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LOCAL MADURA COWPEA (*VIGNA UNGUICULATA* L.) RESPONSE THROUGH MORPHOPHYSIOLOGICAL TRAITS UNDER LIGHT SPECTRUM TYPE EFFECT IN GROWBOX

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SUMMARY

Indoor farming using light-emitting diodes (LED) has received extensive assessment recently, but studies on cultivating local Madura cowpea (*Vigna unguiculata* L.) in indoor farming systems are still few. Using the Internet of Things (IoT) in farming systems can monitor and regulate plant cultivation activities. The existing study aimed to determine the effect of red-blue and white lights on the physiological response of local Madura cowpea plants using an IoT-based growbox. The study was in a factorial completely randomized design (CRD) with three replications. The first factor was the light spectrum, divided into three categories: L0 (sunlight), L1 (full-spectrum red-blue LED), and L2 (full-spectrum white LED). The second factor comprised five local Madura cowpea genotypes collected from various regions. The results revealed light significantly affected the plant height, leaf quantity, leaf area, root volume, root length, and wet and dry root weight. However, it nonsignificantly influenced the chlorophyll content in plant leaves. Additionally, no notable light treatment x genotype interaction occurred in all characters. This study discloses an effect of different light spectra on the growth and morphological traits of the local Madura cowpea.

Keywords: Cowpea (*V. unguiculata* L.), indoor farming, IoT, LED, growth and morphological traits, chlorophyll content

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Key findings: Based on physiological studies, plants with the light treatment experienced an increase in plant length, plant stomatal index, and root and leaf characters. Light makes plants experience efficient photosynthesis processes, causing it to positively impact the growth and development of local Madura cowpea plants.

INTRODUCTION

In previous years, legumes have become increasingly popular as a source of balanced nutrition in the community (Gonçalves *et al.*, 2016). The cowpea (*Vigna unguiculata* L.) is a widely cultivated legume (Gonçalves *et al.*, 2016; Osipitan *et al*., 2021). The cowpeas with agronomic, environmental, and economic advantages have increased the net income and improved the diets of the farming community in Africa, Asia, and South America. The cowpeas are native to Southern Africa; however, their growing prevails in more than 100 countries (Gonçalves *et al.*, 2016). Approximately 97% of the world's cowpea production happens in the African continent (Osipitan *et al*., 2021).

Light has a major role in photosynthesis, photoperiodism, and photomorphogenesis (Jing *et al.*, 2018). Sunlight comprises electromagnetic radiation, including purple, blue, green, yellow, orange, and red wavelengths (Rosyida *et al*., 2022). With the presence of light-absorbing molecules, organisms can respond to the variations in their natural light environment. Depending on the species and the plant’s development stage, variations in light quality (wavelength) can affect several physiological processes in plants, including intra- and intercellular differentiation, seed germination and seedling growth, photosynthesis, and blooming in cowpeas (Nand and Sachan, 2017).

Nowadays, the indoor farming system, by cultivating plants indoors, has been in extensive employment. Artificial environmental conditions used in indoor plant cultivation systems promote plant development. Light can influence the photosynthesis outcomes, plant growth, and plant yield. Crop growth and development and crop yield acquire considerable influences from light parameters, including intensity, frequency, and quality (Rosyida *et al*., 2022). Tanaka *et al.* (2017) observed soybean pods exposed to red light elongated more slowly than those treated with white light in soybeans (*Glycine max* L.). Light quality significantly impacts the variations in melon plant development and various adaptive responses (Jing *et al.*, 2018). Several wavelengths, such as red, blue, green, yellow, and white, determine the quality of LED light. The varied quality of LED light substantially alters the anatomy, physiology, biochemistry, and morphology in various crop plants (Rehman *et al.,* 2017; Zhao *et al.,* 2018). Numerous studies have examined the effects of different light qualities on plant development. Kobayashi *et al.* (2013) reported that treating spinach plants with red LED lights influenced photosynthesis, causing the leaves to appear light green or brighter than the control.

During indoor cultivation, using the Internet of Things (IoT) can serve to monitor and control all the processes. IoT systems utilize sensors that communicate and transmit data via the internet, enabling real-time monitoring and interaction with the environment (Torky and Hassanien, 2020). Precision agriculture technologies extend IoT applications, such as automatic data sensing, data collection, soil management, and monitoring results in the agriculture sector, i.e., seed testing, pak choy cultivation, poultry farming, and greenhouse management (Theparod and Harnsoongnoen, 2022; Kurniyanto *et al.,* 2024). However, a study on the effect of the LED light spectrum on local Madura cowpea genotypes has never transpired before. Therefore, the presented research aimed to use IoT devices to monitor the response of local Madura cowpea plants to red, blue, and white LED light treatments.

MATERIALS AND METHODS

Experimental design and breeding material

Scientists performed the experiment using the growbox (Figure 1), following Kaur *et al.* (2023), with moderate modification. The experiment proceeded using a factorial completely randomized design with three replications. The first factor was the light spectrum (L), divided into L0 = sunlight, L1 = full-spectrum red-blue LED, and L2 = full-spectrum white LED. The second factor was the local Madura cowpea accessions, namely, V1, V2, and V3, comprising the local Madura cowpeas from Sumenep Regency, while V4 and V5 were the local Madura cowpeas from Bangkalan Regency, Indonesia. This research used the treatment combinations, obtaining 3 × 5 combinations, with a total of 15 treatments repeated three times, totaling 45 experimental units. Each unit consisted of two subunits, resulting in the acquisition of 90 plants. The work took place in two locations from December 2023 to March 2024. The cowpea planting in growbox with LED proceeded at the Telang Asri Village, Socah District, Bangkalan Regency. Planting cowpea plants with sunlight occurred in Keleyan Village, Socah District, Bangkalan Regency, Indonesia.

Materials used

In this research, the tools needed were a 2.5 m × 1 m × 1.5 m growbox, ESP8266 microcontroller, 100-watt full-spectrum white and red-blue LED, 12 V DC fan, relay, humidifier, and a 12 V 15 A power supply. The study also used the Blynk application, DS18B20 and BH1750 sensors, a smartphone, a cable, a ruler, stationery, an analytical scale, a poly bag, a scoop, tweezers, and a measuring cup. The materials used were the cowpea seeds, topsoil, husks, manure, silver black mulch, and marking labels.

Growbox setup

The novel research contained five main stages: i) design and preparation of premises, tools, and materials; ii) making a growbox by assembling the equipment through building a growbox using glass measuring 2.5 m × 1 m × 1.5 m. Several components entailed installation in the growbox, including an ESP8266 microcontroller, white and red-blue LEDs, a 12 V DC exhaust fan, a relay, a humidifier, polybags, a 12 V 15 A power supply, cables, and DS18B20 and BH1750 sensors. Afterward, programming continued for the growbox. The LED installed in each growbox bore adjustment to the treatments,

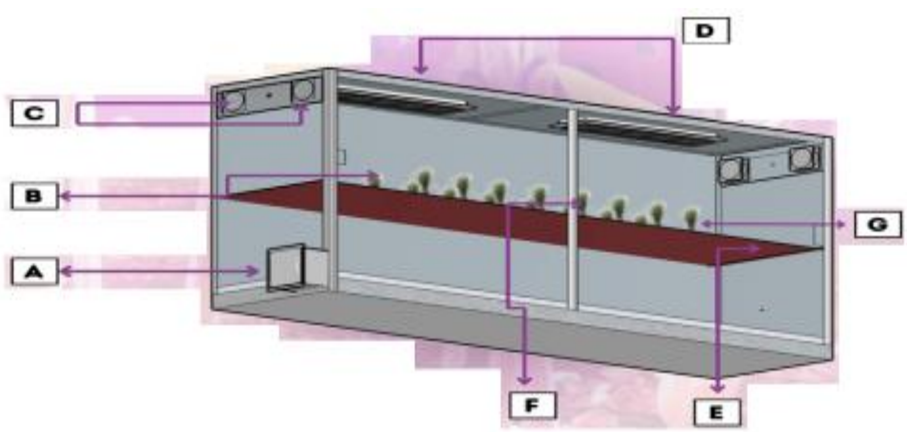

Figure 1. Growth box hydroponic farming setup. Power supply and relay (A), Temperature and Humidity Sensor DSI8B20 (B), Cooler Fan (C), LED Cool White II90 PPFD, Red Blue LE, and LED Pink Full Spectrum 778 PPFD +UV (D), Triplex (E), and Light Sensor BHI750 (F).

i.e., L1 = the red-blue LED panel, and L2 = the white LED panel. The LED on/off settings, light intensity, temperature, and humidity monitoring and control can take place remotely using the Blynk application; iii) planting the media contain a mixture of topsoil, manure, and husks, with a ratio of 1:1:1. The mixed media placement in a 6 m × 15 cm polybags helped plants in the growbox, while for plants in the field, the polybags measure 40 cm × 40 cm. The polybags received a planting of one cowpea seed each; iv) maintenance of the plants in the growbox was by watering them as and when the sensor showed the humidity was below 80%. Field maintenance included irrigation, weeding, and controlling OPT (plant pest organisms); and v) harvesting ensued after the pod skin color turned to brown from green and began to dry.

Observation and data analysis

The data recorded comprised various parameters of the cowpea, including plant height, the number of leaves, leaf area, root volume, root length, plant wet weight, plant dry weight, chlorophyll, and stomatal index, following the methodology of Fendiyanto *et al*. (2024a, 2024b, and 2024c). According to Garuba *et al.* (2014), the stomatal index (IS) calculation uses the following formula:

$$IS = \frac{DS}{DS+E} \times 100\%$$

Where DS = density (the number of stomata per 1 mm^2 of the leaf), and E = the total number of epidermal cells per 1 mm^2 of the leaf.

The obtained data underwent the analysis of variance (ANOVA) at the 5% level of probability using R software. The means with significant differences obtained further comparison and separation using the Duncan's multiple range test (DMRT, $p \leq 0.05$).

RESULTS AND DISCUSSION

Environmental characters of the LED treatment

Temperature and humidity observations took place three times, at the beginning of planting, in the middle of cultivation, and at the end of planting before harvest. Based on observed data, values of temperature and humidity in the growbox were relatively unstable (Figure 2). This may refer to the placement of the growbox, which was semi-open, allowing sunlight and heat from the outside environment to enter, and it was difficult to control. Therefore, the growbox entailed standardization via testing the level of light effectiveness by assessing and taking data during the observation process only at those three times. In each growbox, the highest temperature and humidity values were at the end of the observation (Figure 3). In the white-LED treatment, the optimum temperature was 35.19 °C with 95.34% humidity, while in the red-blue LED treatment, the maximum temperature was 33.38 °C with a humidity of 92.08% (Figure 4). The measurement of temperature and humidity of the sunlight treatment used a hygrometer, and at the beginning of cultivation, the highest temperature was 32.1 °C with a humidity of 64% (Figure 2). It is significantly different with the measurement of the middle (Figure 3) and the end of cultivation (Figure 4).

The cowpea plants' condition with the sunlight treatment was better than plants under the LED treatment. Cowpea plants grown in growboxes were smaller with fewer leaves, while plants in the field have large, wider leaves and longer, creeping stems. The light intensity for plants in the growbox was 22 hours, while in the field it was around 12 hours (Figure 5). The LED treatment used the light intensity of 10,000 lux; however, the light obtained by each plant varies as it depends on the level of light distribution. The average light intensity obtained by plants in the red-blue LED growbox was around 3776.33 lux (68.54

Figure 2. Temperature and humidity data at the start of cultivation: a) sunlight treatment, b) red blue LED treatment, and c) white LED treatment.

Figure 3. Temperature and humidity data in the middle of cultivation: a) sunlight treatment, b) red blue LED treatment, and c) white LED treatment.

Figure 4. Temperature and humidity data at the end of cultivation: a) sunlight treatment, b) red blue LED treatment, and c) white LED treatment.

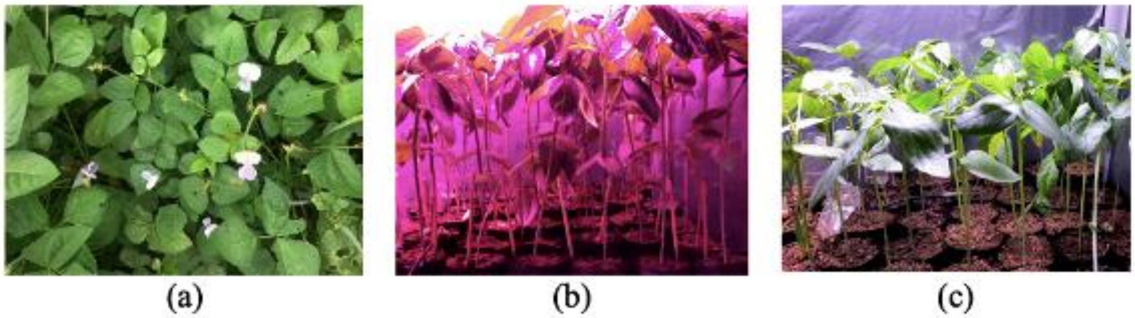

Figure 5. Plant conditions: a) sunlight treatment, b) red blue LED treatment, and c) white LED treatment.

Table 1. Plant height combination of light treatment and accession.

Treatment	Plant height (cm) at 14 day after planting (DAT)
L0V1	6.42
L0V2	8.67
L0V3	11.75
L0V4	8.83
L0V5	10.50
L1V1	20.75
L1V2	22.58
L1V3	21.33
L1V4	15.92
L1V5	22.25
L2V1	16.92
L2V2	21.00
L2V3	17.00
L2V4	15.42
L2V5	17.58
ANOVA 5**%**	*

Note: Numbers followed by the same letter in the same column indicate an effect that is not significantly different at the 5% DMRT test; * = significantly different, NS = not significantly different.

μmol m^{-2} s^{-1}), while in the white LED growbox, it was about 2263.27 lux (28.73 μmol m^{-2} s^{-1}). We also set the wavelengths of blue and white light LEDs at wavelengths of blue light (450–495 nm), red light (620–750 nm), and white light (400–700 nm).

Plant height

The interaction of light treatments and cowpea accessions showed significant differences for plant height only at 14 days after treatment (DAT) (Table 1). However, no notable differences appeared among interactions between the light and genotype in this character. The highest plant height at 14 DAT resulted in the treatment combination L1V2 (22.58 cm), followed by L1V1 (20.75 cm), L2V2 (21 cm), L1V3 (21.33 cm), and L1V5 (22.25 cm). Meanwhile, the lowest plant height surfaced in the treatment combination L0V1 (6.42 cm), which was nonsignificantly different from the two other combinations, L0V2 (8.67 cm) and L0V4 (8.83 cm). However, it considerably differed from all other treatments. This could be due to the different germination rates among the cowpea accessions, resulting in varied initial plant growth rates. Genotypic factors have a significant effect on the germination potential and growth and development of the cowpea genotypes (Wahdah *et al*., 2023).

Table 2. Plant height of light treatments and accessions.

Treatment	Plant height (cm) on the day after planting (DAT)					
	14 DAT	28 DAT	42 DAT	56 DAT	70 DAT	84 DAT
L0	9.23	16.17	39.37	74.82	134.93	162.50
L1	20.57	26.77	41.26	48.86	71.95	95.34
L2	17.58	25.67	36.30	46.88	53.12	66.32
ANOVA 5%	*	*	*	*	*	*
V1	14.69	20.53	35.92	53.36	85.41	105.54
V2	17.42	25.03	41.79	61.58	91.57	116.03
V3	16.69	23.86	38.12	57.52	87.79	112.42
V4	13.39	21.47	37.78	53.19	81.33	99.68
V5	16.78	23.44	41.28	58.61	87.23	106.59
ANOVA 5%	*	*	NS	NS	NS	NS

Note: Numbers followed by the same letter in the same column indicate an effect that is not significantly different at the 5% DMRT test; * = significantly different, NS = not significantly different.

The analysis of variance showed the cowpea accessions gave significant differences at 14 and 28 DAT. However, at 56 DAT, L0 was remarkably different from the other two treatments, and L1 and L2 provided nonsignificant variations. At 70 and 84 days after planting (DAP), the three treatments displayed noteworthy differences. The lowest to highest values entailed sequential recording at 70 and 84 DAP with L2 and L1, followed by L0 (Table 2).

The promising results were in line with past findings, which revealed crops planted under sunlike LEDs (like the sun) have the highest plant height compared with RB (red-blue) and white LEDs (Jie *et al.*, 2020). Livadariu *et al.* (2023) stated the blue LED lights combined with the white LED lights had a considerable negative impact on the wheat plant's growth. This may be because the high proportion of blue light from the WB (white-blue) LED inhibits stem elongation. However, the combined effects of red and blue lights on the growth of some types of plants decrease over time. Ma *et al.* (2021) reported that different LED light colors have varied effects on plant growth and development.

Leaves per plant

The L0 ranks highest in the number of leaves in cowpea plants, ranging from 28 to 84 DAP. This may refer to the complete spectrum of sunlight (L0), which includes all the wavelengths required for photosynthesis. However, at 84 DAT, cowpea plants in the L0 treatment showed a decrease in the number of leaves. This situation could occur due to the senescence activity of leaves. In this phase, the metabolite content becomes degraded and transferred to other tissues that are still under the developing stage (Khafid *et al.,* 2021; Pratami *et al*., 2025).

The analysis of variance enunciated significant differences among the light treatments for the number of leaves from the beginning to the end of plant growth (Table 3). Specifically at 14 DAP, treatment L1 showed the highest number of leaves as compared with the two other treatments. At 28 and 42 DAP, the lowest to highest number of leaves obtained sequential recording in L2 and L1, as compared with L0. This is because the red-blue light provides sufficient energy for the leaf growth process (Zulviana *et al.,* 2020). Apart from it being caused by external factors such as light, the increased number of leaves also resulted from genetic factors and hormones (Wiguna *et al.,* 2017). However, treatments L1 and L2 had a stagnant number of leaves from the beginning to harvest due to the presence of dead leaves.

Leaf area

No significant interaction effects emerged between lights and cowpea accessions on the leaf area (Table 4). However, the light factor individually has a marked effect on the leaf area. The smallest to largest leaf area came

Table 3. Number of leaves of light treatments and accessions.

Treatment	Leaf number on the day after planting (DAT)					
	14 DAT	28 DAT	42 DAT	56 DAT	70 DAT	84 DAT
L0	3.40	6.57	28.37	54.13	65.93	36.27
L1	3.83	5.10	5.77	4.13	5.27	5.47
L2	3.50	3.40	3.53	4.33	4.43	5.10
ANOVA 5%	*	*	*	*	*	*
V1	3.56	4.22	11.72	21.00	26.06	14.89
V2	3.72	5.67	13.61	22.67	27.44	16.83
V3	3.61	5.11	12.72	20.89	24.17	15.72
V4	3.44	4.89	11.44	20.00	24.72	14.44
V5	3.56	5.23	13.28	19.78	23.67	16.17
ANOVA 5%	NS	NS	NS	NS	NS	NS

Note: Numbers followed by the same letter in the same column indicate an effect that is not significantly different at the 5% DMRT test; * = significantly different, NS = not significantly different.

Table 4. Mean leaf area, root volume, root length, wet weight, dry weight, and chlorophyll in light and in the accession treatments.

Treatment	Leaf area (cm^2)	Root volume (mL)	Root length (cm)	Plant wet weight (g)	Plant dry weight (g)	Chlorophyll	Stomatal index (%)
L0	119.11	9.46	53.87	120.48	23.78	46.04	31.52
L1	43.38	1.42	17.54	12.03	1.51	45.12	26.76
L2	28.41	0.42	14.79	6.70	0.87	44.47	25.14
ANOVA 5%	*	*	*	*	*	NS	*
V1	57.57	3.21	30.36	40.80	7.91	42.82	28.80
V2	70.77	4.33	32.12	53.31	9.94	47.22	28.43
V3	66.32	3.90	29.17	48.02	8.94	45.57	28.50
V4	59.78	3.88	27.08	42.93	8.20	44.59	26.60
V5	63.71	3.51	24.94	46.94	8.62	45.84	26.72
ANOVA 5%	NS	*	NS	NS	NS	NS	NS

Note: Numbers followed by the same letter in the same column indicate an effect that is not significantly different at the 5% DMRT test; * = significantly different, NS = not significantly different.

about sequentially from L2 (LED full spectrum white), with an average leaf area of 28.41 cm^2; L1 (LED full spectrum red-blue), with an average of 43.38 cm^2; and L0 (sunlight), with an average leaf area of 119.11 cm^2. L2 has a smaller leaf area than the L1 treatment. Rosniza *et al.* (2023) exposed the 'pak choi' plants to the red-blue LED light and had greater leaf area than plants grown under the white LED because the red-blue wavelength stimulated more photosynthetic performance. However, in this study's results, the treatments L1 and L2 had a much lower average leaf area than treatment L0. An explanation for this is the accessions have poor response to long photoperiods and high radiation (Ghosh *et al*., 2018).

Root volume

Light treatments significantly affected the root volume in cowpea genotypes. Overall, the L0 had the highest root volume (9.46 mL), while L2 had the lowest root volume (0.42 mL). The results were greatly analogous to the findings of Amoozgar *et al.* (2017), which stated that lettuce plants grown under red-blue LEDs had heavier fresh weight than the lettuce planted under white LEDs. Similarly, the lettuce grown in greenhouse conditions had larger roots than those grown under LED lights. The water and nutrient absorption occur through the tips of the roots, which cause root development and a balance between root volume and plant growth (Jafar *et al.,* 2013).

Root length

The light treatments revealed remarkable variations for root length in cowpea genotypes. The L0 has the longest average root length (53.87 cm), which appeared significantly different from L1 (17.54 cm) and L2 (14.79 cm) (Table 4). However, L1 and L2 showed nonsignificant differences in root length in the cowpea genotypes. Bantis *et al.* (2016) reported lettuce plants grown under the red-blue LED treatment had longer roots; however, they were nonsignificantly dissimilar from lettuce plants grown under white lights.

Plant wet weight

The results revealed the best light treatment was the sunlight (L0), with an average wet plant weight of 120.48 g in cowpea genotypes, and the said treatment occurred significantly differently from the two other treatments, L1 (12.03 g) and L2 (6.70 g) (Table 4). However, L1 and L2 treatments were at par statistically at the plant wet weight character. The sunlight treatment had the heaviest plant wet weight, followed by the red-blue and white LED treatments sequentially on the lettuce plants (Jie *et al.,* 2020). Plants grown under sunlike LEDs showed greater size and biomass than plants grown under white and red-blue LEDs. This may be ascribable to the longer photoperiods and high radiation, which result in heat stress effects in crop plants (Ghosh *et al.,* 2018). Heat stress significantly affects the growth of cowpea plants because it results in a low plant biomass due to disturbances in the plant's photosynthetic apparatus, impairing assimilation, inhibiting the N2 fixation, and increasing the leaf senescence (Mekonnen *et al.,* 2022).

Plant dry weight and chlorophyll content

The light treatments showed significant differences for plant dry weight and chlorophyll content in cowpea genotypes (Table 4). Overall, the highest plant dry weight resulted in the treatment L0 (23.78 g), which was notably different from two other treatments. However, the lowest dry weight manifested in treatment L2 (0.87 g), which was also nonsignificantly unusual from treatment L1 (1.51 g). Jie *et al.* (2020) reported lettuce plants with sunlike treatment had the maximum plant dry weight compared with plants treated with red-blue and white LEDs. Plant dry weight is the final product of growth, serving as a growth indicator. If the plant growth process incurs disruptions, the resulting plants will have a low dry weight (Adhim and Suminarti, 2023). Moreover, Jie *et al.* (2020) have researched the chlorophyll content in the lettuce grown under red-blue, white, and sunlike LEDs and obtained varied results.

Stomatal index

The light treatments have a significant effect on the stomatal index of the cowpea genotypes (Table 4). The sunlight treatment revealed the highest stomatal index (31.52%), occurring remarkably differently from other LED treatments. Plant behavior attained marked influences from the spectrum obtained from the light source, both artificial and natural light, revealing different metabolic effects. Plants exposed to the red, blue, and combined LED spectra can experience variations in gas exchange through stomatal density and their opening (Paradiso and Proietti, 2022). Their findings also emphasized how important the light composition is in regulating plant transpiration, especially the quantity of blue light. However, the red, blue, and white LEDs used in this study cannot fully mimic the effects of the full spectrum of sunlight.

CONCLUSIONS

Based on physiological studies, plants with the light treatment experienced an increase in plant length, plant stomatal index, and root and leaf characters. Light makes plants experience efficient photosynthesis processes, causing it to positively impact the growth and development of local Madura cowpea plants. The light spectrum significantly influenced several growth parameters of the cowpea genotype, i.e., plant height, the number of leaves, leaf area, root length, root volume, the plant's wet and dry weights, and stomatal index. The results revealed the cowpea plants exposed to sunlight produced the best growth and development compared with the LED treatments. One can conclude the natural sunlight spectrum proved more supportive of photosynthesis and metabolism processes of cowpea plants than the light spectrum produced by the red, blue, and white LEDs.

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