ABE

Agricultural and Biological Engineering

https://ph04.tci-thaijo.org/index.php/abe/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Effects of photoperiod on the growth and morphology of butterhead lettuce in a vertical hydroponic system

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doi: 10.14456/abe.2026.4

Received 20 November 2025
Revised 9 January 2026
Accepted 19 January 2026

Abstract

This study aimed to investigate the effects of light duration on the growth of butterhead lettuce (Lactuca sativa var. capitata) cultivated in a three-tier vertical hydroponic system. A total of 131 plants were grown: 47 in the first tier and 42 each in the second and third tiers, over a 74-day cultivation period including the seedling stage. The first and second tiers received 12 h of artificial light daily, while the third tier initially received 10 h, later increased to 12–14 h to correct leaf elongation. Environmental factors such as light intensity (105–126 lux), nutrient temperature (22–25 °C), relative humidity (64–81%), pH (6.8–7.5), and EC (1.0–1.15 mS/cm) were continuously monitored. Results showed that longer light exposure enhanced plant growth in terms of leaf number, leaf size, plant height, and overall biomass.

Keywords: Hydroponic system, Butterhead lettuce, Plant growth, Light duration, Vertical farming

1. Introduction

Light is one of the most important environmental factors influencing plant growth and development, as it serves as the primary energy source for photosynthesis. This process directly affects carbohydrate production, biomass accumulation, leaf expansion, and overall plant morphology [1-2]. In addition to light intensity and light quality, light duration or photoperiod is a crucial factor regulating photosynthetic rate, internal resource allocation, and uniformity of plant physical development, particularly in leafy vegetables with short growth cycles [3].

Several studies have reported that increasing light duration can enhance photosynthetic efficiency, resulting in a higher number of leaves, larger leaf area, and greater biomass accumulation. However, inappropriate or excessive light duration may induce light stress, leading to stem elongation, leaf deformation, or inefficient energy utilization [1-2]. found that lettuce exposed to longer light durations exhibited higher growth rates and fresh weight compared to plants receiving shorter light periods. Similarly, [2] reported that restricted light duration could cause uneven leaf development and reduce overall growth potential.

In controlled-environment agricultural systems, such as vertical hydroponic cultivation, light management becomes even more critical because plants rely primarily on artificial lighting. Proper control of light duration is therefore an important strategy to improve energy-use efficiency while promoting plant growth and product quality [3]. Vertical growing systems also provide opportunities to investigate plant responses to light duration at different cultivation levels, where variations in light exposure may result in differential growth responses.

Previous research suggests that increasing light duration within an appropriate range tends to enhance lettuce growth. However, the optimal light duration in vertical cultivation systems remains dependent on specific system configurations and environmental conditions. Therefore, this study aims to investigate the effects of different light durations (10 and 12 h/d) on the growth of butterhead lettuce in a vertical NFT hydroponic system, focusing on growth parameters such as leaf number, leaf size, plant height, and morphological development.

Butterhead lettuce (*Lactuca sativa var. capitata*) is a fast-growing leafy vegetable that exhibits high sensitivity to both light intensity and photoperiod, making it an ideal model crop for studying the effects of light duration [1-3]. Its short growth cycle, adaptability to nutrient-controlled environments, and high market demand for fresh consumption and culinary use make it suitable for vertical hydroponic cultivation [4-5]. By investigating butterhead lettuce, researchers can gain insights into the physiological responses of leafy vegetables to light, including leaf expansion, chlorophyll synthesis, and overall biomass accumulation [1-2].

In this study, butterhead lettuce was grown in a three-tier NFT vertical hydroponic system, focusing on tiers 2 and 3, with 42 plants per tier. Tier 2 received 12 h of artificial light per day, while tier 3 received 10 h/d under strictly controlled environmental conditions, including light intensity of 105–126 lux, nutrient solution temperature of 22–25 °C, relative humidity of 64–81%, pH of 6.8–7.5, and electrical conductivity (EC) of 1.0–1.15 mS/cm [1-3]. This setup allowed for a systematic evaluation of how variations in light duration affect growth rate, leaf size, plant height, and overall biomass (Figure 1).

Therefore, this study based on existing research, increasing light duration within an appropriate range has been shown to promote the growth of lettuce. However, the optimal light duration in vertical cultivation systems still depends on system management and the specific environmental conditions of each experiment. Therefore, this study aims to investigate the effects of different light durations (10 and 12 h/d) on the growth of butterhead lettuce in a vertical NFT hydroponic system, with a focus on growth parameters such as leaf number, leaf size, plant height, and overall morphological development.

A **B**

Figure 1 (A) The perfect stage of butterhead lettuce, (B) growing stage of butterhead lettuce

2. Materials and methods

2.1 Location & Duration

The experiment was conducted in the plant growth room at the Faculty of Engineering, Khon Kaen university, Thailand. The plant growth is rectangular and dimensions of 4.6 m (181.10 in) x 6.75 m (265.75 in). system maintained the temperature between 22 ± 2 °C throughout the experiment.

2.2 Structure of the System and Data analysis

The vertical cultivation rack consists of three layers, constructed with aluminum alloy material to form the overall framework, with specific dimensions of 1.05 m width * 1.35 m length 2.20 m * height (Figure 2-3). Each floor is separated from each other evenly at 0.48 m (Figure 2-3). Each layer is equipped with 3 LED tubes (T8) Each layer is fitted with Water channels made of UPVC plastic, shaped as long bars with a length of 100 cm and a height of 10 cm. The inlet holes (on the left) had a diameter of 2.5cm, and the outlet holes (on the right) were open with an area of 38 cm². Each channel had 6 planting holes on the top, each with a diameter of 4.5 cm, spaced evenly at 11.4 cm apart. accommodating a total of 131 butterhead plants. The water pump draws the nutrient solution to the fourth layer, and then the solution flows to the other layers through gravity. When the water level in the tanks drops below the position of the pump motors, nutrient solution is replenished. The temperature throughout the entire laboratory is maintained through constant temperature control via air conditioning.

Figure 2 Structure of the framework used for cultivating butterhead

Figure 3 Structure of the framework used for cultivating butterhead, including sensors, lighting, water circulation

The experiment was conducted using a completely randomized design (CRD) with two treatments based on light duration: 12 h/d and 10 h/d. Each treatment consisted of 42 butterhead lettuce plants cultivated in a vertical NFT hydroponic system. Data were collected every five days by randomly sampling 22 plants per sampling event to assess growth performance. Throughout the experimental period, environmental factors were maintained under controlled conditions, and key parameters were monitored and recorded, including relative humidity, nutrient solution temperature, pH, electrical conductivity (EC), and light intensity. Differences between treatments were analyzed using an independent samples t-test, with the level of statistical significance set at $p < 0.05$. In addition, a limitation of this experiment was observed during the seed germination stage, as the germination period lasted approximately 20 days, which was longer than the optimal duration of 10–14 days, resulting in incomplete growth of some plants.

2.3 Plant materials

Seed germination was carried out using sponges placed in seedling trays. The trays were covered with opaque boxes to maintain moisture for 2 days. Once germination began, the seedlings were transferred into sponges, which were then placed in seedling trays filled with water to a depth of approximately 5 cm and left for 14 days. After 14 days, the seedlings were transplanted into the cultivation channels. Three days after transplantation, equal amounts of AB nutrient solution were applied, and the plants were allowed to grow until maturity. The harvest was performed at approximately 45–70 days after transplantation. During the cultivation period, the laboratory temperature was maintained at 22 ± 2 °C, with an electrical conductivity (EC) of 1.0–1.15 mS/cm. The nutrient solution pH was maintained at 6.8–7.5. Relative humidity was maintained at 64–81%, monitored using DHT22 sensors. Each layer of supplemental lighting consisted of three T8 LED lamps Light intensity was maintained at 105–126 lux, measured using LDR sensors., spaced 20 cm apart. Each lamp contained red (600–700 nm) and blue (400–500 nm) LED chips. The photoperiod varied by layer: Layer 2 was illuminated for 12 h (06:00–18:00), and Layer 3 for 10 h (06:00–16:00).

2.4 Sensors system

This system uses a total of three sensors, as shown in Figure 4, and one display screen. The DHT22 sensor was used to measure the temperature and humidity inside the growing chamber relative humidity was maintained at 64–81%, with three sensors installed across three levels. The LDR light sensor module was used to measure light intensity, also with three sensors installed on three levels. The DS18B20 water temperature sensor was used to measure the temperature of the water.

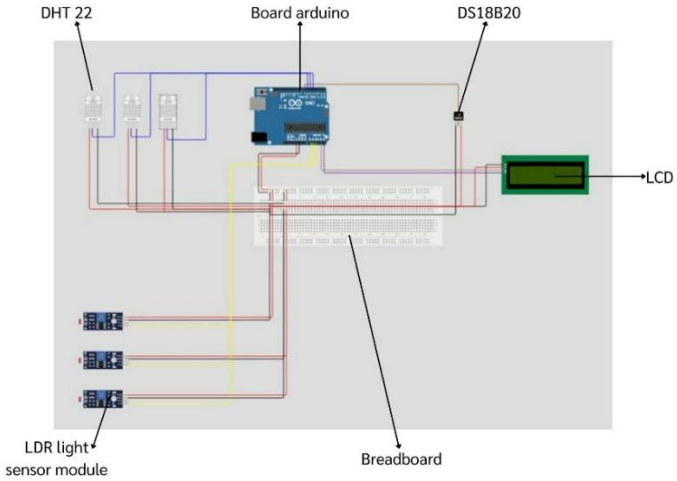

Figure 4 Sensors system of butterhead lettuce in vertical hydroponic system

3. Results and discussion

The independent variables in the experiment were the differences in light duration and the timing of transplanting. The dependent variable was the growth of butterhead lettuce, while the controlled variables included light duration (10 vs 12 h/d), nutrient solution temperature (22–25 °C), air temperature (22 ± 2 °C), relative humidity (64-81%), pH (6.8-7.5), and electrical conductivity (EC) (1.0-1.15 mS/cm).

This study investigated the effects of different light durations on the growth of butterhead lettuce (Lactuca sativa var. capitata) cultivated in a vertical NFT hydroponic system. Growth performance was compared between Tier 2 (12 h light per day) and Tier 3 (10 h light per day) under strictly controlled environmental conditions (Figure 2-3). The cultivation process and environmental monitoring system are shown in Figure 1 and 4, ensuring uniform growing conditions.

Growth data (Table 1) revealed that lettuce grown under a 12-h photoperiod consistently exhibited superior growth, including higher leaf number, larger leaf size, and greater plant height, compared to plants receiving 10 h of light. This trend was further confirmed by graphical analysis, which showed a higher overall growth rate under the longer photoperiod (Figure 5).

Table 1 Butterhead Lettuce Growth Data

Number	Date/month/year	Floor	Number of leaves	Leaf color	Leaf length (cm)	Leaf width (cm)	Plant Height (cm)
1	25/9/2568	2	7	Green	4.3	2.3	6.2
		3	7	Green	4.2	2.2	7.3
2	30/09/2568	2	11	Green	6.7	3.2	8.1
		3	12	Green	5	3.1	8.6
3	05/10/2568	2	13	Green	7.2	3.9	9.4
		3	12.33	Green	7	3.5	9.17
4	10/10/2568	2	14.67	Green	11.3	5.07	14.8
		3	15.33	Green	10.9	5.23	14.2
5	15/10/2568	2	21.43	Green	12.83	7.53	14.53
		3	18.29	Green	12.19	6.34	15.1

Statistical analysis indicated (Table 2) that no statistically significant differences were observed in the growth parameters of butterhead lettuce between the 10-h and 12-h light treatments ($p > 0.05$). This finding suggests that, under well-controlled environmental conditions, both light durations were capable of supporting butterhead lettuce growth at comparable levels.

Mean values of growth parameters were calculated for each cultivation tier to evaluate the effects of light duration and transplanting time. Descriptive statistics (mean ± standard deviation) were applied, and differences among treatments were assessed using an independent samples t-test at a significance level of $p < 0.05$. The results were. Summarized in tables and illustrated using bar graphs to demonstrate growth trends among the cultivation tier

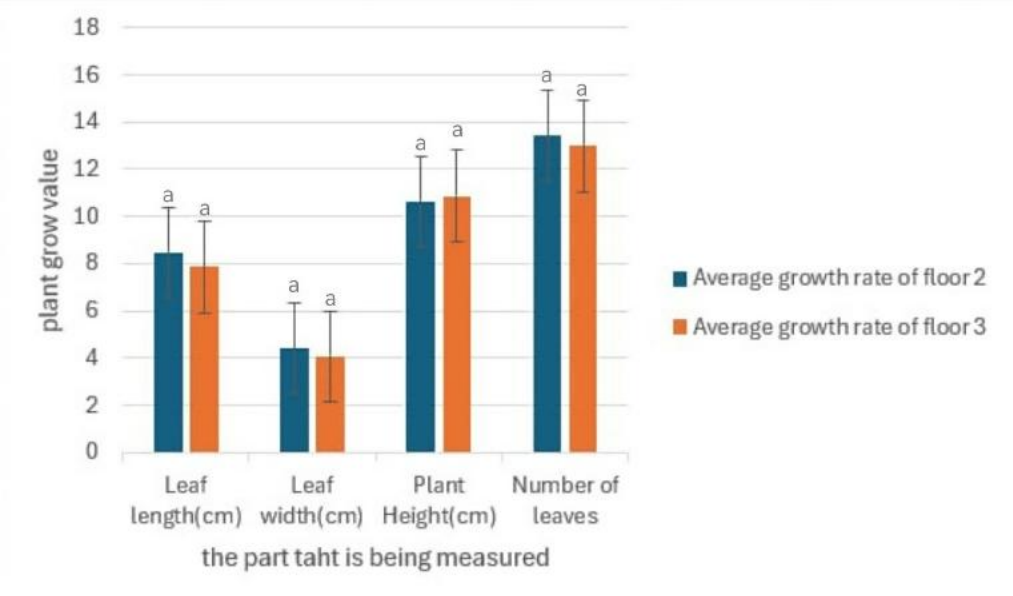

Figure 5 Average growth rate of butterhead lettuce under different light durations
Error bars represent standard deviation. Asterisks indicate significant differences at $p < 0.05$

Butterhead lettuce growth was influenced by different light durations, as shown in the tables and graphs illustrating growth performance at each cultivation tier. Light duration affected leaf number, leaf size, and plant height; however, the overall differences between the two cultivation tiers were relatively small.

Table 2 Summary of statistical significance (P-values) for growth parameters of butterhead lettuce

Parameter	Floor 2 (10 h)	Floor 3 (12 h)	t-value	P-value	Significance
Leaf length (cm)	8.466 ± 3.505	7.858 ± 3.546	0.273	0.792	ns
Leaf width (cm)	4.400 ± 2.022	4.074 ± 1.678	0.277	0.789	ns
Plant Height (cm)	10.606 ± 3.877	10.874 ± 3.527	-0.114	0.912	ns
Number of leaves	13.420 ± 5.314	12.990 ± 4.209	0.142	0.891	ns

Plants receiving 12 h of light per day (Tier 2) showed slightly higher average values for leaf width, leaf length, and overall plant size compared with plants receiving 10 h of light per day (Tier 3). Nevertheless, statistical analysis revealed that these differences were not statistically significant ($p > 0.05$), indicating that both light durations supported comparable growth of butterhead lettuce under the controlled environmental conditions.

Morphological observations showed that Tier 2 plants tended to have marginally more leaves and slightly larger leaves, with average leaf lengths ranging from 9–12 cm, compared with 8–11 cm in Tier 3. Average plant height was similar between the two tiers, with only minor differences observed. These results suggest that increasing light duration from 10 to 12 h/d may improve growth trends slightly, but the effect was not strong enough to produce statistically significant differences.

The experiment was conducted using a completely randomized design (CRD). Data was analyzed using independent samples t-test to compare growth performance between the two light duration treatments (10 h vs. 12 h). This statistical approach was chosen because the study aimed to compare the mean values of two independent groups. Prior to the analysis, the assumptions of normality and homogeneity of variance were verified using the Levene's test, respectively. Both assumptions were satisfied ($p > 0.05$$), justifying the use of a parametric test. All results are presented as mean $\pm$ standard deviation (SD) in both tables and figures to reflect data variability.

Overall, the findings indicate that light duration influenced growth trends; however, under well-controlled conditions, both 10-h and 12-h photoperiods resulted in comparable growth performance of butterhead lettuce in the vertical hydroponic system.

4. Conclusions

The results of this study indicate that light durations of 10 and 12 h/d did not produce statistically significant differences in the growth of butterhead lettuce grown in a vertical hydroponic system. Although plants receiving 12 h of light showed slightly higher growth trends in some parameters, such as leaf number and leaf size, overall growth performance was similar between the two treatments. These findings suggest that, under controlled environmental conditions, both light durations are sufficient to support healthy and uniform growth of butterhead lettuce.

5. Acknowledgements

The authors gratefully acknowledge the Faculty of Engineering, Khon Kaen University, and the Department of Agricultural Engineering for providing essential facilities and equipment. Deep appreciation is also extended to Assoc. Prof. Somboon Sukphanchroen for his invaluable guidance and continuous support. The authors further wish to thank all research group members and colleagues for their kind assistance in maintaining and monitoring the hydroponic system throughout the experiment.

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