Journal of Applied and Natural Science
13(2): 496 - 503 (2021)
Published online: May 22, 2021
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Responses of mixed light-emitting diode ratios on vegetative, flower regulation, and stalk elongation of cut chrysanthemum (*Dendranthema grandiflora* Tzvelev)

Ganesh S*
Department of Floriculture and Landscape Architecture, Horticultural College & Research Institute, Tamil Nadu Agricultural University, Coimbatore - 641003 (Tamil Nadu), India.
Jawaharlal M
Directorate of Extension Education, Tamil Nadu Agricultural University, Coimbatore - 641003 (Tamil Nadu), India.
Rajamani K
Department of Floriculture and Landscape Architecture, Horticultural College & Research Institute, Tamil Nadu Agricultural University, Coimbatore - 641003 (Tamil Nadu), India
Thamaraiselvi SP
Department of Floriculture and Landscape Architecture, Horticultural College & Research Institute, Tamil Nadu Agricultural University, Coimbatore - 641003 (Tamil Nadu), India

*Corresponding author. Email: ganes4u@gmail.com

Article Info
https://doi.org/10.31018/jans.v13i2.2636
Received: March 13, 2021
Revised: May 12, 2021
Accepted: May 15, 2021

How to Cite
Ganesh, S. *et al.* (2021). Responses of mixed light-emitting diode ratios on vegetative, flower regulation, and stalk elongation of cut chrysanthemum (*Dendranthema grandiflora* Tzvelev). *Journal of Applied and Natural Science*, 13(2), 496 - 503. https://doi.org/10.31018/jans.v13i2.2636

Abstract
A Greenhouse experiment on the study of responses of mixed light-emitting diode ratios in cut chrysanthemum (*Dendranthema grandiflora* Tzvelev) was conducted at the Department of Floriculture and Landscape Architecture, Tamil Nadu Agricultural University, Coimbatore during 2019-20. The experiment was laid out in Randomized Block Design with three replications. The treatment comprises of seven varied light-emitting diode irradiance levels *viz*., L_1 – 100% White; L_2 – 100% Red; L_3 - 80% Red + 20% Blue; L_4 – 80% Red + 20% Far-red; L_5 – 75% Blue + 25% Far-red; L_6 – 60% Red + 20% Blue + 20% Far-red; L_7 - High pressure sodium vapour lamp (as check) in Salvador and Pusa Centenary varieties. The results revealed that the growth in terms of height of the chrysanthemum at critical stages was maximum (48.88 cm in Salvador and 41.92 cm in Pusa Centenary) under the light irradiance of $B_{75}FR_{25}$ (L_5) during the peak vegetative stage and registered maximum leaf area. Highest internodal length up to 3rd leaf of 1.07 cm was registered in sodium vapour lamp irradiance (L_7) and 1.39 cm in 100% Red irradiance (L_2). The early flower bud emergence (39 days in Salvador and 50 days in Pusa Centenary) was observed in $B_{75}Fr_{25}$ spectral irradiance (L_5). The highest total cut stem yield per square meter (42.65 in Salvador and 41.99 in Pusa Centenary) was registered in $R_{80}B_{20}$. The study revealed that blue LEDs combined with Far-red promoted early flowering and inhibited stem elongations. Red and Blue wavelength increased the total leaf area and registered improved flower yield.

Keywords: Chrysanthemum, Flower regulation, Flower stalk elongation, Light-emitting diodes, Mixed RBFr irradiance

INTRODUCTION

Chrysanthemum (*Dendranthema grandiflora* Tzvelev), the critical short day plant is the third most important cut flower in the international trade that requires a long night for flowering. Normally chrysanthemums are retained vegetatively at 14 hrs of LD and 10 hrs of SD and promoted flowering at 10/14 hrs of photoperiod. Under greenhouses, the day length can be altered by the installation of supplemental lighting systems, so that the plants will attain the standard quality and also ensures off-season availability of flowers (Thakur and Grewal, 2016). The supplemental lighting also enables year-round flower production by an enhanced photosynthetic process that drives growth and production. In India, cut chrysanthemums are mostly grown in states like Karnataka, Maharashtra, Tamil Nadu, Himachal Pradesh, Punjab, Uttar Pradesh, West Bengal, etc. In Tamil Nadu, chrysanthemum cultivation under greenhouses is only about 8.0 ha at present (2019-20). To-day, although there are over 8 lakhs of stem demand per week, the production of chrysanthemums is hardly 10% of the demand. The supply of chrysanthemum is far less than the demand and there is scope for production under a protected environment.

The management of photoperiod for its successful cultivation is a prerequisite and challenging too. As indicated above, the alteration of photoperiodic duration involves the installation of energy-efficient lighting systems inside the greenhouse. Lighting is an energy-consuming process, the installation of high-intensity discharge lamps (HIDs), incandescent lamps and metal halide lamps for day extending (DE)/supplemental lighting consume more power which results in additional cost in electricity itself. Recent development in LED technology creates new opportunities for low and high-intensity lighting of greenhouse crops. The integration of LEDs in current growing systems receives full attention as they provide the opportunity to control the light spectrum. LEDs are compared to conventional HIDs on the induction of target plant responses such as photosynthetic, photoperiodic, and photomorphogenic, respectively. The combination of different regimens of LEDs can provide improved influence and customized wavelengths for flower cultivation (Monostori *et al*., 2018). Mixed red and blue light may improve photosynthetic activity and regulate morphogenesis (Shen *et al*., 2014). The spectral quality effects have an influence on the plant biometric responses and flower value. Literature revealed that the light quality rich in Red Light (R) relative to Far-Red (F/R) could suppress elongation growth, make plants shorter (Paradiso and Proietti, 2021). On the contrary, light quality relatively rich in Far-Red promotes extension growth, making plants taller and leaf expansion (Zheng *et al*. 2019). An interesting fact that in LEDs, more energy is converted into usable light for photosynthesis or photomorphogenic effects. Red (R) and Blue light (B) enhance photosynthetic metabolism. These are the light sources to provide the capability of true spectral composition control, allowing wavelength to match to plant photoreceptors to optimize production as well as to influence plant morphology and composition. However, the use of LEDs during greenhouse cultivation is rather new and has great potential both from a commercial research point of view. Studies have shown that by increasing canopy photon capture efficiency and/or precisely controlling light output in response to the environment or certain physiological parameters, energy efficiency and plant productivity can be optimized with LEDs (Gomez and Izzo, 2018). Hence, the above study was conducted to understand the spectral quality effects of LEDs and to determine the appropriate colour ratios to regulate growth, flowering, and flower stalk length in the Salvador and Pusa Centenary varieties of chrysanthemum.

MATERIALS AND METHODS

Study area and planting materials

The study was carried out in the aerodynamic polyhouse located at the Department of Floriculture and Landscape Architecture, during the period 2019-20. The polyhouse is geographically located in the Coimbatore district at 110 02" N Latitude, 760 57" E Longitude, and 426.76 m above MSL altitude. The Chrysanthemum varieties “Salvador” supplied by M/s. FLORITEC Breeding by Design, Dutch, and "Pusa Centenary" by Indian Agricultural Research Institute, New Delhi was used in the study. The field was ploughed well and the soils are made into fine tilth and till become powdery. Beds of 12 x 1.0 m^2 size were prepared to a height of 45 cm and width (40 cm) was left as the walking path between the beds. The bed was then dug up to 15-20 cm and weeds and debris were removed. A bed was then raised to 45 cm above ground level. The soil medium was enriched with 3 kg/m^2 of composted coir, 500 g/m^2 of vermicompost, 10 kg/m^2 of well-decomposed farmyard manure, and microbial consortia (Azospirillum, Phosphobacteria, and VAM) @ 50 g each/m^2. The field is then leveled and watered well. The terminal rooted cuttings were then transplanted in the main field at a spacing of 15 cm x 15 cm, accommodating 44 plants per sq.m. Nine plants in the center of the plot in each replication were chosen for recording observations. The cultural operations were followed as per the recommendation from the Tamil Nadu Agricultural University Horticultural Crop Production Guide (2020).

Treatment details

The experiment was laid in Randomized Block Design with three replications. In the experiment, chrysanthemum plants were exposed to LEDs for 4 hr duration (as supplemental lighting) and 4 hr (check) with sodium vapour lamp as long-day exposure. Different wavelengths composed of white (W), Blue (B), Red (R), and Far-red (FR) light-emitting diodes at 4hr each exposed with white (1900 lumens); R (41 μmol/J); BFr (37 μmol/J); RB (43 μmol/J); RFr (41 μmol/J); RBFr (43 μmol/J) and control with HPS lamp for 4hr (725 μmol/s or J) were irradiated to the plants. The treatments comprised of L_1- 100% White (380 to 740 nm); L_2- 100% Red (625 to 700 nm); L_3-80% Red+ 20% Blue; L_4 – 80% Red + 20% Far-red (700 to 850 nm); L_5- 75% Blue + 25% Far-red (445 to 850 nm); L_6 – 60% Red + 20% Blue + 20% Far-red (445 to 850 nm); L_7 – Sodium vapour lamp (check).

Assessment of morphophysiological and yield parameters

The plant morphological parameters were recorded at three critical stages of chrysanthemum *viz.,* peak vegetative stage, bud appearance stage, and peak flowering stage. Nine plants in each treatment were selected at random and tagged for observations on different traits. The mean of nine plants is taken into account. The height of the plant was measured from the base of the plant to the terminal tip at the critical stages and was expressed in centimeters (cms). The internodal length was also recorded by using length between 3rd, 4thand 5th internodes from the tip, and the mean was expressed in centimeter (cm). The total leaf area was calculated by multiplying the length (cm) and breadth (cm) of the leaf with the constant 'K' factor (0.646) and a number of green leaves and expressed in square centimeter (cm^2). Light interception percent was the ratio of a difference between light intensity in the open canopy and average light intensity at the middle of the canopy and ground level (Charles Edwards, 1982). Light Transmission Ratio was the ratio of light intensity at the ground surface and light intensity above the canopy (Subburamu and Ravichandran, 2009)

Statistical analysis

Experimental data is statistically analyzed as suggested by Panse and Sukhatme (2000). The critical differences were worked out for 5 % (0.05) and 1 % (0.01) probability. The treatment differences that were not significant were denoted by "NS".

RESULTS AND DISCUSSION

Influence of light emitting diodes on growth attributes of Chrysanthemum (*D. grandiflora* Tzvelev)

Significant differences were observed for plant height of chrysanthemum varieties of Salvador and Pusa Centenary at critical stages *viz.*, peak vegetative stage, bud appearance stage and flowering stage when exposed to different light treatments (Table 1). The plant height was maximum under the light combinations of 75% Blue + 25% Far-red (L_5) at the peak vegetative stage in both Salvador (48.88 cm) and Pusa Centenary (41.92 cm) of Chryanthemum. Plants grown under the mixture of 75% blue and 25% Far-red registered a significantly ($p<0.05$ and $p<0.01$ respectively) higher plant height at the initial stages of plant development than other light combinations. But during the bud appearance and flowering stage, plants grown under 80% red + 20% blue LEDs (L_3) have registered the highest plant height (85.33 cm & 112.52 cm in Salvador; 62.94 cm & 116.81 cm in Pusa Centenary). Blue light has inhibited stem elongations at the later stage of growth. Reduction in growth attributed to the shorter leaf length and width ultimately the reduction in leaf area. The results are in accordance with the findings of Oyaert *et al*. (1999) in Chrysanthemum (Dendranthem x grandiflorum cv White Reagan) and Lee *et al*. (2011) in Paphiopedilum cv 'Hsingying Carlos'. The growth promotion in 80% R:20%B spectral combinations might be attributed to the delay in conversion of Pr to Pfr phytochromes. Phytochromes regulated the stem elongation and leaf expansion (Urrestarazu *et al.* 2018). The dichromatic spectral distributions at the canopy level might have increased the photosynthetic rate and stomatal size in the leaves (Kim *et al*. 2004 & Bantis *et al*. 2018 in Chrysanthemum (*D. grandiflorum* Kitam 'Cheonsu'). The present findings revealed that at certain stage, the plants which received $B_{75}Fr_{25}$ had stopped the growth and transforms its growth from vegetative to generative stage in both Salvador and Pusa Centenary varieties of Chrysantemum (*D. grandiflora* Tzvelev*)*. This property of spectral distribution might have useful in the growing chrysanthemums for ornamental purpose especially the pot mums. The earliness or premature flowering was noticed at Blue: Far-red combinations. Urrestarazu *et al*. 2018 opined that high Far-red/ Red irradiation caused premature flowering in many species and elongated stems and petioles . Zhen and van Iersel (2017) have reported that an increase of Far-red ratio in a fixture have constantly increased the net photosynthetic rate in lettuce (Lactuca sativa 'Green Towers'). However, no differences were observed in the control plot L_7 ($R_{60}B_{20}Fr_{20}$) in both Chrysanthemum varieties viz. Salvador and Pusa Centenary.

The mixed wavelength of LEDs has significantly affected the internodal elongation in both varieties of chrysanthemum. The internodal length at the 3rd leaf stage and after the 3rd leaf stage showed significant variance ($p<0.05$ and $p<0.01$ respectively) (Table 2). Internodal length in Chrysanthemum varieties was also highest in mixed lights containing Blue wavelength (1.07 cm, 1.03 cm) in Salvador which have influenced the height of the plants receiving Blue LED irradiance for 4-hour extended lighting. The increased internode light is attributed to the increased light distribution within the plant canopy enabling the greater light absorbtion (The lowest internode length was registered in 100% White light irradiance. In contrary to the above results, several workers have reported that Blue light inhibited the internode elongation and also indicated that plants have many Blue light receptors such as cryptochromes might have regulated the plant growth and flowering of marigold (*Tagetes erecta* L. cv. Orange Boy & Salvia (*Salvia splendens* F. Sello ex Ruem & Schult (Heo *et al*. 2002) and *Chrysanthemum morifolium* cv. Radost (Sharathkumar *et al*. 2021). It is also reported that acceleration of stem elongation rate in extended daylights is caused by the depression of blue lights in *Datura ferox* L. and *Sinapis alba* L. (Ballare *et al*. 1991). In Pusa Centenary, the perception of blue light by the leaves is also important, which influences the perception of R: FR (L_4) by the internodes. In the present study, it is observed that number of internodes was

Table 1. Effect of light irradiance on plant height (cm) of *D. grandiflora* Tzvelev at critical stages.

Light irradiance (L)	Plant height at growth stages (cm)					
	Salvador (G)			Pusa Centenary (G)		
	Peak vegetative stage	Bud appearance stage	Flowering stage	Peak vegetative stage	Bud appearance stage	Flowering stage
L1	43.44	82.22	111.50	40.86	66.22	108.11
L2	42.27	75.09	88.42	39.50	65.39	104.73
L3	45.02	85.33	112.52	29.88	62.94	116.81
L4	43.69	78.67	101.45	40.99	69.11	94.95
L5	48.88	68.22	71.05	41.92	67.39	71.00
L6	43.67	71.33	109.62	40.38	69.51	99.77
L7	39.57	70.83	102.34	33.95	65.72	109.94
Mean	43.79	75.96	99.56	38.21	66.61	100.76
S.Em	1.4519	3.2778	1.484	2.915	5.4493	1.6021
SED	2.0533	4.6355	2.0987	4.122	7.7065	2.2658
CD (p=0.05)	4.4737	10.0910	4.5727	8.9821	16.791	4.9367
CD (p=0.01)	6.2718	14.1592	6.4105	12.592	23.540	6.9201

L1 – 100% White (380 to 740 nm); L2 – 100% Red (625 to 700 nm); L3 - 80% Red + 20% Blue; L4 – 80% Red + 20% Far-red (700 to 850 nm); L5 – 75% Blue + 25% Far-red (445 nm to 850nm); L6 – 60% Red + 20% Blue + 20% Far-red (445 to 850 nm); L7 - Sodium vapour lamp (check)

Table 2. Effect of light irradiance on internodal length up to 3rd leaf and after 3rd leaf (cm^2) of *D. grandiflora* Tzvelev.

Light irradiance (L)	Salvador (G)		Pusa Centenary (G)	
	Internodal length (up to 3rd leaf) (cm)	Internodal length (after 3rd leaf) (cm)	Internodal length (up to 3rd leaf) (cm)	Internodal length (after 3rd leaf) (cm)
L1	0.92	2.33	1.00	2.12
L2	0.93	2.25	0.95	1.39
L3	0.97	2.64	0.87	1.85
L4	0.93	2.16	1.39	2.22
L5	1.03	2.33	1.11	2.33
L6	0.99	2.18	1.08	1.98
L7	1.07	1.92	0.83	2.13
Mean	**0.98**	**2.60**	**1.03**	**2.01**
S.Em	0.1017	0.1180	0.2081	0.1024
S.ED	0.1439	0.1669	0.2943	0.1448
CD (p=0.05)	0.3135	0.3637	0.6413	0.3154
CD (p=0.01)	0.4395	0.5099	0.8991	0.4422

L1 – 100% White (380 to 740 nm); L2 – 100% Red (625 to 700 nm); L3 - 80% Red + 20% Blue; L4 – 80% Red + 20% Far-red (700 to 850 nm); L5 – 75% Blue + 25% Far-red (445 nm to 850nm); L6 – 60% Red + 20% Blue + 20% Far-red (445 to 850 nm); L7 - Sodium vapour lamp (check)

lesser in the blue light irradiated plants. The number of internodes was inversely proportional to the length of internodes of *Sinapis alba* L. (Casal and Smith, 1988; Demotes-Mainard *et al*., 2016).

Total leaf area per plant

The study revealed that there were significant differences among the chrysanthemum varieties in different spectral ranges for the total leaf area of chrysanthemum plants. Leaf area is an essential trait to assess the significance of light in terms of photosynthesis. Maximum leaf area was observed in both the genotypes under mixed Red 80% + 20% Blue light, while the minimum leaf area was registered in 80% Red + 20% Far-Red in Salvador and (L_1)100% white light in Pusa Centenary (Fig 1). The highest leaf area might be due to an increase in net photosynthetic rate under RB radiated zones while low under BF and sodium vapour lamp radiated plantlets. Increased total leaf area was observed in the seedlings of begonia, geranium, petunia, and antirrhinum when grown under 100 % Mint White LEDs (MW100) (Park and Runkle, 2018). This is likely because red-blue extension received a higher PPFD of 241.67 μmolm^{-2}s^{-1} and 294.00 μmolm^{-2}s^{-1} compared to 77.67 μmolm^{-2}s^{-1} and 135 μmolm^{-2}s^{-1} under 4h of sodium vapour lamp irradiance extension. The results are in accordance with SharathKumar *et al*. (2021) when the *C. morifolium* cv. Radost plants were grown under 15 h long-day solar photoperiod. Li *et al*. (2020) opined that the leaf area was high in RB, which suggested that the light spectrum was optimum and promotion of whole plant development and increased photosynthesis by increasing Chl a and total Chl contents in seedlings of Sweet Pepper (*Capsicum annum* L.). Ouzounis *et al*. (2014) also found that in *C. morofolium* 'Coral Charm' and *Campanula portenschlagiana* 'BlueOne', 20%B + 80%R showed the highest leaf area expansion. In contrast, the reduction in leaf area at 80%R:20%B LED radiation was registered in Rosa x hybrida cv. Toril (Terfa *et al*., 2013). Reduction in leaf area is attributed to the application of blue lights inhibits cell division and cell expansion (Bugbee, 2017). The increasing trend in the total leaf area of chrysanthemum variety Salvador and Pusa Centenary was registered at the respective critical stages of chrysanthemum (*D. grandiflora* Tzvelev).

Influence of LEDs on flower attributes of Chrysanthemum (*D. grandiflora* Tzvelev)

Acceleration in flowering is observed in many flower crops under low R: Fr ratios. Several traits involved in photosynthesis are regulated by phyB and R and FR lights. The earliness in flower bud emergence (39 days in Salvador and 50 days in Pusa Centenary) was observed in 75% Blue + 25% Far-red at 445 nm to 850nm spectral irradiance (L_5) followed by L_3 ($R_{80}B_{20}$) (Table 3). The result has implied the negative effects of B and BFr on the growth and photosynthesis of chrysanthemum and this might be due to the inhibitory effect of blue light on stalk growth. The findings are concomitant with Kim *et al*. (2004). Mortensen and Stromme (1987) also observed inhibition of stalk growth under blue irradiance in many greenhouse horticultural crops.

Supplemental lighting in greenhouse cultivation is proven to increase the growth and quality of flowers and ornamentals (Zheng and Van Labeke, 2017). The monochromatic or mixed Red/Blue/Far-red LEDs had different influences on the flowering and yield parameters. The flowering parameters are significantly increased in 80% Red + 20% Blue (L_3) LED irradiated plants. The highest stalk length was recorded under mixed R and B but stalk growth was delicate due to the increased internodal length after the third leaf or third node (almost double the length up to 3rd leaf). Under Monochromatic R and RBFr, indifferent to mixed R and B, the internodal length up to the third leaf and after the third leaf was lesser.

Total cut stem yield per square meter (42.65 and 41.99) was highest in 80%R:20%B than other spectral ranges in Salvador and Pusa Centenary varieties (Table 4). The difference in light quality has influenced the duration of the blooming period (Heo *et al*. 2002). In the present study, the increase in yield might be due to light quality, which influenced the plant dry mass accumulation by altering leaf expansion and affected photosynthesis. This process promotes biomass accumulation by increasing photosynthetic carbon

Table 3. Effect of light irradiance on days to first flower bud appearance, days to first harvest and number of flower buds of *D. grandiflora* Tzvelev.

Light irradiance (L)	Salvador (G)			Pusa Centenary (G)		
	Days to first flower bud appearance	Days to the first harvest	Number of flower buds	Days to first flower bud appearance	Days to the first harvest	Number of flower buds
L1	80.11	138.95	8.46	70.22	135.01	13.56
L2	67.56	145.07	12.26	67.22	148.93	12.84
L3	65.29	132.59	13.60	64.11	136.32	15.54
L4	70.33	148.22	11.00	68.22	155.68	13.44
L5	39.00	65.11	8.33	50.00	80.56	8.12
L6	72.67	139.36	10.33	75.78	140.99	21.22
L7	66.11	135.29	11.11	72.44	139.87	12.22
Mean	65.87	129.23	10.73	66.86	133.91	13.85
S.Em	1.7339	0.4395	0.6713	2.2485	0.3762	0.7775
S.ED	2.4521	0.6216	0.9494	3.1798	0.5320	1.0996
CD (p=0.05)	5.3428	1.3543	2.0685	6.9282	1.1591	2.3958
CD (p=0.01)	7.4902	1.8987	2.8998	9.7128	1.6249	3.3587

L1 – 100% White (380 to 740 nm); L2 – 100% Red (625 to 700 nm); L3 - 80% Red + 20% Blue; L4 – 80% Red + 20% Far-red (700 to 850 nm); L5 – 75% Blue + 25% Far-red (445 nm to 850nm); L6 – 60% Red + 20% Blue + 20% Far-red (445 to 850 nm); L7 - Sodium vapour lamp (check)

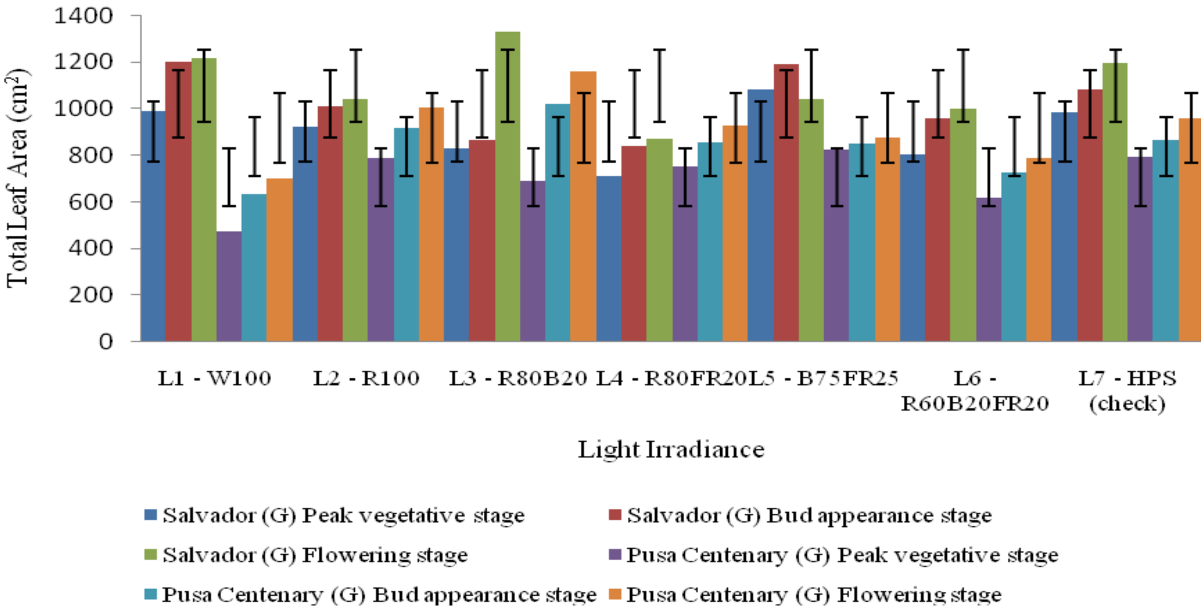

Fig. 1. *Effect of light irradiance on total leaf area per plant (sq.cm) at critical stages*

assimilation. An admixture of Red and Blue light sources may combine the advantages of monochromatic Red and monochromatic Blue and such activity may overcome the individual advantages of these lights. Similar findings were also reported by Surendra Singh Chauhan (2017) in Chrysanthemum cv Zembla and Thai Chen Queen; García-Caparrós *et al.* (2020); in Inch (*Tradescantia zebrina*) and Spider plant (*Chlorophytum comosum*); Choi *et al.* (2018) in Chrysanthemum cv Baekma and Jinba.

The present study showed that in Salvador variety, the spectral composition of 75% Blue + 25% Far-red (L_5) combination has influenced the peduncle length (18.35 cm) followed by L_6 (16.45 cm) and L_3 (15.29 cm), which is on par with $L_{5.}$ L_3 (80% Red + 20% Blue) has recorded the highest total cut stem yield of 42.65 stems per sq.m (Table 4). These spectral ranges not only have increased the flower stalk quality and also have increased the number of marketable stems (i.e Grade A stems - 40.70). The data revealed that in comparison

Table 4. Effect of light irradiance on flower stalk length (cm) and total cut stem yield/m^{2}of *D. grandiflora* Tzvelev.

Light irradiance (L)	Salvador (G)		Pusa Centenary (G)	
	Flower stalk length (cm)	Total cut stem yield/m^2	Flower stalk length (cm)	Total cut stem yield/m^2
L1	108.50	40.25	101.90	41.38
L2	86.65	37.46	100.62	34.12
L3	107.50	42.65	111.58	41.99
L4	99.85	38.47	90.23	36.09
L5	66.50	41.32	69.50	40.33
L6	104.78	42.08	96.00	40.17
L7	97.75	41.55	105.24	40.56
Mean	95.93	40.54	96.44	39.23
S.Em	0.2284	0.0295	0.2085	0.0450
S.ED	0.3230	0.0417	0.2949	0.0636
CD (p=0.05)	0.7037	0.0908	0.6426	0.1387
CD (p=0.01)	0.9865	0.1272	0.9009	0.1944

L1 – 100% White (380 to 740 nm); L2 – 100% Red (625 to 700 nm); L3 - 80% Red + 20% Blue; L4 – 80% Red + 20% Far-red (700 to 850 nm); L5 – 75% Blue + 25% Far-red (445 nm to 850nm); L6 – 60% Red + 20% Blue + 20% Far-red (445 to 850 nm); L7 - Sodium vapour lamp (check).

with the varietal responses, the stalk length of Pusa Centenary was higher (69.50 cm) than Salvador (66.50 cm). In both Salvador and Pusa Centenary varieties, the blue wavelength (445 nm to 850 nm) might affect the earlier transition of vegetaive to reproductive phase or flowering phase under 75% Blue + 25% Far-red irradiance, which promoted early flowering. Park and Jeong (2020) have also reported that blue light has influenced the early flower bud formation and ultimately, the flower yield also increased in Chrysanthemum (*D. grandiflorum* cv. Gaya Yellow).

On the whole, the study elaborately discussed the spectral quality of single spectral light emitting diodes and the combined effect of spectral irradiances in the Chrysanthemum varieties, *viz* Salvador and Pusa Centenary. The different spectral quality of light emitting diodes showed significantly ($p<0.05$ and $p<0.01$) varied responses irrespective of varieties planted. The variations observed were consistently improved. Though the application of light emitting diodes in crop production gains importance a decade ago, several results were recommended with the studies conducted under indoor systems and under soilless conditions. The present attempt envisage the efficacy of light emitting diodes under defined wavelength for chrysanthemum growing in tropical conditions. The results obtained from the study have indicated that spectral irradiance of a single wavelength or in combination have a significant effect on photomorphology and flowering.

Conclusion

In the present investigation, significant differences were observed ($p<0.05$ and $p<0.01$) among all the traits studied. The results of the experiment revealed that the growth in terms of the height of the chrysanthemum plants at critical stages was maximum (48.88 cm and 41.92 cm) under the light irradiance of $B_{75}FR_{25}$ (L_5) during the peak vegetative stage in both the Salvador and Pusa Centenary varieties of chrysanthemum and registered maximum leaf area. Internodal length of the varieties was also highest in mixed lights emitting Blue wavelength (1.07 cm, 1.03 cm) in Salvador under 4-hour extended durations. The early flower bud emergence (39 days in Salvador and 50 days in Pusa Centenary) was observed in 75% Blue + 25% Far-red spectral irradiance (L_5). The early flowering behaviour of the variety Salvador might be due to its photosensitive nature, while Pusa Centenary variety flowers a little later. The highest total cut stem yield per square meter (42.65 and 41.99) was registered in $R_{80}B_{20.}$ The study indicates the effect of different spectral ranges alone or in combination in the enhancement of growth and photosynthesis of chrysanthemum. The study promulgated that irradiance of single wavelength of different spectral ranges or combined wavelengths on improving the growth and yield of polyhouse chrysanthemums var Salvador and var Pusa Centenary. The results of the present study opined that there is uniformity in the growth of the plants at their critical stages, which envisaged that thers is a uniformity in the spectral quality and less heating effect at the plant canopy. The cost of cultivation of the experiment indicated that there is 66 % of the cost on electricity is saved which reflected on the increase of 16.21 % of net income in a unit area. Also the effect of single wavelength on photomorphogenic characters of chrysanthemum plant is well established with improved total leaf area of the plant, stem girth, early flowering, flower yield and colour.

ACKNOWLEDGEMENTS

The authors thank Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu, India, for the financial support through the core research projects funded by the Government of Tamil Nadu and Department of Floriculture and Landscape Architecture, TNAU, for the conduct of the study.

Conflict of interest

The authors declare that they have no conflict of interest.

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