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Research Article

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Light spectrum influences adventitious root formation and shoot growth in *Euphorbia leucocephala* Lotsy stem cuttings

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ABSTRACT

Euphorbia leucocephala Lotsy (commonly known as "pascuita") is a popular ornamental species in Mexico, especially during the Christmas season. It is mainly propagated by stem cuttings; however, low rooting rates and poor plantlet quality limit its commercial potential. Light-emitting diode (LED) lighting has been shown to affect vegetative propagation in various species. This study evaluated the effects of different LED light spectra on adventitious root formation and shoot development in apical and basal cuttings of *E. leucocephala*. A split-plot design was used with four light treatments—white, red, and blue LEDs (90 µmol m^{-2} s^{-1}, 16-hour photoperiod) and natural light—as main plots and cutting types (apical and basal) as subplots. After nine weeks, red LED light induced the highest rooting percentage (82%) and root development. Basal cuttings produced the longest roots (13.65 cm) and the highest number of roots per cutting (7.87). Shoot growth was also enhanced by LED lighting compared to natural light, particularly under red and blue light, with basal cuttings showing the most vigorous development. These results demonstrate that LED lighting, especially red and blue spectra, significantly improves adventitious rooting and the quality of plantlets obtained from stem cuttings of *E. leucocephala*.

KEYWORDS: Adventitious rooting, Steam cuttings, Plantlets, LED lighting

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INTRODUCTION

Euphorbia leucocephala Lotsy, commonly known as "pascuita", is a perennial ornamental plant belonging to the family Euphorbiaceae. Like poinsettia (*Euphorbia pulcherrima*), *E. leucocephala* is a short-day species that flowers naturally during the autumn and winter months. It is native to southern Mexico and Central America; however, its ornamental use during the Christmas season has facilitated its distribution to other regions worldwide (Acevedo-Rodríguez & Strong, 2012).

In Mexico, commercial production of *E. leucocephala* remains limited and is primarily concentrated in areas where poinsettia is grown (García *et al.*, 2019). The absence of commercial cultivars, difficulties in producing compact, pot-adapted plants, and the low rooting success of cuttings—often accompanied by poor seedling quality—are the main limitations to its broader commercial adoption.

Propagation is typically conducted in spring using mature stem cuttings treated with commercial rooting agents rich in indole-3-butyric acid (IBA). These cuttings are usually maintained either outdoors or in greenhouses under high relative humidity. However, this method is associated with high cutting mortality and significant variability in the quality of the resulting plantlets (Martínez-Villegas *et al.*, 2015; García *et al.*, 2019). Successful vegetative propagation of *E. leucocephala* depends on achieving a high rooting rate-ideally close to 100% and producing healthy, compact plantlets with short internodes and at least three new branches to form the plant's primary structure.

Adventitious root formation is a complex physiological process influenced by several intrinsic factors, including plant growth regulators, water relations, nutrient status, and the ontogenetic and physiological maturity of the cutting (Guan *et al.*, 2015). The initiation phase of root formation is characterized by intense metabolic activity, driven by an auxin-rich hormonal

balance in the basal region of the cutting, which stimulates enzymatic activity and the synthesis of DNA, RNA, and proteins (Druege *et al.*, 2016). During the root elongation and shoot development phases, carbohydrate reserves in the stem are depleted to supply energy and structural carbon to the growing tissues (Druege *et al.*, 2019).

In practice, the auxin-dominated hormonal environment is typically achieved through the application of synthetic auxins to the propagules (Roth *et al.*, 2024). Additionally, the rooting potential of a cutting is closely related to the physiological and ontogenetic maturity of the donor tissue, as well as the availability of stored carbohydrates and nutrients-factors that strongly influence both the number and quality of adventitious roots (Druege *et al.*, 2019). A thorough understanding of these aspects, combined with optimal design of rooting environments, can lead to improved propagation outcomes. However, opportunities still exist to enhance the efficiency of the underlying biochemical and physiological processes.

The spectral quality of light plays a critical role in regulating plant biochemical and physiological responses (Abidi *et al.*, 2013; Ouzounis *et al.*, 2015; Kulus & Woźny, 2020; Livadariu *et al.*, 2023). Within the light spectrum, wavelengths between 400 and 700 nm referred to as photosynthetically active radiation (PAR) are absorbed by plants and drive photosynthesis, thereby directly influencing growth (Davis & Burns, 2016). Beyond PAR, both shorter and longer wavelengths can also be perceived by plant photoreceptors, triggering signal cascades that regulate growth, development, morphology, and secondary metabolism (Ouzounis *et al.*, 2015).

In the context of vegetative propagation by stem cuttings, several studies have demonstrated that manipulating light quality, particularly with LEDs, can enhance rooting success and improve the quality of resulting plantlets (Daud *et al.*, 2013; Alallaq *et al.*, 2020; Gil *et al.*, 2020, 2021; Shen *et al.*, 2022). For example, LED light has been shown to facilitate the transport of endogenous auxins from the leaves to the rooting zone (Shen *et al.*, 2022), while blue light can increase the expression of auxin biosynthesis genes, promoting adventitious rooting (Gil *et al.*, 2020, 2021). Red light has been reported to stimulate root formation by suppressing the accumulation of hormones that antagonize auxin activity (Alallaq *et al.*, 2020).

In addition to these hormonal effects, red and blue LED light can influence photosynthetic activity, as their wavelengths align with the peak absorption spectra of chlorophylls (Ouzounis *et al.*, 2015; Davis & Burns, 2016). The sugars produced via photosynthesis serve as essential energy sources and structural precursors for growing roots and shoots, contributing to the development of more vigorous plantlets (Druege *et al.*, 2019); However, this process also increases internal water demand, which can become detrimental if the developing root system is not yet capable of sufficient water uptake (Guan *et al.*, 2015; Druege *et al.*, 2019).

The advent of LED technology has facilitated the development of new artificial lighting systems for rooting chambers and greenhouses. Nonetheless, species-specific responses to light spectra are common (Abidi *et al.*, 2013; Manivannan *et al.*, 2017; Christiaens *et al.*, 2019; Gil *et al.*, 2020; Schroeter-Zakrzewska & Pradita, 2021) In the case of *E. leucocephala*, no published studies have addressed the influence of spectral light quality on adventitious rooting.

Given this knowledge gap, the objective of the present study was to evaluate the effects of LED lighting at different wavelengths on adventitious root formation and shoot development in apical and basal cuttings of *Euphorbia leucocephala*.

MATERIALS AND METHODS

The experiment was conducted from August to October 2022 in a greenhouse at the Graduate Program in Horticulture, Chapingo Autonomous University (Mexico). Three-year-old *Euphorbia leucocephala* mother plants, previously established in the same greenhouse, were used as the source of cuttings. These plants were grown in 12-inch pots filled with a substrate composed of peat, perlite, and soil in equal proportions, and fertilized biweekly with Ultrasol® Multipurpose at a concentration of 2000 mg L^{-1}. Additionally, three weeks prior to cutting collection, Ultrasol® Micro-mix was applied via irrigation at a rate of 1000 mg L^{-1}.

Explants were obtained from the branches of ten randomly selected mother plants out of a total population of 53 plants. Each cutting consisted of a stem segment containing two nodes and the corresponding internode. The lower node was defoliated, while five leaves were retained on the upper node. Cuttings were classified into two types based on their position on the branch: basal (taken from the lower part of the branch) and apical (consisting of the penultimate formed internode). All cuttings were treated with Radix® 1500 rooting hormone at the base prior to planting.

Cuttings were inserted into 50-cell trays, each cavity filled with 100 mL of a substrate consisting of perlite and peat in a 3:1 ratio. Each tray contained 25 apical and 25 basal cuttings, randomly distributed. The trays were then placed inside light-isolated plastic chambers (80×40×80 cm; length×width×height), whose interiors were white and exteriors black. Three light treatments were established inside the chambers using white, red, and blue LED light sources, with two replicates per treatment. Additionally, natural light treatment was included by placing two trays outside the chambers under ambient conditions.

The experiment followed a split-plot design, with light quality as the main plot factor and cutting type (apical or basal) as the subplot factor. The experimental unit was a single *E. leucocephala* cutting.

LED light sources were installed at the top of each chamber at a height that allowed a photosynthetic photon flux density (PPFD) of 90 μmol m^{-2} s^{-1}, measured 10 cm above the substrate using an Apogee® QMSW-SS quantum sensor. Red and blue

light treatments used two HYDROFARM® PPB1004 LED lamps per chamber, while the white light treatment used two TIANLAI® TLRL-02 panels per chamber. The spectral characteristics of each light source (Table 1) were determined after installation using an Apogee® StelarNet PS-300 spectroradiometer. A photoperiod of 16 hours was maintained throughout the experiment.

Inside the isolation chambers, the average temperature was 24.34 °C and the average relative humidity was 58.52% (data logger Elitech® RC-51H). Outside the chambers, the average temperature was 21.8 °C, relative humidity was 49.48%, and average daytime light intensity was 203.44 μmol m^{-2} s^{-1} (data logger HOBO® Onset).

Six weeks after the beginning of the experiment, 10 apical and 10 basal cuttings were randomly taken from each treatment to assess root presence or absence. The same procedure was repeated at nine weeks. To evaluate the morphological characteristics of the plantlets formed at nine weeks, three basal and three apical-derived plantlets were randomly selected from each replicate within each treatment. The number of primary adventitious roots, total root length, and fresh and dry weight of the root system were measured. Weight measurements were conducted using an analytical balance (METTLER® model AJ150L), and drying was performed in a forced-air oven (Aparatos Márquez®) at 60 °C until constant weight.

For the aerial part, the number of new shoots was counted and their length measured using a standard ruler. Fresh and dry weights of the new shoots, including leaves, were determined using the same methodology as for the roots. Leaf greenness index was assessed using a SPAD chlorophyll meter (KONICA MINOLTA®), and total leaf area per plantlet was measured using a leaf area meter (LI-COR®, model LI-3100).

Physiological variables including net CO_2 assimilation, intercellular CO_2 concentration, stomatal conductance, and transpiration rate were measured using an infrared gas analyzer (LI-COR® USA, model LI-6400) on five randomly selected plantlets from each isolation chamber.

To compare rooting percentages across treatments, Kruskal–Wallis tests were applied ($P \leq 0.05$). For variables related to plantlet characteristics, analysis of variance (ANOVA) was conducted using the following model: $Y_{ijkl} = \mu + \beta_i + L_j + \varepsilon_{ij} + M_k + (LM)_{ij} + \varepsilon_{ijk} + R_l + (LR)_{jk} + (MR)_{kl} + (LMR)_{jkl} + \varepsilon_{ijkl}$, where Y_{ijkl} is the observed value of the response variable Y, μ is the overall mean, β_i is the block effect, L_j is the light treatment effect, ε_{ij} is the error a, M_k is the cutting tipe effect, $(LM)_{ij}$ is the light x cutting type interaction, ε_{ijk} is the error b, R_l is the replicate effect, $(LR)_{jk}$ is the light x replicate interaction, $(MR)_{kl}$ is the cutting type x replicate interaction, $(LMR)_{jkl}$ is the three-way interaction and ε_{ijkl} is the error c. For leaf physiological variables, ANOVA was conducted under a randomized complete block design. Where significant differences were detected, Tukey's HSD test was applied for mean separation ($P \leq 0.05$). All analyses were conducted using SAS® software version 9.0.

Table 1: Spectral characteristics of the light sources

	White	Red	Blue
Photon flux density (μmol m^{-2} s^{-1})	90	90	90
Emmision peak (nm)	445 y 556	660	459
UV (300-400 nm)	0.76%	0.17%	0.43%
Blue (400-500 nm)	35.79%	0.29%	97.78%
Green (500-600 nm)	42.95%	0.85%	1.55%
Red (600-700 nm)	18.15%	96.97%	0.11%
Far red (700-800 nm)	2.35%	1.71%	0.13%
Blue/Red	1.97	0.003	903.05

RESULTS

Rooting percentage was statistically significant ($P \leq 0.05$) only in response to light quality (Table 2) at both six and nine weeks after the start of the experiment.

For variables related to plantlet characteristics, the analysis of variance revealed a significant interaction between light quality and cutting type for the following variables: shoot dry weight, number of shoots, leaf area, root fresh weight, and root dry weight (Table 3). For the remaining variables, significant effects ($P \leq 0.05$) were observed for both light quality and cutting type, except for shoot fresh weight and shoot dry weight, where only light quality had a significant effect.

Regarding the physiological variables evaluated in the leaves, the analysis of variance (Table 4) showed statistically significant effects attributable to the type of light applied.

One of the most relevant variables in experiments involving plant propagation by cuttings is the rooting percentage. In the present study, high rooting percentages were observed under red light treatment at six and nine weeks after the experiment began, while the lowest values were recorded under natural light conditions (Table 5).

In addition to promoting a higher rooting percentage, red light also induced a greater number of roots and increased root length (Table 6). Regarding the effect of light color on root fresh and dry weight accumulation, no statistically significant differences were observed ($P \leq 0.05$). When comparing the effects of cutting type within each light treatment, significant differences were detected only under white light and only for the variable root fresh weight, where apical cuttings showed a higher mean value than basal cuttings (Table 6).

Table 2: Results of the Kruskal-Wallis test for rooting percentage

Week	Factor	Chi-square	df	Pr>Chi-square
6	Light quality	10.51	3	0.01*
	Cutting type	0.01	1	0.92
	Light x cutting	12.86	7	0.08
9	Light quality	11.81	3	0.01**
	Cutting type	0.05	1	0.83
	Light x cutting	12.94	7	0.07

df=degrees of freedom; **= $P \leq 0.01$; *=$P \leq 0.05$

Table 3: Analysis of variance (ANOVA) for the evaluated variables

SV	df	SFW	SDW	NS	SL	SPAD	LA	NR	RL	RFW	RDW
Bloque	1	0.017	0.002	0.021	2.341	6.848	24.041	0.083	1.021	0.001	0.00006
L	3	4.77**	0.19**	2.91*	99.183**	286.099**	1930.666**	37.278**	226.38**	0.878**	0.004
Ea	3	0.023	0.0004	0.132	0.21	2.572	2.131	0.139	0.444	0.006	0.0006
C	1	0.004	0.0001	0.187*	11.407**	58.675*	469.062**	14.083**	3.741*	0.091**	0.00002
L x C	3	0.038	0.004	0.41**	1.379	15.371	226.431**	1.361	1.936	0.219**	0.001*
Eb	4	0.006	0.0005	0.021	0.277	3.695	11.296	0.208	0.438	0.002	0.0001
R	2	0.005	0.00003	0.437	0.187	2.313	11.165	0.271	0.226	0.001	0.000005
L x R	6	0.002	0.0001	0.326	0.14	5.573	4.465	0.132	0.115	0.0002	0.00001
C x R	2	0.001	0.0001	0.437	0.062	0.461	19.546	0.396	0.151	0.0003	0.0000002
L x C x R	6	0.001	0.00005	0.16	0.21	0.978	10.141	0.424	0.279	0.001	0.00002
Ec	16	0.001	0.00005	0.125	0.126	0.488	4.632	0.292	0.21	0.0004	0.00002
TOTAL	47										
CVa		14.36	9.11	12.915	5.715	4.186	3.991	5.082	4.983	12.527	31.857
CVb		7.402	9.158	5.132	6.574	5.017	9.188	6.224	4.951	8.142	15.988
CVc		3.565	3.086	12.571	4.434	1.823	5.884	7.364	3.427	3.076	6.113

SV=source of variation; df=degrees of freedom; L=light quality; Ea=error a; C=cutting type; Eb=error b; R: replication, Ec=error c; CV=coefficient of variation; SFW=shoot fresh weight; SDW=shoot dry weight; NS=number of shoots; SL=shoot length; SPAD=chlorophyll index; LA=leaf area; NR=number of roots; RL=root length; RFW=root fresh weight; RDW=root dry weight; **=$P \leq 0.01$; *=$P \leq 0.05$

Table 4: Analysis of variance for leaf physiological variables

Source of variation	df	CO_2 assimilation	CO_2 internal concentration	Stomatal conductance	Transpiration
Block	1	0.04	498.51	0.00005	0.0004
Light quality	3	9.87**	33825.44**	0.008**	4.25**
Error	35	0.50	1958.75	0.0007	0.17
Total	39				
CV		13.48	25.57	34.78	25.67

df=degrees of freedom; CV=coefficient of variation; **=$P \leq 0.01$; *=$P \leq 0.05$

Table 5: Rooting percentage of pascuita cuttings under different LED light treatments

Light treatment	Rooting (%)	
	Week 6	Week 9
White LED	57[az]	67[b]
Red LED	71[a]	82[a]
Blue LED	49[b]	69[b]
Natural light	17[c]	41[c]
CV.	34.07	28.34

CV=coefficient of variation. [z]Percentages followed by the same letters in the same column are not significantly different (Kruskal-Wallis, $P \leq 0.05$)

The accumulation of fresh and dry weight in the adventitious roots formed depended on the interaction between light type and cutting type (Table 3). Fresh root weight did not differ statistically ($P \leq 0.05$) between apical and basal cuttings under red, blue, and natural light. However, under white LED light, apical cuttings accumulated a higher amount of fresh biomass than basal cuttings. Although the analysis of variance revealed a significant interaction effect on dry root weight, Tukey's test did not detect statistically significant differences ($P \leq 0.05$) between apical and basal cuttings for any light treatment. Except for the differences observed under white light, numerically higher mean fresh and dry root weights were recorded in basal cuttings under the other light treatments. Basal cuttings also exhibited a higher number and greater length of roots, which were statistically different (Tukey, $P \leq 0.05$) from those recorded in apical cuttings (Figure 1).

Table 6: Characteristics of adventitious roots in apical and basal pascuita cuttings under different LED light treatments

Light treatment	Cutting type	FRW (g)	DRW (g)	NR	RL (cm)
White LED	Apical	0.98[az]	0.11[a]	7.66[by]	13.84[b]
	Basal	0.48[b]	0.08[a]		
Red LED	Apical	0.85[a]	0.08[a]	8.42[a]	16.67[a]
	Basal	0.90[a]	0.09[a]		
Blue LED	Apical	0.58[a]	0.07[a]	8.50[a]	15.86[a]
	Basal	0.65[a]	0.07[a]		
Natural light	Apical	0.23[a]	0.05[a]	4.75[c]	7.10[c]
	Basal	0.25[a]	0.06[a]		
HSD		0.15	0.04	0.73	1.31

FRW=fresh root weight; DRW=dry root weight; NR=number of roots; RL=root length; HSD=honest significant difference. [z]Means between apical and basal cuttings within each light treatment followed by the same letter are not significantly different (Tukey, $P \leq 0.05$). [y]Means within the same column followed by the same letter are not significantly different (Tukey, $P \leq 0.05$)

The number of newly formed stems in pascuita seedlings was influenced by the interaction between light type and cutting type (Table 3); significant differences between cutting types were detected only under red light (Tukey, $P \leq 0.05$; Table 7), with basal cuttings producing a higher number of stems. The highest means for this variable were recorded in both apical and basal cuttings under blue light, although no significant differences were detected.

The different light types also affected shoot growth (Table 7). Seedlings grown under red light produced stems with the greatest length and fresh weight. Under this light treatment, the highest values for dry weight and leaf area were also observed. For these two variables, the ANOVA indicated a significant interaction between light type and cutting type (Table 3); however, Tukey's test detected a significant difference only for the leaf area of cuttings rooted under white light. Cutting type also influenced the length of the new stems (Figure 2), with longer stems recorded in seedlings from basal cuttings.

Table 7: Characteristics of shoots in pascuita seedlings obtained from apical and basal cuttings rooted under different light treatments.

Light treatment	Cutting type	NS	SL (cm)	SFW (g)	SDW (g)	LA (cm^2)	SPAD
White LED	Apical	2.83^{az}	8.05^{by}	1.13^{b}	0.21^{a}	33.52^{b}	38.77^{b}
	Basal	3.17^{a}			0.26^{a}	51.48^{a}	
Red LED	Apical	2.50^{b}	11.42^{a}	1.80^{a}	0.38^{a}	51.90^{a}	31.78^{c}
	Basal	3.00^{a}			0.38^{a}	48.93^{a}	
Blue LED	Apical	3.33^{a}	8.20^{b}	1.07^{b}	0.27^{a}	30.12^{a}	39.11^{b}
	Basal	3.33^{a}			0.22^{a}	34.30^{a}	
Natural light	Apical	2.33^{a}	4.38^{c}	0.26^{c}	0.07^{a}	18.27^{a}	43.61^{a}
	Basal	2.00^{a}			0.08^{a}	24.10^{a}	
HDS		0.43	0.90	0.30	0.06	10.08	3.16

NS=number of stems; SL=stem length; SFW=shoot fresh weight; SDW=shoot dry weight; LA=leaf area; SPAD=chlorophyll content; HSD=Honest Significant Difference. ^{z}Means between apical and basal cuttings within each light treatment followed by the same letter are not significantly different (Tukey, $P \leq 0.05$). ^{y}Means within the same column followed by the same letter are not significantly different (Tukey, $P \leq 0.05$).

Regarding the physiological characteristics of newly developed leaves in pascuita seedlings (Table 8), the highest values for most variables were recorded under red and blue LED light. An exception was the net CO_2 assimilation rate, for which no statistically significant differences were found (Tukey, $P \leq 0.05$) between these LED light treatments and natural light.

DISCUSSION

At six weeks after the start of the experiment, the highest rooting percentages were observed under red and white LED light treatments, while the lowest rooting percentage was recorded under natural light (Table 5). By week nine, the highest rooting percentage (82%) was obtained under red LED light, whereas natural light produced the lowest average, with only 41% of cuttings rooted. These results also indicate that red LED light accelerates the adventitious rooting process, achieving a higher rooting percentage at week six than that observed under natural light by week nine. A similar effect has been reported in *Tripterospermum japonicum* (Moon *et al.*, 2006), *Protea cynaroides* (Wu & Lin, 2012) and *Jatropha curcas* (Daud *et al.*, 2013).

The effect of red light on adventitious rooting of *pascuita* cuttings not only accelerates this process but also promotes the formation of a greater number of roots and enhances root elongation (Table 6). However, regarding the latter variables, the red-light effect was not statistically different ($P \leq 0.05$) from that of blue light. Positive effects of red and blue light in promoting adventitious root formation have been previously reported, and their explanation has mainly been attributed to the role of these light spectra in promoting a favorable hormonal balance for rooting. Alallaq *et al.* (2020) demonstrated that red light enhances adventitious root formation in *Picea abies* by reducing jasmonate and cytokinin concentrations, which act as repressors of rooting. In rosemary, blue light was shown to accelerate rooting and enhance root growth in cuttings taken from the apical and intermediate parts of the mother plant;

Table 8: Physiological characteristics of leaves formed in pascuita cuttings rooted under different light treatments

Light treatment	A ($\mu mol\ m^{-2}\ s^{-1}$)	CI (ppm)	SC ($mmol\ m^{-2}\ s^{-1}$)	Tr ($mmol\ m^{-2}\ s^{-1}$)
White LED	3.86^{bz}	127.52^{b}	0.03^{b}	0.79^{c}
Red LED	5.97^{a}	242.11^{a}	0.08^{a}	2.03^{a}
Blue LED	5.96^{a}	200.22^{a}	0.07^{a}	2.23^{a}
Natural light	5.25^{a}	122.38^{b}	0.04^{b}	1.39^{b}
CV	13.14	31.4	38.91	26.12
HSD	0.85	53.38	0.02	0.49

A=CO_2 assimilation; CI=intercellular CO_2 concentration; SC=stomatal conductance; Tr=transpiration; CV=coefficient of variation; HSD=honest significant difference. ^{z}Means within each column followed by the same letter are not significantly different (Tukey, $P \leq 0.05$).

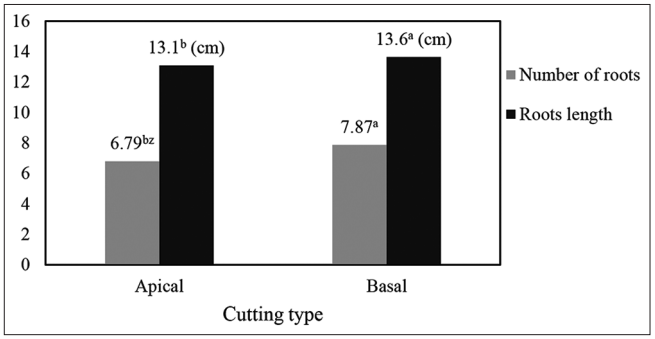

Figure 1: Effect of cutting type on the formation and growth of adventitious roots in pascuita. ^{z}Bars representing the same variable followed by the same letter are not significantly different (Tukey, $P \leq 0.05$).

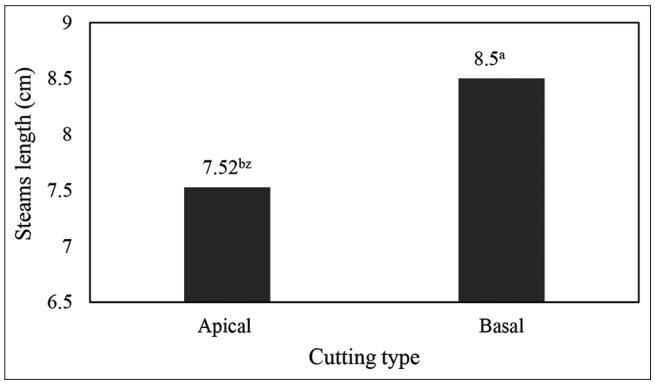

Figure 2: Stem elongation in apical and basal pascuita cuttings rooted under different light treatments. ^{z}Bars followed by the same letter are not statistically different (Tukey, $P \leq 0.05$).

these responses were accompanied by increased expression of genes associated with indole-3-acetic acid (IAA) biosynthesis (Gil *et al.*, 2021). Similary, in tea (*Camellia sinensis*) cuttings, blue and red light were found to influence adventitious rooting by regulating the expression of genes involved in IAA biosynthesis and transport (Shen *et al.*, 2022).

The potential of cuttings to form adventitious roots is influenced by the part of the mother plant from which they are taken (Guan *et al.*, 2015). In the present study, a greater number of roots and increased root length were observed when basal cuttings were used (Figure 1). A higher number of

roots in basal compared to apical cuttings has been reported in rosemary (Gil *et al.*, 2021), *Prunus subhirtella* (Osterc *et al.*, 2016) and *Dalbergia melanoxylon* (Amri *et al.*, 2010). In a rosemary experiment evaluating different LED light colors on adventitious rooting in apical, intermediate, and basal cuttings, greater root formation was observed in basal cuttings. However, the authors could not associate this response with increased expression of genes related to auxin synthesis, as that effect was only observed in apical and intermediate cuttings under blue light (Gil *et al.*, 2021). Similarly, it has been reported that during adventitious rooting in rose, apical cuttings show higher auxin accumulation than basal cuttings (Otiende *et al.*, 2021), an effect also demonstrated in chrysanthemum (Gil *et al.*, 2020). These findings suggest that the higher rooting capacity of basal cuttings is not due to increased auxin accumulation, implying the involvement of other factors. According to Druege *et al.* (2016) the accumulation and availability of carbohydrates and nutrients to meet the demands of the rooting process may be the key factor conferring high rooting capacity to basal cuttings.

In ornamental plants cultivated for their flowers, the number of stems in seedlings is a crucial variable, as it determines the number of subsequent branches and the final plant architecture. In the case of pascuita, seedlings with more stems have greater potential for higher commercial quality. In this study, no statistically significant differences (Tukey, $P \leq 0.05$) were observed for the number of new shoots between cutting types in most light treatments. However, basal cuttings showed a tendency to promote the formation of new shoots (Table 7 & Figure 2).

During vegetative propagation of plants, the growth of new shoots is supported by the reserves stored in the original stems. Once the new leaves are capable of photosynthesis, they become a source of carbohydrates for further growth (Barbier *et al.*, 2015). Similar results to those found in this study have been reported in rosemary, where basal cuttings produced seedlings with greater growth, and artificial fluorescent, red, and blue light enhanced this response compared to natural light (Gil *et al.*, 2021); these authors attributed the response to higher carbohydrate reserves in basal cuttings. Moosavi-Nezhad *et al.* (2022) found that during rooting of chrysanthemum cuttings, red light promoted greater carbohydrate accumulation in the leaves, which functioned as a source for the development of new vegetative organs. However, they also observed that the shoot-to-root weight ratio increased under blue light and decreased under red light.

During adventitious rooting and seedling development, photosynthesis plays an important role as an energy source. Measurements taken in this study (Table 8) showed that CO_2 assimilation was lowest under white LED light (3.857 $\mu mol\ m^{-2}\ s^{-1}$) compared to other treatments, while stomatal conductance, internal CO_2 concentration, and transpiration were higher under red and blue LED light. The photosynthetic process is the result of multiple factors, many of which are influenced by light quality. Chlorophylls absorb most of the light energy in the red and blue regions of the spectrum (Ouzounis *et al.*, 2015; Davis & Burns, 2016), which explains the effects observed under these light colors.

The results of this study demonstrated the potential of using different LED light colors to influence the vegetative propagation process of pascuita using basal and apical cuttings. Although red and blue light were shown to improve adventitious rooting and new seedling formation, large-scale application of this technology should be based on assessments of energy use and economic feasibility, which should be addressed in future research.

CONCLUSIONS

The use of LED lighting during pascuita propagation by cuttings significantly influenced adventitious root formation and new shoot development. The section of the mother plant from which cuttings were taken interacted with the light treatment used during seedling formation. Basal cuttings generally performed better across most evaluated variables. Overall, red and blue LED lighting during adventitious rooting of pascuita cuttings promoted the development of seedlings with desirable traits.

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