactuca sativa* L. VAR. new Grand Rapids, and Siomak lettuce *Lactuca*

sativa L. VAR. Augustuna. Canopy area was measured using the Easy Leaf Area application.

Based on the result, this study used a split-plot design. Shading as the main plot and the first shade was at 55% intensity (S55%+SL), the second shade at 80% intensity (S80%+SL), and the third shade at 100% intensity with artificial light from LED lamps (S100%+LED). Lettuce varieties as a sub-plot consisted of 3 varieties, namely Romaine lettuce, *Lactuca sativa* L. VAR. Longifolia (V1), Grand Rapids lettuce *Lactuca sativa* L. VAR. New Grand Rapids (V2), and Siomak lettuce *Lactuca sativa* L. VAR. Augustuna (V3). Each treatment was replicated 4 times. In addition, all data collected were analyzed by analysis of variance (ANOVA), and the level of significance between treatments was tested with the least significant difference (LSD) at $p < 0.05$. All analyses were performed using RStudio (v2023.06.0+421) for Windows 10.

3. Results and Discussion

The rate of leaf growth varied according to shade intensity. Shade significantly affected the growth of 3 lettuce varieties. Artificial shade under sunlight exposure showed a positive response to the number of lettuce leaves. Lettuce leaves grown under 55% shade were significantly more effective than those grown under 80% shade and 100% with artificial LED lighting. Shade with low light intensity-initiated leaf formation of Grand Rapids lettuce faster than the other 2 varieties (Figure 3). Reduced light intensity caused by shading had a significant effect on the number of leaves formed. A total of 55% shade reduced direct light exposure to protect plants from potential damage from overexposure, while still providing the ability for plants to photosynthesize effectively. Planting under shade 55% allowed plant to receive sufficient light for photosynthesis without triggering an excessive stress response (Shi et al., 2022). Meanwhile, light intensity in 80% shade was insufficient, and photosynthesis was reduced, resulting in plant growth being retarded.

Low light intensity could reduce the ability of plants to produce the energy needed for the growth process (Peter et al., 2022). Intense shading significantly reduced the availability of direct sunlight in plant growth and created an unfavorable environment for the growth and development of plants (Oliveira et al., 2024). In addition, Grand Rapids lettuce leaves grew faster than the other 2 varieties, showing that there were differences in the response of varieties to low light conditions. This could be optimized to increase lettuce production in low-light environments. In addition, this lettuce variety had a high physiological adaptability to use light more efficiently in limited conditions, such as

under 55% shade. The different responses between these varieties were very important to consider in efforts to optimize lettuce production under low-light environments.

Shade had a significant effect on plant height growth, due to changes in the intensity of light received. Siomak grew faster than the other 2 varieties. The influence of shade intensity had no negative effect on the height growth of Siomak. Siomak initiated stem growth faster than the other 2 varieties (Figure 4). This was one of the responses of plants in stressful conditions, particularly in the absence of light. Generally, plants in shade were more likely to etiolate, which was characterized by faster stem elongation to find light source. This condition caused plants to grow taller than those exposed to direct sunlight. Shading played an important role in plant growth because light intensity received by plants strongly influenced the photosynthetic process and cell expansion (Formisano et al., 2021). In this case, according to Zhou et al. (2022), low light intensity due to shading could reduce the photosynthetic rate of plants. Siomak appeared more responsive to shade conditions. This was indicated by the plants' ability to respond to low light conditions by accelerating plant height growth.

The faster growth of stems also showed the ability of this variety to adapt to low light conditions without affecting its growth. However, this trend was not consistently supported by statistically significant differences across all measured traits. These differences in response indicated that lettuce varieties had different potential adaptations to shade environments, which could be used in agricultural practice to select varieties that were more adaptable to specific light conditions.

Grand Rapids lettuce variety was the most adaptable to shade, with an intensity of 55% and 80%. This was reflected in the growth of plant canopy (Figure 5). Increasing shade intensity was inversely proportional to canopy growth. Dense shade inhibited the growth of lettuce canopy. Lettuce needed full sunlight, plants receiving high light intensity stimulated canopy growth of Grand Rapids, and its growth under LED lighting was not optimal. This was because the intensity of LED lights was lower than that of sunlight.

Grand Rapids showed a high ability to adapt to shade conditions at intensities of 55% and 80%, as reflected in canopy growth. This showed that this variety could adapt better to low-light conditions. However, increasing shade intensity had a direct negative effect on canopy growth, indicating that although lettuce could tolerate shade, lettuce still required sufficient sunlight to maximize canopy growth. Dense shading reduced the intensity of light received by plants, inhibiting photosynthesis and retarding plant growth (Jumrani et al., 2024).

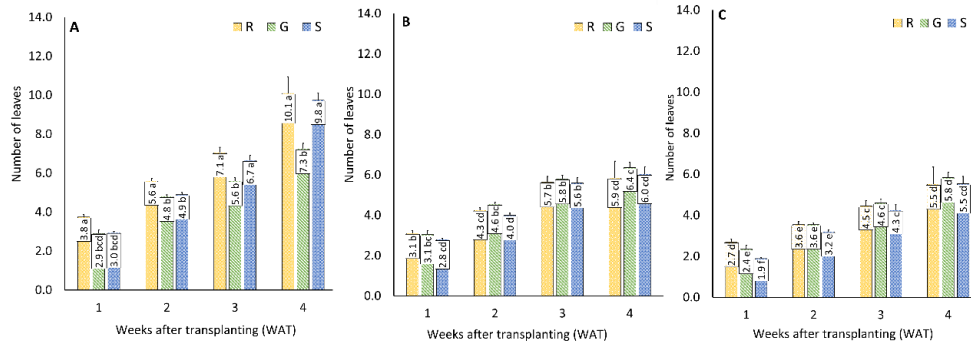


Figure 3. Number of leaves of three lettuce varieties as indicated by shade intensity treatments S55%+SL (A), S80%+SL (B), and S100%+LED (C). Data were presented as the average. The vertical bar showed a standard error. Different letters indicated statistically significant differences at $p < 0.05$ based on the LSD test.

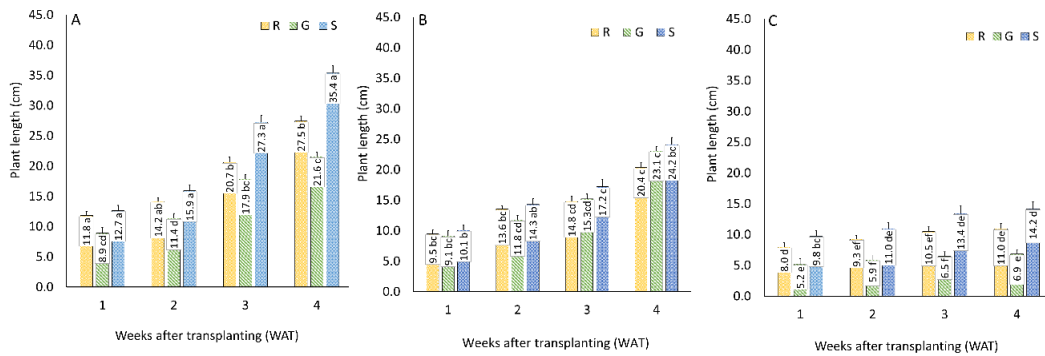


Figure 4. Plant length of Romaine (R), Grand Rapids (G), and Siomak (S) lettuce as indicated by shade intensity treatments S55%+SL (A), S80%+SL (B), and S100%+LED (C). Data were presented as the average. The vertical bar showed a standard error. Different letters indicated statistically significant differences at $p < 0.05$ based on LSD test.

In addition, the low yield obtained under LED lighting emphasized the need for greater light intensity. Although the use of LED lighting was controlled, it could not replace the intensity of sunlight needed to support maximum plant growth, such as stimulating canopy growth (Al Murad et al., 2021).

Growth in leaf length and width was influenced by environmental conditions, including light intensity. The density of shade affected the intensity of light received by lettuce. In addition, Grand Rapids tended to be more responsive to changes in shade, which was reflected in the growth of leaf width at all shade intensities (Figure 6).

Lettuce was a plant that depended on light for photosynthesis, showed varying responses to shade density, and indicated specific physiological adaptations in each variety. In this study, Grand Rapids variety was found to be more responsive to changes in shade intensity. This indicated that Grand Rapids had more adaptive physiological mechanisms to changes in light conditions. According to Bertolino et al. (2019), variation in this response could be due to differences in leaf morphological structure, such as the number and density of stomata, which affected photosynthetic efficiency under low light conditions.

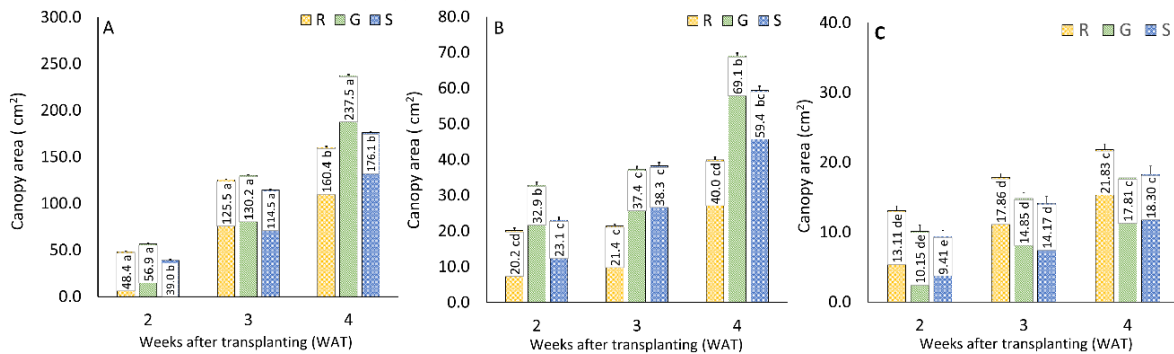


Figure 5. Canopy area of Romaine (R), Grand rapids (G), and Siomak (S) lettuce as indicated by shade intensity treatments S55%+SL (A), S80%+SL (B), and S100%+LED (C). Data were presented as the average. The vertical bar showed a standard error. Different letters indicated statistically significant differences at $p < 0.05$ based on LSD test.

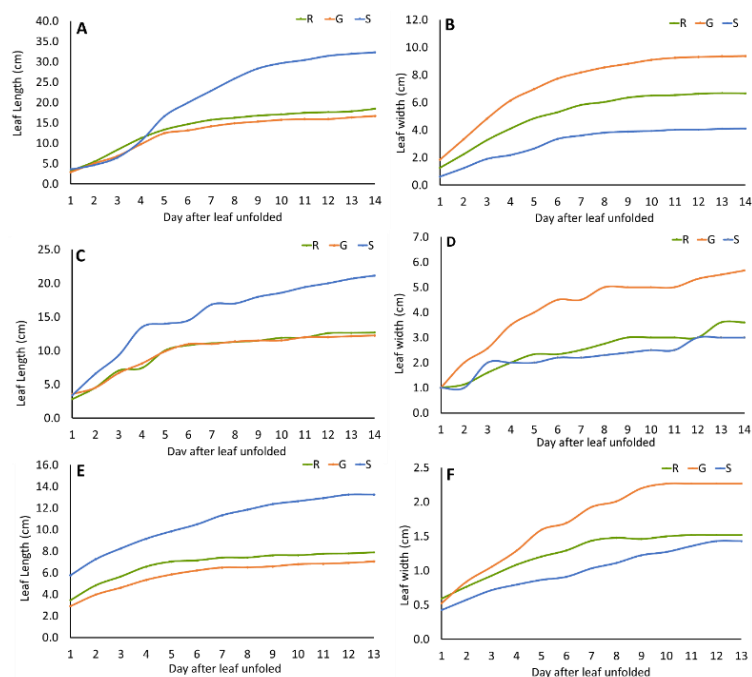


Figure 6. Shading effects on the expansion of daily leaf length and width of Romaine (R), Grand Rapids (G), and Siomak (S) lettuce. A-B (S55%+SL), C-D (S80%+SL) and E-F (S100%+LED).

Under low light intensities, plant leaves were slightly wider in response to the limited light that could be absorbed for photosynthesis (Palma et al., 2021). In this study, Grand Rapids showed adaptability by changing leaf morphology to maximize light absorption under low-light shade conditions.

According to the observation, shading influenced chlorophyll content by reducing light intensity available to plants. In general, plants exposed to direct sunlight had higher chlorophyll content than plants grown under shade in low light conditions. Plants grown under 55% shade combined with supplemental LED light (S55%+SL) exhibited higher chlorophyll content compared to other shade treatments. In addition, 3 lettuce varieties had different chlorophyll levels (Table 1). Leaf growth of the varieties under shade appeared to be different. Lettuce grown under shade tended to have larger and thinner leaves. The differences in shape and size were related to the ability of leaf surface to absorb light, which affected the increase in chlorophyll content (Rezai et al., 2018). Chlorophyll was required for photosynthesis, the process by which plant converts light into chemical energy.

Shade affected light intensity, and the response of plant growth under low light intensity initiated several physiological and morphological changes. These changes were mechanisms by which plants responded to low light. Romaine and Grand Rapids grown in artificial shade S55%+SL and S80%+SL showed a response of morphological changes. An elongation of stem length and a reduction in stem diameter were the

morphological responses of lettuce to low light stress (Table 2).

Under low light intensity conditions, plants tended to show morphological changes (Freschet et al., 2018). One of the morphological changes that often occurred was an elongation of the stem length and a reduction of stem diameter (Wang et al., 2016). An elongation of stem occurred because plants were seeking to find a light source by elongating stem, while a decrease in stem diameter indicated that plants were reducing energy for the growth of the stem diameter as it focused more on height growth to maximize light utilization (Mickens et al., 2019).

Romaine and Grand Rapids grown in artificial shade at intensities of S55%+SL and S80%+SL showed similar responses, elongation of stem, and decreasing stem diameter. This change was an adaptation mechanism to respond to low light stress, where plants tried to adapt to optimum growth by seeking out light sources even in low light conditions.

In addition to these morphological adjustments, the responses of several lettuce varieties under low light were influenced by physiological mechanisms. Differences in photosynthetic capacity among lettuce varieties determined how efficiently they capture and convert limited light into chemical energy (Chen et al., 2025). In addition, lettuce varieties often adjust chlorophyll composition, particularly by increasing chlorophyll b or total chlorophyll, to enhance light absorption efficiency under low light conditions (Fraszczak and Kula, 2021).

Table 1. Chlorophyll Content of Romaine (R), Grand Rapids (G), and Siomak (S) lettuce as indicated by shade intensity treatments.

Varieties	Chlorophyll a	Chlorophyll b	Total chlorophyll
S-55%			
R	14.59 b	6.36 a	20.94 a
G	8.89 f	1.31 g	10.19 f
S	11.08 d	5.40 b	16.46 c
S-80%			
R	14.78 a	3.44 d	18.21 b
G	6.59 g	1.65 f	8.24 g
S	11.26 c	3.01 e	14.26 e
S-100%			
R	10.61 e	4.51 c	15.11 d
G	5.40 i	1.19 i	6.59 i
S	6.47 h	1.20 h	7.67 h

Note: Means followed by different letters indicated statistically significant differences at $LSD < 0.05$. Data are presented as means \pm standard error.

Table 2. The effect of shading intensity on stem morphological characteristics of three varieties of lettuce.

Varieties	Fresh Weight (g)	Dry Weight (g)	Stem Length (g)	Stem Diameter (cm)
S-55%				
R	12.058 \pm 2.205 a	0.944 \pm 0.274 a	22.641 \pm 0.808 a	7.516 \pm 1.298 b
G	8.041 \pm 1.913 b	0.701 \pm 0.296 a	19.008 \pm 1.485 ab	6.631 \pm 0.953 b
S	6.148 \pm 0.706 c	0.307 \pm 0.022 b	7.700 \pm 0.675 cd	8.844 \pm 0.987 a
S-80%				
R	0.975 \pm 0.360 d	0.039 \pm 0.007 b	17.275 \pm 2.097 b	1.940 \pm 0.270 de
G	1.527 \pm 0.340 d	0.068 \pm 0.015 b	22.525 \pm 1.815 a	2.296 \pm 0.205 cd
S	0.457 \pm 0.112 d	0.021 \pm 0.005 b	4.775 \pm 0.252 d	2.960 \pm 0.377 c
S-100%				
R	0.151 \pm 0.391 d	0.013 \pm 0.003 b	7.475 \pm 1.433 cd	1.412 \pm 0.177 de
G	0.308 \pm 0.093 d	0.025 \pm 0.006 b	3.810 \pm 2.833 d	1.562 \pm 0.047 de
S	0.187 \pm 0.086 d	0.017 \pm 0.007 b	10.108 \pm 1.914 c	1.109 \pm 0.178 e

Note: Means followed by different letters indicated statistically significant differences at $LSD < 0.05$. Data are presented as means \pm standard error.

In this study, the influence of artificial shade effects on the growth of lettuce leaves could be shown by the weight of lettuce leaves. The use of denser shade hurt the growth of lettuce leaves, while artificial shade S80%+SL and S100%+LED with LED lights caused not optimal leaf growth, which was indicated by leaf weight. Each variety showed different responses under low light levels. Grand Rapids was more sensitive to the effects of low light intensity than the other 2 lettuce varieties (Table 3). Lettuce grown in dense shade using LED lights showed retarded leaf growth, reflected in lower leaf weight. Slow leaf growth indicates that plant cannot carry out photosynthesis optimally, because light required for this process was limited (Leister, 2023), suggesting that Grand Rapids had higher light requirements to support optimal leaf growth. These differences in response indicated that there were genetic factors influencing how each lettuce variety adapted to limited light conditions.

Lettuce required high light intensity to support plant growth. This was shown by the growth of lettuce roots. The intensity of dense shade affected the intensity of light. Low light intensity in shade caused inhibition of plant root growth. Roots of lettuce grew in S-55% shade, while root growth was inhibited in 80% shade (Figure 7).

Low light intensity had a negative effect on plant root growth, which affected plant growth and yield (Xu et al., 2021). Lettuce grew optimally, including roots, because even when light intensity was reduced, sufficient light was still available to support photosynthesis in shade 55%. However, at shade 80%, root growth was inhibited. Lettuce grew optimally with sufficient light, and under low light, the availability of energy for physiological processes that supported root growth (Ahmed et al., 2020). The effect of reducing light intensity showed the importance of light in supporting not only canopy growth, but also plant roots, which were important in the supply of air and nutrients to plants.

Light was an essential factor in the plant growth process. Plant growth was inhibited at low light intensities. Dense shade reduced light intensity and hurt plant growth, and lettuce tolerated shade S-55%. Romaine was more adaptable to light stress, as observed by plant roots' growth. In addition, Siomak tended to accelerate root growth at low light intensities (Table 4). Low intensity reduced the energy required by plants to effect important physiological processes such as cell division and plant organ development (Slattery et al., 2018).

Table 3. The effect of shading intensity on the fresh and dry weight of lettuce leaves.

Varieties	Fresh Weight (g)	S-55%	
			Dry Weight (g)
R	26.49 ± 7.41 ab		2.07 ± 0.62 a
G	20.84 ± 3.94 b		1.50 ± 0.37 b
S	30.83 ± 1.36 a		2.13 ± 0.09 a
		S-80%	
R	1.50 ± 0.40 c		0.10 ± 0.03 c
G	1.67 ± 0.59 c		0.12 ± 0.02 c
S	2.69 ± 0.90 c		0.17 ± 0.05 c
		S-100%	
R	0.73 ± 0.09 c		0.05 ± 0.03 c
G	0.90 ± 0.30 c		0.08 ± 0.04 c
S	0.74 ± 0.24 c		0.04 ± 0.01 c

Note: Means followed by different letters indicated statistically significant differences at $LSD < 0.05$. Data are presented as means ± standard error.



Figure 7. Root morphology of 3 varieties of lettuce, Romaine *Lactuca sativa* L. VAR. Longifolia (R), *Lactuca sativa* L. VAR. new Grand Rapids (G) and Siomak *Lactuca sativa* L. VAR. Augustuna (S) on different shade treatments.

However, some lettuce varieties showed the ability to adapt effectively to low light conditions. For instance, Romaine was more adaptable to low light, as shown by its relatively optimal root growth in low light shade. This adaptation was related to a physiological mechanism that allowed romaine lettuce to use low light more efficiently. The classical reaction of plant adaptation in response to changes in light conditions was characterized by a change in plant growth (Korsakova et al., 2019). In addition, Siomak tended to accelerate root growth under low light conditions. This accelerated root growth was an adaptive response to limited light conditions. Grand Rapids predominantly promoted shoot growth, and Romaine optimizes physiological processes. Overall, the ability of different lettuce varieties to adapt to low light conditions indicated the importance of genetic and physiological factors in determining plant response under low light conditions.

Although shading with 3 different intensities was applied, it did not significantly affect the internal temperature of the greenhouse. The observed plant responses were more likely related to differences in

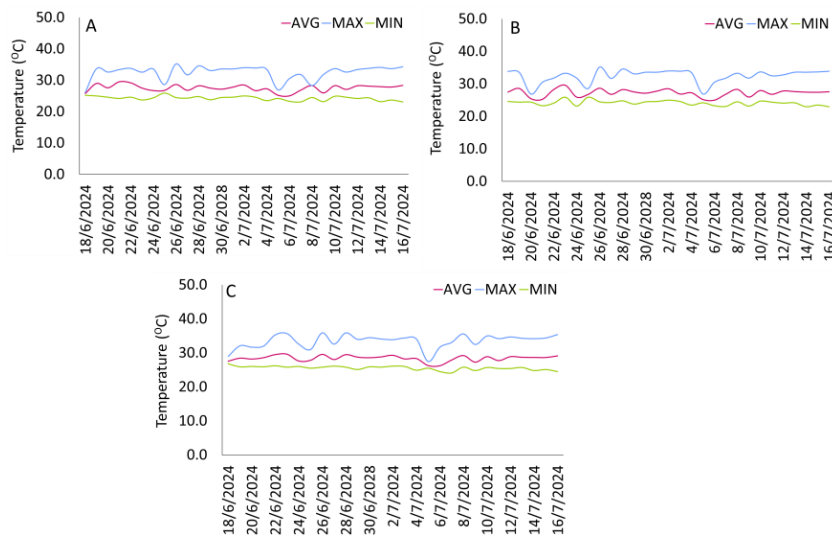
light intensity rather than temperature changes (Figure 8). However, shading could reduce temperature fluctuations around plant canopy, contributing to a more stable microclimate that supported plant growth. Under high-temperature conditions, shade could also protect plants from direct sunlight, which increased leaf temperature and potentially inhibited photosynthesis and plant metabolism (Mathur et al., 2018).

In general, shading had a significant impact on reducing temperature fluctuations around plants. Shading controlled more stable microclimate conditions, which were essential for plant growth. One of the primary functions of shade was to reduce the air temperature around plants, which reduced the risk of heat stress, specifically for plants that were sensitive to high temperatures. In the heat of the day, shade protected by reducing direct exposure to sunlight could cause leaf surface temperatures to increase dramatically. High leaf temperatures interfered with the photosynthetic process because temperatures that were too high damaged photosynthetic enzymes and reduced the efficiency of carbon dioxide uptake (Moore et al., 2021).

Table 4. The effect of shading intensity on the root characteristics of three varieties of lettuce.

Varieties	Fresh Weight (g)	Dry Weight (g)	Root Length (cm)
S-55%			
R	2.264 ± 0.039 a	0.235 ± 0.026 a	11.033 ± 1.30 a
G	1.345 ± 0.099 b	0.132 ± 0.010 b	10.691 ± 0.46 ab
S	1.502 ± 0.145 b	0.153 ± 0.010 b	10.883 ± 0.48 ab
S-80%			
R	0.176 ± 0.05 c	0.016 ± 0.005 c	6.625 ± 1.14 c
G	0.236 ± 0.13 c	0.034 ± 0.01 c	7.475 ± 1.46 c
S	0.268 ± 0.09 c	0.026 ± 0.01 c	8.625 ± 0.85 bc
S-100%			
R	0.048 ± 0.007 c	0.004 ± 0.001 c	3.266 ± 0.42 d
G	0.042 ± 0.010 c	0.003 ± 0.001 c	3.941 ± 0.60 d
S	0.041 ± 0.010 c	0.003 ± 0.001 c	10.108 ± 1.91 ab

Note: Means followed by different letters indicated statistically significant differences at $LSD < 0.05$. Data were presented as means ± standard error.

**Figure 8.** Temperature of three shade intensities S55%+SL (A), S80%+SL (B) and S100%+LED (C).

In addition, high temperatures accelerated air loss through transpiration, causing plants to lose water, which inhibited metabolism and growth (Yang et al., 2024). Although different levels of shading did not significantly affect temperature, shading maintained a more ideal plant temperature, thereby supporting plant physiological processes such as photosynthesis and metabolism. Under high-temperature conditions, shade also protected plants from direct sunlight, which increased leaf temperature and potentially inhibited photosynthesis and plant metabolism (Mathur et al., 2018).

The use of shade affected the humidity around plants, which was relatively more stable in S55%+SL and S80%+SL shades, where the maximum humidity was higher. Meanwhile, S100%+LED shade showed a stable maximum temperature and a more variable minimum temperature (Figure 9). Shade reduced exposure to direct sunlight, decreases temperature, and lowered the rate of evaporation or transpiration (Yu et al., 2024). Therefore, the air transpired by plants was trapped more in the shade, increasing humidity. The use of shade had a

significant effect on the humidity around plants, which in turn affected microclimate conditions and plant growth (Salagovic et al., 2024). Shading with an intensity of S55%+SL and S80%+SL tended to keep it more stable, where the maximum humidity was high, although the minimum humidity fluctuated. This indicated that this shade was effective at maintaining humidity, although fluctuations occurred. However, the S100%+LED shade had a more stable maximum temperature but a more variable minimum temperature. This could be related to the characteristics of LED light, which was not as intense as sunlight, affecting evaporation and temperature fluctuations under the shade.

Shading essentially controlled exposure to direct sunlight, which lowered the temperature around plants and reduced the rate of air evaporation from plant surface. In addition, it had direct and indirect effects on plant growth and development since shading altered the microclimate conditions under shading (Fadilah et al., 2022). Lower temperatures could reduce plant heat stress while maintaining higher humidity (Fahad et al., 2017).

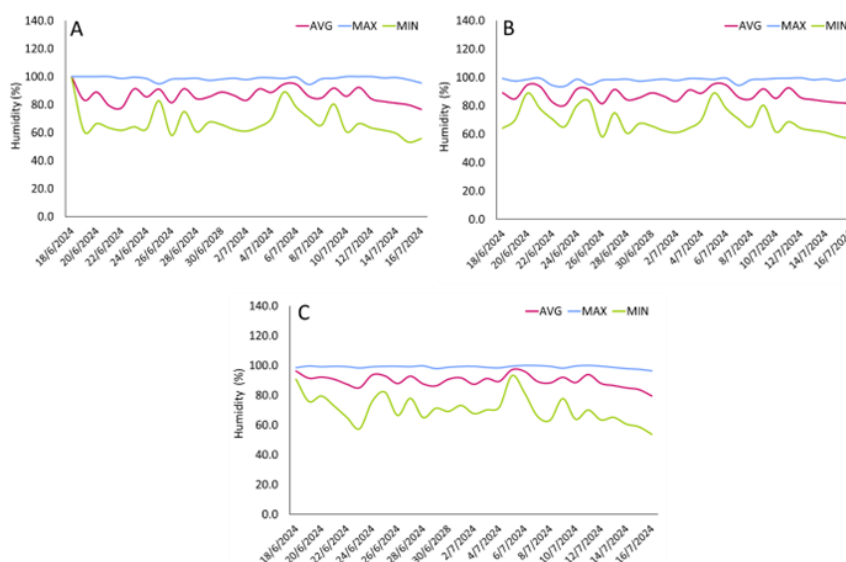


Figure 9. Humidity of 3 shade intensities S55%+SL (A), S80%+SL (B) and S100%+LED (C).

The higher humidity increased plant physiological processes, such as the absorption of water and minerals from soil, as well as maintaining water balance in plant (Navyashree, 2023). Therefore, the use of shade affected not only temperature but also humidity, which was essential for maintaining optimum plant growth.

The use of shade had a significant effect on light

intensity received by plants, as shown in S100%+LED shade. Under S55%+SL and S80%+SL shades, the highest light intensity occurred significantly at midday, while the morning showed a lower intensity. In addition, light intensity in the afternoon was very low and stable. Light conditions in S-100% shade showed conditions where light intensity was very low in the day (Figure 10).

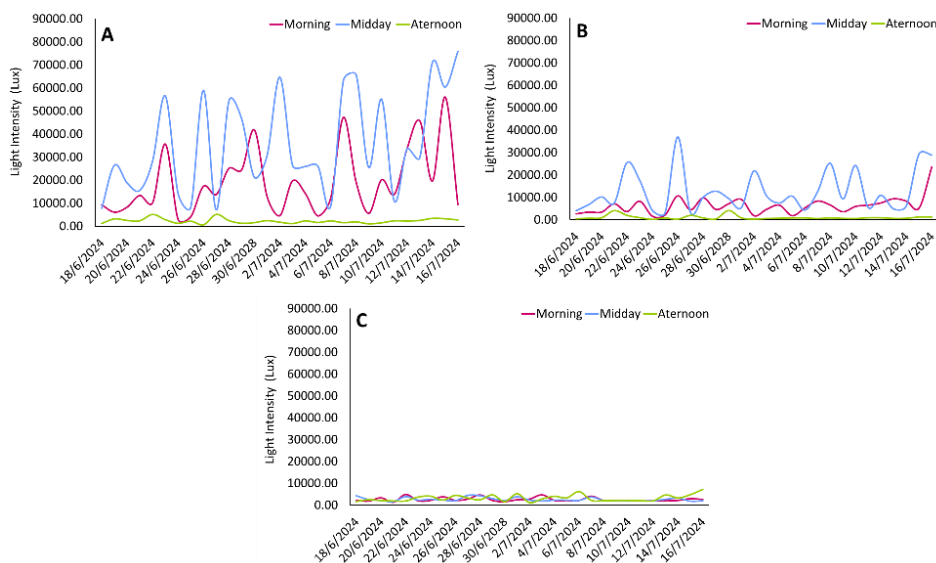


Figure 10. Light Intensity of three shade intensities S55%+SL (A), S80%+SL (B) and S100%+LED (C).

This was due to the use of artificial LED lights at too low an intensity. Meanwhile, this condition was beneficial to avoid excessive light or heat stress, but when light intensity was too low, it could inhibit the photosynthetic process of plants (Ghorbanzadeh et al 2021). Therefore, optimum light intensity under shade was essential in plant production to maintain optimum growth.

4. Conclusions

In conclusion, the adoption of shading led to a decrease in the growth and yield of 3 varieties of lettuce through an alteration in the morphological traits of stems, leaves, and roots. The growth and yield of 3 varieties of lettuce under 3 shading intensities are not yet optimal. In this study, shading intensity of S80%+SL and S100%+SL with LED lighting inhibits the growth of lettuce due to the low light intensity.

Romaine, Siomak, and Grand Rapids require optimum light intensity to stimulate growth. Shading reduces not only the quantity but also the quality of the yield. The use of shade controls microclimate conditions in the lettuce growing area. Lettuce can live at low temperatures, but still needs full sunlight to fulfill the metabolic process.

Authors' Contribution

All authors contributed to this manuscript. Fitri Ramadhani: research execution, data collection, data analysis, drawing graph, and writing original manuscript. Benyamin Lakitan: corresponding author, idea conception, methodology, data interpretation, manuscript revision, and supervision. Rujito Agus Suwignyo, Susilawati Susilawati: experimental design, methodology, data analysis, manuscript revision, and supervision. Muhammad Umar Harun, Yakup Yakup: data interpretation, methodology, and manuscript revision.

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