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# Effects of the different LED light colors on the growth and yield of cos lettuce (*Lactuca sativa* L. *var. longifolia*)

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**Abstract** The effect of nighttime supplemental lighting using different colored light-emitting diodes (LEDs) on the growth and yield of cos lettuce (*Lactuca sativa* L. var. *longifolia*) was investigated. Red LED light significantly enhanced plant height (20.54 cm) compared to other colors and a control group without supplemental light (17.84-19.74 cm). While red light also produced the highest average leaf count (17.25 leaves)It was not statistically different from other light treatments, though it surpassed the control (13.25 leaves). Notably, red LED light was significantly increased in fresh weight yield (83.0 g) and all other treatments which averaged from 49.45 to 73.75 g). These findings demonstrated that the red LED light's superior efficacy to promote the growth and yield of cos lettuce. Practical application of this technology in a field trial through the Future Farmers of Thailand Organization in Phetchaburi province resulted to increase yield of 20%, which accompanied by high participant satisfaction with the potential of cos lettuce production for future careers.

**Keywords:** Cos lettuce, LED light, Growth performance

## Introduction

The cultivation of salad vegetables, particularly those grown for household consumption and supplementary income, has seen a surge in popularity in recent years (Liu *et al*., 2023; Tripodi *et al*., 2021). This trend is largely attributed to the adaptability of salad vegetables to small-scale cultivation, making them well-suited for limited spaces such as balconies, rooftops, and even indoor environments (Alrajhi *et al*., 2023; Panyakom *et al*., 2020; Sardsud, 2007). However, the success of such cultivation efforts is often hindered by inadequate sunlight, a challenge especially prevalent in urban settings and during periods of unfavourable weather conditions (Plieninger *et al*., 2022; Suwanmaneepong *et al*., 2023). Insufficient sunlight, a common constraint in condominiums, apartments, and other enclosed spaces, can severely impede the growth and quality of salad vegetables (He *et al*., 2020; Sena *et al*., 2024). Plants grown in

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such environments often exhibit etiolation, characterized by elongated stems, pale coloration, and weak overall growth (Tripodi *et al*., 2021). Moreover, when natural light availability is reduced during the rainy or cold seasons, salad vegetable crops may experience stunted growth, reduced yield, and susceptibility to diseases (Sinkovič *et al*., 2023).

Innovative lighting technologies such as Light-emitting diodes (LEDs) have emerged as promising solutions to overcome the limitations imposed by inadequate sunlight. LEDs offer several advantages over traditional lighting sources, including higher energy efficiency, longer lifespan, and the ability to emit specific wavelengths of light that can be tailored to the specific needs of plants (Sena *et al*., 2024). The strategic use of LED lighting during nighttime hours can effectively supplement natural sunlight and create a more conducive environment for plant growth. The efficacy of LED lighting in promoting plant growth depends on several factors, including light wavelength (color) and intensity. Different wavelengths of light trigger specific physiological responses in plants, influencing photosynthesis, photomorphogenesis, and other critical processes (Lee *et al*., 2020). Red and blue light is particularly crucial for photosynthesis, while other colors like green and yellow may also play roles in plant growth and development. However, the optimal combination of light colors and intensities for maximizing the yield and quality of specific salad vegetables remains an area of active research.

Therefore, the study investigated the effects of different colored LED lights on the growth and yield of cos lettuce (*Lactuca sativa* L. var. *longifolia*), a popular salad green. By evaluating the impact of red, blue, green, yellow, and turquoise light on cos lettuce under controlled conditions, this research aimed to identify the most effective lighting strategies for optimizing crop performance.

## Materials and methods

### *Plant materials and growth conditions*

The study was conducted at Sioless Farmwork, Plant Science Division, Petchaburi College of Agriculture and Technology, Sam Phaya Sub-district, Cha-am District, Petchaburi Province. The experiment lasted for 123 days, from November 1, 2020, to January 21, 2021. This study investigated the growth response of Cos lettuce (*Lactuca sativa* L. *var. longifolia*) to various monochromatic LED light treatments during nighttime hours. Four independent light treatments were established, each using LED lamps with an average light intensity of 150 $\mu mol/m^{-2}/s^{-1}$ and emitting the following wavelengths: red (peak ~660 nm), blue (peak ~450 nm), yellow (peak ~590 nm), and green (peak ~530 nm) (Matysiak, 2021).

After germination, two hundred Cos lettuce seeds were sown in seedling trays and transplanted into 100 individual 6-inch black plastic pots. Each pot contained a uniform growth substrate composed of 50 kg soil, 10 kg fresh chaff, 10 kg raw rice husk, 10 kg black chaff, 10 kg cow manure, 10 kg broiler manure, 10 kg coconut flakes, and 10 kg chopped coconut. Pots were randomly assigned to one of the four light treatments or a control group (no supplemental light) within six identical vegetable greenhouses. Each treatment group consisted of 20 replicate pots. Growth parameters, including plant height (cm), number of leaves, and fresh weight (g), were measured at regular intervals throughout the study period. Height was measured from the base of the plant to the tip of the tallest leaf using a ruler, while direct count recorded the number of leaves. Fresh weight was determined immediately after harvest using a digital weighing scale.

***Experimental method and statistical analysis***

**Plant and experimental preparations**

The experiment was conducted in a hydroponics vegetable greenhouse divided into five sections to prevent light contamination between treatments. Each section was inspected before the experiment to ensure the proper functioning of the root and electrical systems. Monochromatic LED lamps (yellow, blue, red, and green) were installed in four greenhouse sections (one color per section). The control section remained without supplemental lighting. The LED lights were operated on a 12-hour light/dark cycle, turning on at 6:00 PM and turning off at 6:00 AM daily throughout the 30-day experimental period. A standardized potting mix was prepared for all experimental units. The mix consisted of soil, broiler manure, cow manure, and coconut flakes combined in a 1:1:1:1 ratio by volume. This mixture was thoroughly homogenized to fill 100 individual 6-inch black plastic pots.

Cos lettuce seeds were sown individually into seedling trays filled with the prepared potting mix. Each seed was moistened with a Trichoderma solution to mitigate the risk of root rot. Seedlings were nurtured in the trays for two weeks under ambient nursery conditions until they reached a suitable size for transplanting. Seedlings of uniform size were carefully transplanted into individual 6-inch pots, one seedling per pot. The pots were then transferred to a convalescent greenhouse for a two-week hardening-off period. During this time, plants were watered daily using a watering can and received a weekly application of hydroponic vegetable fertilizer. After the hardening-off period, the pots were randomly assigned to one of the five treatment greenhouses (including the control). Each greenhouse received 20 pots, ensuring a balanced distribution of plants across treatments. Throughout the 30-day experimental period within the greenhouses, plants were maintained under consistent watering practices specific to each greenhouse environment.

**Data collection**

Data collection started two weeks after the cos lettuce seedlings were transplanted into individual pots. For each of the four replications within a treatment group, five plants were randomly selected for weekly measurements of leaf count and plant height. Plant height was measured from the base of the stem to the tip of the tallest leaf using a ruler, while leaf count was determined by direct visual assessment. Eight weeks after transplanting, all cos lettuce plants were harvested. Upon harvest, the fresh weight of each plant was immediately recorded using a digital scale. A final measurement of plant height and leaf count was conducted as previously described.

**Complete Randomized Design (CRD)**

The experiment was performed using a completely randomized design (CRD) with five treatments, including a control group (no supplemental light) and four monochromatic LED light treatments (red, blue, yellow, and green). Each treatment was replicated four times, totaling 20 experimental units (pots) distributed across five vegetable greenhouses.

Cos lettuce seeds were initially sown in seedling trays and, upon germination, were transplanted individually into 6-inch black plastic pots containing the standardized growth substrate. After a two-week hardening-off period in the nursery, pots were randomly assigned to the five greenhouses, with each greenhouse housing four replicates per treatment. The LED lights were installed in their respective greenhouses and operated during nighttime hours, providing supplemental light for 30 days. Plant height and leaf count were recorded at regular intervals throughout this period. After the light treatments, all plants were harvested, and their fresh weights were measured.

The data collected at the final measurement point (week 8), specifically plant height, leaf count, and fresh weight, were subjected to statistical analysis. A one-way analysis of variance (ANOVA) was conducted to determine if significant differences existed among the treatment groups for each growth parameter. When the ANOVA indicated a significant effect ($p < 0.05$), post-hoc tests and Duncan’s Multiple Range Test (DMRT) were performed to identify specific treatment pairs with statistically significant differences.

## Results

In the second week of the experiment, there were not significantly differed in the height of cos lettuce among the different light treatments (Table 1). The average height ranged from 5.60 cm for the control group (no light) to 5.65 cm for the blue light treatment. The coefficient of variation (CV%) of 2.24% indicates relatively low variability within treatments. Similarly, there were not significantly different in the number of leaves among the different light treatments in the second week (Table 2). The average number of leaves ranged from 4.30 for the control and blue light treatments to 4.40 for the red-light treatment.

**Table 1.** Height of cos salad lettuce (cm) in the second week

| Treatments | Replications | | | | |
|---|---|---|---|---|---|
| | R1 | R2 | R3 | R4 | Mean |
| T1: no light | 5.56 | 5.64 | 5.44 | 5.75 | 5.62 [ab] |
| T2: red light | 5.72 | 5.48 | 5.50 | 5.76 | 5.65 [b] |
| T3: blue light | 5.76 | 5.62 | 5.60 | 5.62 | 5.63 [ab] |
| T4: red light | 5.54 | 5.76 | 5.70 | 5.52 | 5.61 [a] |
| T5: green light | 5.64 | 5.86 | 5.54 | 5.38 | 5.62 [ab] |
| CV% | | | | | 2.24 |

*1 Statistical difference with a reliability level of 95% ($p<0.05$)
*2 No statistical difference with a reliability level of 95% ($p>0.05$)
*3 Vertically different letter had statistical differences with the reliability level at 95% ($p<0.05$). (Vertically different mean values were compared between treatment using Duncan's New Multiple Ranges Test).

**Table 2.** Count of leaves of cos salad lettuce in the second week

| Treatments | Replications | | | | |
|---|---|---|---|---|---|
| | R1 | R2 | R3 | R4 | Mean |
| T1: no light | 4.6 | 4.2 | 4.4 | 4.0 | 4.30 [a] |
| T2: red light | 4.2 | 4.4 | 4.6 | 4.2 | 4.35 [ab] |
| T3: blue light | 4.2 | 4.6 | 4.0 | 4.4 | 4.30 [a] |
| T4: red light | 4.2 | 4.2 | 4.6 | 4.6 | 4.40 [b] |
| T5: green light | 4.6 | 4.4 | 4.4 | 4.0 | 4.35 [ab] |
| CV% | | | | | 4.76 |

*1 Statistical difference with a reliability level of 95% ($p<0.05$)
*2 No statistical difference with a reliability level of 95% ($p>0.05$)
*3 Vertically different letter had statistical differences with the reliability level at 95% ($p<0.05$). (Vertically different mean values were compared between treatment using Duncan's New Multiple Ranges Test).

The growth progression of cos lettuce under different LED light treatments from the fifth to the eighth week of the experiment was shown in Table 1. The height of cos lettuce plants over time is shown in Table 3. A clear and consistent trend emerged, with the red-light treatment (T4) found to promote the most substantial increased in height throughout the four-week period. By the eighth week, cos lettuce grown under red light reached an average height of 20.54 cm, which was significantly higher than the control group (T1, no light), which averaged 17.84 cm. While other light treatments (yellow, blue, and green) resulted in taller plants than the control.

The number of leaves the cos lettuce plants is shown in Table 4. Similar to plant height that the red light (T4) consistently induced to be the highest average leaf count in each week, reaching 17.25 leaves in the eighth week. It was found to be higher than the control (T1, no light), which averaged 13.25 leaves. The blue (T3) and green (T5) light treatments were positively affected the leaf production as compared to the control, but their values were not as high as those observed under red light. Interestingly, the yellow light treatment (T2) was not significantly differed on leaf count as compared to the blue and green light treatments.

**Table 3.** Height of cos salad lettuce (cm) during the fifth to eight weeks

| Treatments | Height of cos salad lettuce | | | |
|---|---|---|---|---|
| | 5th week | 6th week | 7th week | 8th week |
| T1: no light | 11.28 | 13.48 | 15.82 | 17.84 [a] |
| T2: yellow light | 13.64 | 14.64 | 16.61 | 19.31 [ab] |
| T3: blue light | 13.81 | 14.28 | 16.19 | 19.74 [ab] |
| T4: red light | 14.03 | 16.02 | 18.02 | 20.54 [b] |
| T5: green light | 14.63 | 15.32 | 16.48 | 18.43 [ab] |
| CV% | | | | 8.34 |

*1 Statistical difference with a reliability level of 95% ($p<0.05$)
*2 No statistical difference with a reliability level of 95% ($p>0.05$)
*3 Vertically different letter had statistical differences with the reliability level at 95% ($p<0.05$). (Vertically different mean values were compared between treatment using Duncan's New Multiple Ranges Test).

**Table 4.** Number of leaves of cos salad lettuce during the fifth to eighth weeks

| Treatments | Average number of leaves | | | |
|---|---|---|---|---|
| | 5th week | 6th week | 7th week | 8th week |
| T1: no light | 9.25 | 10.25 | 12.75 | 13.25 [a] |
| T2: yellow light | 10.25 | 12.25 | 13.75 | 16.00 [ab] |
| T3: blue light | 11.00 | 13.50 | 14.75 | 16.50 [ab] |
| T4: red light | 12.00 | 13.50 | 15.25 | 17.25 [b] |
| T5: green light | 10.75 | 12.50 | 13.50 | 15.50 [ab] |
| CV% | | | | 9.71 |

*1 Statistical difference with a reliability level of 95% ($p<0.05$)
*2 No statistical difference with a reliability level of 95% ($p>0.05$)
*3 Vertically different letter had statistical differences with the reliability level at 95% ($p<0.05$). (Vertically different mean values were compared between treatment using Duncan's New Multiple Ranges Test).

The red-light treatment (T4) resulted in the tallest plants, with an average height of 20.54 cm. It was significantly greater than the height of plants in the control group (T1, no light), which averaged 17.84 cm. While other light treatments (yellow, blue, and green) were found to be taller plants than the control which averaged heights of 18.43-19.74 cm, but it was not significantly differed from each other or the red-light treatment.

Result showed that leaf count in red light treatment (T4) found to be the highest average number of leaves per plant (17.25). It was significantly higher than the leaf count in the control group (T1), which averaged 13.25 leaves. The blue and green light treatments resulted in a higher number of leaves as compared to the control, but their averaged values of 15.50- 16.50) which were not significantly differed from each other or from the red-light treatment. The yellow light treatment was not significantly differed on leaf count as compared to the blue and green light treatments.

**Table 5.** Height of cos salad lettuce in the eighth week (cm.)

| Treatments | Replications | | | | |
|---|---|---|---|---|---|
| | R1 | R2 | R3 | R4 | Mean |
| T1: no light | 16.36 | 15.6 | 16.3 | 16.6 | 17.84[a] |
| T2: yellow light | 16.8 | 15.22 | 20.40 | 17.80 | 19.31[ab] |
| T3: blue light | 19.34 | 16.82 | 16.62 | 18.98 | 19.74[ab] |
| T4: red light | 19.80 | 20.08 | 21.94 | 20.34 | 20.54[b] |
| T5: green light | 18.12 | 19.72 | 18.30 | 17.58 | 18.43[ab] |
| CV% | | | | | 8.34 |

*1 Statistical difference with a reliability level of 95% (p<0.05)
*2 No statistical difference with a reliability level of 95% (p>0.05)
*3 Vertically different letter had statistical differences with the reliability level at 95% (p<0.05). (Vertically different mean values were compared between treatment using Duncan's New Multiple Ranges Test).

**Table 6.** Count of leaves in the eighth week

| Treatments | Replications | | | | |
|---|---|---|---|---|---|
| | R1 | R2 | R3 | R4 | Mean |
| T1: no light | 14 | 13 | 13 | 13 | 13.25[a] |
| T2: yellow light | 16 | 16 | 17 | 15 | 16.00[b] |
| T3: blue light | 17 | 16 | 16 | 17 | 16.50[ab] |
| T4: red light | 17 | 18 | 16 | 18 | 17.25[b] |
| T5: green light | 16 | 15 | 15 | 16 | 15.50[b] |
| CV% | - | - | - | - | 9.71 |

*1 Statistical difference with a reliability level of 95% (p<0.05)
*2 No statistical difference with a reliability level of 95% (p>0.05)
*3 Vertically different letter had statistical differences with the reliability level at 95% (p<0.05). (Vertically different mean values were compared between treatment using Duncan's New Multiple Ranges Test).

The fresh weight (g/plant) of cos lettuce at harvest (eight weeks after transplanting) under different LED light treatments is shown in Table 7. The red-light treatment (T4) was found to be the highest averaged fresh weight (83.00 g/plant), which was significantly higher than the control group (T1, no light) with an average of 49.45 g/plant ($p < 0.05$). It indicated that red light was significantly enhanced for biomass accumulation in cos lettuce as compared to the control.

While the yellow (T2) and blue (T3) light treatments resulted in higher averaged fresh weights (73.75 g/plant and 69.25 g/plant, respectively) as compared to the control, they were not statistically differed as compared to the control. The green light treatment (T5) increased in fresh weight (61.75 g/plant) which higher than the control, but it was not significantly differed. Result demonstrated that the red light promoted biomass accumulation and fresh weight yield in cos lettuce as compared to other light treatments and the control.

**Table 7.** Effects of different LED light treatments on the fresh weight (g/plant) of cos lettuce at harvest (eight weeks after transplanting)

| Treatments | Replications | | | | |
|---|---|---|---|---|---|
| | R1 | R2 | R3 | R4 | Mean |
| T1: no light | 50 | 50 | 49.8 | 48 | 49.45[a] |
| T2: yellow light | 70 | 72 | 78 | 75 | 73.75[c] |
| T3: blue light | 75 | 60 | 70 | 72 | 69.25[c] |
| T4: red light | 82 | 82 | 80 | 88 | 83.00[d] |
| T5: green light | 65 | 62 | 60 | 60 | 61.75[b] |
| CV% | | | | | 17.95 |

*1 Statistical difference with a reliability level of 95% (p<0.05)

*2 No statistical difference with a reliability level of 95% (p>0.05)

*3 Vertically different letter had statistical differences with the reliability level at 95% (p<0.05). (Vertically different mean values were compared between treatment using Duncan's New Multiple Ranges Test).

***Satisfaction level in project implementation***

The technology transfer project focused on empowering Future Farmers of Thailand Organization in Phetchaburi unit members with the knowledge and skills for cos lettuce production. Participants are successfully implemented a comprehensive cultivation process, including growing, watering, fertilizing, pest control, harvesting, and packaging. This resulted in a substantial yield of 92 kilograms, which was sold through pre-orders with a company (3.20 kg at 28 baht/kg) and online platforms (60 kg at 30 baht/kg), generating a total revenue of 10,760 baht. Notably, the use of red LED light treatment in the project led to an increase in yield per plot of 20% compared to control plants grown without supplemental lighting. It contributed to a net profit of 7,760 baht (after a 3,000-baht investment), averaging 597.77 baht per member. This economic success encouraged members to continue cos lettuce cultivation for both commercial and direct-to-consumer sales.

Result revealed a high overall satisfaction level among participants (Table 8). The highest satisfaction was reported for the potential of cos lettuce production to guide future career choices (mean = 4.33, SD = 0.485). High satisfaction was also expressed for the application of acquired knowledge and skills (mean = 4.11, SD = 0.832) and the comprehensive practice of cos lettuce cultivation (mean = 4.06, SD = 0.802). It indicated that the project was successfully transferred the technical skills and inspiring and motivating participants for potential agricultural careers.

**Table 8.** Monitoring the project implementation based on the satisfaction of the sample group

| Item | Mean | SD. | Satisfaction |
|---|---|---|---|
| 1. Application of acquired knowledge, skill, and experience to cos salad lettuce production | 4.11 | 0.832 | High |
| 2. Comprehensive practice of cos salad lettuce growing (planning, growing, packaging, and selling) | 4.06 | 0.802 | High |
| 3. Gaining increased incomes for schooling and daily expenses | 4.00 | 0.907 | High |
| 4. Experience in cos salad lettuce production can be a guideline for future career | 4.33 | 0.485 | Very high |
| 5. Satisfaction with the cos salad lettuce growing project | 3.72 | 0.826 | High |
| **Total** | **4.07** | **0.852** | **High** |

## Discussion

The results demonstrated the significant impact of different LED light treatments on cos lettuce growth and yield for six weeks of nighttime supplemental lighting, and they showed a distinct difference in plant height, leaf count, and fresh weight. Red light was significant mostly enhanced all three growth parameters as compared to the control group (no light) and other light colors.

Specifically, red light induced a 15% increase in average height (20.54 cm) and a 30% increase in average leaf count (17.25 leaves) as compared to the control (17.84 cm and 13.25 leaves, respectively). Moreover, red light dramatically boosted fresh weight yield by 64% (83.00 g/plant) compared to the control (49.45 g/plant). These findings are consistent with previous research by He *et al*. (2020) and Jeephet *et al*. (2022), which also highlighted the superior efficacy of red and blue light in promoting crop growth. The positive effect of red light can be attributed to its specific wavelengths being optimal for photosynthesis, a fundamental process for plant growth (Di *et al*., 2021, p. 202; Saleem *et al*., 2020). Additionally, red light positively influenced the functional response of chlorophyll and carotenoids, essential pigments for light absorption and photosynthesis (Croce and Van Amerongen, 2020).

The practical application of these findings was further validated through a technology transfer project with the Future Farmers of Thailand Organization in the Phetchaburi unit. Participants have successfully adopted a comprehensive cos lettuce production process, incorporating the use of red LED light. It resulted in a substantial 20% increase in yield per plot compared to non-supplemented controls, translating to significant economic gains. The project generated a net profit of 7,760 baht, with each participant earning an average of 597.77 baht. This economic success was a strong motivator for the continued cultivation of cos lettuce for commercial purposes and direct-to-consumer sales.

Beyond economic benefits, the project fostered a high level of satisfaction among participants, particularly regarding the potential of cos lettuce production to guide future career choices. This outcome underscores the importance of experiential learning in agricultural education and career development, as emphasized by Sangnate and Intrarathed (2015). By providing hands-on experience and tangible results, the project not only transferred technical knowledge but also inspired and empowered participants to consider cos lettuce cultivation as a viable career path. While the project successfully demonstrated the effectiveness of red LED light and its economic benefits, it also highlighted areas for further improvement. Production management practices can be optimized to enhance efficiency further and reduce costs. Additionally, market strategies can be refined to expand and maximize profitability. For instance, exploring alternative sales channels like farmers' markets or local restaurants could supplement the existing pre-order and online sales model.

Further research is warranted to investigate the underlying mechanisms by which red light is influenced cos lettuce growth and physiology. Investigating the interactions between light wavelengths and plant photoreceptors, hormone signaling pathways, and gene expression could provide valuable insights for developing tailored lighting strategies for different growth stages and environmental conditions. Combining scientific knowledge with practical applications for cos lettuce cultivation can be optimized for small-scale farmers and larger agricultural operations and contribute to food security and sustainable livelihoods.

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