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BIOLOGY

Lantana flowering at an indoor active living wall in a light-restricted environment

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ABSTRACT: The time spent by urban residents indoors has been increasing annually, thus, prioritizing the enhancement of indoor spaces into green spaces to improve the quality of life. Even with limited environmental conditions indoors, an active living wall and LED light techniques have enabled us to explore indoor green environments. In the present study, the yellow/orange-colored flowers invasive ornamental species, *Lantana camara* 'splendens', was cultivated in 4.0 m^2 of the active living wall under a non-decorative LED lamp, adjusted to optimize performance in the coverage area. This study evaluated the development of lantana in the active living wall under different light intensities (135 watts and 90 watts) in a room with light restriction. Parameters such as plant height, flowering, SPAD chlorophyll content, and vegetative cover were analyzed. The results indicated that *Lantana camara* 'splendens' is suitable for use in active living walls and blooms at a low light intensity when the light is uniformly applied.
Key words: flower culture, plasticity, ornamental, good health, *Lantana camara* L.

Florescimento de Lantana em jardim vertical indoor em ambiente com restrição de luz

RESUMO: O tempo gasto pelos moradores urbanos em ambientes fechados vem aumentando anualmente, assim, priorizando a valorização dos espaços internos em espaços verdes para melhorar a qualidade de vida. Mesmo com condições ambientais limitadas em ambientes internos, o uso de jardins verticais e técnicas de luz de LED nos permitiram explorar ambientes verdes internos. No presente estudo, a espécie ornamental invasora de flores de coloração amarela/alaranjada, *Lantana camara* 'splendens', foi cultivado em 4,0 m^2 de jardim vertical sob luminária LED não decorativa, ajustada para otimizar a performance na área de cobertura. Este estudo teve como objetivo avaliar o desenvolvimento da *Lantana camara* 'splendens', em jardim vertical, sob diferentes intensidades de luz (135 watts e 90 watts), em ambiente com restrição total de luz. Foram analisados parâmetros como altura da planta, floração, teor de clorofila SPAD e cobertura vegetativa. Os resultados indicam que *Lantana camara* 'splendens' é adequada para uso em jardim vertical e floresce em baixa intensidade de luz quando a luz é aplicada uniformemente.
Palavras-chave: floricultura, plasticidade, ornamental, boa saúde, *Lantana camara* L.

INTRODUCTION

The cultivation of indoor plants using an active living wall (ALW) represents a technological advancement that can be applied in urban environments, such as malls and corporate companies. In addition to the beauty provided by natural plants, the use of indoor ALW improves the air quality (particles and VOC - volatile organic compounds - retention) and environmental conditions (temperature and humidity levels) and reduces noise pollution (GUNAWARDENA & STEEMERS, 2019; MOYA et al., 2019). Recently, the use of ALW in domestic environments has significantly increased due to extended family time at home. Home office activities, distance learning, and social restrictions due to the recent COVID-19 pandemic have greatly contributed to this change in habits; thus, ALW is the preferred option for the inclusion of green plants indoors (PÉREZ-URRESTARAZU et al., 2021). Additionally, renewing indoor esthetics has positive psychological effects on residents and workers (LOHR et al., 1996; QIN et al., 2014). However, the intensity of natural light in indoor environments is often insufficient for the complete development of ornamental plant species. Studies using artificial light, mainly LED light, have shown the different lighting options on the present market restrictions of indoor ALW plants (TAN et al., 2017; KALTSIDI et al., 2020).

Adjusting the light intensity (LI) is difficult because the position of the light source in ALW does not allow for uniform light distribution and harms the

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environmental esthetics (EGEA et al., 2014). Thus, plants that require a low LI are suitable for indoor ALW cultivation, making green tropical plants an ideal option (GUNAWARDENA & STEEMERS, 2019; KAZEMI et al., 2020). Plant colors can influence the behavior of indoor inhabitants. The use of green-yellow and light green colored species is recommended in relaxing and tranquil environments while dark red and green plants can improve the energy in workplaces and children's areas (LINTON, 1999; ELSADEK & FUJII, 2014; ELSADEK et al., 2017). Most biodiversity studies on indoor ALW cultivation have been conducted on green plants while only a few studies have been conducted on species having flowers of varying colors. Lantana (*Lantana camara* L) has interesting characteristics for indoor ALW cultivation. Although, lantana is an invasive crop in landscape gardens, its cultivation in pots and benches is highly recommended (PASSOS et al., 2009; NEGI et al., 2019). This species has a great diversity of colors, is rustic in cultivation, and can be pruned if necessary. Furthermore, it responds well to variations in LI (MUTHAHARA et al., 2018; GOYAL & SHARMA, 2019). Thus, the present study evaluated, under a light-restrict environment, the effect of two different LIs of a non-decorative light lamp on growing *Lantana camara* 'splendens' in ALW.

The ornamental *Lantana camara* '*splendens*' was selected due to its commercial value and yellow- and orange-colored flowers, which convey a feeling of well-being (LINTON, 1999). The study was performed in a room with light restriction (LR) maintained at a uniform temperature of 25 °C (±2 °C) and constant relative humidity of 60%. Two different LIs, 90 Watts = W90 and 135 Watts = W135, were evaluated using a non-decorative LED lamp, model Avena (ONNO®,Piracicaba, Brazil), with characteristics and relative emission intensity spectra as shown in Figures 1A, B, and C. The LED lamp set from each treatment was arranged in the front and middle of the upper part of ALW with an adjustable metallic bar - 1.0 m from the module (Figure 1D). The angle between the bar and wall was 80°, and the angle between the LED lamp set and bar was 135°. The adjustments were made to optimize performance in the coverage area (Figure 1E). The distributed LI was measured at 25 points of each ALW using a light meter LI-250A and quantum sensor LI-190R (Li-Cor, Nebraska, USA) to obtain the average density of photosynthetic photon flux (µmol m^{-2} s^{-1}) (Figures 1F and G). The ALW modules were based on a commercial system (Vertigarden®, Piracicaba, Brazil), with dimensions 1.0 m wide x 1.0 m high x 0.10 m deep. Each module structure comprised two synthetic layers, a hydrophobic layer of polypropylene alveolar anti-UV treatment (Brasken®, São Paulo, Brazil) and overlapping layers of a non-putrescible hydrophilic felt screen (geotextile, 1.5 cm thick), forming 25 bags per m^2 (five rows and five columns), arranged equidistantly from the position of insertion of plants. The synthetic layers were clipped together on an aluminum layer (1.0 m wide x 1.0 m high) with press buttons (Figures 1D and E).

A total of four modules were installed side by side (two for each LI) at a height of 0.8 m from the floor. Between the modules, an anti-reflective curtain (1.0 m x 0.5 m) was installed perpendicular to the wall, and a constant 12-h photoperiod was maintained. Fertigation by drippers located on top of the modules (5 drips m^{-1} with a flow of 0.001 m^3 h^{-1}) in a 15-min/4-h regimen was adjusted using a timer to an electric pump of 1.5 CV (Schneider BC-92S, flow of 0.10 m^3h^{-1}). The liquid formulation (Vertigarden® NPK 4-14-8 + Micronutrients) was adjusted to supply nutrients to the plants until they flowered (15 ml L^{-1}). The drained solution was collected via a common gutter installed at the base of the modules, and it was stored in a 0.05 m^3 tank. Every two weeks, the solution used was replaced, and an EC of 1.3 and pH of 5.9 was maintained. Following this, a lantana plant with three stems (10.0 cm in height) was planted in each bag. After two weeks of the plantation, data on the plant height (from base to apex - cm), number of flowers per individual lantana, and photosynthetic activity (SPAD units, chlorofiLOGFalker® SPAD-500, Porto Alegre, Brazil) were collected. Three measurements were taken per leaf in four leaves per plant of nine plants per module. The green cover evolution (RGB images) of each ALW module was evaluated from the same position. The fraction of the ALW area covered by the lantana plants was determined using ImageJ software (RUEDEN et al., 2017), separating the pixels corresponding to the green cover of the background. The experimental design used was completely randomized, with two LI treatments (W90 and W135) and 18 replicates each. These repetitions were evaluated at six different time intervals (I) of the plant cycle, with data being collected every 15 days for a total of 90 days. As these data did not meet the assumption of normality of the residuals, mixed generalized linear models were used. The results were analyzed using R software (version 4.0.3) and package lme4 (BATES et al., 2015). Posthoc pairwise contrasts between least square means were evaluated using the package emmeans (LENTH et al., 2022). All analyses were performed considering a confidence level of 0.05.

LUMINAIRE MODEL	PROJECTOR	MANUFACTURER	POWER (W)	PPF (μmol/s)	VIEWING ANGLE	COLOR OF LIGHT
LINHA AVENA		ONNO LED. BRASIL	90	146	35°	WHITE, BLUE, RED
LINHA AVENA		ONNO LED. BRASIL	135	219	35°	WHITE, BLUE, RED

A

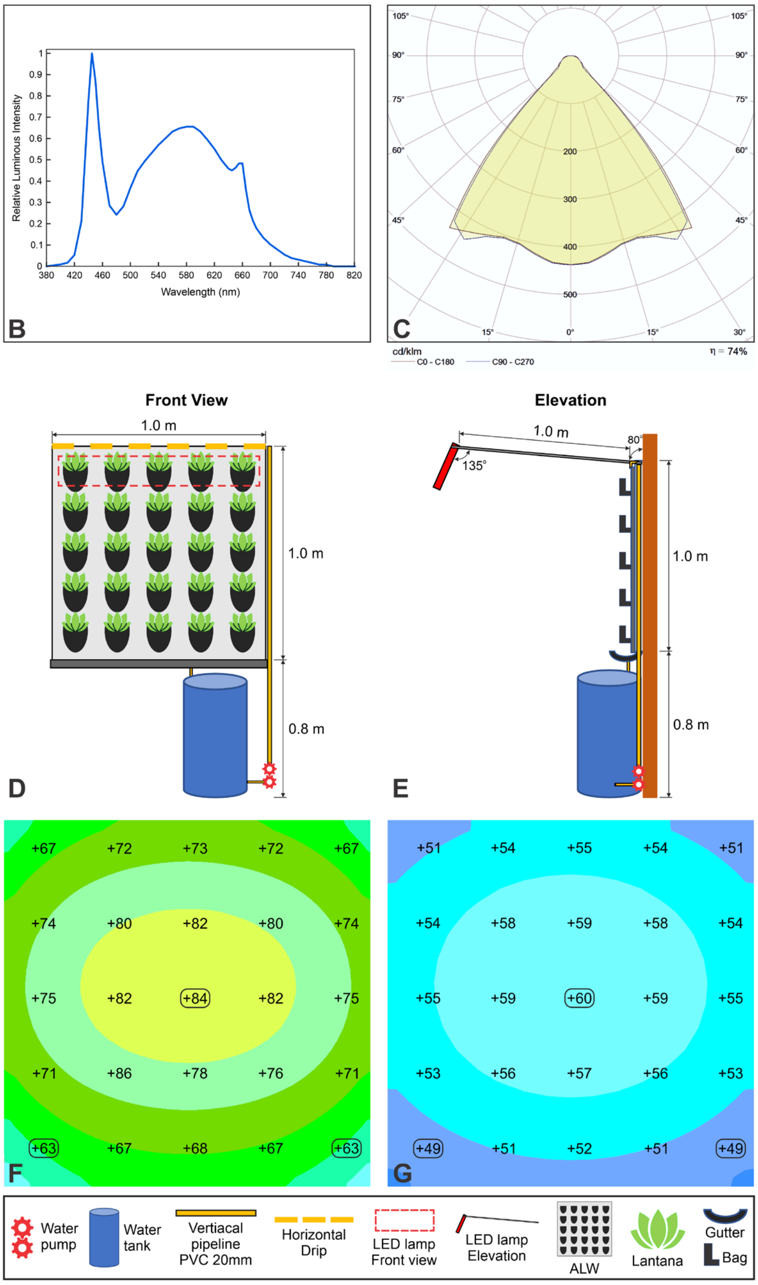

Figure 1 - Led lamps used in the study and their characteristics- Graphs courtesy ONNO® (A, B, and C); Layout of the experiment – Front view (D) and Elevation view (E); Light intensity - µmol m^{-2} s^{-1} – in different locations of ALW – W135 (F) and W90 (G).

During the vegetative development of lantana, the plant height significantly differed from I1 to I4; conversely, there was no significant difference between I4 and I6. This was observed for the two LIs studied. When comparing LI, no significant difference was observed for any of the evaluated intervals (Table 1). LI did not cause etiolation, and from I4 onwards, the plant height stabilized. This result suggested that the LED lamp coverage area was adequate to maintain the plant height from I4 to I6. In field cultivation, *Lantana camara* 'splendens' responded to different LIs. Plants grown under 50% shade (1048 µmol $m^{-2}s^{-1}$) showed twice the vegetative growth as compared to those grown under complete sunlight (2329 µmol $m^{-2}s^{-1}$). Conversely, while comparing plants grown under full sun and 25% shading (1668 µmol $m^{-2}s^{-1}$), no significant difference was observed in plant height (MUTHAHARA et al., 2018; GUNASEKARA & RANWALA, 2018). In the present research, the effective LIs were 146 µmol $m^{-2}s^{-1}$ (W90) and 219 µmol $m^{-2}s^{-1}$ (W135), with plants receiving approximately 50-70 µmol $m^{-2}s^{-1}$ (W90) and 70-90 µmol $m^{-2}s^{-1}$ (W135), respectively. In other words, despite the LI being approximately 25 times lower than that in the natural environment, the plants had good vegetative development. Additionally, in ALW, the plant growth was non-invasive, keeping plants in a good vegetative state without the occurrence of visual symptoms of nutritional deficiency. Possibly, the environmental conditions of LR room and the regular supply of water and nutrients provided minimal stress on the plants.

Table 1 - Mean ± standard error of height (cm), number of flowers, chlorophyll *a,* chlorophyll *b*, total chlorophyll, and green cover (%) in cultivation at lantana living wall, under LED light of 90 W and 135 W of power, after six evaluations.

Light source	----------Evaluation----------						Average across evaluations
	1	2	3	4	5	6	
----------Height----------							
90 W	9.00 ± 0.37	12.50 ± 0.56	18.67 ± 0.77	22.97 ± 1.32	23.83 ± 1.17	24.72 ± 1.37	18.62 ± 0.70 a
135 W	9.61 ± 0.40	13.44 ± 0.70	18.44 ± 0.76	24.31 ± 1.13	25.67 ± 1.19	25.97 ± 1.39	19.57 ± 0.73 a
Average	9.31 ± 0.27 D	12.97 ± 0.45 C	18.56 ± 0.54 B	23.64 ± 0.86 A	24.75 ± 0.84 A	25.35 ± 0.97 A	
p-values	0.3748 (light source); <0.0001 (evaluation); 0.5041 (interaction)						
----------Number of flowers----------							
90 W	0.06 ± 0.06 Ca	1.44 ± 0.27 Ba	0.89 ± 0.28 Bb	3.61 ± 0.52 Aa	3.94 ± 0.55 Ab	3.72 ± 0.51 Aa	2.28 ± 0.22
135 W	0.11 ± 0.11 Ba	3.06 ± 0.48 Aa	2.72 ± 0.56 Aa	3.78 ± 0.45 Aa	4.44 ± 0.35 Aa	4.44 ± 0.35 Aa	3.10 ± 0.22
Average	0.08 ± 0.06	2.25 ± 0.30	1.81 ± 0.35	3.69 ± 0.34	4.19 ± 0.32	4.08 ± 0.31	
p-values	0.0354 (light source); <0.0001 (evaluation); 0.0073 (interaction)						
----------Chlorophyll *a*----------							
90 W	289.47 ± 8.45	352.28 ± 9.46	376.92 ± 4.57	386.67 ± 2.38	407.08 ± 4.91	392.44 ± 4.67	367.48 ± 4.49 b
135 W	299.94 ± 8.86	377.92 ± 5.73	396.92 ± 5.43	398.33 ± 5.51	422.53 ± 4.42	407.89 ± 7.60	383;92 ± 4.63 a
Average	294.71 ± 6.10 D	365.10 ± 5.87 C	386.92 ± 3.88 B	392.50 ± 3.12 B	414.81 ± 3.51 A	400.17 ± 4.58 AB	
p-values	0.0114 (light source); <0.0001 (evaluation); 0.7765 (interaction)						
----------Chlorophyll *b*----------							
90 W	61.47 ± 3.06	81.72 ± 3.54	97.61 ± 3.28	108.33 ± 1.88	113.83 ± 2.97	117.14 ± 3.66	96.69 ± 2.27 b
135 W	61.06 ± 2.60	89.19 ± 3.09	107.44 ± 4.31	120.61 ± 5.09	130.47 ± 5.26	140.67 ± 10.38	108.24 ± 3.45 a
Average	61.26 ± 1.98 E	85.46 ± 2.40 D	102.53 ± 2.80 C	114.47 ± 2.87 BC	122.15 ± 3.29 A	128.90 ± 5.78 AB	
p-values	0.0376 (light source); <0.0001 (evaluation); 0.6213 (interaction)						
----------Total Chlorophyll----------							
90 W	350.14 ± 11.61	433.94 ± 13.21	473.22 ± 7.83	494.42 ± 4.15	521.58 ± 7.56	509.67 ± 8.64	463.83 ± 6.73 b
135 W	361.42 ± 11.39	467.64 ± 8.60	503.28 ± 10.32	518.47 ± 10.80	553.72 ± 8.85	549.33 ± 17.19	492.31 ± 7.81 a
Average	355.78 ± 8.07 E	450.79 ± 8.27 D	488.25 ± 6.87 C	506.44 ± 6.05 BC	537.65 ± 6.35 A	529.50 ± 10.06 AB	
p-values	0.0201 (light source); <0.0001 (evaluation); 0.9146 (interaction)						
----------Green Cover (%)----------							
90 W	34.50	61.80	76.48	87.80	90.57	93.82	
135 W	40.73	71.21	84.87	92.84	93.32	98.09	

Uppercase letters compare different evaluations in time with the same light source, whereas lowercase letters compare different light sources in the same evaluation. Different letters indicate significant differences (P < 0.05).

At W90, no significant difference was observed between I1 and I2, and flowering remained stable between I2 and I3. Additionally, no significant difference was observed between I3 and I4 as well as I4 and I6. Conversely for W135, no significant difference was observed between I1 and I2, and no significant difference was observed in I2 until the end of the evaluation in I6. Thus, in W135, flowering was anticipated, and it resulted in a higher number of flowers as compared to W90, which was irregular. When comparing LI, a significant difference was observed between W90 and W135 in the intervals I2, I3, and I5, with a higher number of flowers in W135 than in W90 (Table 1). In addition, in the natural environment, the lantana wild cultivar produces more flowers in full sun than grown in shaded environments with low LI. It has been reported that wild cultivars showed a direct correlation between LI and flowering (MUTHAHARA et al., 2018; GOYAL & SHARMA, 2019). In the present study, the LIs studied (W90 and W135) are considered low when compared to a natural light environment, even in shade. Thus, the results indicated that *Lantana camara* 'splendens' responds to LI in ALW, even at low LIs.

In the evaluated pigments of chlorophyll *a* and *total* (SPAD index), a significant and increasing difference was observed in the SPAD index from I1 to I5, and it remained stable or with a significant and decreasing difference between I5 and I6. On the other hand, when comparing LI, a significant difference was observed at all evaluated time points, with a higher SPAD index for chlorophyll *a* and *total* in W135 than in W90. The same did not occur with the SPAD index for chlorophyll *b*, with no significant difference between different LIs (Table 1). In the full-sun natural environment, *Lantana camara* 'splendens' produces low levels of chlorophyll *a* and *b* when compared to shaded environments (GUNASEKARA & RANWALA, 2018). The production of high levels of chlorophyll *a* and *b* in shaded environments is the plastic response of this cultivar to optimizing light capture (VALLADARES & NIINEMETS, 2008). Additionally, in our study, the pigments chlorophyll *a* and *total* were directly proportional to the LI levels.

The green cover analyzed using ImageJ was superior in W135 at all time points. From I4 onwards, the panels had approximately 90% green cover for the two LIs evaluated (Table 1). Tests with different LED lamps on green plant species showed that the green cover was up to 80% of the LW for plants closer to the light source while in distant plants, they resulted in a green cover of 65%. In this case, the variations in the green cover rate were justified by the non-centered positioning of the light source (KALTSIDI et al., 2020).

In the present study, a non-decorative LED lamp covered a 1.0 m^2 panel area. This type of lamp, in the adjusted position with the panel, kept the plants growing uniformly, and the LI was sufficient for flowering in the LR environment. The favorable results justify an improvement in the engineering and esthetics of this type of LED lamp, thus, maintaining the lighting coverage area and dimming the luminous intensity. Recent studies have demonstrated reduced options for LED lamp system fixtures to meet the needs of flowering plants (KALTSIDI et al., 2020). An LED lamp system can be set up on the ceiling, and it can be activated using synchronized pneumatic mechanisms according to photoperiod and luminous intensity commanded via artificial intelligence.

The results obtained for *Lantana camara* 'splendens' in ALW confirmed the modulation capacity of this species in adapting to low LI environments. In some plant species, when they compete for essential resources for survival, especially limiting ones, they adapt to the new environment and induce changes in biomass allocation patterns for plant architecture, forming tissues to obtain the maximum benefit from available resources (VALLADARES & NIINEMETS, 2008). Thus, even at low LIs, differences were observed in flowering, chlorophyll *a* content, and total and green cover at the highest LI applied. This result is important because lantana showed plasticity at a minimum intensity of 50-70 $\mu mol\ m^{-2}s^{-1}$. The adaptation of this species to indoor ALW cultivation at low LIs can help color the most varied indoor urban environments, thus, improving the quality of life in these environments.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

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