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Light emitting diodes in greenhouse chrysanthemum: Effect on morphoanatomy and physiological responses

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Abstract
Light Emitting Diodes in greenhouse industry have increased the light use efficiency under cut flower production. In the present study, the morphoanatomy and physiological responses of LEDs was tested in two cut flower varieties of chrysanthemum under controlled conditions at Coimbatore. The investigation revealed that the spectral combination of 80% Red + 20% Blue (L_3) registered improved morphoanatomic characters such as total leaf area at growth stages (1327.48 cm^2 and 1155.55 cm^2); total stem yield/sq.m (41.99) and marketable high grade flowers (Grade A - 40.07 stems/sq.m and 40.70 stems/sq.m) respectively and physiological parameters such PPFD (573 $\mu molm^{-2}s^{-1}$ at above the canopy and 241.67 $\mu molm^{-2}s^{-1}$ at inter canopy level in Salvador and 578.67 $\mu molm^{-2}s^{-1}$ at above the canopy and 294 $\mu molm^{-2}s^{-1}$ at inter canopy level in Pusa Centenary); light interception level at both varieties (17.115% at canopy surfaces) and high light transmission ration of 57.245as followed by the spectral composition of 75% Blue+25% Far-red (L_5). The quality of light have influenced the high light incident at above canopy and intercanopy level, net photo synthetic rate and thereby increase the plant dry mass accumulation by altering leaf total leaf area, stomatal conductance and improve photosynthetic carbon assimilation under RD radiated zones.

Keywords: cut chrysanthemum, controlled environment, light emitting diodes, morphoanatomic, physiological response

Introduction

Chrysanthemum (*Dendranthema grandiflora* Tzvelev) is the third most important cut flower in the International market. It is a short day plant i.e., it requires a long night for flowering. Retaining chrysanthemum in the vegetative phase to a certain extent is a prerequisite so that the plants attain the quality standard as cut flowers. To enable year-round plant production supplemental light is necessary to enhance photosynthesis the primary process that drives growth and production. Hence, the chrysanthemum varieties available now in our country should be studied for their potential under varied light sources and in different spectral ranges. Such a study can provide information to classify the chrysanthemum varieties into their response group and their sensitivity to photoperiodism for year-round programmed blooming. The varied range of light signals, morphogenesis, and other physiological processes are activated by light (Chen et al., 2004) [4]. The different spectral composition of light such as wavelength, intensity, duration, and direction can influence plant growth and development. The response of plants to varied spectrum depends on the lighting environment, season, genotype, cultivation practices, and many others (Kozai, 2016; Bayat et al., 2018) [8,1]. In recent days, the canopy lighting is used to promote photosynthesis of the middle leaves and lower leaves. Supplemental lighting in greenhouse cultivation is proven to increase the growth and quality of flowers and ornamentals (Zheng and Van Labeke, 2017) [24]. The combination of different regimens of LEDs can provide improved influence and customized wavelengths for flower cultivation (Monotsori et al., 2018) [10]. Mixed red and blue light may improve photosynthetic activity and regulate morphogenesis (Shen et al., 2014) [18]. In order to assess the morphoanatomy and physiological responses of LEDs in greenhouse chrysanthemum, the study was carried out.

Materials and methods

The present investigation on was carried out at the naturally ventilated aerodynamic polyhouse 40 x 13 m^2 area with 800 gauge UV stabilized polythene sheet in East-West orientation situated at the Department of Floriculture and Landscape Architecture, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu during June 2020. Spray varieties of cut flower chrysanthemum *viz.*, “Salvador” and “Pusa Centenary” are used for the study. The experiment was laid in Randomized Block Design with three replications. The LED Irradiance (L) and Genotypes (G) are the factors and evaluated. The LED irradiance comprises 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 nm to 850nm); L_6 – 60% Red + 20% Blue + 20% Far-red (445 to 850 nm); L_7 - Sodium vapour lamp (check). The other cultural operations were followed as per the recommendation from the TNAU Horticultural Crop Production Guide (2020) [22]. The parameters are recorded at critical stages of chrysanthemum such as peal vegetative stage, bud appearance stage and peak flowering stage. Nine plants in each treatment were selected at random and tagged for recording observations on different traits.

Total leaf area per plant

The leaf area was calculated by multiplying length and breadth of the leaf with the constant ‘K’ factor (0.646) and number of green leaves and expressed in cm^2.

Photosynthetic photon flux density (PPFD)

The photosynthetic photon flux density is the amount of photosynthetically active photons (400 – 700 nm) hitting a surface per unit area per unit time. The PPFD from the light spectrum is measured with the line quantum sensor at above canopy level and at inter canopy level and units are expressed in µmol (of photons) $m^{-2}s^{-1}$.

Light interception

Light interception is the ratio of difference between light intensity in the open canopy and average light intensity at the middle of the canopy and ground level and it is expressed in percentage (Charles Edwards, 1982) [3].

$$\text{Light interception} = \frac{\text{Light intensity in the open} - \text{Average of light intensity at The middle of the canopy and ground level}}{\text{Light intensity in the open}} \times 100$$

Light Transmission Ratio

Light Transmission Ratio is the ratio of light intensity at the ground surface and light intensity above the canopy (Subburamu and Ravichandran, 2009) [19].

$$\text{Light Transmission Ratio} = \frac{I_1 \text{ Light intensity at the ground surface}}{I_0 \text{ Light intensity above the canopy}} \times 100$$

Pedicel length

The pedicel length was measured from the point of pedicel attachment to the stalk to its attachment to the base of the flower and it expressed in centimeter.

Number of quality grade flowers/m^2

The number of quality grade flowers was calculated with the below mentioned stalk length and the mean was expressed it as A, B and C grade. The grades *viz*., A grade**:** 75 cm and above**;** B grade**:** 45 cm to 60 cm and C grade**:** 30 cm to 44 cm.

Cut stem yield/m^2

The number of stems harvested per square meter area was counted and expressed in numbers for yield/m^2.

Results and Discussion

Effect of mixed LEDs on morphoanatomical changes

The study revealed the significant differences were observed among the chrysanthemum genotypes and different spectral light for total leaf area of chrysanthemum at their critical stages. 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 L1 100% white light in Pusa Centenary (Table 1). The highest leaf area might me due to 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) [13]. 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 extension. The results are in accordance with SharathKumar et al. (2021) [17] in chrysanthemum and Li et al. (2020) [9] reported 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. Ouzounis et al. (2014) [12] also found that in chrysanthmeums and campunalas, the 20%B + 80%R showed 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) [21]. Reduction in leaf area is attributed to application of blue lights inhibits cell division and cell expansion (Bugbee, 2017) [2]. The increasing trend in the leaf area showed that the increases with the increase in critical stages of chrysanthen.

Table 1: Effect of light irradiance on total leaf area (cm^2) of *Dendranthema grandiflora* Tzvelev at critical stages

Light irradiance (L)	Total leaf area at growth stages (cm^2)					
	Salvador (G)			Pusa Centenary (G)		
	Peak vegetative stage	Bud appearance stage	Flowering stage	Peak vegetative stage	Bud appearance stage	Flowering stage
L1	987.16	1197.24	1216.13	472.07	634.27	697.46
L2	918.94	1009.65	1039.20	788.05	918.70	1004.57
L3	826.73	864.06	1327.48	691.10	1020.52	1155.55
L4	708.04	837.65	871.24	751.77	856.45	928.39
L5	1082.37	1188.82	1037.36	821.81	850.00	873.75
L6	805.19	955.44	997.60	620.09	725.70	789.87
L7	980.80	1079.63	1191.58	792.73	865.29	959.23
Mean	901.32	1018.93	1097.23	705.37	838.70	915.55
S.Em	98.6216	111.0989	69.0474	93.5134	90.0988	68.6788
S.ED	139.472	157.1176	97.6477	132.248	127.4189	97.1265
CD (p=0.05)	303.883	342.3299	212.7562	288.143	277.6219	211.6205
CD (p=0.01)	426.023	479.9220	298.2689	403.956	389.2060	296.6768

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 nm to 850nm); L_6 – 60% Red + 20% Blue + 20% Far-red (445 to 850 nm); L_7 - Sodium vapour lamp (check).

Physiological changes due to mixed R:B:Fr LEDs

The absorption of photosynthetic photon flux density (PPFD) varied significantly among the different spectral ranges for the two chrysanthemum genotypes studied at 5% and 1% level. The PPFD measured at above the canopy level and at intercanopy level recorded differences in the PAR absorption in both the cultivars (Table 2). The mixed LED combination of 80% R: 20%B registered 573 µmolm^{-2}s^{-1} at above the canopy and 241.67 µmolm^{-2}s^{-1} at inter canopy level in Salvador cultivar. The same trend of registering PPFD value was observed in Pusa Centenary cultivar. The plants grown under red-blue extended either 4 h received high PPFD than Far-Red mixed LEDs and 100% W LEDs.

High PPFD is attributed to the promotion of stomatal opening more than the other wave lengths. Red and Blue spectral ranges have increased the photosynthetic rate by increase in stomatal conductance which leads to improvement of the plant biomass. The results are in coherence with Ohashi Kaneko *et al*. (2006) [11] in grafted tomato plug seedlings and Seif et al. (2021) [16] in Chrysanthemum.

Table 2: Effect of light irradiance on photosynthetic photon flux (µmolm^{-2}s^{-1}) of *Dendranthema grandiflora* Tzvelev at above canopy and intercanopy level

Light irradiance (L)	Salvador (G)		Pusa Centenary (G)	
	PPF above canopy (µmolm^{-2}s^{-1})	PPF at inter canopy (µmolm^{-2}s^{-1})	PPF above canopy (µmolm^{-2}s^{-1})	PPF at inter canopy (µmolm^{-2}s^{-1})
L1	556.33	167.00	509.33	283.67
L2	397.00	127.00	459.67	140.00
L3	573.00	241.67	578.67	294.00
L4	444.33	128.33	553.67	169.00
L5	562.33	142.33	490.67	235.67
L6	555.33	196.67	535.00	187.00
L7	409.67	77.67	505.00	135.00
Mean	499.71	154.38	518.86	206.33
S.Em	38.6881	38.5669	32.7824	29.8559
S.ED	54.7132	54.5419	46.3614	42.2226
CD (p=0.05)	119.2098	118.8365	101.0127	91.9952
CD (p=0.01)	167.1236	166.6003	141.6126	128.9707

Responses of mixed LEDs on Light Interception and Light Transmission Ratio

Light incepted level and light transmission ratio exhibited significant differences among the varied spectral ranges (Fig 1). The photosynthetic productivity of chrysanthemum is influenced by the quantum of light received by the plants. Chrysanthemum plants of Salvador and Pusa Centenary which have received 80%R: 20% B intensity have intercepted about 17.115 per cent of the light incident on the canopy surfaces followed by sodium vapour lamp (16.244 % interception). The better use of resources can be assessed Land Transmission Ratio which exhibited significant differences for the mixed LEDs. The higher light interception/light transmission ratio in the combination of 80% Red + 20% Blue (57.245) was due to improved growth of plants by increased photosynthetic rate, which helped in better interception of light.

The lower light transmission ratio was recorded in 100% Red (5.704) which implies the highest light utilization efficiency as compared other spectral distributions. It is clear from the above study that the growth and yield performance in L_3 (80%Red:20%B) was due to better overall use of resources. The results are in agreement with the findings of Sase et al. (2012) in leafy vegetables, Udaya Nandhini and Latha, (2015) and Warren Wilson et al. (1992) [15, 23, 24].

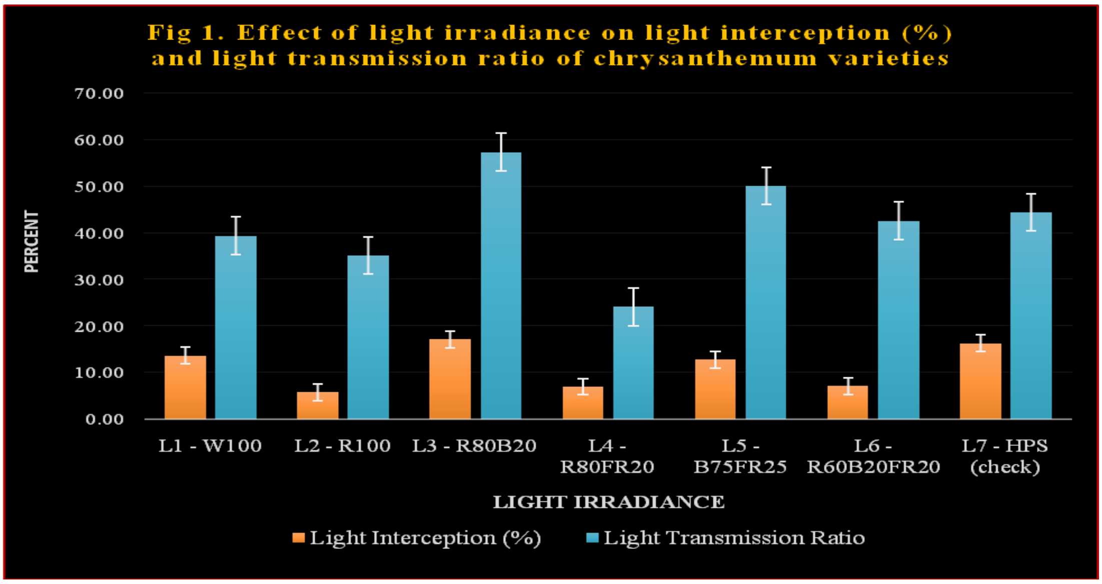

Fig 1

Influence of Red, Blue and Far-Red LEDs combinations in flower yield

Supplemental lighting in greenhouse cultivation is proven to increase the growth and quality of flowers and ornamentals (Zheng and Van Labeke, 2017) [24]. The monochromatic or mixed Red/Blue/Far-red LEDs had different influence on the flowering and yield parameters. The flowering parameters are significantly increased in 80% Red + 20% Blue (L_3) LED irradiated plants. Total cut stem yield per square meter (42.65 and 41.99) was very greater in 80%R: 20%B than other spectral ranges in Salvia and Pusa Centenary varieties (Table 3 & 4). Difference in light quality have influenced the duration of the blooming period (Heo et al. 2002) [7]. The increase in yield might be due to the quality of light which influenced the plant dry mass accumulation by altering leaf expansion and effected photosynthesis. This process promotes biomass accumulation by increasing photosynthetic carbon 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. The findings of Surendra Singh Chauhan (2017) [20] in chrysanthemum; García-Caparrós et al. (2020) [6] in indoor plants; Choi et al (2018) [5] in chrysanthemum were in line with the findings.

Table 3: Effect of light irradiance on peduncle length (cm), flower yield (No./m^2) and total cut stem yield/m^2 of *Dendranthema grandiflora* Tzvelev *var.* Pusa Centenary

Light quality	Pusa Centenary (G)				
	Peduncle length (cm)	Flower yield (No./m^2)			Total cut stem yield/m^2
		A Grade	B Grade	C Grade	
L1	17.30	39.25	1.61	0.52	41.38
L2	11.20	25.84	5.37	2.90	34.12
L3	9.45	40.07	1.15	0.78	41.99
L4	9.40	27.50	4.94	3.66	36.09
L5	12.15	4.13	17.43	18.77	40.33
L6	11.38	37.26	1.54	1.37	40.17
L7	6.40	37.79	1.65	1.12	40.56
Mean	11.04	30.26	4.81	4.16	39.23
S. Em	0.0512	0.1965	0.0890	0.0999	0.0450
S.ED	0.0724	0.2778	0.1259	0.1414	0.0636
CD (p=0.05)	0.1577	0.6053	0.2743	0.3081	0.1387
CD (p=0.01)	0.2210	0.8486	0.3846	0.4319	0.1944

In Salvador, 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 while L_3 (80% Red + 20% Blue) have recorded 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 - 40.70). Park and Jeong (2020) [14] have reported that blue light have influenced the early flower bud formation and ultimately the flower yield increased.

Table 4: Effect of light irradiance on peduncle length (cm), flower yield (No./m^2) and total cut stem yield/m^2 of *Dendranthema grandiflora* Tzvelev *var.* Salvador

Light quality	Salvador (G)				
	Peduncle length (cm)	Flower yield (No./m^2)			Total cut stem yield/m^2
		A Grade	B Grade	C Grade	
L1	13.28	38.18	1.57	0.50	40.25
L2	8.50	28.37	5.90	3.19	37.46
L3	15.29	40.70	1.16	0.79	42.65
L4	13.15	29.31	5.26	3.90	38.47
L5	18.35	4.24	17.85	19.23	41.32
L6	16.45	39.03	1.62	1.43	42.08
L7	15.01	38.71	1.70	1.14	41.55
Mean	14.29	31.22	5.01	4.31	40.54
S. Em	0.0477	0.1967	0.0914	0.1023	0.0295
S.ED	0.0646	0.2782	0.1293	0.1447	0.0417
CD (p=0.05)	0.1470	0.6062	0.2817	0.3153	0.0908
CD (p=0.01)	0.2060	0.8499	0.3950	0.4420	0.1272

Conclusions

The present study revealed that the spectral combination of 80% Red + 20% Blue (L3) registered improved morphoanatomic characters such as total leaf area at growth stages (1327.48 cm^2 and 1155.55 cm^2); total stem yield/sq.m (41.99) and marketable high grade flowers (Grade A - 40.07 stems/sq.m and 40.70 stems/sq.m) respectively and registered improved physiological parameters such PPFD (573 µmolm-2s-1 at above the canopy and 241.67 µmol$m^{-2}s^{-1}$ at inter canopy level in Salvador and 578.67 µmol$m^{-2}s^{-1}$ at above the canopy and 294 µmol$m^{-2}s^{-1}$ at inter canopy level in Pusa Centenary); light interception level at both varieties (17.115% at canopy surfaces) and high light transmission ration of 57.245 as followed by the spectral composition of 75% Blue+25% Far-red (L_5). It is evident from the study that the qualities of light has influenced the high light incident at above canopy and intercanopy level, net photo synthetic rate and thereby increase the plant dry mass accumulation by altering leaf total leaf area, stomatal conductance and improve photosynthetic carbon assimilation under RD radiated zones.

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