The Effect of Light-Emitting Diode, Planting Medium, and Nutrient Concentration on the Plant Growth and Chlorophyll Content of Lemon Basil

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Abstract. Plant productivity and quality in plant factories with artificial lighting (PFAL) depend on lighting control. Planting medium and plant nutrient affect aromatic crop germination, crop growth, and essential oil yield. For 12 h, LEDs provided artificial grow illumination in three ratios: 100% blue, 100% white, and combination of 67%:20%:13% red:blue:white. Lemon basil was grown using cocopeat:peat moss:perlite mixtures of 70:10:20 and 70:20:10. Lemon basil plants were watered twice daily with commercial AB mix at 500 and 700 ppm plant nutrients. Different LED ratios have different lux and Photosynthetic Photon Flux Density (PPFD), such as 100 lx and 44.26 mol·m-2·s-1 for 100% blue, 1000 lx and 95.92 mol·m-2·s-1 for 100% white, 350 lx and 37.33 mol·m-2·s-1 for 67%:20%:13% red:blue:white at 25-27oC and 70–80% relative humidity. The 100% white LED lamp with 700 ppm of plant nutrient concentration produced the best lemon basil growth, with height, leaf area, fresh weight, chlorophyll SPAD, a, b, and total chlorophyll content of 11.88 cm, 8.61 cm2, 0.8043 g, 27.1, 22.679 mg/L, 32.578 mg/L, and 40.427 mg/L for 70:10:20 ratio of planting medium, and 11.29 cm, 11.19 cm2, 0.6447 g, 26.2, 21.022 mg/L, 40 mg/L, 46.18 mg/L for 70:20:10 ratio of cocopeat:peat moss:perlite combination.

Keywords: Plant factory · Lemon Basil · Artificial Lighting · Planting Medium · Nutrient Concentration

1 Introduction

Lemon basil (*Ocimum basilicum* var. *Anisatum* Benth.) is an aromatic basil variety. The germination period for lemon basil is four to six days, with coarse, hairy stems and lanceolate leaves [1]. The culinary, fragrance, and pharmaceutical industries utilize lemon basil extensively, primarily utilized through the extraction of its essential oil, particularly during its completely flowering phase [2]. Lemon basil's phenolic content

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in the form of rosmarinic and caffeic acids is an effective antioxidant, and it has also been demonstrated that this substance can inhibit harmful fungus by 100 percent [3, 4].

Like all chlorophyll-containing green plants, chlorophyll content in lemon basil functions in energy absorption during photosynthesis. Chlorophyll converts the light energy absorbed into chemical energy needed in photosynthesis [5]. Plants have several forms of chlorophyll, including chlorophyll a and b, and each chlorophyll plays a unique role in the absorption of different light durations. Chlorophyll a absorbs red wavelengths at 675 nm more efficiently than chlorophyll b, which absorbs blue wavelengths at 470 nm [6]. Lemon basil chlorophyll research has been conducted by analyzing chlorophyll fluorescence to evaluate basil stress levels and plant growth [7].

The varied LED light on plant factories with artificial lighting (PFAL) produces distinct colors and wavelengths and has distinct effects on plant growth. Blue light growth results in greener plants, but red-light growth is three times more [5]. The ideal development and chlorophyll synthesis of plants is enhanced when red and blue light are combined as opposed to red or blue light alone [8]. In addition, planting medium and plant nutrients greatly impacts germination quality, the proportion of growing shoots, plant growth, crop yields, and the total chlorophyll content, implying that plants can create distinct nutrients in various growing conditions [9]. Thus, differences in water-holding capacity, porosity, drainage, nutrient content, and chemical properties influence the selection of planting media and nutrients [10, 11]. Previously, research on the composition of planting media in plants was conducted using Pakchoi plants, which revealed minor changes in chlorophyll content but large differences in plant height and leaf number [12].

Consequently, the purpose of this study was to determine and model the growth response and chlorophyll content of lemon basil to various LEDs, namely blue LEDs, white LEDs, and a combination of red, blue, and white LEDs with two different plant nutrient concentrations, 500 and 700 ppm, and also two different ratios of planting media, consisting of a mixture of cocopeat, peat moss, and perlite. This study's findings can be utilized as a roadmap for developing the cultivation of lemon basil in plant factories utilizing artificial lighting (PFAL).

2 Material and Method

2.1 Plant Materials

The research used lemon basil (*O. basilicum* var. *Anisatum* Benth.) with Garuda seed® branded seeds. Planting was carried out using a planting medium in the form of a mixture of cocopeat, peat moss, and perlite in a tray measuring 24 × 19 cm. The various planting media ratios were 70:10:20 (PM) and 70:20:10 (PT) of cocopeat:peatmoss:perlite. Each tray contains ± 0.5 g of seed and is placed in a planting room measuring 75 × 60 × 28 cm at a temperature of 24–26 °C and RH 68–70%. The planting room is made of an iron frame with 95% paranet covered. Plants were watered once a day using AB Mix (Nutrisiip) as plant nutrient with two variations of concentration, 500 ppm, and 700 ppm.

Three different types of LED lamps were used as artificial grow for 12 h (from 7:00 a.m. to 7:00 p.m.), with varying lux, PPFD, and wavelength, i.e., 100 lx, 44.26 mol·m^{-2}·s^{-1} of PPFD, and 470 nm of wavelength for 100% blue; 600 lx,

Table 1. The formula of chlorophyll content analysis

Parameter	**Equation**
Chlorophyl a	$\text{Chla}(\text{mg}.L^{-1}) = (13.7\text{x}OD_{663}) - (5.76\text{x}OD_{645})$
Chlorophyl b	$\text{Chlb}(\text{mg}.L^{-1}) = (25.8\text{x}OD_{645}) - (7.7\text{x}OD_{663})$
Total chlorophyl	$\text{Chltotal}(\text{mg}.L^{-1}) = (20\text{x}OD_{645}) - (0.1\text{x}OD_{663})$

20.32 mol·m^{-2}·s^{-1} of PPFD, and 660 nm of wavelength for 100% red; 1000 lx, 95.92 mol·m^{-2}·s^{-1} of PPFD, and 550 nm of wavelength for 100% white; 350 lx, 37.33 mol·m^{-2}·s^{-1} of PPFD, with 660, 470, and 550 nm of wavelengths for 67%:20%:13% red:blue:white, respectively. PPFD, lux, and wavelength were measured using a PAR meter and quantum sensor (LICOR LI-250Q PAR comprising LI-250 Light Meter and LI-190R Quantum Sensor) and a light meter (Lutron LX-107).

2.2 Plant Growth and Chlorophyll Content Analysis

The height of the plant was measured at random lemon basil on each tray for each 0, 7, 14, 21, and 28 days. Random samples of harvested lemon basil plants were measured for leaf area and fresh weight. The leaf area was measured using the ImageJ tool, while the fresh weight was measured using an analytical balance, the data was collected with 10 replications for each tray. Lemon basil harvested on the 28$^{\text{th}}$ day after planting (DAP) was weighed as much as 0.5 g with six replications per tray then extracted using acetone:ethanol (2:1 v:v) with maceration technique for 24 h until the sample was completely white. The filtrate was used to measure chlorophyll levels using an Ultraviolet-Visible Spectrophotometer (UV-Vis, LW Scientific UV-200-RS). Measurements using UV-VIS were carried out with wavelengths of 645 nm (maximum absorption peak of chlorophyll a) and 663 nm (maximum absorption peak of chlorophyll b) to obtain Optical Density (OD) values [13]. The chlorophyll value was calculated using the equivalence formula, as shown in Table 1. The SPAD measurement was carried out with six replications using the SPAD meter Chlorophyll Meter SPAD-502Plus - Konica Minolta.

2.3 Statistical Analysis

Plant height, leaf area, fresh weight, SPAD, chlorophyll a, chlorophyll b, and total chlorophyll were analyzed using multivariate analysis of variance (MANOVA) to investigate the combined influence of LED lighting, nutrition concentration, and planting medium on lemon basil plants after 28 days after planting. Duncan's Multiple Range Test (DMRT) was used to estimate the significance of each LED ratio fluctuation based on the data.

A growth model was created using linear regression based on the plant height data collected every seven days beginning at day zero, day seven, day fourteen, day twenty-one, and day twenty-eight after planting. The data on plant height for the ten replicates were separated into seven sets of calibration data and three sets of prediction data. The linear regression model was constructed utilizing calibration data, and its accuracy was subsequently evaluated using prediction data. As indicated in Table 2, the calibration and

Table 2. The formula of linear regression model and model evaluation

Parameter	Equation
Linear regression	$y = \beta_0 + \beta_1 X_1 + \cdots + \beta_K X_K + \varepsilon$
RMSE	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$
MAE	$\frac{1}{n}\sum_{i=1}^{n}\lvert y_i - \hat{y}_i\rvert$
MAPE	$\frac{1}{n}\sum_{i=1}^{n}\frac{\lvert y_i - \hat{y}_i\rvert}{y_i}x100$
R^2	$\frac{\sum_{i=1}^{n}(y_i-\overline{y_i})(\hat{y_i}-\overline{\hat{y_i}})^2}{\sum_{i=1}^{n}(y_i-\overline{y_i})^2\sum_{i=1}^{n}(\hat{y_i}-\overline{\hat{y_i}})^2}$

prediction error values are compared to determine the model's accuracy using RMSE, MAE, MAPE, and R2 [14].

3 Result and Discussion

3.1 LEDs, Planting Medium, and Plant Nutrient Concentration Effect on Chlorophyll and Growth of Lemon Basil

The three-way MANOVA was used to compare plant height, leaf area, fresh weight, SPAD, chlorophyll a, chlorophyll b, and total chlorophyll of lemon basil plants under the varied LEDs, nutrient concentration, and planting medium. Table 3. Indicates that the application of various LED lighting significantly affected the lemon basil plant's height, fresh weight, and leaf area. White LEDs produce the most significant average of growth parameter, followed by blue LEDs, whereas the combination of red:blue:white LEDs produce the lowest average with the slightest impact. Likewise, the content of chlorophyll a with the UV-Vis analysis and the chlorophyll content with the SPAD value method is influenced by the use of LEDs. White LEDs have a higher effect on chlorophyll content, while blue and the combination of red:blue:white LEDs produce the same lowest effect. Plants have the ability to absorb light differently in each LED wavelength. at the wavelength with maximum absorption capacity, photosynthetic activity and chlorophyll concentration will increase [15].

Based on another study, white LED lights produced the tallest plants whereas blue LEDs and the red-blue mix produced significantly shorter plants. In addition, plants cultivated under white LED light produced considerably more fresh weight than those grown under blue, red, and green LED lights. White light is a combination of red light, blue light, and various light spectrums with wavelengths of low-intensity light, and it provides a more substantial growth response than other monochromatic LEDs [16–18]. Plants respond differently at different wavelengths. Blue LEDs are widely absorbed by plant photoreceptors which affect stem elongation and leaf expansion, cryptochromes which affect the optimization of light harvesting, and phytotropins' which affect the prevention of photoinhibition, while red LEDs stimulate phytochrome photoreceptors that affect germination and stem elongation [19].

The basil plant height, leaf area, and chlorophyll content of the lemon basil plant are also regulated by the plant's nutrient content, with 700 ppm AB mix concentration of plant nutrients being the greatest, while 500 ppm AB mix concentration produced the lowest mean of growth response parameter. 700 ppm AB mix has a more significant impact than 500 ppm mix, and the plant's height, leaf area, and chlorophyll content were increased proportionally to the nutrient content (Table 3). This research conforms to prior findings regarding the optimal concentration of AB Mix nutrients for leafy vegetable plants, such as pakchoi. The composition of macro and micronutrients significantly impacts plant growth due to concentration balanced on fertilizer application according to the plant's requirements [20].

The use of a mixture of cocopeat:peatmoss:perlite planting media with a ratio of 70:20:10 (PT) had the most significant influence on leaf area and chlorophyll content compared to media with a 70:10:20 ratio (PM) (Table 3). Compared to cocopeat growing media, peat moss growing media provides the best results for all.

observation growing parameters [21]. According to a previous study, peat moss contains the phosphorus (P) necessary for plant growth [22]. In addition, peat moss includes magnesium (Mg), which aids in the metabolism of plants, particularly in the production of sugar and starch and the translocation of nutrients in enzymes. Photosynthate results in the leaves being delivered by the xylem and phloem tissues, stimulating cambium activity in the plant stem's lateral region and expanding its diameter. In addition to magnesium (Mg), peat moss contains calcium (Ca), which functions in the mechanism of nutrient translocation and plays a vital role in plant physiological processes, including photosynthesis [23].

3.2 Lemon Basil Growth Model Based on Plant Height Under Different Artificial Light, Planting Medium, and Plant Nutrient

Based on plant height measurements taken on days 0, 7, 14, 21, and 28, it is possible to create a growth model for basil plants of three distinct artificial light LEDs. Based on the average plant height, lemon basil plants grew highest under white LEDs on varied plant nutrient concentrations (500 and 700 ppm) and planting media (PT and PM plant media) (Fig. 1). White light is a variety among several light spectrums with low-intensity wavelengths, and it delivers a greater growth response than monochromatic LEDs [16–18].

Table 4 provides the growth linear model equation for the lemon basil plant. The model has an overall high linear coefficient of determination. The linear coefficient of determination (R^2) was 0.9772 for white LEDs, 0.9722 for blue LEDs, and 0.9984 for the combination of red:blue:white LEDs, demonstrating a significant correlation between the height of the lemon basil plant and the day of observation (0, 7, 14, 21, and 28 days after planting). This growth model can predict the height of lemon basil plants grown under different LED lighting and medium conditions.

Table 3. The harvest quality of lemon basil after 28 days of planting under varied LED lighting, planting medium, and plant nutrient concentration.

LED Light	Plant Nutrient	Planting Medium	Plant Height	Leaf Area	Fresh Weight	SPAD	Chlorophyll Content		
							a	b	total
			i	ii	iii	iv	ii	v	v
White	500 ppm	PM	7.78 ± 2.13	5.30 ± 1.87	0.8520 ± 0.3692	22.9 ± 1.9	22.424 ± 1.663	22.971 ± 4.12	31.763 ± 3.684
		PT	9.32 ± 1.81	4.68 ± 1.64	0.5118 ± 0.2283	26.6 ± 1.3	22.194 ± 1.218	32.990 ± 6.569	40.547 ± 5.227
	700 ppm	PM	11.88 ± 1.86	8.61 ± 2.03	0.8043 ± 0.5245	27.1 ± 3.0	22.679 ± 1.204	32.578 ± 5.391	40.427 ± 4.179
		PT	11.29 ± 2.66	11.19 ± 2.18	0.6447 ± 0.4855	26.2 ± 4.7	21.022 ± 1.161	40.000 ± 5.200	46.180 ± 4.031
Blue	500 ppm	PM	5.91 ± 1.00	5.67 ± 1.81	0.4494 ± 0.1789	18.3 ± 0.6	21.136 ± 1.041	22.649 ± 4.707	30.825 ± 4.679
		PT	5.72 ± 1.15	3.72 ± 1.38	0.3225 ± 0.2786	20.4 ± 1.6	23.738 ± 0.508	26.778 ± 1.861	35.811 ± 1.438
	700 ppm	PM	6.39 ± 1.71	6.14 ± 0.67	0.4203 ± 0.1948	22.1 ± 1.2	22.468 ± 1.099	32.629 ± 4.451	40.365 ± 3.408
		PT	5.88 ± 1.57	6.56 ± 0.96	0.5374 ± 0.2442	21.5 ± 1.1	22.040 ± 1.417	35.442 ± 6.348	42.647 ± 4.921
Red: Blue: White	500 ppm	PM	2.9 ± 0.76	2.32 ± 0.59	0.2524 ± 0.0851	18.2 ± 0.9	23.696 ± 0.544	25.072 ± 2.042	34.275 ± 1.988
		PT	2.72 ± 0.66	1.74 ± 0.53	0.1846 ± 0.1037	20.6 ± 0.7	21.986 ± 1.33	28.324 ± 1.604	36.296 ± 1.147

(continued)

Table 3. (*continued*)

LED Light	Plant Nutrient	Planting Medium	Plant Height	Leaf Area	Fresh Weight	SPAD	Chlorophyll Content		
							a	b	total
			i	ii	iii	iv	ii	v	v
	700 ppm	PM	4.56 ± 1.31	4.83 ± 0.52	0.3285 ± 0.0516	21.7 ± 1.0	22.657 ± 1.038	30.672 ± 1.845	38.723 ± 1.514
		PT	3.90 ± 0.40	4.13 ± 0.65	0.3098 ± 0.0691	22.1 ± 0.6	22.161 ± 1.184	34.388 ± 5.942	41.772 ± 4.691
White			10.07 ± 2.12 c	7.45 ± 1.93 c	0.7032 ± 0.4019 c	25.7 ± 2.7 b	22.080 ± 1.312 a	32.135 ± 5.230 b	39.729 ± 4.280 b
Blue			5.98 ± 1.36 b	5.52 ± 1.21 b	0.4324 ± 0.2241 b	20.6 ± 1.1 a	22.346 ± 1.016 a	29.375 ± 4.342 a	37.412 ± 3.612 a
Red: Blue: White			3.52 ± 0.78 a	3.26 ± 0.57 a	0.2688 ± 0.0774 a	20.7 ± 0.8 a	22.625 ± 1.024 a	29.614 ± 2.858 ab	37.767 ± 2.335 ab

Note: (i) The result of plant height was significantly affected by combination factor of varied LED and plant nutrient; (ii) the result of leaf area and chlorophyll a were significantly affected by combination factor of varied LED, plant nutrient, and planting media; (iii) the result of fresh weight was significantly affected by varied LED; (iv) the result of SPAD was significantly affected by the combination factor of varied plant nutrient and planting media; (v) the result of chlorophyll b and total chlorophyll were significantly affected by single factor of varied plant nutrient and planting media independently; ^{a,b} means with the different letter were significantly different between varied LED using Duncan test.

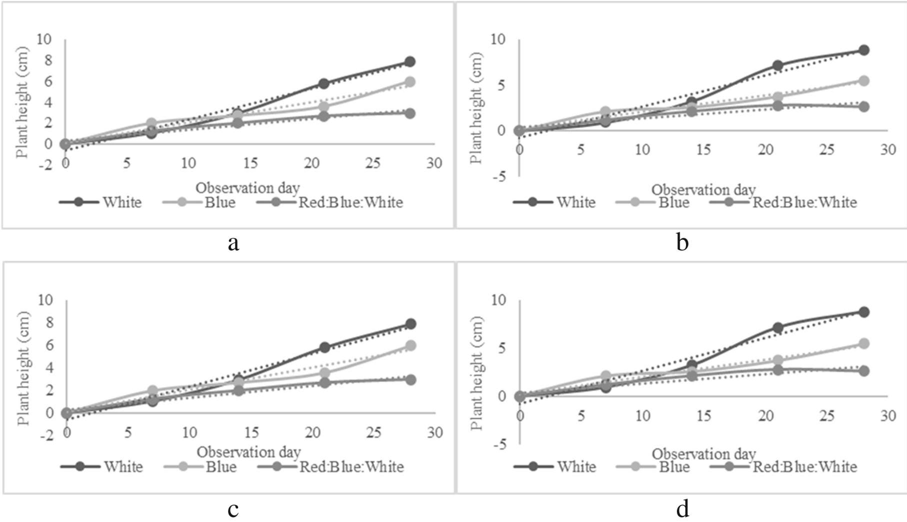

Fig. 1. Observed lemon basil plant height for 28 days of 500 ppm AB Mix and PM planting media (a), 500 ppm AB Mix and PT planting media (b), 700 ppm AB Mix and PM planting media (c), and 700 ppm AB Mix and PT planting media (d).

Table 4. The linear model equation and its coefficient of determination of plant height for lemon basil grown under varying LED lighting conditions, planting medium, and plant nutrient concentration.

LED Light	Plant Nutrient	Planting Media	Linier model equation	R^2
White	500 ppm	PM	y = 0.2924x + 0.5724	0.9772
		PT	y = 0.3400x + 0.7505	0.9611
	700 ppm	PM	y = 0.4452x + 1.3971	0.9400
		PT	y = 0.4269x + 1.3200	0.9338
Blue	500 ppm	PM	y = 0.1935x + 0.1314	0.9560
		PT	y = 0.1794x + 0.2571	0.9640
	700 ppm	PM	y = 0.2172x + 0.0552	0.9504
		PT	y = 0.1959x + 0.0724	0.9722
Red:Blue:White	500 ppm	PM	y = 0.1045x + 0.2971	0.9505
		PT	y = 0.0965x + 0.3800	0.8691
	700 ppm	PM	y = 0.1478x + 0.3140	0.9984
		PT	y = 0.1384x + 0.0657	0.9955

As shown by the model evaluation in Table 5, the plot results between the observed plant height data and the predicted height data calculated based on the linear model equation resulted in various performance comparisons. The highest R^2 value in white

Table 5. Performance comparisons of plant height calibration and validation for lemon basil produced under varying LED lighting conditions, planting medium, and plant nutrient concentration.

LED Light	Plant Nutrient	Planting Media	Calibration				Validation			
			RMSE	MAE	MAPE	R^2	RMSE	MAE	MAPE	R^2
White	500 ppm	PM	**0.2153**	**0.1636**	**6.3399**	**0.9772**	**0.4117**	**0.3424**	**14.3004**	**0.9765**
		PT	0.3900	0.2100	6.7600	0.9600	1.5200	0.6500	16.4400	0.9500
	700 ppm	PM	1.2924	0.3992	7.8778	0.9400	2.0189	0.7646	17.3192	0.9557
		PT	1.1761	0.3771	7.7963	0.9338	2.1048	0.7778	18.0288	0.9449
Blue	500 ppm	PM	0.0241	0.0001	2.2865	0.9560	0.0343	0.0002	5.2761	0.9720
		PT	0.0168	0.0000	2.0835	0.9640	0.0935	0.0000	5.3002	0.9332
	700 ppm	PM	0.0362	0.0158	3.0265	0.9504	0.0152	0.0002	5.6056	0.9881
		PT	**0.0154**	**0.0000**	**2.4423**	**0.9722**	**0.0164**	**0.0001**	**5.8620**	**0.9873**
Red: Blue:White	500 ppm	PM	0.0080	0.0000	2.0172	0.9505	0.0116	0.0000	5.6113	0.9679
		PT	0.0196	0.0000	1.8988	0.8691	0.0108	0.0000	5.0942	0.9725
	700 ppm	PM	**0.0176**	**0.0494**	**4.6003**	**0.9984**	**0.2469**	**0.2087**	**13.2017**	**0.9060**
		PT	0.0012	0.0001	2.6686	0.9955	0.0055	0.0046	6.8577	0.9903

LEDs was obtained at 500 ppm nutrition with PM plant media were 0.9772 and 0.9765, for the calibration and prediction sets, with both models obtaining a comparatively high degree of fitting. The highest R^2 value in blue LEDs was obtained at 700 ppm nutrition with PT plant media were 0.9772 and 0.9873, while the highest R^2 value in the combination of red:blue:white LED was obtained at 700 ppm nutrition with PM plant media were 0.9984 and 0.9060, for the calibration and prediction sets. RMSE, MAE, and MAPE of blue LEDs planted with PT plant media and 700 ppm nutrition has the lowest value, followed by red:blue:white LEDs, whereas the white LEDs produce highest, for the calibration and validation sets. Based on the performance of the model, the study revealed that the diverse LED lighting provided a more precise and reliable plant height prediction model.

4 Conclusion

The influence of varied LED, plant nutrient concentration, and planting media on leaf area and chlorophyll is substantial. Combining various LEDs and planting media yielded significant plant height. While the combination of different LED and plant nutrient concentrations considerably impacts plant height, the effects of LED variations alone are negligible. The combination of plant nutrient concentration and planting media on the SPAD value also produced significant outcomes. Chlorophyll b and total chlorophyll were shown to be significantly affected by plant nutrient variation and planting medium in this study. The model's performance analysis was accurate and dependable, with a high R^2 value for each combination of varied LED, plant nutrient concentration, and planting media. While the RMSE, MAE, and MAPE results obtained were relatively small. Consequently, the lemon basil growth model based on plant height can predict the height of basil plants grown in plant factories with artificial lighting (PFAL).

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