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EFFECT OF DIFFERENT LIGHT SPECTRA ON THE SEEDLING GROWTH OF LETTUCE (*Lactuca sativa*)

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ABSTRACT

In tropical regions like the Philippines, lettuce production requires optimized lighting, yet local data on the economic and physiological impacts of specific LED recipes remains scarce. This study aimed to evaluate how different LED spectral compositions influence the growth, morphological development, and financial viability of 'Olmetie RZ' lettuce seedlings. Using a Completely Randomized Design, four treatments were evaluated over 21 days: White Light, Red Light, Balanced Spectrum (50:50 Red-Blue), and Tri-color Full Spectrum. Findings revealed that the Balanced Spectrum significantly outperformed all other treatments, yielding the highest fresh weight (2.91 g) and superior leaf morphology. Conversely, Red Light produced "leggy," less marketable growth. Economically, the Balanced Spectrum proved most efficient, yielding an 80% batch ROI and a 197% projected annualized ROI. The study concludes that a 50:50 Red-Blue ratio is the optimal "light recipe" for this variety. This project is significant for Philippine controlled environment agriculture, providing local growers with a scientifically-backed strategy to maximize seedling vigor and long-term financial sustainability through cost-effective, high-value lighting systems.

Keywords: *Controlled Environment Agriculture, LED Spectra, Lettuce Seedlings, ROI, Olmetie RZ*

INTRODUCTION

Lettuce *(Lactuca sativa L.)* is a priority crop in controlled environment agriculture due to its short growth cycle, high market value, and strong response to light conditions. As a widely consumed leafy vegetable, optimizing its production is crucial, especially in tropical regions like the Philippines. The use of Light Emitting Diodes (LEDs) has revolutionized lighting systems, allowing precise control of light spectrum and photoperiod for specific growth stages.

The seedling stage is particularly critical: vigorous, uniform seedlings support faster crop establishment, higher yield, and better quality after transplanting. In protected cultivation and plant factories, light is not only the primary driver of photosynthesis but also a major operating cost, making its efficient use essential for profitable production (Xin Zhang et al. 2018).

Light-emitting diodes (LEDs) now allow precise control of light spectrum, intensity, and photoperiod, enabling "light recipes" tailored to lettuce growth. Different spectra strongly affect germination, seedling vigor, morphology, and pigment formation. Combinations of red and blue light generally enhance germination traits, shoot and root length, and early fresh weight compared with white or ambient light (H. Soufi et al. 2025) (C. Hernández-Adasme et al.2022).

Despite this, there is limited locally oriented information on how specific LED spectra influence the seedling growth of lettuce under conditions relevant to Philippine nurseries. Since

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light environment at the seedling stage can produce carry-over effects on later growth and yield, identifying suitable spectra is
important for both commercial and educational production systems. This thesis, “Effect of Different Light Spectra on the Seedling Growth of Lettuce (*Lactuca sativa L.)”,* therefore aimed to evaluate selected LED light spectra on key seedling growth parameters, provided a scientific basis for more efficient light management in lettuce seedling production in the Philippines.

Objectives of the Study

This study aimed to evaluate the influence of different Light Emitting Diode (LED) spectral compositions on the growth and morphological development of lettuce (*Lactuca sativa* L.) seedlings in a controlled environment.

Specifically, this study was conducted to:

1. Evaluate morphological development of Lettuce seedlings in terms of plant height (cm), and leaf area as influenced by varying light spectra.
2. Determine the fresh weights of the whole seedlings (shoots and roots) to assess the resource allocation under each light treatment.
3. Identify the optimal light spectrum that produced the highest quality lettuce seedlings based on morphological and biomass data.
4. Evaluate the cost-efficiency (Return on Investment) of each light treatment relative to the growth performance of the seedlings.

METHODOLOGY

The experiment was conducted in Diffun, Quirino, using a Completely Randomized Design (CRD). The setup utilized 18-watt LED units. Four treatments—T1 (White), T2 (Red), T3 (Balanced 50:50 R+B), and T4 (Tri-color)—were applied to *Olmetie RZ* seedlings over a 21-day cycle. Each replication consisted of 50 seedlings. To mitigate tropical heat, a fine-mist spray bottle was used for manual cooling during peak hours. Data on shoot height and leaf length were gathered at 7 and 14 DAS. At 21 DAS, a representative sample of 10 seedlings per replicate was harvested using a water-wash technique to preserve root integrity. Fresh weight was determined using a digital weighing scale. Data were subjected to one-way ANOVA at a 0.05 level of significance.

RESULTS AND DISCUSSION

1. Early Seedling Observation (7 DAS)

Observations conducted at 7 Days After Transplanting (7 DAS) showed no measurable leaf emergence or shoot length across all treatments (T1–T4). At this stage, the *Olmetie RZ* seedlings were primarily in the germination and radicle protrusion phase.

The lack of visible growth at 7 DAS was consistent with the initial "lag phase" of lettuce development, where energy was diverted from the seed's cotyledons toward root establishment. This indicated that the influence of the different LED light spectra began to manifest more significantly during the second week of growth (14 DAS onwards).

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2. Morphological Development at (14 DAS)

Table 1. Mean Leaf Length (cm) 14 DAS of Lettuce Grown with Different Light Emitting Diode (LED)

Treatments	Means
T_1 – White Light	1.89^d
T_2 – Red Light	3.12^a
T_3 – Balance Spectrum (R+B, 50:50)	2.55^c
T_4 – Tri-color (Full Spectrum)	2.62^b
ANOVA Result	**
CV (%)	**1.91**

By the second week, it was clear that the seedlings in Treatment 2 (Red Light) were stretching much faster than the others, leading with a mean of 3.12 cm. While this looked like rapid growth, it appeared to be a classic "Shade Avoidance Response." Essentially, because these plants were only receiving red light, they were "panicking" to find blue light, causing them to elongate their leaves as a survival tactic.

it also noticeable that while the T2 leaves were the longest, they appeared somewhat pale and thin compared to the more vibrant leaves in the among other treatments.

This observation aligns with Modarelli *et al.* (2022) and Qiao *et al.* (2025), who noted that monochromatic red light triggers phytochromes to prioritize length over leaf thickness.

Table 2. Mean Leaf Width (cm) 14 DAS of Lettuce Grown with Different Light Emitting Diode (LED)

Treatments	Means
T_1 – White Light	1.40^b
T_2 – Red Light	1.40^b
T_3 – Balance Spectrum (R+B, 50:50)	1.49^a
T_4 – Tri-color (Full Spectrum)	1.44^b
ANOVA Result	*
CV (%)	**2.40**

At this stage of development, Treatment 3 (Balanced Spectrum) achieved the significantly widest leaves at 1.49 cm. This finding is crucial as it indicates that the inclusion of blue light was already influencing leaf development within the first two weeks. Blue light is scientifically recognized for its ability to inhibit excessive vertical elongation and promote lateral expansion. Consequently, T3 produced leaves that were more robust and better equipped for light interception compared to the narrower, more linear leaves observed in T1 and T2. Morphologically, the leaves in T3 exhibited a broader and more rounded structure, indicating a transition toward a more advanced vegetative architecture earlier in the growth cycle than the other treatments.

This observation aligns with the findings of Azad *et al.* (2020), who stated that increased blue light fractions improve photosynthetic parameters and produce more compact, sturdy seedlings by promoting horizontal leaf development rather than vertical stretching.

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Table 3. Mean Shoot Length (cm) 14 DAS of Lettuce Grown with Different Light Emitting Diode (LED)

Treatments	Means
T_1 – White Light	1.94^{d}
T_2 – Red Light	3.18^{a}
T_3 – Balance Spectrum (R+B, 50:50)	2.57^{c}
T_4 – Tri-color (Full Spectrum)	2.71^{b}
ANOVA Result	**
CV (%)	**2.72**

The shoot length results mirrored the leaf length, with T2 reaching over 3 cm. This high height-to-width ratio made the seedlings look "leggy." It became evident that the red light was driving the height, but without blue light, the seedlings lacked structural balance.

It was observed that the T2 seedlings were so tall and thin that they were much more prone to leaning toward the chamber walls than the T3 seedlings. This supports Hernández-Adasme *et al.* (2022), who found that early vertical growth under red light is often a result of hypocotyl elongation rather than actual tissue accumulation.

3. Peak Morphological Growth at 21 DAS

Table 4. Mean Leaf Length (cm) 21 DAS of Lettuce Grown with Different Light Emitting Diode (LED)

Treatments	Means
T_1 – White Light	4.45^{d}
T_2 – Red Light	7.20^{b}
T_3 – Balance Spectrum (R+B, 50:50)	7.64^{a}
T_4 – Tri-color (Full Spectrum)	4.81^{c}
ANOVA Result	**
CV (%)	**1.74**

A major shift occurred by the final week of the study . Treatment 3 finally surpassed the "stretching" T2 seedlings to reach 7.64 cm. This suggests that while red light is good for a quick start, the balanced spectral mix in T3 provides a more sustainable energy source for long-term leaf expansion and more sturdy plant structure.

By day 21, the T3 seedlings looked significantly more 'filled out' and vigorous than any other treatments.This findings is consistent with *Soufi et al.* (2025), who argued that combined red-blue spectra provide a better overall "energy package" for lettuce vigor than monochromatic light.

Table 5. Mean Leaf Width (cm) 21 DAS of Lettuce Grown with Different Light Emitting Diode (LED)

Treatments	Means
T_1 – White Light	3.99^{b}
T_2 – Red Light	3.19^{d}
T_3 – Balance Spectrum (R+B, 50:50)	4.63^{a}
T_4 – Tri-color (Full Spectrum)	3.38^{c}
ANOVA Result	**

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CV (%)	**0.93**

At 21 DAS, Treatment 3 maintained its lead in leaf width (4.63 cm), while Treatment 2 produced the significantly narrowest leaves at 3.19 cm. This confirms the "Trade-off Effect" pure red light results in length without width, but T3 utilizes blue light to expand the leaf surface area.

Upon futher observation, the leaves in T3 were wide enough that they were beginning to overlap with neighboring seedlings, creating a full canopy in the tray

Basir and Masri (2021) emphasized that specific red: blue ratios at the nursery stage lead to superior leaf area, which is essential for capturing light once the seedling is transplanted.

Table 6. Mean Shoot Length (cm) 21 DAS of Lettuce Grown with Different Light Emitting Diode (LED)

Treatments	Means
T_1 – White Light	5.44^{d}
T_2 – Red Light	8.64^{b}
T_3 – Balance Spectrum (R+B, 50:50)	8.76^{a}
T_4 – Tri-color (Full Spectrum)	5.77^{c}
ANOVA Result	**
CV (%)	**0.92**

The final shoot length was greatest in Treatment 3 (8.76 cm), followed closely by T2 (8.64 cm). Although both treatments produced tall seedlings, the structural quality differed. T3 shoots were thicker and supported broader leaves, whereas T2 shoots were "leggy." The statistical superiority of T3 confirms that the 50:50 ratio provides the necessary triggers for both elongation (red) and structural integrity (blue).

This structural balance aligns with *Boros et al.* (2023), who argued that red/blue ratios strongly affect vegetative growth and spatial light distribution, leading to a more vigorous "morphotype" compared to the leggy plants under monochromatic light.

4. Root Elongation and Resource Allocation

Table 7. Mean Root Length (cm) 21 DAT of Lettuce Grown with Different Light Emitting Diode (LED)

Treatments	Means
T_1 – White Light	6.88^{a}
T_2 – Red Light	5.73^{b}
T_3 – Balance Spectrum (R+B, 50:50)	4.53^{c}
T_4 – Tri-color (Full Spectrum)	4.72^{c}
ANOVA Result	**
CV (%)	4.83

The roots told a very different story. White Light (T1) produced the longest roots (6.88 cm), while T3 had the shortest. It appeared that the plants in T1 were "searching" for better light quality by sending roots deeper.

Upon sampling, the T1 roots were long and spindly, almost as if they were trying to outgrow the seedling tray, while T3 roots were shorter but looked denser.

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This "root foraging" behavior as a stress response is a key strategy described by *Legendre and Van Iersel* (2021).

5. Total Fresh Weight

Table 8. Mean Fresh Weight (g) 21 DAS of Lettuce Grown with Different Light Emitting Diode (LED)

Treatments	Means
T_1 – White Light	2.15[b]
T_2 – Red Light	2.19[b]
T_3 – Balance Spectrum (R+B, 50:50)	2.91[a]
T_4 – Tri-color (Full Spectrum)	2.22[b]
ANOVA Result	**
CV (%)	5.85

The final biomass assessment at 21 DAS showed that T3 (Balanced Spectrum) achieved a mean fresh weight of 2.91grams, which was significantly higher than T4 (2.22 g), T2 (2.19 g), and T1 (2.15 g).The increase in weight compared to T1 (White Light) confirms that the 50:50 Red-Blue ratio is the most efficient "light recipe" for the *Olmetie RZ* variety.even before weighing it is noticeable that T3 has meatier leaf midrib that provides sturdier stalk among other treatments.

This result strongly supports the findings of *Kumarasena et al. (2025)* and *Soufi et al.* (2025), who concluded that enhanced light quality through red-blue combinations maximizes photosynthesis and fresh weight accumulation

Table 9. Comparative Economic Analysis and Return on Investment (ROI)

Financial Indicator	**T1 (White)**	**T2 (Red)**	**T3 (Balanced)**	**T4 (Tri-color)**
Sales (Gross Revenue)	₱7,200.00	₱4,500.00	₱9,000.00	₱4,500.00
Total Expenses per Batch	₱2,966.17	₱2,920.84	₱2,752.17	₱3,024.84
Variable & Labor Costs	₱2,332.28	₱2,332.28	₱2,332.28	₱2,332.28
Depreciation Expense	₱633.89	₱588.56	₱419.89	₱692.56
Net Income (per batch)	₱4,233.83	₱1,579.16	₱6,247.83	₱1,475.16
Batch ROI (%)	**40%**	**16%**	**80%**	**13%**
Annualized ROI (%)	**118%**	**45%**	**197%**	**40%**

When transitioned from the biological data to the financial analysis. Treatment 3 (Balanced Spectrum) emerged as the best choice, it achieved a staggering Batch ROI of 80%, which is double that of the white light control. This success was driven by two practical factors: T3 had the lowest depreciation expense because the light units were more affordable, and it produced the highest quality seedlings.

In pricing the lettuce seedling, the morphological characteristic was considered, Treatment 3 (Balanced Spectrum) command a premium selling price of ₱10.00 per unit due to its superior

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leaf width and fresh weight. Conversely, T2 (Red) and T4 (Tri-color) seedlings were valued at only ₱5.00 per unit because their morphological "legginess" and lower biomass reduced their marketability.

The annualized ROI of 197% for T3 also proves that investing in the right "light recipe" is just as important as the seeds themselves. As the data suggests, a farmer in Diffun, Quirino, could potentially see a net income of ₱6,247.83 per batch, generating a total annual net income of ₱74,973.91. simply by switching to a 50:50 Red-Blue LED ratio. This confirms that optimizing the light spectrum for lettuce seedlings in the Philippines is a highly lucrative venture, provided the 50:50 Red-Blue ratio is utilized to ensure both plant vigor and cost efficiency.

Conclusions

Based on the findings, the 50:50 Red-Blue spectrum (T3) provides the optimal balance of light energy for lettuce seedlings, promoting sturdy morphological development and the highest biomass accumulation.

T3 is the most financially viable "light recipe," yielding a Batch ROI of 80% and an Annualized ROI of 197%. This is due to its lower equipment depreciation costs and the premium market value of the high-quality seedlings produced.

Recommendations

Based on the conclusions, the researcher recommends the following:

1. **For Lettuce Growers**

It is highly recommended to Adopt the 50:50 Balanced Red/Blue LED spectrum for indoor nursery systems in the Philippines to ensure uniform, vigorous, and highly marketable seedlings.

2. **For Local Entrepreneurs**

Utilize this study to set up small-scale, indoor seedling nurseries, as the 197% annualized ROI indicates high profitability. Local agricultural offices may consider promoting LED-based controlled environment agriculture (CEA) to safeguard seedling production against seasonal climate variations and typhoons.

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